INVESTIGATING STRATEGIC SOURCING PERFORMANCE IN RESPONSE TO AN INNOVATION SHOCK - THE ROLE OF KNOWLEDGE, EXPERIENCE, AND MARKET DYNAMICS

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CERTIFICATE OF ORIGINALITY

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____________________(Signed)

Faisal Khurshid (Name of Student)

Dated: 25/06/2019

DEDICATION

To my parents

خورشید انور اور رخسانہ کوثر

and siblings

For all their love and support over the years

ABSTRACT

Industry evolution starts with a major technological breakthrough also known as innovation shock. Innovation shocks are sometimes so fundamentally different from the previously dominant technology that incumbent firms need new knowledge and capabilities to cope with such innovations. Strategic sourcing decisions of incumbent firms can play an important role in acquiring the required knowledge and capabilities. In the later stage of the industry evolution competition begins to intensify. In order to successfully cope with strong competition, incumbent firms tend to follow a differentiation strategy i.e. offer products in small untargeted niches. The success of differentiation strategy also depends upon strategic sourcing decisions of incumbent firms. In three studies of this dissertation, I attempt to investigate the performance impact of strategic sourcing in different stages of industry evolution.

In the first study, I attempt to investigate the role of market dynamics (competition and technological niche width) in the relationship between strategic sourcing and performance in the later stage of industry evolution. Despite there being numerous studies exploring the relationship between competition and vertical integration, the empirical findings regarding the nature of this relationship are still unclear. In first study, I suggest that technological niche width mediates the relationship between competition and vertical integration. In addition, technological niche width and vertical integration play complementary roles in enhancing firm performance. In the second study, I investigate the performance impact of outsourcing strategy in response to an innovation shock. In previous literature examining the performance impact of outsourcing, one stream of scholars has underscored the importance of prior green innovation experience, and another stream of scholars has underscored the importance of the in-house possession of outsourced component knowledge. However, the empirical findings regarding the positive role of both scholarly streams when studied separately are mixed and sometimes contradictory. I bridge these two distinct but related streams and suggest that prior green innovation experience and in-house knowledge regarding outsourced components play a complementary role in enhancing performance. In the third study, I found that the effect of outsourced components knowledge on product quality performance is greater at the later stage of the new product life cycle than of at the early stage.

I examined the United States hybrid electric vehicle market from 1999 to 2017 for empirical support for the arguments presented in three studies of this dissertation. Specifically, I investigated firms' strategic sourcing decision regarding six main components of the drivetrain system of a hybrid electric vehicle. I gathered data from multiple proprietary and non - proprietary archival sources. The nature of the data utilized in this dissertation is an unbalanced short panel. I utilized fixed vs random effects for model estimation. I addressed the endogeneity issue by utilizing the two-stage least squares (2SLS) regression method with an instrumental variable approach. The arguments proposed in three studies of this dissertation have found empirical support. This dissertation provides us with an opportunity to better understand the relationship between competition, vertical integration and technological niche width.

LIST OF PUBLICATIONS

Journal Papers

Khurshid, F, Park, W-Y, Chan, F. Innovation shock, outsourcing strategy, and environmental performance: The roles of prior green innovation experience and knowledge inheritance. *Business Strategy and the Environment*. 2019; 28: 1572– 1582. https://doi.org/10.1002/bse.2333

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Conference Papers

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"Relationship between knowledge search portfolio and new knowledge development: the moderating role of firms' R&D structure," with Woo-Yong Park and Felix T.S. Chan, in Proceedings of the ***British Academy of Management*** **(BAM)** 2018, Sep 4-6, 2018 at University of the West of England, Bristol, United Kingdom.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

Abbreviation	Word
2SLS	Two-Stage Least Squares
AC	Alterative Current
AFDC	Alternative Fuels Data Centre
CARB	California Air Resources Board
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
DC	Direct Current
EH	Exchange Hazards
EPA	Environmental Protection Agency
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
GDP	Gross Domestic Production
GHG	Greenhouse Gas
HEV	Hybrid Electric Vehicle
HH	Hierarchy Hazards
ICE	Internal Combustion Engine
IPC	International Patent Classification
IV	Instrumental Variable
KBV	Knowledge-based View
OCK	Outsourced Component Knowledge
OLS	Ordinary Least Squares
PGIE	Prior Green Innovation Experience
PHEV	Plug-in Hybrid Electric Vehicle
R&D	Research and Development
RBV	Resource-based View
TCE	Transaction Cost Economics
TNW	Technological Niche Width
USPTO	United States Patent and Trademark Office
VI	Vertical Integration
VRIN	Valuable, Rare, Inimitable and Non-Substitutable
WIPO	World Intellectual Property Organization
ZEV	Zero Emission Vehicle

CHAPTER 1

INTRODUCTION

Starting from the seminal work of Coase (1937), a key question in the literature on organizational theory is whether a firm should conduct transactions internally or externally. Internal transactions are referred to as vertical integration (insourcing) and external transactions are referred to as non-integration (outsourcing). Whether a firm should prefer a vertical integration or outsourcing strategy has been investigated through different theoretical lenses such as transactions cost economics (Coase, 1937, Williamson, 1981), knowledge-based view (Conner and Prahalad, 1996, Kogut and Zander, 1992) and capabilities (Barney, 1991, Nickerson and Zenger, 2004) among others. Scholars investigating the impact of vertical integration and outsourcing on performance have underscored the importance of industry evolution stage (Balakrishnan and Wernerfelt, 1986, Thompson, 1967, Williamson, 1985).

In the first stage of industry evolution, a disruptive technological change (also known as innovation shock) creates significant market fluctuations (Argyres et al., 2015, Christensen, 1997, Henderson and Clark, 1990). Innovation shocks are sometimes so fundamentally different from previous dominant technologies that they turn out to be competence-destroying discontinuities. In order to successfully manage an innovation shock, incumbent firms need to acquire new knowledge and develop capabilities conducive for new technology (Anderson and Tushman, 1990, Tushman and Anderson, 1986). Incumbent firms' strategies, therefore, should be formulated and executed through considerable attention to the innovation shock.

In the later stage of industry evolution, technology begins to stabilize, encouraging new entrants to enter the market (Lieberman and Montgomery, 1988). This situation leads to strong competition in the market. Incumbent firms can manage this competition by expanding technological niche width (i.e. offering differentiated products to small niches) (Bayus and Putsis, 1999, Giachetti and Dagnino, 2014, Shugan, 1989). By doing so, an incumbent firm can prevent the entry of new entrants and capture new customers by providing differentiated products that best meet the needs of new customers (Schmalensee, 1978). However, this expansion may cause diseconomies associated with design, production, and distribution (Aaker and Joachimstahler, 2000, Kumar, 2003). In addition, it may threaten the competitive position of current products offered by the incumbent firm. This may happen due to resources sharing between new and old markets (John et al., 1998, Morrin, 1999). In this situation, a firm may decide to reorient its resources from low-selling technological niches to high-selling niches, thereby narrowing the technological niche widths (Draganska and Jain, 2005). Thus, the expansion and contraction in technological niche widths can be a strategic choice in the face of fierce competition. The emergence of a specialized supplier market is another important development at the later stage of industry evolution. Specialized suppliers generally offer less expensive solutions. While most firms tend to prefer outsourcing over vertical integration, some firms still prefer vertical integration (Helfat and Peteraf, 2015, Kapoor, 2013). Thus, it is interesting to explore how incumbent firms can better utilize strategic sourcing (vertical integration or outsourcing) for superior performance in the different stages of industry evolution. The main research question addressed in this dissertation is as following.

“How firms can achieve superior performance through strategic sourcing?”

To address this main research question, this dissertation investigates the following three specific questions in automobile industry-context.

1. **How market dynamics impact firms' strategic sourcing decisions?**
2. **Why some firms pursuing outsourcing strategy perform better than the others?**
3. **How and why the performance of firms pursuing outsourcing strategy improves over time?**

Regarding the first stage of industry evolution, the relationship between innovation shock and strategic sourcing has received considerable attention in previous literature over the years (Balakrishnan and Wernerfelt, 1986, Thompson, 1967, Williamson, 1985). Although this relationship has progressed, findings about the influence of strategic sourcing on performance are contradictory (David and Han, 2004). Much research has predominantly underscored the virtues of vertical integration over outsourcing since it facilitates efficient flow and exchange of knowledge through effective control mechanisms within the firm boundaries (Conner and Prahalad, 1996, Demsetz, 1988, Thompson, 1967, Weigelt, 2009). Contrastingly, more recent studies tend to argue that an outsourcing strategy is better since it allows firms to easily access cutting-edge knowledge beyond the firm boundaries (Brown and Eisenhardt, 1997, Eisenhardt and Martin, 2000, Spencer, 2003). Given that switching from one strategic option to the another (e.g. from vertical integration to outsourcing or vice versa) involves financial and managerial constraints (such as organizational inertia), therefore, recently focus of research has shifted on how to improve the performance of a firm's already chosen sourcing option. Specifically, research focus in this domain has shifted from "whether the vertical integration or outsourcing strategy provides better competitive advantage" to "under what conditions' vertical integration or outsourcing strategy can deliver better performance than the others".

In order to address the 'under what conditions' question in the first stage of industry evolution, prior studies have made some progress in providing initial hints. Long-term relationships between a firm and its supplier is a critical factor by which both parties can create mutual trusts (Gulati, 1995) and thus firms pursuing an outsourcing strategy can achieve the goal of superior performance (Dyer, 1996, Dyer, 1997). Similarly, Hoetker (2005) found that while a majority of firms preferred vertical integration strategy, firms that had long-term relationships with their suppliers tended to remain with the same suppliers, i.e., continue with outsourcing strategy. Thus, long-term relationships between a firm and its supplier can enhance firm's performance pursuing an outsourcing strategy. In the same vein, Novak and Stern (2008) in the investigation of global automotive industry suggested that contracts with high-quality suppliers can help firms in achieving superior performance through outsourcing strategy. Because reputation of such suppliers is at stake, they tend to provide superior solutions to keep high-quality supplier reputation. Kotabe et al. (2012) suggested that the degree of market competition and the strengths of firm resources could affect outsourcing performance. Although these studies have generated some progress in providing initial hints to answering the 'under what conditions' question posed earlier, the research question is still under-explored (Bigelow et al., 2019, Park et al., 2018). This dissertation, therefore, attempts to shed light on the 'under what conditions' question in response to an innovation shock.

Building upon the notion that the firm and its knowledge boundary can differ (Brusoni et al., 2001), I investigate the impact of in-house knowledge regarding the outsourced components on performance for firms pursuing an outsourcing strategy (Brusoni and Prencipe, 2006). Much of the literature has suggested the positive role of outsourced component knowledge in enhancing performance. Because it may help firms in monitoring suppliers and reducing the chance of opportunistic behavior (Akerlof, 1970, Brusoni et al., 2001, Kapoor and Adner, 2012, Park and Ro, 2013). However, Park et al. (2018) recently have suggested the possibility of a negative effect of outsourced component knowledge on performance. In this dissertation, I attempt to shed light on the positive and negative role of outsourced component knowledge. Specifically, I propose that outsourced component knowledge and prior innovation experience play complementary roles in enhancing performance. I also propose that impact of outsourced component knowledge on performance becomes more positive during the later stage of new product life-cycle than of the initial.

In order to address the ‘under what conditions’ question in the later stage of industry evolution, previous studies have provided preliminary indications. The prior literature has reported conflicting findings regarding the impact of sourcing strategy on performance. Some scholars argued that in the later stage of industry evolution firms pursuing vertical integration strategy showed superior performance (Afuah, 2001, Baldwin and Clark, 2000, Fine, 1999, Kapoor and Adner, 2012, Park and Ro, 2013). However, another group of scholars presented an opposite argument by suggesting that in the presence of specialized component suppliers, a vertical integration strategy, in fact, undermines performance (Abecassis-Moedas and Benghozi, 2012, Jaspers et al., 2012, Jones and Hill, 1988, Park and Ro, 2011). In addition, some researchers have argued that in knowledge-intensive industries, where a systematic pattern of innovations is followed, incumbent firms tend to pursue vertical integration despite compromises on short-term performance. Incumbent firms prefer to maintain and upgrade their technological knowledge pool through vertical integration i.e. learning by doing (Helfat and Campo-Rembado, 2016, Kapoor, 2013). Although these studies have generated some progress in providing initial hints to answering the 'under what conditions' question posed earlier, the research question is still under-explored. This dissertation, therefore, attempts to shed light on the 'under what conditions' question in the later stage of industry evolution.

Regarding the later stage of industry evolution, I investigate the role of market dynamics specifically competition and technological niche width in relationship between sourcing strategy and performance. Given that the expansion and contraction in technological niche widths can help firms survival in later stage of industry evolution. Argyres and Bigelow (2010) have recently suggested that it is difficult for firms offering differentiated products to find suppliers providing components with appropriate features and tailored designs. I propose that a firm's decision regarding expansion and contraction in technological niche widths- whether it wants to emphasize on differentiation strategy or emphasize on a cost reduction strategy (Bayus and Putsis, 1999, Giachetti and Dagnino, 2014, Shugan, 1989) - should be in tandem with its vertical integration strategies.

Chapter 2 present a critical overview of previous literature. In this chapter, I provide the building blocks and theoretical foundations for the three specific questions under investigation in this dissertation. I first explain the technological evolution stages of an industry. Second, I explain the impact of these evolution stages on strategic sourcing decisions. Third, I critically review the role of prior innovation experience and its interplay with strategic sourcing. Finally, I bring into discussion the role of market dynamics.

Chapter 3 provides the rationale for selecting the United States automobile industry as empirical setting and explains data sources and procedures adopted for data collection. In order to explore the above-mentioned specific questions, this dissertation investigates the U.S. hybrid electric vehicle market from 1999 to 2017. Specifically, I examined the firms' strategic sourcing decision regarding drivetrain system of a hybrid electric vehicle. The drivetrain system of a hybrid electric vehicle comprises of six main components: battery, motor, engine, transmission, DC-DC converter, and DC-AC converter. Given that automobile manufacturers make distinct strategic sourcing decisions regarding each of the six components used in a vehicle model. Examining this interesting market for addressing the above-mentioned three specific research questions is quite meaningful. I gathered and compiled data from several archives such as *MarkLines* - a proprietary database, Alternative Fuels Data Centre, Advanced Vehicle Testing - a U.S. Department of Energy National Laboratory, United States Patent and Trademark Office (USPTO), Consumer Reports, J.D. Power and Associates, Thomson Reuters Eikon database, Complete Catalog of Cars, Factiva - an industry news portal, Business Source Complete database, trade magazines and annual reports of firms. The nature of the data utilized in this dissertation is an unbalanced short panel. Since the use of ordinary least squares (OLS) regression for panel data is inappropriate, the recommended approach for this type of data is fixed or random effects. I conducted the Hausman (1978) specification test to decide between fixed or random effects models. I addressed the endogeneity issue by utilizing the two-stage least squares (2SLS) regression method with an instrumental variable approach (Wooldridge, 2002).

Chapter 4 attempts to answer the first specific question: **How market dynamics impact firms' strategic sourcing decisions?** In this study, I investigate the role of market dynamics in firms' strategic sourcing decisions and consequently on performance. Particularly two aspects of market dynamics - competition and technological niche width - have been studied in the relationship between strategic sourcing and performance. Despite there being numerous studies exploring the relationship between competition and vertical integration, the empirical findings regarding the nature of this relationship are still unclear. In this study, I provide two hypotheses. First, technological niche width mediates the relationship between competition and vertical integration. Second, technological niche width and vertical integration play complementary roles in enhancing firm performance. These arguments have found empirical support in an examination of the U.S. hybrid electric vehicle market from 2008 to 2016. In so doing, this study provides us with an opportunity to better understand the relationship between competition, vertical integration, and technological niche width. In addition, it explains how firms can effectively manage fierce competition and achieve the goal of superior performance by making strategic decisions regarding vertical integration and technological niche width.

Chapter 5 attempts to answer the second specific question: **Why some firms pursuing outsourcing strategy perform better than the others?** This chapter focuses on the performance impact of an outsourcing strategy. In previous literature in order to investigate under what conditions an outsourcing strategy can show superior performance, one stream of scholars has underscored the importance of prior green innovation experience, and another stream of scholars has underscored the importance of the in-house possession of outsourced component knowledge. However, the empirical findings regarding the positive role of both scholarly streams when studied separately are mixed and sometimes contradictory. In this study, I bridge these two distinct but related streams and suggest that prior green innovation experience and in-house knowledge regarding outsourced components play a complementary role in enhancing environmental performance. The investigation of U.S. hybrid electric vehicle market from 1999 to 2017 provides support to the arguments proposed. This chapter suggests that firms with prior green innovation experience and outsourced component knowledge perform better than others. In this chapter, I also provide guidance for managers and policymakers on how to achieve superior performance in outsourcing.

Chapter 6 attempts to answer the third specific question: **How and why the performance of firms pursuing outsourcing strategy improves over time?** Given that exchange hazards arising from outsourcing strategy in the face of an innovation shock can potentially undermine firm performance, in this chapter, I investigate how firms can successfully manage the exchange hazards. I propose that although in-house possession of outsourced component knowledge can help firms in mitigating exchange hazards, it does not always improve performance. I found that the effect of outsourced components knowledge on product quality performance is greater at the later stage of the new product life cycle than of at the early stage. In addition, the weak (or negative) effect of outsourced components knowledge at the early stage product quality performance is positively moderated by the component's technological complexity. The investigation of the United States hybrid electric vehicle market from 1999 to 2017 provides empirical support to the arguments proposed.

Finally, Chapter 7 presents the general conclusions and discussions of this dissertation from the findings of Chapters 4, 5 and 6.

CHAPTER 2

LITERATURE REVIEW: A CRITICAL LOOK AT INDUSTRY EVOLUTION AND STRATEGIC SOURCING

Chapter Introduction

This chapter provides the building blocks and theoretical foundations upon which the three studies of this dissertation are based. I first explain the technological evolution stages of an industry. Second, I explain the impact of these evolution stages on strategic sourcing decisions. Third, I critically review the role of prior innovation experience and its interplay with strategic sourcing. Finally, I bring into discussion the role of market dynamics.

Technological Evolution Stages of an Industry

The technology as defined by Christensen (1992) is a process, technique or methodology which transforms the input of labor, capital, information, materials, and energy into an output of greater value. Therefore, technological changes or simply innovations are the development of new products, processes and/or techniques (Pistorius and Utterback, 1997). Depending upon the technological advancement within the components and their mutual interactions these innovations can be classified as radical, architectural, modular, and incremental. Radical innovations at one end are the most dramatic where core concepts of product components and their mutual interaction are dramatically changed (Henderson and Clark, 1990), thus it can be a source of competence enhancing or competence destroying for incumbent firms (Christensen, 1992, Tushman and Anderson, 1986). Incremental innovations at the other end are a mere refinement of previous technology. Radical (or architectural) innovations are sometimes so fundamentally different from previous dominant technologies that they turn out to be competence-destroying discontinuities (Anderson and Tushman, 1990, Tushman and Anderson, 1986) also known as innovation shock. Given that innovation shocks can drive the competitive position of incumbent firms operating in technology-intensive industries, incumbent firms' resources, capabilities and strategic decisions thus play a critical role in managing innovation shocks.

Next stage of industry technological evolution comes when technology is relatively stable (also known as dominant design). The dominant design concept provides interesting insights for understanding the market dynamics. Utterback and Abernathy (1975) first coined this concept since then it has received tremendous scholarly attention in technology management, strategic management, and organizational ecology literature (Anderson and Tushman, 1990, Christensen et al., 1998, Suarez et al., 2015, Suárez and Utterback, 1995). Dominant design is a point at which the market competition shift from product differentiation to economies of scale - mass production of standardized products (Suárez and Utterback, 1995). Before the emergence of the dominant design, technical performance play a crucial role so different firms (and sometimes different technologies) tend to compete for satisfying customer needs. As customers' needs are fluid at that stage a lot of firms successfully get support from different market segments. After a dominant design, suppliers market also tend to establish that generally provide cost-effective components to incumbent firms. Given that dominant design is an important stage of industry evolution, firms sourcing strategies are, therefore, adjusted contingent upon the pre-dominant design or post dominant design era (Park et al., 2018).

Recently, Suarez et al. (2015) have suggested that firms tend to shift their strategic orientation even before the emergence of the dominant design. Trough market forces, similar products are grouped together to form a category (dominant category). These categories are either introduced by firms to differentiate their product from others in the market or by stakeholders, considering performance differences of the products. Like the dominant design, these categories diverge in the first stage due to an increase in a number of products and categories but converge later on eventually leading to the emergence of the dominant category. Contrary to dominant design where it is technically impossible for a firm to change the trajectory and reverse product technology, the dominant category offers a solution for these firms to reposition their products in a different category to meet the needs of new customers.

Argyres et al. (2015) argued that both dominant design and dominant category approaches are retrospective in nature with least managerial implications. They further argue that these approaches consider only the supply side. Contrary to prevailing concepts of dominant design and the dominant category they underscored the importance of the innovation shock. Because identification of innovation shock is relatively easy and can be predicted by looking at the demand of new innovation. The increase in sales or market share of new innovation can easily be assessed. Similiarly Dosi (1982) provided a comprehensive overview of the technology change process and argued that technological trajectories and paradigms are path dependent. Scientific developments and dedicated R&D efforts provide a foundation to different technological alternatives but the market mechanism decides which innovation to surface and which technology to change. Given that innovation shock can be radical or architectural in nature, market acceptability is a key essence of innovation shock. The uncertainties and disadvantages associated with first movers reported by several authors have already been settled down by this point (e.g. (Christensen et al., 2002, Lieberman and Montgomery, 1988)).

Despite recent criticism, the dominant design theory provides useful insights to understand how the fundamentals of market competition and product technology evolve. The context of the two studies of this dissertation is innovation shock (Chapter 5 and 6) and for the third study (Chapter 4) it is after dominant category but before dominant category (although I did not explicitly use the terms dominant category or dominant design in both the studies, these concepts have implicitly been used).

Innovation Shock and Incumbent Firms

The main question in strategic management literature is; why there is heterogeneity in firms' performance? To answer this question, some scholars have focused on favorable industry conditions, others have highlighted the role of resources and capabilities (Barney, 1991, Teece et al., 1997, Wernerfelt, 1984). Once a firm realizes that a major technological change has emerged, an adequate response, at the right time for the technological change is important for the survival and success of the firm. Although being an external factor, a new-fangled technological change should have a similar impact on incumbent firms, but in reality, firms respond differently depending on the heterogeneity of their capabilities and resources (Barney, 1991, Teece et al., 1997). Thus, firms' attributes play an important role in strategic response to an externally originated innovation shock. The resource-based view (RBV) argues that fear of becoming obsolete and urge to gain and sustain competitive advantages requires incumbent firms to accumulate valuable, rare, inimitable and non-substitutable resources

(VRINs) (Teece et al., 1997, Barney, 1986, Dierickx and Cool, 1989, Peteraf, 1993). Teece et al. (1997) proposed that beyond the VRIN resources, incumbent firms' ability to reconfigure resources for capabilities development is key to success in a rapidly changing environment. Knowledge-based view (KBV) theory argued that among other resources and capabilities, knowledge is the primary source of competitive advantages. In the face of an innovation shock, the role of knowledge becomes even more critical. Recent developments in strategic management and technology management research have further reinforced this argument of KBV (Barney, 1986, Grant, 1996).

Given that technological innovations, in broader terms, are knowledge creation process. Organizational learning literature suggests that major technological changes are made by integrating internal knowledge with external knowledge (Berchicci, 2013, Sampson, 2007). It is almost impossible for incumbent firms to have comprehensive knowledge regarding new innovation due to the scarcity of resources. Thus, in order to meet the challenges posed by innovation shocks, incumbent firms are required to acquire external knowledge (Chesbrough, 2006, Dushnitsky and Lenox, 2005, Helfat, 1997). Incumbent firms, therefore, need to develop methods and routines that simultaneously facilitate the exploitation of existing knowledge and the exploration of new knowledge (March, 1991). Learning by doing and investments in R&D are major sources of internal knowledge. Internal knowledge also enhances firms' absorptive capacity, defined as firms' ability to understand assimilate new knowledge. Thus, higher the level of absorptive capacity better will be firms' ability to identify, acquire and integrate useful external knowledge for sustainable competitive advantage (Cohen and Levinthal, 1990, Mowery et al., 1996).

Given that technological changes are made by advancements in component technology or by modifications in the interaction mechanism amid components. Therefore, effective communication and coordination among different component producers and assemblers are critical for successfully managing technological change. The extant literature in technology management area suggests that when a new technological innovation emerges, there are two requirements needed to successfully deal with the new innovation (Christensen, 1997, Henderson and Clark, 1990). The first is to competently manage the component coordination and interdependence demanded by the new innovation through the acquisition of new architectural knowledge. The second is to create fresh information-processing structures and routines since architectural knowledge is typically embedded in organizational arrangements and processes. This dissertation suggest that these requirements may be fulfilled through strategic sourcing and prior innovation experience.

Strategic Sourcing in the face of Innovation Shock

In the face of an innovation shock, a critical strategic decision is to decide which function and components should be developed in-house (vertical integration strategy) and which component should be outsourced (outsourcing strategy). Coase (1937) reported that outside firm boundaries ‘price’ control transactions and movement of resources but inside the firm it does not, employees are rather ordered to move from one job to another. To minimize the costs associated with writing and managing the contracts, firms normally tend to sign long term contracts (Dyer, 1996, Dyer, 1997, Dyer and Hatch, 2006), but it’s risky due to future uncertainty (e.g. forecasting errors). The solution is to form an organization (entrepreneur) give resources and power to manage (the direction of) both internal and external relations in a cost-effective manner. Size of firms depends upon transactions made by the entrepreneur (more transactions means large in size and vice versa). Larger the size of firms greater will be the costs to manage it (Chandy and Tellis, 2000), sometimes this phenomenon suggests buying from other firms (due to cost differences). Reducing the distance among factors of production, enabling effective communication channels and improved managerial techniques will result in increased in the size of the firm. In summary, transaction cost economics (TCE) approach helps to understand the overall structure of the firm and provide useful information about which functions to perform inside or which from the outside firm (Williamson, 1981). Firm's strategic sourcing decision based upon TCE proposed by seminal work of Coase (1937) and Williamson (1981) indeed provided a foundation but over the time different researchers contributed and enriched this theory, for instance, resource-based view by Wernerfelt (1984) and knowledge based view (Nickerson and Zenger, 2004).

The relationship between innovation shock and strategic sourcing decision has received great attention among scholars working in the technology management area. One stream of scholars argues that vertical integration strategy is better as it enables firms to exercise greater control over different departments. Through this control, the firm can manage effective communication and coordination mechanism for effective knowledge flow required to manage new technological change. Much research has predominantly underscored the virtues of a vertical integration strategy over an outsourcing strategy since a vertical integration strategy allows firms to facilitate knowledge exchange more efficiently (Conner and Prahalad, 1996, Demsetz, 1988, Thompson, 1967, Weigelt, 2009) than an outsourcing strategy. Contrastingly, more recent studies tend to argue that an outsourcing strategy is better than of vertical integration strategy since it allows firms to easily probe and access cutting-edge knowledge (Brown and Eisenhardt, 1997, Eisenhardt and Martin, 2000, Spencer, 2003).

Both the vertical integration and outsourcing strategies have certain advantages and disadvantages over each other. Through effective control mechanisms within the firm boundaries, vertical integration strategy facilitates high coordination and communication channels to help systematize diffusion of knowledge (Monteverde, 1995). An outsourcing strategy is inefficient in dealing with high coordination tasks required for effective knowledge sharing (Nickerson and Zenger, 2004). Since the latest knowledge required for a technological change is normally scattered outside a firm's boundary. To acquire that knowledge an outsourcing strategy is more efficient as it allows the firm to enhance its knowledge stock and meet the shortcomings in required technological knowledge (Powell et al., 1996, Womack et al., 1990). An outsourcing strategy can enable firms to avoid core rigidities or missed opportunities (Leonard-Barton, 1992). Since the vertical integration strategy is better for knowledge sharing within the firm, but over-reliance on internal knowledge can lead to the risk of lock-in (Hill and Hoskisson, 1987, Jones and Hill, 1988). Hence, employing an outsourcing strategy may demonstrate better performance than employing a vertical integration strategy under conditions of drastic technological change. In conclusion, the advantage of a vertical integration strategy is its knowledge transformation capability and its disadvantage is its lack of knowledge acquisition capability, an outsourcing strategy's advantage is its knowledge acquisition capability and its weakness lies in its lack of knowledge transformation capability.

Considering the relative advantages and disadvantages of both the vertical integration and outsourcing strategies, a hypothetical situation is possible. In this situation, if a firm pursuing vertical integration strategy can exploit the relative advantages of an outsourcing strategy – knowledge acquisition – in parallel to the advantages of a vertical integration strategy– knowledge transformation – the firm may demonstrate enhanced technological performance compared to a firm pursuing a pure vertical integration strategy. Similarly, if a firm pursuing an outsourcing strategy can exploit the relative advantages of vertical integration – knowledge transformation – in parallel to the advantages of an outsourcing strategy – knowledge acquisition – the firm may demonstrate enhanced technological performance compared to a firm pursuing a pure outsourcing strategy. Depending on whether the locus of our investigative focus is on knowledge acquisition capability or knowledge transformation capability, the relative advantages provided by one form of governance over another becomes clear.

However, the arguments promoting outsourcing over vertical integration are not fully empirically supported (David and Han, 2004). Thus, they have shifted their research focus from "whether the outsourcing or vertical integration strategy provides better competitive advantage" to "under what conditions an outsourcing strategy can deliver better performance than a vertical integration strategy". For example, through long-term relationships between a firm and its supplier, both parties can create mutual trusts (Gulati, 1995) by which the firm pursuing an outsourcing strategy can enjoy advantages of both the market and vertical integration strategy (Dyer, 1996, Dyer, 1997). Hoetker (2005) found that while majority of firms preferred a vertical integration strategy, firms which had long-term relationships with their suppliers tended to remain with the same suppliers, i.e., continue with market governance, in periods of rapid technological change. Novak and Stern (2008) in the global automotive industry suggested contracts with high-quality suppliers as a factor increasing the performance of firms pursuing an outsourcing strategy. Kotabe et al. (2012) suggested that the degree of market competition and strengths of firm resources could affect outsourcing performance (Handley, 2012). Although these studies have generated some progress in providing initial hints to answering the ‘under what conditions’ question posed earlier, the research question is still under-explored. This study, therefore, attempts to shed light on the ‘under what conditions’ question by suggesting an important moderating factors – the in-house retention of knowledge regarding outsourced components and prior innovation experience.

The literature has established the idea that the firm and knowledge boundary can differ (Brusoni et al., 2001), suggesting that not all the firms practicing a outsourcing strategy may have same level of knowledge regarding the outsourced components (Brusoni and Prencipe, 2006). Furthermore, a few related studies suggest that the retaining in-house knowledge of outsourced component can enhance performance (Tiwana and Keil, 2007). Recently, Kapoor and Adner (2012) demonstrated that among firms pursuing an outsourcing strategy, those that have in-house knowledge of outsourced component showed better performance than others. Although these studies are meaningful since they demonstrate that the retention of outsourced component knowledge may positively affect performance, they do not conduct a direct performance comparison a outsourcing strategy with in-house knowledge of outsourced component and a between a vertical integration strategy. In order to have a clear understanding of the role of in-house knowledge regarding outsourced components. It should draw a comparison that how it is better than pure outsourcing and pure vertical integration strategy. Unless proven so, simply arguing that in face of technological change outsourcing strategy provides better implication than a vertical integration strategy is already proven fact in dominant previous literature arguments (Demsetz, 1988, Kogut and Zander, 1996, Monteverde, 1995).

Given that an outsourcing strategy is an important tool for acquiring new knowledge from external partners. It provides an opportunity to bring close different knowledge bases and facilitate firms to familiarize external knowledge (Nonaka, 1994). Although an outsourcing strategy facilitates exposure to novel knowledge they do not guarantee that focal firms will fully be able to transfer and acquire external knowledge. Furthermore; unique knowledge is more often tacit in nature and largely depend upon the context of the parent firm. This feature of tacit knowledge makes it hard to transfer knowledge to other contexts (Dahlander et al., 2016, Von Hippel, 1994). Thus, firms differ in their ability to acquire knowledge from alliance partners depending upon absorptive capacity. The recipient firms experience, culture, and knowledge retention abilities also affect its absorptive capacity. Due to different levels of absorptive capacity firm learning in alliances also differ. Those firms with a higher level of absorptive capacity identify, transfer, and acquire external knowledge earlier than others (Cohen and Levinthal, 1990, Todorova and Durisin, 2007, Zahra and George, 2002). Considering that internal knowledge base is important for identifying and absorbing external knowledge, the next section explains the critical role of prior innovation experience.

Strategic Sourcing and Prior Innovation Experience

Organizational learning literature suggests that major technological changes are made by integrating internal knowledge with external knowledge (Berchicci, 2013, Sampson, 2007). Therefore, firms need to develop such methods and routines that simultaneously facilitate the exploitation of existing knowledge and the exploration of new knowledge (March, 1991). Learning by doing and investments in R&D are major sources of internal knowledge. Internal knowledge also enhances firms' absorptive capacity, defined as firms' ability to understand assimilate new knowledge. Thus, higher the level of absorptive capacity better will be firms' ability to identify, acquire and integrate useful external knowledge for sustainable competitive advantage (Cohen and Levinthal, 1990, Mowery et al., 1996). Over time, both the partner firms mutually develop such mechanisms that facilitate the flow of knowledge as a result mutual learning gradually increases (Dyer and Hatch, 2006, Dyer and Singh, 1998, Inkpen and Dinur, 1998, Kogut and Zander, 1992). The development of effective routines knowledge flow mechanisms shared languages for communication and formal and informal network ties enable alliance partners transfer and absorb difficult to learn knowledge, as a corollary, learning from alliance partners increase over the time (Simonin, 1999).

Since learning process follows path dependency, possession of prior related knowledge is, therefore, important. The main function of a firm is to integrate the required knowledge so coordination is very important especially in case of basic tacit knowledge. Organizational structure and decision-making authority play a vital role in this regard. Horizontal team-based structure and inter-firm alliances are examples of such structures (Grant, 1996). Product architecture is an important part of managerial decision making especially in industrial firms where product design is an important component of R&D (Ulrich, 1995). Klepper and Simons (2000) reported that the probability to enter, survive and grow in a new industry is much higher if the firm has prior innovation experience in related technology. They tested their predictions in the US television industry identified those firms that were previously producing home radio set to measure prior innovation experience in related technologies. Organization's absorptive capacity depends upon the knowledge transfer within and across subunits of the organization so the communication system plays an important role in this regard (Cohen and Levinthal, 1990). To facilitate this communication, shared language and organizational structure are important. The shared language, on one hand, facilitates the exploitation of internal knowledge but at the same time may slow down the process of acquiring diverse external knowledge (March, 1991).

The retention of prior innovation experience leads to better organizational routines, expertise, and mechanisms that facilitate knowledge integration within and outside the firm, leading to better technological performance. By contrast, firms with little or no prior innovation experience lack the maturity of information scanning and filtering that allow the firm to deal with new radical technological changes. Macher and Boerner (2006) found that technological experience tended to shorten firms' drug development completion time for both outsourced and insourced drug development. Thus, in rapidly changing technological environment survival of a firm depends upon its ability to respond to a new market. To develop such capabilities appropriate type of prior innovation experience and manager's abilities to exploit this experience are very important.

Prior experience of an organization and capabilities of its managers, in utilizing those experiences in a positive direction are critical for the firms to enter successfully in a new market niche. Dynamic capabilities are the strategies and routines of the organization to meet the pace of emerging markets (Eisenhardt and Martin, 2000, Teece et al., 1997, Winter, 2003). These capabilities can act either an advantage or disadvantage of the firms. A number of scholars argue that some routines- static experience- create organizational inertia that restricts the ability of firms to adopt market changes thus such experience leads to failure to enter a new market. At the same time, some scholars suggest modification routines -transformational experience- increase dynamic capabilities. Thus, the role of managers (minor, moderate or aggressive) decides the future of the firm. Experience in one market enables firms to enjoy a reduction in marginal cost when they enter in the new market of similar industry. Sometimes the firm has the ability but managers' rigidness stops the organization to adopt change (Helfat and Peteraf, 2015, King and Tucci, 2002). Furthermore, top management incentives strategies sometimes stop adaptation of change. Transformational experience (experience of changing routines) enables dynamic capabilities by limiting the impact of organizational inertia and/or shaping organizational routines of reducing cost and learning from previous misperceptions. "Experienced firms entered in old markets will enter in the new market as well". A large number of researchers argue that it is unusual for an incumbent to introduce a radical product innovation. Because incumbent firms over time capture a large market share and to achieve economies of scale they start mass production, which requires expensive machinery and a large number of skillful workforce. To have effective organizational control incumbent firms normally start following different layers of bureaucratic management model. But at the same time, this bureaucratic model (that involves different layers of management) leads to organizational inertia that restricts organizational change and consequently incumbent firms fail to introduce radical product innovation (Chandy and Tellis, 2000). To fill this gap small firms or even individual entrepreneur come up with an idea to gather resources and launch a new radical innovation (product). Initially incumbent, due to the low price and large market franchising abilities (but of course relatively old technology-based products) have an upper hand, and small firms initially face stiff competition, but over the time customer start switching to a superior product. So, incumbents market share start shifting to a new entrant.

Thus, along with prior innovation experience, managerial experience, and other related capabilities play a significant role. Despite the critical role of dynamic capabilities and managerial experience, this dissertation is limited to prior innovation experience.

Organizational growth and competitive advantage has been considered as a function of learning activities. Levitt and March (1988) proposed a framework for organizational learning which suggests learning is path dependent and grounded in routines that should accept change and alternation. Therefore, in order to survive in highly dynamic environment organizations should spend time and resources required for effective learning through a change in its routines and enhance adaptivity. The requirements of high-velocity markets may organizational change to such an extent that a firm must switch its routines to an entirely different level. Although, in contexts of a highly dynamic environment, current routines may provide comparatively better performance in short-run the cost of this short-term performance advantage may not last for long-term and drag firms to failure (Ahuja and Lampert, 2001, Leonard-Barton, 1992). Firms that engage in technological exploration in the midst of rapid technological change and acquire organizational and strategic routines prior to a pervasive technological change are likely to show different levels of performance than firms which do not have such experiences in the face of radical technological change. Firms can learn technology by supplying components and this learning increases when the organization is involved in both designing and manufacturing of components. The perceived switching cost and inertia stop both organizations in changing their buyer and supplier relationship (Alcacer and Oxley, 2014). Firms with better organizational learning will adopt new knowledge easily and earlier. Cohen and Levinthal (1990) termed this ability as absorptive capacity which is an organization's ability to identify external knowledge, accumulate it and apply it for commercialization of innovation.

Under a pure outsourcing strategy where firms have little or no prior innovation experience, they would likely have difficulty effectively developing organizational routines and spanning technological boundaries since this governance mode is likely to preclude such internal know-how regarding the effective development of firm-specific routines. Thus, firms adopting an outsourcing strategy with a history of prior innovation experience may encounter more chances to learn and integrate useful technical knowledge than those adopting an outsourcing strategy without prior innovation experience. Thus, the knowledge generation and integration chances in case of an outsourcing strategy with prior innovation experience can improve technological performance (Brown and Eisenhardt, 1997). It is generally known that, compared to an outsourcing strategy, a vertical integration strategy more readily permits organizations to create firm-specific systems of communication and routines for new knowledge sharing and integration. However, the vertical integration strategy can lead firms to stick to firms' own firm-specific channels and routines, and the routines can be a barrier to adopt new external knowledge so that firms' routines can be core rigidity for new knowledge identification and acquisition (Leonard-Barton, 1992).

However, prior innovation experience enables firms pursuing vertical integration to come up for this limited knowledge acquisition capability, but also keep enjoying the knowledge transformation capability when pursuing a vertical integration strategy. Through engagement with prior innovation experience, firms can further develop capabilities. Thus, in situations where firms employ a vertical integration strategy, firms may exhibit varying levels of technological performance depending on the existence of prior innovation experience. Thus far, we have looked into performance advantages potentially obtained through prior innovation experience within each governance mode choice.

As argued prior innovation experience allows firms pursuing an outsourcing strategy to not only identify new knowledge but also to create new firm-specific routines by which firms can efficiently integrate new and existing knowledge needed. An outsourcing strategy with prior innovation experience gives firms access to sources of external knowledge through strategic alliances and allows them to assimilate this knowledge such that it becomes an integral part of in-house activities. Through prior innovation experience, firms can grow and sustain external sourcing relationships (Powell et al., 1996, Rothaermel et al., 2006) since they can retain relevant knowledge of outsourced components in-house through prior innovation experience. In addition, through prior innovation experience, firms can mature their understanding of the technological linkages amid components and preserve their component-specific competence (Akerlof, 1970, Brusoni et al., 2001). A higher level of in-house component knowledge retention gained through prior innovation experience also enables a firm better deal with suppliers (Tushman, 1977, Tushman and Katz, 1980).

Through prior innovation experience, firms pursuing a vertical integration strategy are willing to search externally to identify and acquire new knowledge beyond their current routines and competence. And, creating a history of frequent prior innovation experience helps firms better leverage knowledge transformation and facilitates firms' capabilities to develop and refine routines that can facilitate the integration of new and existing knowledge, enhancing manufacturing responses, improving quality, reducing costs, and contributing to positive technological performance outcomes.

Although an outsourcing strategy provides space for firms to add new knowledge, under an outsourcing strategy without prior innovation experience, it may prove difficult to integrate any new knowledge with existing firm knowledge since pure market governance precludes the development of an internal knowledge base. The outsourcing strategy without prior innovation experience possesses inherent disadvantages in developing new communication channels and organizational routines. Under market governance without prior innovation experience, a firm would likely have difficulty effectively developing organizational processes and spanning technological boundaries since it would not possess a deep understanding of any new technical knowledge concerning its supplier's design and manufacturing capabilities.

The existence of prior innovation experience can help firms overcome the disadvantages of outsourcing strategy, but without prior innovation experience, firms have little chance to develop any new and effective practices and routines critical for new knowledge integration. Thus, based on their relative strengths, firms pursuing a vertical integration strategy with prior innovation experience may encounter more opportunities to learn and integrate valuable new knowledge than those pursuing an outsourcing strategy without prior innovation experience. The retention of prior innovation experience is highly likely to improve the technological performance of firms pursuing either vertical integration or outsourcing strategy. When considering the vertical integration strategy, prior innovation experience allows firms to improve new knowledge identification and acquisition capabilities, but also to develop new internal routines, expertise, and mechanisms that facilitate the acquisition of new knowledge and integration of the new knowledge into existing knowledge, leading to the improvement of technological performance.

However, although prior innovation experience can enhance the performance of firms pursuing an outsourcing strategy still firms pursuing a vertical integration strategy with prior innovation experience outperform. Because firms with vertical integration strategy can better control the employees than controlling suppliers with the virtue of prior innovation experience. Even if firms acquire a deep understanding of the knowledge in the domain of their suppliers through prior innovation experience, a high level of technological fluctuations can make the writing and enforcement of contractual arrangements very difficult It is also uncertain whether technological know-how necessarily leads to market success. Adding new knowledge or redesigning current technologies for their integration with new technologies can be more effective courses of action, degrading the value of selected technologies. Thus, on account of the unpredictability from technological changes, increased amounts of relevant component knowledge garnered through prior innovation experience can diminish suppliers' opportunistic behaviors to a great degree (Mayer and Salomon, 2006), nonetheless, it may not guarantee to account for all possible contingencies. Not surprisingly, this renegotiation cycle can expose transaction partners to opportunistic behaviors which leads to relatively lower performance (Leiblein et al., 2002). Assuming a supplier that does not show any opportunistic behavior, still, a supplier's limitations in providing quality products at the right time may become obsolete due to radically changing technology, has negative performance implications. Given that prior innovation experience distinctively affects vertical integration and outsourcing strategies, it would be interesting to explore the interplays among innovation shock, strategic sourcing and prior innovation experience.

Strategic Sourcing and Market Dynamics

The external environment can potentially influence the internal decisions of a firm. Uncertainty in the external environment is one such decision that may impact strategic sourcing decisions of a firm. Although the transaction cost economics (TCE) literature has widely asserted that when uncertainty is high, vertical integration is a superior strategic choice (Leiblein and Miller, 2003, Williamson, 1981, Williamson, 1991). However, starting from the seminal work of Balakrishnan and Wernerfelt (1986), an opposing argument suggests under certain conditions, such as fear of technological obsolescence (Balakrishnan and Wernerfelt, 1986), regulatory restriction (Gil and Ruzzier, 2018) and innovation shock (Park et al., 2018), vertical integration is not a superior strategic choice. A recent discussion in this area suggested that competition is another cause of uncertainty that may affect vertical integration decisions (Bloom et al., 2012, Bloom and Van Reenen, 2007). However, there is little empirical research on the impact of competition on vertical integration (Gil and Ruzzier, 2018).

Prior studies examining the relationship between competition and vertical integration suggested contradictory findings. One group of scholars suggested that when competition becomes intense, firms with the goal of reducing costs begin to approach specialized external suppliers. These specialized suppliers tend to offer cost-effective components. Therefore, there is a negative correlation between competition and vertical integration (Cachon and Harker, 2002, Shy and Stenbacka, 2003). On the other hand, some scholars argued that in knowledge-intensive industries, where a systematic pattern of innovations is followed, despite the availability of suppliers offering cost-effective components, firms normally forgo this short-term cost benefit. Rather, in such industries, firms tend to pursue vertical integration so that they can maintain and upgrade their technological knowledge pool (Helfat and Campo-Rembado, 2016, Kapoor, 2013). In the same vein, Levy (1985) suggested a positive correlation between competition and vertical integration. In addition, other studies reported a U-shaped relationship between competition and vertical integration (Aghion et al., 2006). Given the inconsistent and contradictory findings in the previous literature, it is interesting to further explore the significance of this relationship.

Despite the presence of the correlation between competition and vertical integration, it will be interesting to uncover the direction of causality between these two variables. One augment is that reduction in the level of vertical integration (or increase in the level of non-integration) diminishes a firm’s distinctive features and promotes standardization in the market. This standardization reduces the entry barriers and new entrants can intensify the competition (Bettis et al., 1992). Thus, vertical integration determines the level of competition in the market. However, this argument is empirically not well supported. Recently, Gil and Ruzzier (2018) addressed the same question and found empirical support for the opposite direction of this causal relationship i.e. competition determines the level of vertical integration.

In response to increasing competition, one possible strategic action is to alter technological niche breadth (Bayus and Putsis, 1999, Giachetti and Dagnino, 2014, Shugan, 1989). By doing so, a firm can prevent the entry of new entrants and capture new customers by providing differentiated products that best meet the needs of new customers (Schmalensee, 1978). This new entry into previously untargeted market provides firms with an opportunity to increase market share and may also compensate for the damage occurred due to the increase in competition in the previously targeted markets. However, this approach may lead to diseconomies associated with design, production, and distribution (Aaker and Joachimstahler, 2000, Kumar, 2003). Also, it may threaten the present competitive position of the firm's products due to the sharing of resources and focus between new and old markets (John et al., 1998, Morrin, 1999). In this situation, a firm may decide to reorient its resources from low-selling technological niches to high-selling niches, thereby narrowing the technological niche breadths (Draganska and Jain, 2005).

Prior research suggests that at the early stage of technological evolution, firms are normally vertically integrated. Over time, at the later stages of technological evolution specialized suppliers' market emerges encouraging firms to switch towards non-integration (Klepper, 1997). Despite, these specialized suppliers generally offer less expensive solutions and most firms tend to switch towards non-integration, some firms however still prefer vertical integration. This situation leads to the co-existence of vertical integrated and non-integrated firms (Colfer and Baldwin, 2010). The prevalent explanation for this co-existence is that vertical integration enables firms to develop integrative capabilities. These capabilities facilitate the communication and coordination required for knowledge accumulation and are therefore essential for firms competing in industries that follow a pattern of successive systemic technological innovations (Helfat and Campo-Rembado, 2016, Kapoor, 2013).

Another explanation for not switching towards less expensive specialized suppliers is a firm's tendency towards offering products with a wider technological niche breadth. Argyres and Bigelow (2010) have recently suggested that it is difficult for firms offering products with a wider technological niche breadth to find suppliers providing components with appropriate features and tailored designs. Even in case of suppliers are available, assets specificity associated with for these customized components may cause additional costs. Crafting and enforcing contracts with suppliers may also cause additional costs (Mayer and Argyres, 2004). In addition, a supplier after realizing the firm's dependence may show opportunistic behavior which also undermines a firm's performance. Considering these factors, firms offering products with a wider technological niche breadth tend to pursue vertical integration. Given that expansion and contraction in technological niche breadths can be a strategic choice in the face of stiff competition, it is interesting to explore how firms can better utilize this strategic option for superior performance.

Final Remarks

The critical review presented in this chapter provides an overview of the different theoretical lenses and the research perspectives upon which the key arguments of this dissertation are developed. First, previous literature suggests that strategic sourcing decisions are made in light of the evolution of the industry. The same strategic sourcing decision (i.e. vertical integration or outsourcing) can have different effects on performance, depending on the early or late period of technological evolution. Second, the literature suggests that weakness or disadvantages associated with the strategic sourcing alternative can be mitigated by creating certain conditions (such as the long-term relationship with suppliers can help firm overcoming disadvantages associated with an outsourcing strategy). Thirdly, the literature underscores the positive role of prior innovation experience for performance advantages of each strategic sourcing alternative. Finally, the crucial role of market dynamics, in particular, product market competition and technological niche width, is examined in relation to the strategic sourcing and performance implications. This chapter provides the extensive background knowledge that serves as building blocks for hypotheses development presented in the main studies of this dissertation (Chapters 4, 5 and 6).

CHAPTER 3

EMPIRICAL SETTING - UNITED STATES AUTOMOBILE INDUSTRY

Chapter Introduction

In this chapter, I explain the overall empirical setting that is employed in three essays of this dissertation. In the first section, I explain the rationale for selecting the United States automobile industry as an empirical setting. The main objective is to explain how new technologies have affected the automobile industry and what other relevant factors may have had an impact on strategic sourcing, market dynamics, and performance. In the second section, I explain the data sources employed, and measurement of the main variables of this dissertation.

Industry Selection

Automobile Industry 1990 -1999

The United States automotive industry has experienced major technological changes during the period from 1990 to 1999. In the late 1980s and early 1990s, conventional internal combustion engine (ICE) technology was criticized mainly for two reasons. First, due to emissions of carbon dioxide this technology was considered as a major cause of environmental pollution and climate change. Second, macroeconomics level issues were highlighted by arguing that ICE burns fossil fuels that have a limited supply; therefore, the demand-supply mismatch was predicted as a major cause for future economic crises. While the incumbent firms were making profits through well-established ICE technology, they were reluctant to address these issues related to environment and macroeconomics. Considering these circumstances, the U.S. government decided to impose regulatory pressure on auto-manufacturers to produce fuel efficient and environment-friendly vehicles. Starting from 1990 the Zero Emission Vehicle (ZEV) mandate - introduced by the Californian Air Resources Board's (CARB)[1]- has been continuously pushing auto-manufacturers to produce environment-friendly vehicles and consequently address the aforementioned issues.

The automobile industry started two major initiatives to comply with restrictions imposed by the ZEV mandate. First, they refined conventional ICE technology to reduce the emissions of carbon dioxide (CO_2). These improvements were incremental in nature. Since this research focuses on major technological changes, studying these refinements and incremental innovations is, therefore, beyond the scope of this dissertation. The second initiative was the introduction and development of new technologies. Between 1990 and 1999, car manufacturers experimented with different environmentally friendly vehicle technologies such as E85, CNG (dedicated and Bi-Fuel), Propane (dedicated and Bi-Fuel), Hydrogen, Methanol (M85) and Electric Vehicles (collectively referred to as prior green innovation experience). Table 3.1a and Table 3.1b present the summary of automobile industry's efforts in producing green vehicle technologies to comply with the ZEV mandate. However, none of these technologies were commercially viable until 1999, when Toyota launched the first hybrid electric vehicle (HEV) in the U.S. market. HEV used the battery as a power source instead of fossil fuels, and electric motor as a source to generate the energy required for the movement of wheels. This battery-motor propulsion mechanism challenged the dominant

[1] Detailed information about CARB regulation can be found at https://www.arb.ca.gov/msprog/zevprog/zevregs/zevregs.htm

design of conventional ICE. The drivetrain system of a hybrid electric vehicle comprises of six main components: battery, motor, engine, transmission, DC-DC converter, and DC-AC converter.

Automobile Industry 1999 -2008

Starting from 1999, the automobile industry has commercialized various vehicle technologies under the umbrella of battery-motor propulsion mechanism most prominently Hybrid Electric Vehicle (HEV), Fuel Cell Electric Vehicle (FCEV), Plug-in Hybrid Electric Vehicle (PHEV) and Electric Vehicle (EV). Appendix A explains the underlying propulsion mechanism in each of these technologies in comparison to ICE technology (Plugin, 2014). Appendix B presents the adoption timing of each of these green vehicle technologies.

Toyota's first HEV model offered in the U.S. market had exceptional fuel consumption and road performance. That motivated other auto-manufacturers to adopt HEV. Despite the successful commercialization of the first HEV model in 1999, the market share of these vehicles was very low during the early years. As figure 3.1 shows, the market share of HEV was less than 4% during the period from 1999 to 2008. However, some factors significantly contributed to enhancing the market share over time.

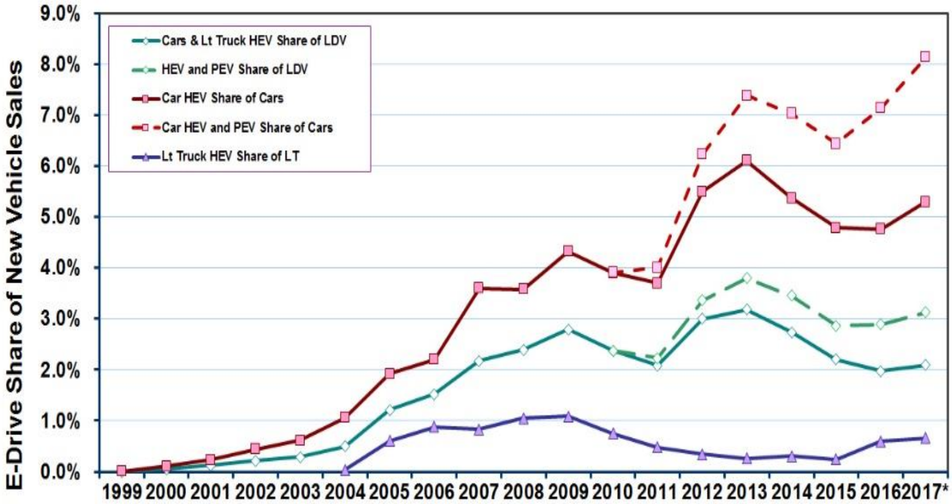

Figure 3.1: Market Share of HEV

Source: Anl (2014)

First, the enforcement of the progressive restrictions by the U.S. government, which hard-pressed auto-manufacturers and parts suppliers to invest in research and development activities. Figure 3.2 presents the timeline of the progressive restrictions under CARB's ZEV mandate. As a result of these restrictions, research and development activities were intensified that resulted in significant improvements in the component technologies. For instance, the battery technology evolved from Lead-acid to Nickel metal hydride and then to Lithium-ion. As figure 3.3 shows, Lithium-ion technology has better "acceleration power" and "driving range per charge"[2] than Nickel metal hydride and Lead-acid battery technologies.

[2] The current driving range per charge is approximately 300 km, however, to match the performance of the ICE technology this range should be atleast 500 km (Amine, 2010).

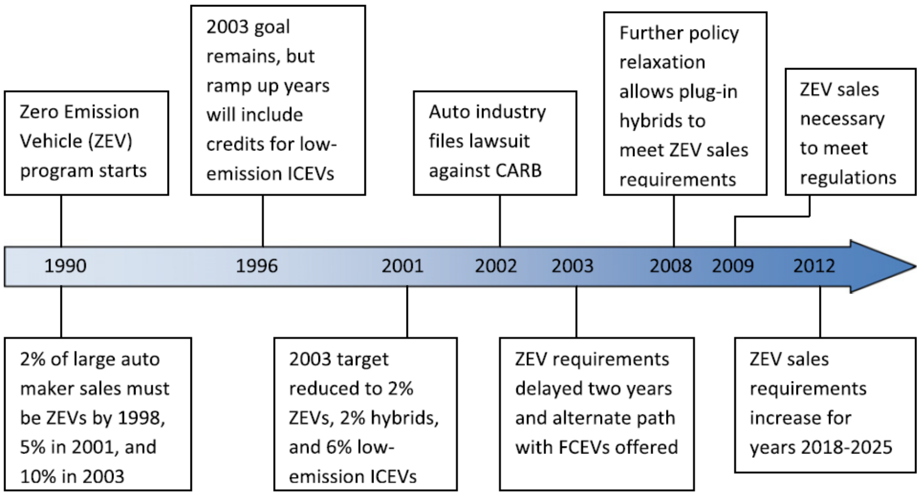

Figure 3.2: Timeline of the Progressive Restrictions Under CARB's ZEV Mandate

Source: Sierzchula and Nemet (2015)

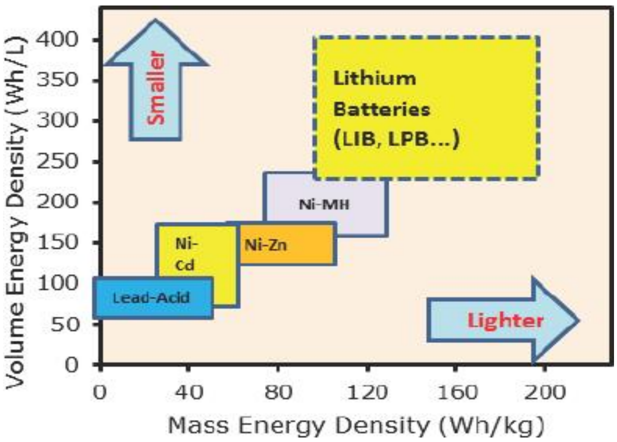

Figure 3.3: Volume Energy-Density and the Mass Energy-Density for Various Battery Types

Source: Amine (2010)

Second, vehicle component prices significantly reduced over time. For instance, the research and development in component technologies and stiff competition among suppliers resulted in a significant reduction in prices of lithium-ion battery technology as shown in figure 3.4. Panasonic holds the largest share in the lithium-ion battery market, followed by LG Chem and Samsung, cumulatively these three suppliers' control about 55% of the market share. These suppliers' firms among others are continuously making efforts to improve battery technology to achieve the desired goal of 500 km driving range per charge.

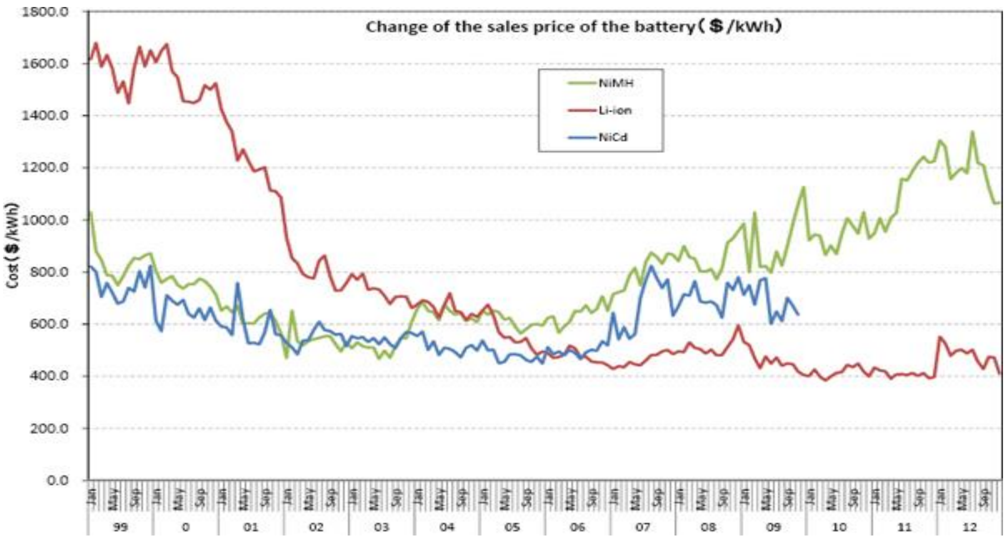

Figure 3.4: Cost of Battery Technologies Over Time
Source: Maruyama (2013)

Third, the worldwide oil crisis during the period from 2004 to 2008 facilitated the diffusion of HEV technology. The sudden and significant increase in oil prices shifted the customer preferences towards fuel-efficient vehicles as shown in figure 3.5. To be successful in the HEV market, automobile manufacturers need to acquire new knowledge in the external domains such as electronics, control devices, motor, and battery technologies among others. Some auto-manufactures preferred a vertical integration strategy while others opted for outsourcing strategy. Appendix C presents an overview of sourcing strategies adopted by major automobile firms regarding the main components of different HEV based models.

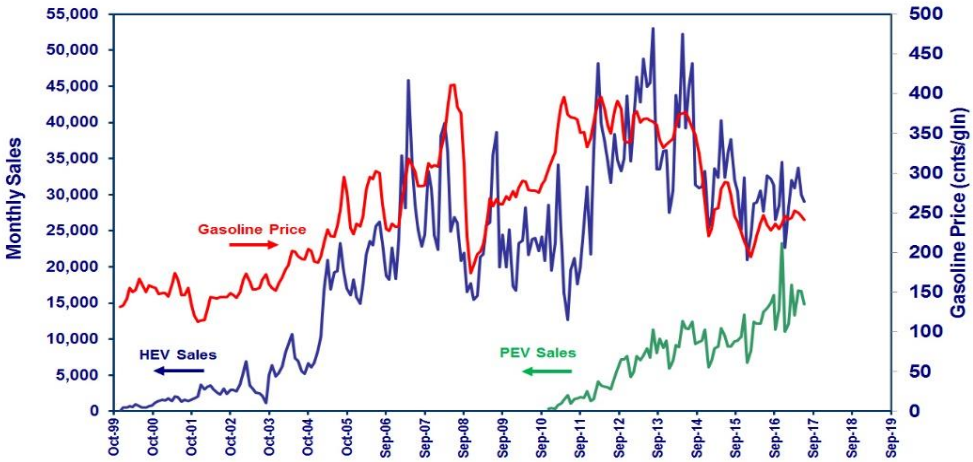

Figure 3.5: U.S. HEV Sales Overlapped with U.S. Gasoline Prices.

Source: Anl (2014)

The drivetrain mechanism of the HEV-based vehicle differs fundamentally from that of the internal combustion engine-based vehicle (Berger, 2009). HEV uses a battery as a power source instead of fossil fuels, and electric motor as a source to generate the energy required for the movement of wheels. The basic principle of an HEV's transmission is to regulate the sources of power generation (engine and motor) and power storage (fuel tank and battery) to an optimal level. The battery and electric motor components, therefore, take the central position of importance in HEV drivetrain as compared to the combustion engine and gearbox components in conventional vehicles. The electric motor technology has remained somewhat stable over the years, the battery system technology, however, has evolved rapidly over this study period (Gaines, 2014). In addition, a higher power-to-weight ratio is considered a critical success factor for any HEV (Amine, 2010).

Although the HEV transmission is composed of six essential components – namely, the battery system, traction motor, transmission system, DC-DC converter, DC-AC converter, and engine (Erjavec, 2013), the battery system has a central position in achieving the required performance (Erjavec, 2013, Golembiewski et al., 2015).

Table 3.1a: Original Equipment Manufacturer: Green Vehicle Models Offerings by Fuel Type 1991-2017[3]

Fuel Type	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**Total**
E85	0	1	1	1	0	1	1	2	6	8	11	16	22	19	24	**1420**
CNG (Dedicated and Bi-Fuel)	0	2	2	2	10	10	9	12	16	15	16	18	16	16	5	**458**
Diesel	17	14	5	12	13	12	11	11	7	3	3	4	4	7	8	**679**
Electric Vehicle*	0	0	0	0	1	0	3	8	16	12	10	6	5	1	0	**420**
Hybrid	0	0	0	0	0	0	0	0	0	2	2	3	3	3	8	**660**
Propane (Dedicated and Bi-Fuel)	0	0	0	0	0	0	3	3	5	2	5	5	1	1	0	**140**
Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**24**
Methanol (M85)	2	2	4	2	2	1	1	0	0	0	0	0	0	0	0	**28**
Total	**19**	**19**	**12**	**17**	**26**	**24**	**28**	**36**	**50**	**42**	**47**	**52**	**51**	**47**	**45**	**3829**

Table 3.1b: Original Equipment Manufacturer: Green Vehicle Models Offerings by Fuel Type 1991-2017

Fuel Type	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Total**
E85	22	31	31	36	34	72	62	84	90	84	66	45	**657**
CNG (Dedicated and Bi-Fuel)	5	1	1	1	1	1	6	11	19	17	12	9	**84**
Diesel	6	7	6	12	14	16	17	22	35	39	29	21	**224**
Electric Vehicle*	0	0	1	1	1	2	6	15	16	27	29	51	**149**
Hybrid	8	11	16	19	20	29	31	38	43	46	31	44	**336**
Propane (Dedicated and Bi-Fuel)	0	0	1	1	0	0	1	6	14	10	5	8	**46**
Hydrogen	0	0	0	0	0	0	1	1	2	3	3	2	**12**
Methanol (M85)	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total	**41**	**50**	**56**	**70**	**70**	**120**	**124**	**177**	**219**	**226**	**175**	**180**	**1508**

[3] Data Source: AFDC www.afdc.energy.gov/afdc/ (all years for AFVs), fueleconomy.gov (all years for diesels, count all models and transmission types)

Automobile Industry 2008 -2017

Given that HEV technology achieved some initial success in the market till 2008, based on this technology some other technologies surfaced during the period from 2008 to 2017 notably[4] FCEV in 2008, PHEV in 2011 and EV in 2012. The drivetrain mechanism of each of these technologies was significantly different than others but overall all these technologies followed battery-motor propulsion mechanism initially offered by HEV technology. In addition, HEV technology experienced the significant refinement and significantly increased its market share. Although PHEV, FCEV, and EV technologies paved some commercial success during the period from 2008 to 2017, this dissertation only focuses on the U.S. HEV market.

Data Sources

To examine the effect of sourcing strategies on performance, this dissertation investigates the U.S. hybrid electric vehicle. I gathered data from several archives such as *MarkLines Information Platform*- a proprietary database, *Alternative Fuels Data Centre*, *Advanced Vehicle Testing* - U.S. Department of Energy National Laboratory, *United States Patent and Trademark Office* (USPTO), *J.D. Power and Associates*, *Thomson Reuters Eikon* database, *Complete Catalog of Cars*, *Factiva*- industry news, *Business Source Complete* database, *Hybrid Cars*- a trade magazine, *Autonews* magazine, industry reports, and annual reports of firms. The sample includes 67 HEV models offered by 14 unique firms in the US

[4] Although starting from 1991, auto-manufactures have experimented different fuel type vehicles notably, E85, CNG (Dedicated and Bi-Fuel), Propane (Dedicated and Bi-Fuel), Methanol (M85) but none of these fuel type vehicles got market success. The detailed information about these vehicle technologies can be found at https://www.afdc.energy.gov/data/10303

market from 1999 to 2017. Table 3.2 presents the definitions, measurements and data sources of main variables.

Table 3.2: Main Variables, Definitions, Measurements, and Data Sources

Variables	Definition	Measurement	Data Sources
Governance Choice (Vertical Integration) (Outsourcing)	Vertical Integration: Incumbent firm design and manufacture components in-house. Outsourcing: Supplier design and manufacturing of components.	Average of drivetrain system components designed and manufactured in-house by the incumbent firm. Since most of the firms in our sample were not fully vertically integrated or non-integrated (Outsourcing), vertical integration measure ranges between 0 and 1. Binary (1, 0) measure that takes the value of "1", when automobile firm pursued outsourcing strategy for battery component otherwise a value of "0" (Argyres and Bigelow, 2010, Novak and Eppinger, 2001, Novak and Stern, 2008, Novak and Stern, 2009)	Marklines database
Environmental Performance (Greenhouse gas score) (Environmental performance score)	The U.S. Environmental Protection Agency conducts laboratory testing of each hybrid electric vehicle model and based upon the level of tailpipe carbon dioxide emissions, it provides EPA and GHG scores to each vehicle-model-year	Higher EPA / GHG score suggests a lower level of carbon dioxide emissions. "10" is the highest score "1" is the lowest score (Mahmoudzadeh et al., 2017, Messagie et al., 2015, Palencia et al., 2017)	U.S. Environmental Protection Agency database
Early Stage Product Quality Performance	This measure is based on customer feedback about the problems related to the battery component.	Based upon customer feedback during the first 90 days of their purchase J.D. Power gives rating scores to each vehicle-model-year.	J.D. Power and Associates database

Later Stage Product Quality Performance		"5" being the best "2" the worst Based upon customer feedback after 3 years of vehicle usages, J.D. Power gives rating scores to each vehicle-model-year "5" being the best "2" the worst Kalaignanam et al. (2017)	
Prior Green Innovation Experience	Automobile firms experience with other green vehicle technologies before the launch of the hybrid electric vehicle market.	Count of the number of green vehicle models offered from 1991 (the year of the ZEV launch) until the commercialization of the first HEV by the given firm (Benner and Tripsas, 2012)	Alternative Fuels Data Centre database
Outsourced Component Knowledge (In house component knowledge)	Battery-specific patents granted to each automobile firm by USPTO.	Based on the definitions provided by the *World Intellectual Property Organization (WIPO)* through the *International Patent Classification (IPC)* system, I identified battery-specific patents granted to each firm and used a 5-year moving window. Table A1 presents the details of IPC sub-classes of major HEV drivetrain components (Borgstedt et al., 2017, Mawdsley and Somaya, 2018, Wu and Mathews, 2012)	USPTO database
Competition	Direct rivalry among hybrid electric vehicle models in the U.S. market.	I utilized two proxies for competition. *Competition-I* has been computed by counting the number of HEV models offered by rival firms in the U.S. market in a given year.	Marklines database

		Competition-II has been computed based on the entropy measure that takes into account the number of models and the number of firms (Anand et al., 2016, Barroso and Giarratana, 2013, Danzon and Sousa Pereira, 2011, Federico et al., 2018, Gil and Ruzzier, 2018, Mulotte, 2014, Mulotte et al., 2013, Tripsas, 1997).	
Technological Niche Width	Range of engine capacity (in horsepower) across all HEV models in the given year. Firms producing vehicles with a wider range of engine capacity have greater technological niche width compared to those firms producing vehicles with similar engine capacity	I computed a firm i's technological niche width at time point t using below formula $$Technological\ Niche\ Width_{it} = Emax_{it} - Emin_{it}$$ where $Emax_{it}$ and $Emin_{it}$ indicates a firm ***i***'s largest and smallest engine capacity in year ***t*** respectively industry (Argyres et al., 2015, Dobrev et al., 2001, Dobrev et al., 2002).	Marklines database J.D. Power and Associates database Consumer Reports database
Technological complexity	In battery systems, technological complexity arises in an effort to maintain a balance between battery power, drive per charge, and weight.	I used a composite measure based upon • *battery type (lead acid, nickel-metal hydride, lithium-ion, and lithium polymer),* • *total voltage of battery pack(s), and* • *battery specific energy (Watt-hr/kg)* The underlying intuition is that batteries with high voltage, high power, and advanced type tend to be technologically complex Kalaignanam et al. (2017)	Marklines database

Final Remarks

In summary, the U.S. government has forced automakers to produce fuel efficient and environmentally friendly vehicles under CARB's ZEV mandate. In response, a breakthrough innovation in the form of the first HEV surfaced. Toyota pioneered HEV technology by introducing the first HEV-based vehicle model to the US market in 1999. Following this breakthrough innovation, the automotive industry has experimented with other competing technologies such as PHEV, FCEV, and EV. All of these technologies used a similar mechanism of battery-motor propulsion. Initially, the market share of these vehicles was very low, but some factors contributed to the success of these new technologies. The main factors were the improvement of battery technology, the reduction in selling prices of the more efficient lithium-ion batteries and a surge in oil price from 2004 onwards. To be successful in the HEV market, automobile manufacturers need to acquire new knowledge in the external domains such as electronics, control devices, motor, and battery technologies among others. Some auto-manufactures preferred a vertical integration strategy while others opted for outsourcing strategy. Given that the main objective of this dissertation is to examine the performance of incumbent firms' strategic sourcing, this industry thus provides an excellent setting to test our predictions. The first specific question addressed in Chapter 4 focuses on six major drivetrain system components (battery, motor, engine, transmission, DC-DC converter, and DC-AC converter) during the period from 2008 to 2016. Regarding second and third specific questions of this dissertation (Chapters 5 and 6), I focused on battery component during the period from 1999 to 2017.

CHAPTER 4

IMPACT OF COMPETITION ON VERTICAL INTEGRATION: ROLE OF TECHNOLOGICAL NICHE WIDTH[5]

Introduction

The level of competition in the market influences the internal decisions of a firm. Vertical integration- to make components within the firm or buy from outside suppliers- is one such internal decision. Although many studies have shown a correlation between competition and vertical integration, the findings are contradictory (Cachon and Harker, 2002, Shy and Stenbacka, 2003, Aghion et al., 2006, Bloom et al., 2012, Gil and Ruzzier, 2018). Some studies have shown a positive correlation (Levy, 1985), others a negative correlation between competition and vertical integration (Cachon and Harker, 2002, Shy and Stenbacka, 2003). Moreover, the direction of causality between competition and vertical integration has remained unclear until recently when Gil and Ruzzier (2018) suggested competition determines the level of vertical integration. Specifically, they suggested that in high competition, firms should reduce the level of vertical integration. However, some firms continue to pursue vertical integration regardless of external environmental factors (Helfat and Campo-Rembado, 2016, Kapoor, 2013). This study aims to explore the heterogeneity in firms' vertical integration strategy in the face of high competition.

[5] This study has been resubmitted to Business Strategy and the Environment after a series of revisions and submissions rounds and is currently under review. I presented an abridged version of this study at the Production and Operations Management Society Conference (2019), USA. Additionally, I would like to thank Professor Young Ro for his valuable comments on this study.

Prior literature has suggested that a firm can better manage intense competition by changing the technological niche width of its products (Bayus and Putsis, 1999, Giachetti and Dagnino, 2014, Shugan, 1989). Related research has suggested that technological niche width has an impact on vertical integration decision (Argyres and Bigelow, 2010). Considering the critical role of technological niche width in the relationship between competition and vertical integration, this study proposes two arguments. First, the technological niche width mediates the relationship between competition and vertical integration. Second, the technological niche width and vertical integration play complementary roles in enhancing firm performance.

This study investigates the U.S. hybrid electric vehicle market from 2008 to 2016 for empirical support. Although this market emerged in 1999, initially the level of competition in this market was very low. However, starting from 2008 onwards this market has experienced a significant increase in competitive pressure. The focus of this study is on firms' vertical integration strategies for the main components of the HEV powertrain value chain (that includes the battery, motor, inverter, DC-converter, engine, and transmission). In addition, incumbent firms have made various adjustments in their product technological niche widths. Given the surge in competition, heterogeneity in firms' level of vertical integration and technological niche width, this market provides an ideal setting for testing the arguments proposed in this study. Empirical support is found for the arguments suggested.

This study contributes to the literature on strategy and technology management by linking three distinct but related research streams: competition, vertical integration, and technological niche width. The mediating role of technological niche width in the relationship between competition and vertical integration is highlighted. In addition, it suggests that technological niche width and vertical integration play a complementary role in enhancing firm performance. To the best of our knowledge, this is the first study in this direction that provides meaningful insights, with both theoretical and managerial implications, on the beneficial role of technological niche width.

Theory and Hypotheses

Competition and Vertical Integration

Uncertainty in the external environment may influence the internal decisions of a firm. The transaction cost economics (TCE) literature has widely asserted that when uncertainty is high, firms should pursue a vertical integration strategy (Leiblein and Miller, 2003, Williamson, 1981, Williamson, 1991). However, starting from the seminal work of Balakrishnan and Wernerfelt (1986), some scholars have suggested that under certain conditions, such as fear of technological obsolescence (Balakrishnan and Wernerfelt, 1986), regulatory restriction (Gil and Ruzzier, 2018) and innovation shock (Park et al., 2018), vertical integration is not a good strategy. A recent discussion in this area has suggested that competition is another cause of uncertainty that may affect vertical integration decisions (Bloom et al., 2012, Bloom and Van Reenen, 2007). However, there is little empirical research exploring the impact of competition on vertical integration (Gil and Ruzzier, 2018).

Prior studies examining the relationship between competition and vertical integration have suggested contradictory findings. Some scholars have reported a positive relationship (Levy, 1985), a negative relationship (Galdon-Sanchez et al., 2015, Gil and Ruzzier, 2018) and a U-shaped relationship (Aghion et al., 2006) between competition and vertical integration. Apart from the contradictory findings, the direction of this relationship is also not clear. One cornerstone of research suggests that a reduction in the level of vertical integration (or increase in the level of non-integration) diminishes firms' distinctive features and promotes standardization. Increase in this standardization facilitates new entrants and ultimately intensifies the competition (Bettis et al., 1992). In broader terms, this stream of research suggests that vertical integration drives competition. However, this argument is empirically not well supported. Recently, Gil and Ruzzier (2018) found empirical support for the opposite direction of this causal relationship i.e. competition determines the level of vertical integration. Given the rare and contradictory findings regarding the impact of competition on vertical integration, it is interesting to unpack this relationship and explore under what conditions competition stimulates vertical integration. In the next section, we review the literature exploring the relationship between competition and a firm's technological niche width.

Competition and Technological Niche Width

In the face of increased competition, a possible strategic action is to adjust the technological niche width (Bayus and Putsis, 1999, Giachetti and Dagnino, 2014, Shugan, 1989). In doing so, a firm can prevent the entry of new entrants and capture new customers by providing differentiated products that best meet the needs of new customers (Schmalensee, 1978). New entry into the previously untargeted market provides firms with an opportunity to increase market share and may also offset the damage caused by increased competition in previously targeted markets. However, this approach may lead to diseconomies associated with design, production, and distribution (Aaker and Joachimstahler, 2000, Kumar, 2003). In addition, this could threaten the current competitive position of the firm's products due to the sharing of resources and focus between new and old markets (John et al., 1998, Morrin, 1999).

In this situation, a firm may decide to reorient its resources from low-selling technological niches to high-selling niches, thereby narrowing the technological niche widths (Draganska and Jain, 2005). Thus, changing the technological niche width is an effective tool for managing intense competition. It is interesting to explore how firms can better utilize this strategic option. In the next section, we review the literature exploring the relationship between a firm's technological niche width and vertical integration.

Technological Niche Width and Vertical Integration

Previous research has suggested that at the beginning of technological evolution; firms are normally vertically integrated. Over time, the specialized supplier market tended to establish, prompting firms to opt for non-integration (Klepper, 1997). While these specialized suppliers generally offer less expensive solutions, normally the majority of the firms opt for non-integration, some firms however still prefer vertical integration. This situation leads to the co-existence of vertical integrated and non-integrated firms (Colfer and Baldwin, 2010). The prevalent explanation for this co-existence is that vertical integration enables firms to develop integrative capabilities. These capabilities facilitate the communication and coordination required for knowledge accumulation and are therefore essential for firms competing in industries that follow a pattern of successive systemic technological innovations (Helfat and Campo-Rembado, 2016, Kapoor, 2013).

Another explanation for not switching towards less expensive specialized suppliers is a firm's tendency towards offering products with a broader technological niche width. Argyres and Bigelow (2010) recently suggested that it is difficult for firms offering products with a greater technological niche width to find suppliers providing components with appropriate features and tailored designs. Even if suppliers are available, asset specificity associated with for these customized components may cause additional costs (Williamson, 1985). Crafting and enforcing contracts with suppliers may also cause additional costs (Mayer and Salomon, 2006). In addition, a supplier, after realizing the dependency of the firm, may show opportunistic behaviour undermining firm performance. Given these factors, firms offering products with a broader technological niche tend to pursue vertical integration.

As suggested above, competition leads to a reduction in the level of vertical integration (Gil and Ruzzier, 2018). Also, competition can influence technological niche width (Bayus and Putsis, 1999, Giachetti and Dagnino, 2014, Shugan, 1989) and finally the technological niche width can influence a firm's decision to pursue vertical integration (Argyres and Bigelow, 2010). We bridge these arguments and propose that the relationship between competition and vertical integration is mediated by the technological niche width of a firm's product. Based upon this line of reasoning, the first hypothesis of this study is:

Hypothesis 1: The relationship between competition and vertical integration is mediated by the technological niche width.

Complementarities Between Technological Niche Width and Vertical Integration

Previous research linking vertical integration with performance suggests conflicting findings. A group of scholars argues that, at the later stage of technological evolution, when competition intensifies, firms pursuing a vertical integration strategy show superior performance (Afuah, 2001, Baldwin and Clark, 2000, Fine, 1999, Kapoor and Adner, 2012, Park and Ro, 2013). More generally, this group of scholars argues that firms pursuing vertical integration can better understand the underlying technological features at the component level as well as at the product level. Such understanding helps firms to constantly survey existing customers' demands and try to satisfy them creatively (Lubatkin et al., 2006). The second group of scholars argues that non-integration is a superior choice which enables firms to access better quality components at a lower cost (Abecassis-Moedas and Benghozi, 2012, Jaspers et al., 2012, Jones and Hill, 1988, Park and Ro, 2011). Given the contradictory findings regarding the impact of vertical integration strategy on performance, we suggest that a firm's technological niche width can help explain this burry relationship.

We propose that a firm's decision regarding its vertical integration should be in tandem with its technological niche width strategy. Firms normally market themselves either by differentiation strategy- offering products with a broader technological niche width, or by cost-reduction strategy-offering products with a smaller technological niche width (Bayus and Putsis, 1999, Giachetti and Dagnino, 2014, Shugan, 1989). Given that firms pursuing a broader technological niche width- having products in vast number of small niches- can better prevent the entry of new entrants, vertical non-integration strategy may yield inferior performance. The reason for this inferior performance is that incorporating component-level innovations into system-level features can be a daunting task. A supplier supplying poor quality components may result in a deterioration of the functionality of the product as a whole, thereby jeopardizing the reputation and performance of the buying firm. Firms offering products with a broader technological niche width, therefore, should pursue a vertical integration strategy for performance benefits. This line of reasoning leads to the second hypothesis of this study:

> *Hypothesis* 2: *Vertical integration and technological niche width play a complementary role in enhancing firm performance.*

Method

U.S. Hybrid Electric Vehicle Market

To test the hypotheses above, we examined the U.S. hybrid electric vehicle market from 2008 to 2016. The sample includes mild and full HEVs, but not plug-in hybrids and fully electric vehicles. The reason for selecting this market and the specific period are threefold. First, this market emerged in response to regulatory pressure, particularly the Zero Emission Vehicle (ZEV) mandate of the Californian Air Resources Board (CARB). The ZEV mandate required automobile firms to produce vehicles that are fuel efficient and environmentally-friendly. This regulatory pushed technological change appeared as an innovation shock for incumbent firms (Wesseling et al., 2015). Initially, due to limited capabilities, the majority of automobile firms failed to enter in the HEV market. However, starting from 2008 onwards, the majority of firms developed the required capabilities and successfully entered the market. In addition to capabilities development, some external factors such as the worldwide oil crises that shifted customer preferences towards fuel-efficient vehicles (Zhou, 2016), rapid technological advancement in battery systems (Amine, 2010) and reduction in the price of the most efficient lithium-ion batteries (Maruyama, 2013) have played a positive role in the development of the HEV market and have therefore increased competition in this market. The observation window of this study is thus quite significant. Second, despite the suppliers' market for HEV drivetrain system being significantly developed by 2008, some firms still preferred vertical integration strategy. Third, to better manage increased competition, firms started to penetrate in different technological niches to attract new customers, and thus expanded the technological niche width. Since this study aims to examine the interplays among the competition, vertical integration and technological niche width and the subsequent performance implications, we believe this market provides an ideal setting for testing the proposed hypotheses.

Sample and Data

The sample includes firms that offered at least one HEV-based model in the U.S. market during the observation period of this study. We collected data from several archival sources. We first identified the firms in our sample utilizing information available at *Alternative Fuels Data Centre (AFDC).* AFDC reports the yearly sale of all HEV-based vehicle models in the U.S. market. We gathered vertical integration data for HEV drivetrain system-specific components from *Marklines*- a leading proprietary database that tracks the global automotive industry. Vertical integration indicates that a firm has internally designed, and manufactured a given component. The data related to vehicle drivetrain system quality was collected from *Consumer Reports*, which is an independent market research company. We utilized the *U.S. Department of Energy National Laboratory* database to operationalize each vehicle's model-year environmental performance (greenhouse gas scores). Finally, we utilized the *Automobile-catalog* database to operationalize technological niche width (engine horsepower) for each firm in a given year.

To collect information required to measure the control variables of this study, we utilized several databases such as *Thomson Reuters Eikon*, *Statista, Business Score Complete and Advanced Vehicle Testing Activity* – conducted by *Vehicle Technologies Office*. In addition, we also utilized firms' annual reports, industry publications, *Hybrid Cars* magazine, and *Autonews* magazine.

Measures

Dependent Variables

Vertical Integration

We measured *vertical integration* as a percentage of the drivetrain system produced internally. For a given model in a year, if a firm has internally manufactured all major drivetrain-related components (specifically, battery, motor, engine, transmission, inverter, and DC converter), we coded that model-year as 1. On the other hand, if a firm has outsourced all these components for a given model in a year, we coded that model-year as 0. Since, most of the firms in our sample were not fully vertically integrated or non-integrated, our vertical integration measure thus ranges between 0 and 1. This measure is in lines with previous studies on the automobile industry (Argyres and Bigelow, 2010, Novak and Eppinger, 2001, Novak and Stern, 2008, Novak and Stern, 2009).

Environmental Performance

Given that the main purpose of hybrid electric vehicle technology is to offer environmentally friendly and fuel-efficient vehicles, in order to ensure compliance with CARB requirements, the *U.S. Environmental Protection Agency (EPA)* regularly conducts laboratory testing and publishes greenhouse gas scores (GHG) foreach vehicle model. A higher GHG score suggests lower tailpipe emissions of carbon dioxide (Mahmoudzadeh et al., 2017, Messagie et al., 2015, Palencia et al., 2017). The GHG scoring by EPA is ordinal in nature with “10” being the highest and “1” being the lowest scores. Our GHG score-based approach is, therefore, an appropriate measure of environmental performance.

Product Quality Performance

Although hybrid electric vehicles are generally more environmentally friendly than internal combustion-based vehicles, customers were initially reluctant to adopt this technology. It was assumed that HEV provides an inferior drive experience compared to ICE-based vehicles. Since our first performance measure (i.e. environmental performance) is primarily focused on technical aspects (i.e. emissions of carbon dioxide), in order to have a more robust performance impact of vertical integration and technological niche width strategies, we have used another performance measurement, namely product quality performance. This measure is based on customer feedback.

Consumer Reports conducts an annual survey and asks customers to share their experiences and problems with “*alternator, starter, hybrid/electric battery replacement, hybrid/electric battery related systems, regular battery, battery cables, engine harness, coil, ignition switch, electronic ignition, distributor or rotor failure, spark plugs and wires failure”*. Given that all these small components belong to HEV drivetrain system (National Research

Council, 2015), the use of these scores for measuring product quality performance for HEV drivetrain system is quite meaningful.

Based upon this feedback, *Consumer Reports* then publishes evaluation rating, with ratings "5" being the best and "1" the worst. We utilized this evaluation rating to operationalize the product quality performance. This measure is in lines with previous studies on the automobile industry (Kalaignanam et al., 2017, Novak and Stern, 2008). Thus, our two performance measures - environmental performance and product quality performance- allow our analysis to be more robust.

Independent Variables

Competition

We utilized two proxies for competition. *Competition-I* has been computed by counting the number of HEV models offered by rival firms in the U.S. market in a given year. Our measurement of *Competition-I* is arguably supported in the literature (Anand et al., 2016, Barroso and Giarratana, 2013, Danzon and Sousa Pereira, 2011, Federico et al., 2018, Gil and Ruzzier, 2018, Mulotte, 2014, Mulotte et al., 2013, Tripsas, 1997). *Competition-II* has been computed based on the entropy measure that takes into account the number of models and firms (Frenken et al., 2004, Wesseling et al., 2014).

Technological Niche Width

We measured a firm's technological niche width as a range of engine capacity (in horsepower) across all HEV models in any given year (Dobrev et al., 2003). This measure has been used in previous studies investigating the automobile industry (Argyres et al., 2015, Dobrev et al., 2001, Dobrev et al., 2002). Specifically, we computed a firm **i**'s technological niche width at time point **t** using below formula

$$\textit{Technological Niche Width}_{it} = \textit{Emax}_{it} - \textit{Emin}_{it}$$

where $Emax_{it}$ and $Emin_{it}$ indicates a firm ***i***'s largest and smallest engine capacity in year ***t*** respectively (Dobrev et al., 2001, Rhee et al., 2006). Thus, firms producing vehicles with a wider range of engine capacity have greater technological niche width as compared to those firms producing vehicles with similar engine capacity.

Control Variables

We have included drivetrain system-specific controls such as technological complexity, supplier availability, and strategic positioning.

Technological complexity can lead to a situation where suppliers may show opportunistic behavior and thus can negatively affect firms' performance. Previous research suggests that a firm should opt for vertical integration when the level of technological complexity is high (Ernst, 2005, Nickerson and Zenger, 2004). We followed Kalaignanam et al. (2017) for measuring the *technological complexity* variable

Supplier availability may impact a firm's decisions regarding vertical integration and technological niche width because the availability of capable suppliers can impact on bargaining powers of buyers and suppliers (Pisano, 1990, Williamson, 1985). We, therefore, have included a control variable called *supplier availability* in our analysis (Argyres and

Mostafa, 2016, Novak and Stern, 2009) and measured it by counting the number of major suppliers in drivetrain-specific components listed in the *top 100 global parts suppliers list* which is published annually by *Autonews* magazine.

Strategic positioning we have also included a vehicle-specific control called *strategic positioning*, measured by taking the natural logarithm of the vehicle price (Argyres et al., 2015, Argyres and Mostafa, 2016).

We have included firm-specific controls such as firm age, firm size, R&D intensity and innovation experience with other green vehicle technologies.

Firm size may impact a firm decision regarding R&D and in-house development and production of critical components. Large size firms having greater access to complementary resources tend to be more productive than small size firms (Cohen and Klepper, 1996, Panzar and Willig, 1981). We have used the natural logarithm of a firm's total number of employees in the given year to operationalize this variable (Rothenberg and Zyglidopoulos, 2007).

Firm age may influence a firm's decision regarding vertical integration and ultimately firm performance (Amburgey et al., 1993, Barnett, 1990). Old firms tend to have more experience, well-developed information processing structures and communication system, therefore, older firms may show superior performance. We measured firm age by counting the number of years since the incorporation of the firm to the current year of analysis.

R&D intensity is widely used as a proxy for innovation capabilities (Cohen and Levinthal, 2000, Zahra and George, 2002). The level of a firm's *R&D intensity* may influence its vertical integration and technological niche width decision. We have measured *R&D intensity* as the ratio of the firm's R&D expenditures to total sales in the given year (Eberhart et al., 2008, Manikandan and Ramachandran, 2015).

Innovation experience may also influence the firm capabilities and ultimately vertical integration decision (King and Tucci, 2002, Klepper, 2004, Eggers, 2012, Anand et al., 2016). Before the introduction of HEV, some automobile firms have experimented with different green vehicle technologies such as E85, CNG (dedicated and Bi-Fuel), Propane (dedicated and Bi-Fuel), Hydrogen, Methanol (M85) and Electric Vehicle. We categorized all these technologies as green vehicles and included a dummy variable in our analysis, where 1 indicates that the firm has *innovation experience* of green vehicles, and 0 indicates no experience (Honjo et al., 2014).

In additon, we have also controlled for industry and macroeconomics level factors in our analysis. Following previous studies on the automobile industry, we have included the annual ***industry production*** (measured by counting the number of cars produced in the auto industry), the U.S. ***gross domestic production*** (GDP) and ***inflation*** in the given year (Carroll et al., 1996, Argyres and Bigelow, 2010, Argyres et al., 2015).

Analysis

As described above, Hypothesis 1 of this study suggests that *Technological Niche Width* mediates the relationship between *Competition* and *Vertical Integration*. Baron and Kenny

(1986) suggested three essential conditions for a mediation analysis. First, the mediator (*Niche Width*) should have a significant impact on the independent variable (*Competition*). Second, in the absence of the mediator (*Technological Niche Width*), the effect of the independent variable (*Competition*) on the dependent variable (*Vertical Integration)* should be significant. Lastly, when the mediator (*Technological Niche Width*) is included in the analysis, the effect of the independent variable (*Competition*) on the dependent variable (*Vertical Integration)* should either reduce or disappear. Therefore, the three expressions to be estimated are provided as follows:

$$\textit{Technological Niche Width} = \alpha_1 + \beta_1 * \textit{Competition} + \varepsilon_1 \quad (1)$$

$$\textit{Vertical Integration} = \alpha_2 + \beta_2 * \textit{Competition} + \varepsilon_2 \quad (2)$$

$$\textit{Vertical Integration} = \alpha_3 + \beta_3 * \textit{Competition} + \beta_4 * \textit{Technological Niche Width} + \varepsilon_3 \quad (3)$$

For Hypothesis 2, the dependent variables were *Environmental Performance* and *Product Quality Performance*; both product-level measures. Given that each individual drivetrain system was the unit of analysis, the inclusion of independent and control variables at product- and firm-level variables may cause estimation problems. Specifically, same firms would have repeated observations that may lead to the violation of the independence assumptions. In such situations, the OLS estimation is considered as inefficient (Klein and Kozlowski, 2000). Since the firm-specific residuals remain constant for the same firm but change between firms, we included the firm size, age, R&D intensity, and innovation experience as firm-level effects (Bowen and Wiersema, 1999, Greene, 2003). To decide between fixed vs. random effects we conducted the Hausman (1978) specification test. The results provided justification for the random-effect model. While both the dependent variables for Hypothesis 2 are ordinal in nature, we utilized random effect ordered probit model for this analysis. Also, we included clustering option in STATA to correct standard error for robustness. The final model to test Hypothesis 2 took the form where ***i*** represents the drivetrain system, ***j*** the firm, ***k*** level of competition, ***t*** the year, and ε_{ijk} a random error term. The performance model is presented below

$$
\begin{aligned}
Performance_{ijkt} = \beta_0 &+ \beta_1 * Vertical\ Integration_{ijkt} \\
&+ \beta_2 * Technological\ Niche\ Width_{ijkt} \\
&+ \beta_3 * Vertical\ Integration * Technological\ Niche\ Width_{ijkt} \\
&+ \beta_4 * Controls_{ijkt} + \varepsilon_{ijk} \qquad (4)
\end{aligned}
$$

Table 4.1: Summary of Correlation Statistics – Study I

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Environmental Performance	1.000														
2	Product Quality Performance	-0.030	1.000													
3	Vertical Integration	+0.239*	+0.009	1.000												
4	Competition-I	-0.084	+0.496*	-0.074	1.000											
5	Technological Niche Width	+0.118	+0.127	+0.396*	-0.106*	1.000										
6	System Complexity	-0.362*	+0.101	-0.069	+0.147*	-0.015	1.000									
7	Suppliers Availability	-0.037	+0.311*	-0.044	+0.576*	+0.148*	+0.097	1.000								
8	Product differentiation	-0.823*	+0.056	-0.138*	+0.132*	-0.059	+0.455*	+0.021	1.000							
9	Firm Age	-0.183*	+0.123	-0.382*	+0.283*	-0.201*	+0.038	+0.165*	+0.184*	1.000						
10	Firm Size	+0.047	+0.148*	-0.004	-0.042	+0.547*	+0.022	+0.082	+0.114	+0.022	1.000					
11	R&D Intensity	-0.206*	-0.092	-0.233*	-0.131*	-0.087	-0.055	-0.052	+0.044	+0.198*	+0.004	1.000				
12	Industry Production	+0.151*	+0.478*	+0.116*	+0.862*	+0.027	+0.181*	+0.455*	+0.027	+0.153*	+0.063	-0.173*	1.000			
13	Gross Domestic Production	+0.120	+0.455*	+0.066	+0.801*	+0.115*	+0.225*	+0.553*	+0.016	+0.197*	+0.122*	-0.198*	+0.956*	1.000		
14	Inflation	-0.026	-0.341*	+0.002	-0.420*	-0.045	-0.088	-0.575*	-0.026	-0.124*	-0.027	+0.016	-0.415*	-0.309*	1.000	
15	Innovation Experience	+0.191*	-0.067	+0.336*	-0.273*	+0.212*	-0.332*	-0.104*	-0.249*	+0.240*	+0.117*	+0.104*	-0.115*	-0.123*	+0.045	1.000
	Mean	7.790	4.700	0.488	31.770	171.706	5.320	36.109	4.602	82.018	5.345	0.044	93100000.000	15638.240	1.744	0.818
	S. D	1.771	0.617	0.307	12.534	121.394	0.796	3.885	0.213	18.841	0.213	0.010	42100000.000	984.386	1.061	0.387
	Max	10.000	5.000	1.000	48.000	340.000	7.670	41.000	5.211	115.000	5.797	0.065	143000000.000	17092.700	3.800	1.000
	Min	3.000	2.000	0.000	0.000	0.000	3.660	24.000	4.160	23.000	4.474	0.009	9673364.000	12065.900	-0.400	0.000

*$p<0.05$

Table 4.2: Estimation Results- Mediation Analysis – Study I

	Vertical Integration	Technological Niche Width	Vertical Integration	Vertical Integration	Vertical Integration	Technological Niche Width	Vertical Integration	Vertical Integration
	Model 1	Model 2	Model 3	Model 4 (H1)	Model 5	Model 6	Model 7	Model 8 (H1)
Competition-I	-0.008 (0.004)**	-7.450 (1.580)***		-0.006 (0.004)				
Competition-II					-0.018 (0.024)	+29.199 (8.555)***		-0.035 (0.025)
Technological Niche Width			+0.001 (0.000)***	+0.000 (0.000)**			+0.001 (0.000)***	+0.001 (0.000) ***
Vertical Integration (VI)								
System Complexity	-0.001 (0.024)	-3.510 (9.483)	+0.009 (0.023)	+0.004 (0.023)	-0.001 (0.024)	-0.986 (9.045)	+0.009 (0.023)	+0.004 (0.023)
Suppliers Availability	+0.000 (0.003)	+1.049 (1.218)	-0.001 (0.003)	+0.000 (0.003)	+0.000 (0.003)	-2.108 (1.170)*	-0.002 (0.003)	+0.001 (0.003)
Product differentiation	+0.128 (0.144)	+6.454 (44.581)	+0.107 (0.137)	+0.125 (0.138)	+0.115 (0.151)	-20.839 (58.794)	+0.109 (0.137)	+0.120 (0.138)
Firm Age	-0.014 (0.002)***	-2.280 (0.533)***	-0.012 (0.002)***	-0.013 (0.002)***	-0.014 (0.002)***	-1.974 (0.750)***	-0.012 (0.002)***	-0.012 (0.002)***
Firm Size	-0.182 (0.132)	+217.655 (40.055)***	-0.282 (0.134)**	-0.308 (0.136)**	-0.123 (0.134)	+285.068 (51.515)***	-0.285 (0.135)**	-0.309 (0.136)**
R&D Intensity	+1.661 (1.992)	-444.375 (776.694)	+1.624 (1.964)	+2.132 (1.977)	+1.278 (1.995)	-2234.741 (770.101)***	+1.687 (1.965)	+2.049 (1.974)
Innovation Experience	+0.307 (0.083)***	+27.189 (26.055)	+0.311 (0.078)***	+0.290 (0.079)***	+0.000 (0.000)	+0.000 (0.000)**	+0.000 (0.000)	+0.000 (0.000)
Industry Production	+0.000 (0.000)	+0.000 (0.000)***	+0.000 (0.000)	+0.000 (0.000)	+0.000 (0.000)	+0.040 (0.028)	+0.000 (0.000)**	+0.000 (0.000)
Gross Domestic Production	+0.000 (0.000)	-0.079 (0.024)***	+0.000 (0.000)**	+0.000 (0.000)	+0.015 (0.014)	+1.705 (4.866)	+0.017 (0.014)	+0.016 (0.014)
Inflation	+0.014 (0.014)	-3.296 (6.284)	+0.020 (0.014)	+0.017 (0.014)	+0.335 (0.085)***	+60.902 (34.883)*	+0.310 (0.078)***	+0.301 (0.078)***
Constant	+1.157 (1.121)	+407.286 (435.260)	+0.432 (0.992)	+1.206 (1.099)	+0.861 (1.426)	-1717.008 (507.584)***	+0.439 (0.957)	+1.965 (1.444)
N	170	172	170	170	170	172	170	170
Overall R^2	0.542	0.657	0.584	0.585	0.512	0.480	0.584	0.582
F Statistic	85.85	143.39	98.32	99.90	75.11	77.85	98.60	100.03
Log likelihood								

***p<0.01, **p<0.05, *p<0.1 / Robust (Cluster) standard error in parentheses

Table 4.3: Estimation Results- Performance Models – Study I

	Product Quality Performance			Environmental Performance		
	Model 9	Model 10	Model 11 (H2)	Model 12	Model 13	Model 14 (H2)
Technological Niche Width (TNW)	-0.014(0.005)***		-0.022 (0.006)***	-0.006 (0.004)		-0.012 (0.004)***
Vertical Integration (VI)		-0.028 (1.146)	-3.512 (2.517)		+1.142 (1.336)	-1.691 (2.486)
VI * TNW			+0.026 (0.010)**			+0.016 (0.008)**
System Complexity	-0.696 (0.558)	-0.120 (0.467)	-1.274 (0.601)**	+1.477 (0.851)*	+1.389 (0.821)*	+1.111 (0.722)
Suppliers Availability	-0.113 (0.052)**	-0.074 (0.048)	-0.133 (0.055)**	-0.107 (0.053)**	-0.093 (0.056)*	-0.119 (0.055)**
Product differentiation	+7.344 (3.059)**	+2.124 (1.883)	+10.768 (3.173)***	-22.047 (3.921)***	-20.384 (3.535)***	-19.513 (2.898)***
Firm Age	-0.052 (0.019)***	-0.004 (0.018)	-0.044 (0.048)	-0.073 (0.034)**	-0.038 (0.033)	-0.058 (0.035)
Firm Size	+20.916 (5.502)***	+7.076 (1.394)***	+18.190 (5.539)***	+2.350 (2.596)	+0.639 (1.994)	+0.945 (2.214)
R&D Intensity	+8.273 (22.561)	+9.248 (23.594)	+36.833(60.639)	-75.414 (38.008)**	-58.465 (35.972)	-66.644 (36.167)*
Innovation Experience	-6.356 (1.946)***	-3.053 (1.450)**	-8.542 (3.536)**	+3.749 (1.812)**	+2.815 (1.432)**	+2.866 (1.466)*
Industry Production	+0.000 (0.000)	+0.000 (0.000)	+0.000 (0.000)*	+0.000 (0.000)***	+0.000 (0.000)***	+0.000 (0.000)***
Gross Domestic Production	+0.000 (0.001)	+0.001 (0.001)	+0.000 (0.001)	-0.006 (0.001)***	-0.005 (0.001)***	-0.006 (0.001)***
Inflation	-0.953 (0.497)*	-0.683 (0.424)	-1.241 (0.612)**	-0.824 (0.280)***	-0.731 (0.346)**	-0.939 (0.293)***
Constant						
N	96	96	96	123	123	123
Overall R^2						
F Statistic	110.07	210.02		123.12	68.84	154.81
Log likelihood	-24.523	-27.588	-23.204	-115.591	-116.948	-113.640

***p<0.01, **p<0.05, *p<0.1 / Robust (Cluster) standard error in parentheses

Results

Table 4.1 presents the summary statistics and correlation coefficients between the variables used in the analyses. The correlation between the main independent variables is less than 0.7, so multicollinearity is not a problem. However, a strong correlation exists between *Environmental Performance* and *Log Price* (r = -0.823), *Competition* and *Industry production* (r = 0.862), and *Competition* and *Gross Domestic Products* (r = 0.801). We dropped these controls to see if this correlation influences the estimate and we found that the results of the estimate were not affected. Thus, the final model included all control variables.

The mediation effect results are presented in Models 1 through 8 in Table 4.2. Hypothesis 1 states that technological niche width mediates the relationship between competition and vertical integration. Models 1 through 4 utilized *Competition-I* measure of competition. The coefficient of the competition variable was negative and significant in Model 1 (-0.008, $p<0.01$). This result suggests that with an increase in competition, firms are less likely to pursue vertical integration. When the technological niche width was included in Model 4, we found that the competition coefficients was still negative but no more significant (-0.006). However, the technological niche width were positive and significant (+0.000, $p<0.05$). This result suggests the presence of inconsistent meditation. Mackinnon et al. (2007) described inconsistent meditation as a case where the mediator has the opposite effect than the direct effect that may result in suppression of the total effect. For further clarity, we investigated the effect of the independent variable (competition) on the mediator (technological niche width), and the mediator (technological niche width) effect on the dependent variable (vertical integration). We found that the relationship between the independent variable (competition) and mediator (technological niche width) was negative and significant (-7.450, $p<0.01$, in Model 2). However, the relationship between the mediator (technological niche width) and the dependent variable (vertical integration) was positive and significant (+0.001, $p<0.01$, in Model 3). These results verify the presence of inconsistent meditation in our analysis. Hypothesis 1 is thus supported. Models 5 through 5 utilized *Competition-II* measure of competition. The coefficient of competition variable was still negative but not significant in Model 5 (-0.018). Given that the base argument suggesting the negitive relationship between competition and vertical integration is not supported, this measurement is not appropriate in our analysis.

Hypothesis 2 suggests the complementary role of vertical integration and technological niche width for enhancing performance. The performance models are shown in Models 9 through 14 in Table 4.3. The dependent variable for Models 9 through 11, is product quality performance. Model 9 and Model 10 present the individual effect of vertical integration and technological niche width on product quality performance respectively. Model 11 is the main interest of this study, that includes the interaction term (vertical integration* technological niche width) in addition to the main independent variables. The coefficient of the interaction term was positive and significant in Model 11 (+0.026, $p<0.05$). This result suggests that vertical integration and technological niche width complement each other for enhancing product quality performance. The dependent variable for Models 12 through 14 is environmental performance. Model 14 includes the interaction terms (vertical integration* technological niche width) in addition to main independent variables and suggests a positive and significant effect of interaction term (+0.016, $p<0.05$ in Model 14). This result supports the complementary roles of vertical integration and technological niche width for enhancing environmental performance. Thus, Hypothesis 2 is also supported.

Discussion and Conclusion

Both arguments in this study found robust empirical support in the analysis of the U.S. hybrid electric vehicle market. First, we found that the relationship between competition and vertical integration is mediated by firms' technological niche width. This finding suggests that in the presence of fierce competition, firms offering products with a greater technological niche width are more likely to pursue a vertical integration strategy than firms offering products with smaller technological niche width (standardized products). Second, we found that vertical integration and technological niche width strategies play a complementary role in enhancing firm performance.

The theoretical contributions of this study are as follows. First, this study concurs with scholars suggesting that expansion or contraction of technological niche width is an effective strategic tool to manage stiff competition (Bayus and Putsis, 1999, Giachetti and Dagnino, 2014, Shugan, 1989). Specifically, this study contributes to the existing literature in this domain by proposing the mediating role of firms' technological niche width in the relationship between competition and vertical integration. To the best of our knowledge, this is the first study in this direction. Also, agreement is shown with scholars who suggested that firms offering differentiated products are more likely to pursue the vertical integration strategy (Argyres and Bigelow, 2010).

Second, this study contributes to the transaction cost of economies (TCE) literature that addresses a key question of whether a firm should develop components from within the firm or by outside suppliers. While the TCE literature has widely suggested when uncertainty is high, firms should produce components internally (Leiblein and Miller, 2003, Williamson, 1981, Williamson, 1991), some scholars reported contradictory findings (Balakrishnan and Wernerfelt, 1986, Gil and Ruzzier, 2018, Park et al., 2018). This study further strengthened the argument suggesting competition prompts firms not to pursue verticle integration.

Third, this study contributes to the literature focusing on enhancing firm performance by suggesting that vertical integration and technological niche width strategies play a complementary role in enhancing firm performance. This study further strengthened the argument suggesting that firms pursuing vertical integration would show superior performance (Afuah, 2001, Baldwin and Clark, 2000, Fine, 1999, Kapoor and Adner, 2012, Park and Ro, 2013). Specifically, the current study suggests that the positive impact of vertical integration on performance is strengthened when the firm is offering products with a broad technological niche width.

Finally, this study also provides valuable guidance to managers and policymakers on how to achieve superior firm performance. We suggest that when devising strategies for enhancing firm performance, managers should also consider the level of vertical integration and technological niche width. Without proper alignment between the level of vertical integration and technological niche width, efforts to improve firm performance may have limited chances of success.

Limitations

The following are the main limitations of this study. First, we examined a single, idiosyncratic industry that may limit the chances of generalizability of our findings. However, it should be noted that the results are normally more accurate and robust when the analysis is conducted on a single industry. Second, our analysis focused only the HEV market, the level of competition, firm capabilities, and strategies regarding vertical integration and technological niche width in other technologies such as pure electric vehicles, conventional internal combustion engine based vehicles might influence the firm's strategic decision regarding HEV. Future research may be conducted by integrating overall firm capabilities and strategic behavior

CHAPTER 5

INNOVATION SHOCK, OUTSOURCING STRATEGY AND ENVIRONMENTAL PERFORMANCE: THE ROLES OF EXPERIENCE AND KNOWLEDGE INHERITANCE[6]

Introduction

Road transportation causes air emissions (carbon dioxide emissions) that contribute to environmental pollution and climate change (Uherek et al., 2010). In order to solve this environmental problem, the Californian Air Resources Board (CARB) mandate was introduced in 1990. Under this legislative program, car manufacturers were forced to produce vehicles that were both fuel efficient and environmentally friendly. Between 1990 and 1999, car manufacturers experimented with different environmentally friendly vehicle technologies such as E85, CNG (dedicated and Bi-Fuel), Propane (dedicated and Bi-Fuel), Hydrogen, Methanol (M85) and Electric Vehicles *(collectively referred to as prior green innovation experience).* However, none of these technologies were commercially viable until 1999, when Toyota launched the world's first hybrid electric vehicle (HEV). The drivetrain mechanism of the HEV-based vehicle differed fundamentally from that of the internal combustion engine-based vehicle (Berger, 2009); the battery and electric motor components take the central position of importance in the drive train as compared to the combustion engine and gearbox components in conventional vehicles. The emergence of HEV technology is a classic example

[6] This chaper is based on a publised study and being reproduced with the permission of John Wiley & Sons, Inc.
Khurshid, F, Park, W-Y, Chan, F. "Innovation shock, outsourcing strategy, and environmental performance: The roles of prior green innovation experience and knowledge inheritance". *Business Strategy and the Environment.* 2019; 1– 11. https://doi.org/10.1002/bse.2333

of an innovation shock (Argyres et al., 2015). Since the main objective of HEV technology is to reduce carbon dioxide emissions and to offer fuel-efficient solutions, environmental performance is therefore considered a key success factor for any HEV-based vehicle.

The problem for incumbent vehicle manufacturers at this time was to quickly acquire new knowledge and develop capabilities conducive for a new technology paradigm (Anderson and Tushman, 1990, Tushman and Anderson, 1986). Since the required knowledge is often inherited from other industries, the literature on technology and strategic management has underscored the importance of pursuing an outsourcing strategy. This strategy allows firms to search for new knowledge beyond their internal boundaries (Powell et al., 1996, Womack et al., 1990) and helps firms develop required capabilities by reconfiguring information-processing arrangements (Abecassis-Moedas and Benghozi, 2012, Ahuja and Lampert, 2001, Jaspers et al., 2012, Jones and Hill, 1988, Leonard-Barton, 1992, Park and Ro, 2013). Considering the benefits of the outsourcing strategy in the face of an innovation shock, the current study's focus is on the role of using the outsourcing strategy for environmental performance improvement.

Despite the critical role of the outsourcing strategy in acquiring new knowledge and capabilities, this strategy presents (at least) two critical challenges for dealing with suppliers (Park et al., 2018). First, incumbent firms will have developed firm-specific communication channels and routines with current suppliers to facilitate the appropriate diffusion and transformation of current knowledge (Monteverde, 1995). These effective and superior communication channels with current suppliers may create a situation of lock-in, turning core competencies into core rigidities when dealing with a new innovation shock (Leonard-Barton, 1992). Second, since firms lack the direct authoritative mechanisms to control suppliers when pursuing an outsourcing strategy, they cannot fully control suppliers' opportunistic behaviors (i.e., shirking and hiding information as to whether their component satisfy critical CARB mandates) (Williamson, 1985). In essence, while the outsourcing strategy is very critical in helping incumbents acquire new knowledge and capabilities required in dealing with an innovation shock, incumbents must manage these two challenges in dealing with suppliers to obtain desirable environmental performance.

Given that, this study aims to examine ways to effectively and efficiently manage the outsourcing strategy to improve environmental performance. The overarching arguments of this study are that prior green innovation experience (*PGIE*) may allow incumbents and their suppliers to avoid becoming rigidly locked into existing processes and communication routines through frequent experimentation and prior green innovation experiences. In addition, possessing knowledge regarding outsourced components (*OCK)* in-house can help incumbents mitigate the opportunistic behaviors of suppliers. *PGIE* and *OCK* thus play a complementary role in improving environmental performance.

This study examines the U.S. hybrid electric vehicle market from 1999 to 2017, a period during which this market emerged and experienced major technological changes. The outsourcing strategy for vehicle battery systems – a critical component of both the HEV powertrain and value chain, and a primary determinant of the environmental performance of the vehicle – has been investigated. Given that most automakers pursued an outsourcing strategy for battery systems, this market provides an ideal setting for testing the arguments proposed in the current study. Empirical support is found for the arguments presented.

The main contribution of this study is therefore to help us better understand the conditions under which firms pursuing an outsourcing strategy can significantly improve environmental performance by suggesting the complementary role of *PGIE* and *OCK*. This study bridges two distant but related scholarly streams by proposing that the joint possession of *PGIE* and *OCK* lead to superior environmental performance, providing imperative managerial implications regarding how incumbents pursuing outsourcing can improve environmental performance in the face of an innovation shock.

Theory and Hypotheses Development

Environmental performance is broadly defined as the impact of a firm's activities on environmental conditions (Claver et al., 2007). It is therefore important to take into consideration the environmental aspect while making organization-level decisions. The previous literature suggests that diverse strategic decisions can play a significant role in enhancing environmental performance – top management support (Pujari et al., 2003), regulatory compliance policy (Nyiwul et al., 2015), corporate political strategy (Cho et al., 2006) and lean production strategy (Maxwell et al., 1998) among others.

However, there is a dearth of studies exploring the importance of the role of the outsourcing strategy for enhancing environmental performance in the context of an innovation shock. An innovation shock indicates a situation where an innovator(s) hits the market with a revolutionary breakthrough, which is disruptive to incumbents (followers). For survival in the market, incumbents need to develop and acquire knowledge and capabilities newly required in dealing with a new innovation (Anderson and Tushman, 1990, Tushman and

Anderson, 1986). The outsourcing strategy helps firms searching for new knowledge beyond their internal boundaries, and fosters the more efficient build-up of new capabilities (Abecassis-Moedas and Benghozi, 2012, Hill and Hoskisson, 1987, Park and Ro, 2011, Powell et al., 1996, Womack et al., 1990). This study develops arguments as to how incumbents can improve their environmental performance in pursuing an outsourcing strategy in dealing with an innovation shock.

Role of Prior Green Innovation Experience

When pursuing an outsourcing strategy, firms need to manage two critical challenges – one is how to efficiently create new communication routines and solution-search processes with suppliers for a new innovation, and the other is how to efficiently manage suppliers' opportunistic behaviors (Park et al., 2018). Both are potentially critical to environmental performance. Having *PGIE* can help firms deal with the first critical issue – how to efficiently create new communication routines and processes with current suppliers.

PGIE indicates that a firm has experimented with different green vehicle technologies in the past with their suppliers. Through these trial and error experimentations, the firm is likely to realize that its current organizational routines and systems created with suppliers may not be suited for the new innovation (Raisch and Birkinshaw, 2008). This realization can prompt the overhauling of current organizational routines as well as the creation of fresh information channels and communication systems that facilitate the efficient flow of new knowledge. With *PGIE*, firms can thus avoid being rigidly locked into existing processes and communication routines (Henderson and Clark, 1990), developing new ones with suppliers.

In contrast, firms lacking *PGIE* may not encounter chances to realize the criticality of developing fresh communication processes and the need for overhauling organizational routines (Koberg et al., 2003). New HEV-based vehicles are likely require incumbents and their partner firms to abandon already established organizational routines and systems (which may be obsolete) and instead, create new ones for the new innovation. Based upon this line of reasoning, we hypothesize:

Hypothesis 3: In response to an innovation shock, prior green innovation experience enhances environmental performance.

Role of Outsourced Component Knowledge

Another critical issue in pursuing an outsourcing strategy is how to efficiently manage suppliers' opportunistic behaviors, potentially leading firms' products to under-perform with regards to mandated environmental levels (Williamson, 1985). This situation can have a negative impact on environmental performance. To avoid such opportunistic situations, many scholars have highlighted the role of establishing mutual trusts through the development of long-term relationships between the firm and its supplier (Gulati, 1995, Hoetker, 2005).

This study suggests that *OCK* may enable firms to enhance environmental performance (Brusoni et al., 2001, Kapoor and Adner, 2012, Park and Ro, 2011). Without component-specific knowledge acquired through dedicated R&D activities, the objective of monitoring suppliers' quality and reducing their chances of opportunism to achieve mandated environmental levels is difficult. However, by holding knowledge associated with outsourced components in-house, a firm can convey technical requirements to its supplier partner on a timely basis to make sure that the outsourced components are produced according to specifications to achieve environmental mandates (Park and Ro, 2011). In addition, firms holding *OCK* can more thoroughly assess a supplier partner's capability to complete necessary tasks so that firms can better integrate any external/internal knowledge needed to fulfill environmental mandates. We therefore hypothesize:

Hypothesis 4: In response to an innovation shock, outsourced component knowledge enhances environmental performance.

The Interplay between Prior Green Innovation Experience and Outsourced Component Knowledge

We argue that both *PGIE* and *OCK* play a complementary role. An in-depth understanding of the interactions between internally and externally manufactured subsystems (components) is indispensable for superior environmental performance. One of the main problems in effectively managing this interaction is insufficient knowledge of the underlying components. While *PGIE* allows firms and their suppliers to build up new communication routines and processes, simply focusing on creating new communication routines and processes (i.e., *PGIE*) does not guarantee that a firm will acquire sufficient knowledge of the underlying components. An in-depth understanding of the interactions between internally and externally manufactured subsystems (components) is indispensable for superior environmental performance. Takeishi (2002) suggested that component-specific knowledge is a pre-requisite for the integration of internal and external components. In order to achieve expertise in knowledge integration, dedicated R&D efforts regarding outsourced component are needed. The continuous engagement in R&D allows firms to further develop processes and routines facilitating the integration of new and existing knowledge (Arora and Gambardella, 1994). As a result, *OCK* may facilitate the role of *PGIE*.

On the other hand, while *OCK* indicates the acquisition of outsourced component-specific knowledge, the in-house retention of outsourced component knowledge may lead firms to stick to their internal knowledge stocks and their current solution-searching routines, hindering any new solution search for the new innovation (Park et al., 2018, Tiwana and Keil, 2007). *PGIE* can serve as input for dedicated R&D efforts regarding outsourced components. Through frequent efforts regarding *PGIE*, firms may create learning opportunities that allow them to better understand the need and directions for future R&D activities for the new innovation. R&D investments, based on *PGIE*, create capabilities that enable a firm to identify, understand, and acquire new externally generated knowledge (Helfat, 1994, Mowery, 1983). *PGIE* may therefore foster *OCK*. The aforementioned line of reasoning yields the main hypothesis of this study:

> *Hypothesis 5: In response to an innovation shock, prior green innovation experience and outsourced component knowledge play a complementary role for enhancing environmental performance.*

Method

U.S. Hybrid Electric Vehicle Market

To test this study's hypotheses, we examined the U.S. hybrid electric vehicle (HEV) market from 1999 to 2017. This market emerged and enjoyed significant commercial success during this period. Unlike conventional internal combustion engine (ICE) technology, which solely focuses on the burning of fossil fuel, this new technology uses an additional battery-motor propulsion mechanism to drive vehicles. Thus, HEVs can simultaneously drive by utilizing the energy generated by the engine and the battery-motor (Wesseling et al., 2015). In doing so, HEVs tend to offer fuel-efficient and environmentally friendly driving.

The basic principle of an HEV's transmission is to regulate the sources of power generation (engine and motor) and power storage (fuel tank and battery) to an optimal level. While the HEV transmission is composed of four essential components – namely, the battery system, traction motor, inverter, and engine (Erjavec, 2013), the battery system has a central position in achieving this optimal level (Erjavec, 2013, Golembiewski et al., 2015). The battery system technology has evolved rapidly over this period (Gaines, 2014) and a higher power-to-weight ratio is considered a critical success factor for any HEV (Amine, 2010). Most automotive firms pursued an outsourcing strategy regarding the battery component. Specifically, in the U.S. market, 12 firms (75% of the total firms) developing 45 different models (69% of the total models) opted for an outsourcing strategy regarding the battery system. Given that this study is concerned about the outsourcing strategy in the face of an innovation shock, investigating this market would provide a viable opportunity to test this study's hypotheses.

Sample and Data Collection

The sample includes automobile firms that opted for the outsourcing strategy regarding the battery system and offered at least one HEV model in the U.S. market between 1999 and 2017. We gathered data from several archival sources. The data regarding outsourcing strategy was collected from *MarkLines*, a leading proprietary database that tracks the global automotive industry. The data on *PGIE* was collected from *Alternative Fuels Data Centre*. Of all the firms, 36% had some type of *PGIE*.

To measure *OCK*, we collected patent data from the United States Patent and Trademark Office (USPTO). In the first step, we identified that USPTO has a separate class 903 that *"includes all the patents relating to components, arrangements / control systems of components specifically adapted for hybrid electric vehicles (HEVs) and related topologies"*. This class included 2364 patents that were both applied for and granted from 1976 to 2017. We manually collected patent specific information such as the name of the assignee, application date, title, abstract and international classification for all the patents in this class. Since a patent's assignee may be a parent firm, a subsidiary, or an affiliate, it is important to link the subsidiaries/affiliates to the ultimate global parent firm. We utilized the *Business Source Complete* database to find the parent firms of all the subsidiaries/affiliates. Before further analysis, we excluded patents granted to non-automotive manufacturers, such as individual inventors, suppliers, government agencies, universities, and other not-for-profit research centers/bodies. In the next step, we linked each patent to its underlying component based on the subclasses. By so doing, we collected battery system-related patents granted to each firm in our sample *(more details are available in the Measurement section).*

To track the technological changes associated with battery systems and the vehicle as a whole, we relied upon technical reports published by the *U.S. Department of Energy National Laboratory*, *MarkLines*, *Consumer Reports*, *Alternative Fuels Data Center*, firms' annual reports and industry trade news. Data related to macroeconomic-level indicators was collected from *Statista*. Finally, we relied upon *Thomson Reuters Eikon* database to obtain firm-level financial information, such as total sales, total assets and R&D expenditure over the years.

Measures

Dependent Variables

Environmental performance

The primary goal of HEV technology is to produce fuel efficient and environmentally friendly vehicles. In order to monitor the environmental performance of these vehicles, the *U.S. Environmental Protection Agency* conducts laboratory tests and publishes EPA (environmental protection agency) and GHG (greenhouse gas) scores. In general, higher EPA and GHG scores suggest lower tailpipe emissions of carbon dioxide (Mahmoudzadeh et al., 2017, Messagie et al., 2015, Palencia et al., 2017). The higher power and storage of the battery allows the HEV to operate without the use of fossil fuels that are generating carbon dioxide emissions. The battery is therefore the most critical component of any HEV-based vehicle for its environmental performance (Messagie et al., 2015).

Independent Variables

Prior green innovation experience

Before the introduction of HEV, car manufacturers experimented with different environmentally friendly vehicle technologies, such as E85, CNG (dedicated and Bi-Fuel), Propane (dedicated and Bi-Fuel), Hydrogen, Methanol (M85) and the Electric Vehicle. The fundamental objective of these efforts was to design and manufacture fuel-efficient and environmentally friendly vehicles and to meet the US government's regulatory requirements under the zero-emission vehicle (ZEV) mandate. We postulate that the more experience a firm has with these technologies, the better it would be able to acquire skills to select and monitor capable suppliers in pursuing outsourcing. We measured *PGIE* by counting the number of green vehicle models offered from 1991 (the year of the ZEV launch) until the commercialization of the first HEV by a given firm (Benner and Tripsas, 2012). We utilized the natural log of *PGIE* to avoid skewness in our data.

Outsourced component knowledge

We measured *OCK* using USPTO's battery-specific patents granted to our sample firms. To determine whether a patent is related to the battery system, we employed the definitions provided by the *World Intellectual Property Organization (WIPO)* through the *International Patent Classification (IPC)* system. The use of *IPC* classifications for measuring technological knowledge has been widely used in previous research (Borgstedt et al., 2017, Mawdsley and Somaya, 2018, Wu and Mathews, 2012). We manually tracked and read the definitions of each patent's *IPC* sub-classes to determine their relevance to the battery system. For instance, class *H01M* is defined as "*processes or means, e.g. batteries, for the direct conversion of chemical energy into electrical energy",* which clearly indicates its relevance to the battery system. By doing so, we were able to identify all the subclasses primarily focusing on the battery system. By counting the number of battery-specific patents granted to each firm we, thus, computed *OCK* with a 5-year moving window.

Instrumental Variable

To correct for potential endogeneity, we utilized a two-stage regression model for data analysis. In the first stage, we computed the predicted values of *OCK* and in the second stage, we tested the performance models.

IV for Outsourced component knowledge

We utilized the *HEV industry concentration* as an instrumental variable for *OCK* and measured it by counting the total number of *HEV* models active in the US market offered by all the firms in a given year. The underlying intuition is that, with greater industry concentration, the accumulated knowledge-base would have increased, allowing incumbents to acquire more *OCK*. As explained in the *Analysis* section, we computed and incorporated the predicted values for *OCK* in the final models for hypothesis testing.

Control Variables

Technological complexity

The technological complexity of outsourced components can lead to a situation where suppliers may behave opportunistically and thus have a negative impact on environmental performance. Therefore, we controlled for the technological complexity of battery systems that arises as firms try to maintain a balance between battery power, drive per charge, and weight. We computed a composite measure for this variable using three indicators: first, battery type (*lead acid, nickel-metal hydride*, *lithium-ion,* and *lithium polymer)*; second, the total voltage of battery pack(s); and third, battery specific energy (Watt-hr/kg).

Number of battery suppliers

The market saturation of supplier firms can reduce the risks of their opportunistic behaviors; therefore, we included a control variable *number of battery suppliers.* We measured it by counting the number of major battery suppliers included in the *Top 100 global parts suppliers list* of *Autonews* magazine published yearly.

Competitive intensity

Given that competitive pressure may encourage incumbents to produce vehicles with superior environmental performance, we have therefore included a control variable called *competitive intensity* measured using market share.

Product differentiation

Vehicle models with greater product differentiation may require customized design and the manufacturing of outsourced components. We included two proxies for this control variable; the natural logarithm of the vehicle model price and the battery-specific energy. Vehicles with a higher price and more battery-specific energy are considered as luxury cars that may require customized efforts for the design and manufacturing of outsourced components.

R&D intensity

Firms' internal innovation efforts are normally measured through R&D intensity and firms with a higher level of R&D intensity are thus considered more innovative (Cohen and Levinthal, 2000, Zahra and George, 2002). We operationalized firms' R&D intensity as the ratio of R&D expenditures to total sales by year and controlled it in our analysis.

Innovation capabilities

The organizational learning literature suggests that internal knowledge stock and innovation capabilities facilitate new knowledge acquisition (Cohen and Levinthal, 2000, Zahra and George, 2002). We have therefore controlled for innovation capabilities of each firm in the given year measured as the total number of patents (Decarolis and Deeds, 1999).

Firm size

Larger firms with better resources may show superior environmental performance. On the other hand, size may become a source of inertia that can adversely affect environmental performance. We utilized the natural logarithm of a firm's total assets to operationalize it and included it as a control variable (Hörisch et al., 2015, Knight et al., 2019, Lee, 2017).

Firm age

Older firms may be more experienced and knowledgeable. These firms may also have older established communication channels and an organizational structure that may create problems in the face of an innovation shock (Sorensen and Stuart, 2000). Thus, we included firm age as a control variable and measured it by counting the number of years since the incorporation of the firm to the current year of analysis.

Financial crisis

A major financial crisis occurred from 2008 to 2012 that might also have impacted automobile firms' approaches towards environmental performance. Therefore, we included a binary variable that takes a value of '1' for the period from 2008 to 2012, or otherwise a value of '0' (Lee et al., 2009).

Labor intensity

We measured this as the ratio of the number of employees to sales revenue and included it as a control variable. Firms with a higher labor intensity are considered less innovative (Thirumalai and Sinha, 2011).

Finally, we controlled for ***gross domestic product*** (GDP) and ***inflation***, since macroeconomic conditions may also impact suppliers' profit margins, customer preferences, and the firm's performance.

Analysis

We employed the two-stage least squares (2SLS) regression approach with an instrumental variable (Wooldridge, 2002) to correct for potential endogeneity. Given that endogeneity may arise due to the use of interaction terms that can lead to biased estimations (Mayer and Nickerson, 2005), without correcting for endogeneity, the regression results may be inappropriate (Leiblein et al., 2002). We utilized the predicted values from the first stage as instruments for the endogenous variable in the second stage.

In the first stage, we predicted *OCK* with an instrumental variable, IV_OCK, which is an industry specific variable. It should be noted that the instrumental variable should affect the first-stage dependent variable *(OCK)* but not directly impact the second-stage dependent variable (environmental performance). It can also be associated with government policies, industry-wide changes or legal issues (Hamilton and Nickerson, 2003) that influence all firms. The instrumental variable used in this study satisfies both these conditions. The first stage model is presented below, where *i* represents the battery system, *j* the firm, *t* the year, and ε_{ijt} the random error term:

$$Outsourced\ Component\ Knowledge_{ijt} = \beta_0 + \beta_1 * IV\_Outsourced\ Component\ Knowledge_{ijt} + \beta_2\ Control\ Variables_{ijt} \qquad (1)$$

In the second stage, we tested this study's hypotheses. The performance model included the predicted values for *OCK*, *PGIE* and the interaction term *(PGIE*OCK)* along with all the control variables that jointly influenced performance so as to obtain unbiased estimates. Since the dependent variables are rank-ordered, we used the ordered probit model. To decide between fixed versus random effects models, we conducted the Hausman (1978) specification test, and the random effects model emerged as superior. We thus used the random effects ordered probit model for testing the hypothesis of this study. To be more precise, we utilized the 'xtoprobit' command in STATA 13. The second stage performance models, where *i* represents the battery system, *j* the firm, *t* the year, and ε_{ijt} the random error term, are presented below:

$$Performance_{ijt} = \alpha_0 + \alpha_1 * Prior\ Green\ Innovation\ Experience_{jt}$$

$$+ \alpha_2 * P\_Outsourced\ Component\ Knowledge_{ijt}$$

$$+ \alpha_3 * Prior\ Green\ Innovation\ Experience_{jt} * P\_Outsourced\ Component\ Knowledge_{ijt}$$

$$+ \alpha_4 * Control\ Variables_{ijt} \qquad (2)$$

Table 5.1: Summary of Correlation Statistics – Study II

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Environmental Performance (EPA Score)	1.000																	
2	Environmental Performance (GHG Score)	+0.998	1.000																
3	Prior Green Innovation Experience	-0.039	-0.032	1.000															
4	Outsourced Component Knowledge	+0.380	+0.383	-0.105	1.000														
5	Technological Complexity	-0.032	-0.045	-0.366	-0.099	1.000													
6	Number of Suppliers	-0.136	-0.137	-0.041	-0.101	+0.025	1.000												
7	Product Differentiation (Battery Power)	-0.001	-0.015	-0.489	+0.038	+0.636	-0.098	1.000											
8	Product Differentiation (Vehicle Price)	-0.775	-0.776	-0.138	-0.253	+0.236	+0.085	+0.221	1.000										
9	Firm Age	-0.255	-0.258	+0.764	-0.175	+0.058	+0.033	-0.031	+0.170	1.000									
10	Firm Size	+0.183	+0.186	-0.180	+0.615	+0.090	+0.132	+0.143	-0.005	-0.033	1.000								
11	R&D Intensity	-0.336	-0.341	+0.279	-0.295	+0.090	-0.006	+0.190	+0.188	+0.570	-0.054	1.000							
12	Labor Intensity	-0.204	-0.195	-0.060	-0.048	-0.314	+0.169	-0.178	+0.099	-0.080	+0.247	+0.517	1.000						
13	Innovation Capabilities	+0.391	+0.394	-0.170	+0.995	-0.076	-0.099	+0.062	-0.233	-0.223	+0.619	-0.306	-0.033	1.000					
14	Production Capabilities	-0.019	-0.007	+0.310	+0.552	-0.222	+0.157	-0.152	-0.037	+0.248	+0.730	+0.007	+0.187	+0.500	1.000				
15	Competitive Intensity	+0.334	+0.343	+0.641	+0.554	-0.333	-0.044	-0.335	-0.435	+0.306	+0.306	-0.099	-0.137	+0.485	+0.659	1.000			
16	Financial Crisis (Dummy)	-0.070	-0.133	-0.109	-0.083	+0.209	+0.031	+0.225	+0.095	+0.061	-0.064	+0.105	-0.127	-0.072	-0.180	-0.171	1.000		
17	Inflation	+0.119	+0.109	+0.110	+0.146	-0.024	-0.737	+0.116	-0.034	+0.077	+0.004	+0.066	-0.217	+0.150	+0.001	+0.127	+0.155	1.000	
18	Cross Domestic Product (GDP)	-0.044	-0.030	-0.059	-0.238	-0.093	+0.516	-0.200	-0.086	-0.069	+0.186	-0.011	+0.196	-0.259	+0.191	-0.047	-0.213	-0.503	1.000
	Mean	7.933	7.790	0.856	43.41	2.043	6.960	39.67	4.602	82.02	8.300	0.044	0.002	223.7	3.390	0.029	0.346	1.744	16553.3
	S.D	1.661	1.771	0.769	55.19	0.434	2.342	12.36	0.213	18.84	0.240	0.010	0.000	285.9	0.388	0.033	0.476	1.061	1985.73
	Max	10.000	10.000	2.127	375.0	4.000	10.00	71.80	5.211	115.0	8.649	0.065	0.004	1327	4.277	0.351	1.000	3.800	19386.8
	Min	4.000	3.000	0.000	0.000	1.000	1.000	4.500	4.160	23.00	7.263	0.009	0.000	1.000	1.946	0.003	0.000	-0.400	9660.60

Table 5.2: Estimation Results – Study II

	1st Stage P_ Outsourced Component Knowledge	2nd Stage (Environmental Protection Agency Rating Score)			2nd Stage (Greenhouse Gas Rating Score)		
	Model 1	Model 2 (H1)	Model 3 (H2)	Model 4 (H3)	Model 5 (H1)	Model 6 (H2)	Model 7 (H3)
Prior Green Innovation Experience (PGIE)		-5.644 (3.322)*		-5.007 (2.905)*	+1.439 (1.318)		+0.963 (1.240)
P_ Outsourced Component Knowledge (P_ OCK)			+0.276 (0.211)	+0.214 (0.229)		-0.420 (0.093)***	-0.727 (0.209)***
PGIE * P_ OCK				+0.228 (0.080)***			+0.092 (0.043)**
IV for Outsourced Component Knowledge	+0.740 (0.219)***						
Technological Complexity	-1.593 (1.990)	-4.438 (3.049)	-1.721 (2.007)	-3.041 (2.779)	-0.180 (1.958)	-3.548 (1.527)**	-4.225 (2.108)**
Number of Suppliers	-0.263 (0.174)	+0.189 (0.053)***	+0.252 (0.115)**	+0.397 (0.092)***	+0.141 (0.098)	-0.008 (0.115)	-0.046 (0.131)
Product Differentiation (Battery Power)	-0.114 (0.055)**	-0.116 (0.046)**	+0.010 (0.038)	-0.141 (0.043)***	+0.032 (0.026)	-0.030 (0.021)	-0.052 (0.022)**
Product Differentiation (Vehicle Price)	-1.061 (0.329)***	-1.303 (0.143)***	-1.065 (0.215)***	-1.145 (0.272)***	-1.844 (0.532)***	-2.192 (0.524)***	-2.365(0.492)***
Firm Age	+0.017 (0.059)	+0.291 (0.104)***	+0.113 (0.020)***	+0.225 (0.087)***	+0.092 (0.048)*	+0.152 (0.036)***	+0.079 (0.039)**
Firm Size	+1.945 (5.580)	+9.661 (5.178)*	+7.630 (4.248)*	+16.606 (6.305)***	+3.208 (2.715)	+8.488 (3.434)**	+12.99 (5.053)***
R&D Intensity	+0.398 (1.031)	-1.736 (0.759)**	-1.118 (0.357)***	-1.276 (0.678)*	-1.327(0.455)***	-1.330 (0.299)***	-0.502 (0.454)
Labor Intensity	-0.427 (0.289)	-0.549 (0.143)***	-0.295 (0.153)*	-0.957 (0.218)***	-0.209 (0.127)	-0.510 (0.149)***	-0.893 (0.291)***
Innovation Capabilities	+0.189 (0.006)***	-0.035 (0.026)	-0.078 (0.056)	-0.129 (0.054)**	-0.053 (0.026)**	+0.056 (0.025)**	+0.073 (0.032)**
Production Capabilities	+9.833 (3.246)***	-1.680 (3.192)	-5.394 (2.973)*	-6.771 (3.427)**	+0.972 (2.513)	+2.588 (2.577)	+3.523 (2.469)
Competitive Intensity	-0.212 (0.940)**	+0.204 (0.163)	-0.071 (0.078)	-0.162 (0.243)	-0.116 (0.050)**	-0.239 (0.078)***	-0.334 (0.084)***
Financial Crisis (Dummy)	-4.854 (1.386)***	-0.924 (0.710)	+0.643 (1.464)	+1.278 (1.610)	-2.689 (1.201)**	-6.549 (1.160)***	-7.217 (1.502)***
Inflation	+0.502 (0.815)	+1.134 (0.304)***	+1.038 (0.310)***	+1.186 (0.338)***	+0.129 (0.429)	-0.065 (0.541)	-0.361 (0.624)
Cross Domestic Product (GDP)	-0.002 (0.001)**	-0.001 (0.000)	(omitted)	(omitted)	-0.002 (0.001)**	-0.002 (0.001)**	-0.002 (0.001)***
Constant	+24.42 (38.12)						
N	172	52	52	52	63	63	63
Overall R2	0.979						
F Statistic	6486	926.5	238.7	216.4	353.3	491.7	681.6
Log Likelihood		-34.30	-36.41	-32.97	-54.62	-49.34	-47.26

***p<0.01, **p<0.05, *p<0.1 / Robust (Cluster) standard error in parentheses

Results

Table 5.1 presents descriptive statistics and correlation coefficients of the study variables. The correlation between the main independent variables of this study is less than 0.6, so multicollinearity is not a problem. However, a strong correlation exists between the innovation capabilities and outsourced component knowledge ($r = +0.995$), so we dropped these controls to see if this correlation influenced the estimate and found that the results of the estimate were not affected. Thus, the final model included all control variables.

Model 1 in Table 5.2 displays the results of the first stage regression. It should be noted that we included an instrumental variable *IV_OCK* in this first stage but excluded it in the second stage. The coefficient in Model 1 was positive and significant (+0.740, $p < 0.01$), justifying the use of *IV_OCK* as an instrumental variable.

The performance models are shown in Models 2 through 7. Models 2 and 5 are related to the role of *PGIE* on environmental performance. The coefficient of Model 2 is negative and significant (-5.644, $p < 0.1$) whereas the coefficient of Model 5 is positive and not significant (+1.439, $p > 0.1$). These results suggest that prior experience with other competing technologies before the emergence of HEVs has a mixed and weak effect on environmental performance when dealing with HEV technology. Hypothesis 3 is not fully supported. Model 3 and 6 are related to the role of *OCK* on environmental performance. We utilized the predicted values of *OCK* computed in the first stage. Again, the coefficients of Models 3 and 6 showed a mixed and weak effect of *OCK* on environmental performance where the effect is positive and not significant in Model 3 (+0.276, $p > 0.1$) and negative and significant in Model 6 (-0.420, $p < 0.01$). Hypothesis 4 is also not fully supported. These results suggest that mere possession of *OCK* or *PGIE* has no significant effect on environmental performance. Finally, in order to test the main Hypothesis (Hypothesis 5) of this study, we included *PGIE*, *P_OCK* and the interaction term (*PGIE* * *P_OCK*) in Models 4 and 7. The coefficients for the interaction term are positive and significant in these Models (+0.228, $p < 0.01$ in Model 4; +0.092, $p < 0.05$ in Model 7). These results suggest that *PGIE* and *OCK* play a complementary role in enhancing the environmental performance when pursuing an outsourcing strategy in the face of innovation shock. Thus, the main Hypothesis of this study is strongly supported.

Discussion and Conclusions

Main Findings

This study's central argument suggesting the complementary role of prior green innovation experience (*PGIE*) and outsourced component knowledge (*OCK*) for enhancing environmental performance has found robust empirical support in our analysis of the U.S. Hybrid Electric Vehicle market. This finding is in line with the arguments of Park et al. (2018) suggesting that when encountering an externally originated innovation shock, firms need to simultaneously upgrade organizational routines and effectively manage suppliers. In particular, this study found that *PGIE* and *OCK* are likely to help incumbents efficiently upgrade communication routines and processes for new innovations, and manage suppliers' opportunistic behaviors in complementary way, leading to superior environmental performance.

Theoretical Contributions

Based on the findings of this study, we submit the following theoretical contributions. First, we contribute to the literature investigating the impact of firms' strategic decisions on environmental performance. While there is a burgeoning literature examining the impact of firms' strategic decisions for enhancing environmental performance (Arfi et al., 2018, Chen, 2017, Ding et al., 2017, Laari et al., 2018), there is a dearth of studies focusing on the impact of follower's strategic outsourcing decisions on environmental performance in the face of an innovation shock *(outsourcing and strategic outsourcing terms are interchangeably in this thesis)*. In particular, this study bridges two research streams – one stream advocates learning-by-doing (e.g. *PGIE*) (Christensen, 1992, Macher and Boerner, 2012, Mayer and Salomon, 2006, Mitchell et al., 1994) and another stream advocates reliance on external knowledge (Akerlof, 1970, Brusoni et al., 2001, Kapoor and Adner, 2012, Park and Ro, 2013). By suggesting complementarities between *PGIE* and *OCK* for environmental performance improvement, our conceptual argument and results provide a novel contribution to the extant literature. This study may be the first to investigate the (environmental) performance implication contingent upon the complementarity of *PGIE* and *OCK*.

Second, we further enhance the burgeoning literature on *OCK* and its effect on performance heterogeneity. Much of the literature suggests the positive role of *OCK* in enhancing performance by underscoring the importance of *OCK* for monitoring suppliers and reducing the chance of opportunistic behavior (Akerlof, 1970, Brusoni et al., 2001, Kapoor and Adner, 2012, Park and Ro, 2013). However, Park et al. (2018) recently suggested the possibility of a negative effect of *OCK* on performance. The current study helps in understanding how to compromise the disadvantages of *OCK* on performance. This study contributes to the extant literature by suggesting that the positive and negative effects of *OCK* may also be contingent upon firms' prior green innovation experience (*PGIE*).

Third, like the second, we contribute to the literature on performance heterogeneity due to *PGIE*. Although most of the published literature has underscored the positive role of *PGIE* on performance (Macher and Boerner, 2012), some studies have suggested otherwise (Moorman and Miner, 1997, Nerkar and Roberts, 2004). *PGIE* provides firms with an informational advantage, enhances the ability of firms to absorb relevant knowledge, and overhauls organizational routines. However, when pursuing an outsourcing strategy, the central objective is to reduce the chances of opportunistic behavior and monitoring suppliers' performance, and the mere possession of *PGIE* is not sufficient to meet this objective. We thus help in understanding the root cause of the positive and negative effects of *PGIE* on performance by suggesting the complementary role of OCK.

Finally, this study suggests important managerial implications. First, this study can help managers in understanding why firms should engage in trial-and-error experimentation in pursuing outsourcing (i.e., *PGIE* in this study). However, simply engaging in trial-and-error experimentation may not directly lead to performance advantages. This study suggests that such experimentation and R&D endeavors should also open fresh knowledge gateways to facilitate the acquisition of *OCK*. So, when firms acquire *OCK* through trial-and-error experimentation, firms may maximize the performance benefits of such R&D endeavors (i.e., complementarities between *PGIE* and *OCK*) in pursuing outsourcing. By doing so, decision makers can better understand and justify the cost-benefit analysis of internal R&D efforts.

Limitations

It should be noted that this study has certain limitations that also create an opportunity for future research. The following are the main limitations. First, we examined a single, idiosyncratic market that limits the chances of generalization. However, it should be noted that the results are normally more accurate when the analysis is conducted on a single industry. Second, our analysis included only the HEV market, however the knowledge-set, and performance in other related technologies (e.g. a pure electric vehicle) could have an impact on the performance of HEVs. Therefore, we consider that a more informative analysis may be conducted by including other competing technologies in the analysis. Third, we measured the *PGIE* by counting the number of models offered in the U.S. market prior to the introduction of HEVs. We, however, did not include the relatedness of *PGIE* to HEV technology. Given the fact that the experience of some technologies might have more impact on HEV environmental performance than others, investigating the relative importance of different types of experiences can provide useful insights. Thus, future research may be conducted to address the limitations of this study.

CHAPTER 6

DIFFERENTIAL EFFECT OF OUTSOURCED COMPONENT KNOWLEDGE ON PERFORMANCE IN THE FACE OF AN INNOVATION SHOCK

Introduction

Competence-destroying innovation shocks are so fundamentally different from the previously dominant technology that incumbent firms need new knowledge and capabilities to cope with such innovations (Christensen, 1997, Henderson and Clark, 1990, Tushman and Anderson, 1986). While most innovation shocks are developed by integrating specialized knowledge lying with different industries, the existing literature has emphasized the importance of outsourcing strategy for acquiring this new knowledge (Powell et al., 1996, Womack et al., 1990). However, despite the facilitating role in new knowledge acquisition, outsourcing poses some serious challenges for incumbent firms. Exchange hazard is the one of those challenges (Park et al., 2018).

Exchange hazards occur when an outsourcing firm fails to manage its suppliers effectively and, as a consequence, the suppliers tend to show opportunistic behavior (Handley, 2012, Nickerson and Zenger, 2004, Williamson, 1979) that negatively affects outsourcing performance (Kalnins and Mayer, 2004, Lafontaine, 1999, Lumineaua and Hendersonb, 2012). The extant literature has suggested some ways through which an outsourcing firm can arguably avoid exchange hazards. Novak and Stern (2008) suggested that contracting with high-quality suppliers is an effective way to avoid exchange hazards because the market reputation of such suppliers is at stake. Some scholars suggested that long-term relationships between a firm and its supplier can create mutual trust (Gulati, 1995) that can potentially eliminate exchange hazards. Engaging suppliers in the early stages of new product development can also develop the trust required to reduce opportunism (Gulati, 1995, Uzzi, 1997). In their seminal work, Brusoni et al. (2001) suggested that keeping in-house knowledge regarding outsourced component is an effective tool for monitoring and evaluating potential suppliers (Mayer and Salomon, 2006) and decreasing the probability of suppliers' opportunistic behavior. Following Brusoni et al. (2001) who suggested that division of labor and division of knowledge can be different, a considerable academic debate began.

This study defines outsourced component knowledge (OCK) as the knowledge possessed by the outsourcing firm regarding an outsourced component (Brusoni et al., 2001, Takeishi, 2002). This knowledge is not usually related to the core business of the outsourcing firm, for instance, the digital electronic circuits related knowledge possessed by jet aircraft engines manufactures (Brusoni et al., 2001), and the satellite navigation systems related knowledge possessed by auto manufacturers (Takeishi, 2002) are typical examples of OCK. While most of the extant literature in this domain has underscored the positive role of *OCK* in reducing exchange hazards (Brusoni et al., 2001, Kapoor and Adner, 2012, Park and Ro, 2013, Takeishi, 2002), recent discussion in this domain has suggested that *OCK* is in fact a double-edged sword (Park et al., 2018, Tiwana and Keil, 2007). That can potentially undermine the outsourcing performance. Considering the possibility that *OCK* can play both a positive and a negative role in mitigating exchange hazards, this study explores under what conditions *OCK* can be more beneficial.

This study proposes that incumbent firms with greater *OCK* are more likely to prescribe procedures and methods that the supplier should follow (Lacity, 2002, Park and Ro, 2011, Park and Ro, 2013, Ulrich and Ellison, 2005). Although the objective of doing so is to avoid exchange hazards, there is a possibility that it may backfire (Park et al., 2018, Tiwana and Keil, 2007). *OCK*, according to its definition, is of a generic nature and incapable of encompassing technical details at the micro level. In such a situation, if a supplier's performance is judged on the basis of the procedures and methods prescribed by the incumbent firm, the employees of the supplier firm may refrain from utilizing the best of their technical expertise and skills in order to avoid any possible deviation from the prescribed procedures. The urge of the supplier firm to abide by the prescribed procedures and methods ends up with inferior quality solutions. In response to the inferior quality solutions, incumbent firms are more likely to take corrective actions. These actions could be either relaxation in the contract's terms and conditions by giving more autonomy to the supplier or redefining the contract's terms based upon their updated knowledge. In both cases, the incumbent firm tends to adjust its relationship with the supplier in order to achieve superior quality performance. This study thus postulates that the performance benefits of *OCK* would be greater at the later stage of the new product's life cycle than at the early stage. In addition, this study also suggests that the negative effect of *OCK* on early-stage quality performance will decrease when the technological complexity of the outsourced component is high. Incumbent firms with greater *OCK* are more likely to realize and understand the technological complexity of outsourced components. This awareness can help incumbent firms not to prescribe detailed procedures rather place more focus on practical and effective monitoring criteria to mitigate exchange hazards.

This study investigates the U.S. hybrid electric vehicle (HEV) industry from 1999 to 2017 for empirical support. The reason for choosing this industry is threefold. First, contrary to the dominant technology of internal combustion engines (ICE), this new innovation offers an additional battery-powered propulsion mechanism and has thus turned out to be a competence-destroying innovation shock for incumbent firms demanding new knowledge and capabilities. Hence, this setting matches with the theoretical context of the study. Second, given that HEV technology started achieving commercial success in 1999, the window of observation thus covers all major events that happened in this market. Third, the focus is on outsourcing strategy regarding the battery system which is one of the main components of HEV transmission system (Erjavec, 2013). Battery system technology has evolved rapidly over the period and a higher power-to-weight ratio is considered to be a critical success factor for any HEV-based vehicle (Amine, 2010). In addition, most automobile firms pursued an outsourcing strategy regarding battery component making this market an ideal setting for investigating the arguments presented in this study and have found robust empirical support.

The main contribution of this study is to advance understanding of the technology management literature on how to effectively manage exchange hazards associated with outsourcing strategy, precisely in response to competence-destroying innovation shock. Given that the extant literature has reported conflicting findings regarding the impact of *OCK* on performance, this study provides an initial understanding as to why *OCK* exhibits this differential effect on the new product life cycle. In addition, this study demonstrates that the outsourced component's technological complexity also play an important role in explaining the positive and negative role of in-house component knowledge on performance.

Theory and Hypotheses Development

Theoretical Background – Innovation Shock and Outsourcing Strategy

Inter-firm performance heterogeneity in response to innovation shock is a key concern for strategy scholars. Although innovation shock is a broad term, in this study, innovation shock indicates a context where a technology, which normally evolves through numerous incremental innovations within the frame of a dominant design, is punctuated by a major change that is fundamentally different from the previous technology. Such innovation shocks are so fundamentally different from the previously dominant technologies that the knowledge and capabilities required to cope with them also change drastically (Tushman and Anderson, 1986). The extant literature in this area of research suggests that firms should have two different capabilities simultaneously in order to effectively manage such innovation shocks, (Zahra and George, 2002). First, the firm should be able to identify, understand, and acquire the new knowledge essential to cope with the new innovation shock. Second, the firm should be able to reconfigure its routines to facilitate the integration of existing and newly acquired knowledge (Nelson and Winter, 1982, Zollo et al., 2002).

In order to successfully develop these capabilities, selection and execution of appropriate strategies that are conducive to the new environment determine the firm's competitiveness, success, and survival in the marketplace. Therefore, the choice of appropriate strategies to deal with innovation shock is very important (Tushman and Anderson, 1986). Given that major technological changes are taking place in incorporating specialized knowledge from different industries, outsourcing strategy is an appropriate means for acquiring cutting-edge knowledge that typically dwells outside the firm's boundaries (Powell et al., 1996, Womack et al., 1990). In addition, outsourcing also helps firms to avoid being trapped in firm-specific routines (Leonard-Barton, 1992) and can develop fresh information-processing arrangements (Abecassis-Moedas and Benghozi, 2012, Jaspers et al., 2012, Park and Ro, 2011). Thus, outsourcing strategy help firms in developing essential capabilities to manage competence-destroying innovation shocks.

Hierarchy Hazards and Exchange Hazards

Outsourcing firms are required to effectively deal with suppliers – to avoid exchange hazards, and create fresh organizational routines - to avoid hierarchy hazards (Park et al., 2018). Exchange hazards occur when a firm fails to effectively manage suppliers and, as a result, the supplier begins to show opportunistic behavior (Handley, 2017, Nickerson and Zenger, 2004) that can undermine firm performance. Hierarchy hazards, on the other hand, limit a firm's ability to develop fresh information-processing systems and routines. Such fresh information-processing structures and routines are essential to stop a firm from becoming trapped in its old routines. That may reduce a firm's ability to acquire and assimilate the essential knowledge required to deal with innovation shock. Thus, managing both exchange hazards and hierarchy issues is essential.

Given that hierarchy hazards are at the extreme when a firm develops firm-specific communication channels and routines to facilitate appropriate transformation and diffusion of old knowledge (Monteverde, 1995), it increases the risk of lock-in, turning core competencies into core rigidities (Leonard-Barton, 1992). To avoid hierarchy hazards, outsourcing firms should overhaul their old routines so that new knowledge acquisition and integration is facilitated (Cohen and Levinthal, 1990). The existing literature suggests that prior innovation experience can help firms to overhaul their old routines, thus in avoiding hierarchy hazards

(Mitchell et al., 1994, Park, 2018, Raisch and Birkinshaw, 2008). While the focus of the current study is on exchange hazards, the theoretical and empirical context make a critical assumption that hierarchy hazards do not present an issue for the focal firms under investigation.

Exchange hazards are at the extreme when an outsourcing firm fails to efficiently manage its suppliers and as a result the suppliers may show opportunistic behavior (Handley, 2012, Nickerson and Zenger, 2004, Williamson, 1979). This opportunistic behavior can negatively affect outsourcing performance (Kalnins and Mayer, 2004, Lafontaine, 1999, Lumineaua and Hendersonb, 2012). The existing literature has described some ways to avoid exchange hazards. For example, Novak and Stern (2008) asserted that contracting with high-quality suppliers is an effective way to avoid exchange hazards because the market reputation of such suppliers is at stake. Some scholars suggested that long-term relationships between a firm and its supplier can create mutual trust (Gulati, 1995) that can potentially eliminate exchange hazards. Engaging suppliers in the early stages of new product development can also develop the trust required to reduce opportunism (Gulati, 1995, Uzzi, 1997). In their seminal work, Brusoni et al. (2001) suggested that keeping in-house knowledge regarding outsourced component is an effective tool for monitoring and evaluating potential suppliers (Mayer and Salomon, 2006) and decreasing the probabilities of suppliers' opportunistic behavior. Following Brusoni et al. (2001) suggestion that division of labor and division of knowledge can be different; a considerable academic debate thus began.

Outsourced Component Knowledge and Exchange Hazards

One major concern in dealing with a competence destroying innovation shocks is the creation of contracts that provide safeguards for mitigating any potential exchange hazards (Nickerson and Zenger, 2004) and threats of opportunism in knowledge sharing (Williamson, 1991) arising from the high coordination of innovations The existing literature on the transaction cost of economy (TCE), suggests that when a dispute arises, both the parties tend to address the contingencies in subsequent contracts (Mayer and Argyres, 2004). Thus firms, in an effort to better draft future contracts and avoid future exchange hazards, should retain knowledge generated through prior learning in the suppliers area of expertise (Mayer and Salomon, 2006).

Similarly, from the knowledge-based view (KBV) perspective, Brusoni et al. (2001) argued that even in cases of product modularity, firms should keep in-house knowledge related to outsourced components in order to avoid exchange hazards and to manage future situations where new and existing knowledge integration is required. An outsourcing firm must invest time and resources to facilitate modes of learning if it wishes to adapt to a dynamic environment (Cyert and March, 1963, Nelson and Winter, 1982). Zirpoli and Becker (2011b) emphasized the importance of firm R&D activities for the acquisition of component-specific knowledge (i.e., learning by doing) regarding outsourced components in order to understand the linkages between subsystems, suggesting that it is nearly impossible to possess a deep understanding of component linkages apart from component-specific knowledge (Takeishi, 2002). More recently, some industry studies empirically demonstrated that the retention of knowledge regarding externally sourced components positively affected performance (Kapoor and Adner, 2012, Park and Ro, 2011). Thus, both the TCE and KBV perspectives suggested that in-house knowledge of outsourced components allows firms to avoid exchange hazards and improve performance in the face of innovation shocks.

OCK, which implies that a firm has accumulated component specific-knowledge in the domain of its partners, may help outsourcing firms in drafting effective contracts and in establishing procedures that its suppliers should follow (Lacity, 2002, Tiwana and Keil, 2007, Ulrich and Ellison, 2005). Through OCK, firms can enhance the monitoring capabilities required to track the progress of a suppliers' investment and hinder any attempts by suppliers to shirk their responsibilities (Tiwana and Keil, 2007). Thus, OCK may enable firms to become proficient at selecting capable project partners and shunning low-quality partners (Akerlof, 1970, Brusoni et al., 2001).

Additionally, through OCK, firms can provide suppliers with technical specifications and facilitate effective boundary-spanning activities (Tushman, 1977, Tushman and Katz, 1980), factors essential for creating unique boundary-spanning routines (Brusoni et al., 2001). This boundary spanning, in turn, helps firms develop model- and firm-specific routines (Simon, 1985) that facilitate the development of capabilities to integrate, reconfigure, and reengineer components to efficiently acquire new knowledge. The beneficial role of OCK in understanding component coordination and enhancing monitoring capabilities suggests that OCK may help firms in reducing exchange hazards.

Role of Outsourced Component Knowledge over New Product Life-cycle

Although most of the existing studies suggest a positive role of OCK in reducing exchange hazards (Brusoni et al., 2001, Kapoor and Adner, 2012, Park and Ro, 2013, Takeishi, 2002), recently, some studies have reported a negative role of OCK. Tiwana and Keil (2007) have thus termed OCK as a double-edged sword. Given the contradictory findings in previous studies, this study explores under what conditions OCK can be more beneficial.

OCK helps firms in providing suppliers with technical specifications (Tushman, 1977, Tushman and Katz, 1980), and prescribing procedures and methods that the supplier should follow (Lacity, 2002, Park and Ro, 2011, Park and Ro, 2013, Ulrich and Ellison, 2005), with an aim to avoid exchange hazards. However, OCK according to its definition is of generic nature and incapable of encompassing technical details at the micro level. Thus, providing suppliers with technical specifications and linking performance to the fulfilment of such specifications can potentially undermine outsourcing performance. The reason for this negative effect is that the employees in the supplier firm tend to refrain from utilizing the best of their technical expertise and skills because they try to avoid any possible deviation from the contract terms and conditions. This under-utilization of expertise leads to an inferior quality solution. Thus, OCK can arguably undermine outsourcing performance at the early stage of a new product life cycle.

However, outsourcing firms tend to redefine contracts based upon experience. Mayer and Argyres (2004) found in their case study of a computer software firm and its contractor that rather than anticipating exchange hazards or important contingencies likely to arise in contracts, it was only after disputes arose that both parties addressed the contingencies in subsequent contracts. In a similar vein, after realizing inferior quality solutions, outsourcing firms are more likely to take corrective actions. These actions could be either relaxation in the contract's terms and conditions by giving more autonomy to the supplier or redefining the contract terms based upon their updated knowledge. In both cases, the incumbent firm tend to adjust its relationship with the supplier in order to achieve superior quality performance. Thus, the performance benefits of OCK should be greater at the later stage of the new product's life cycle than of at the early stage. Given that the reason for the negative effect of OCK on early-stage performance is the outsourcing firm's tendency to dictate the exact specification and procedures to suppliers, and this tendency may diminish, contingent upon technological complexity of outsourced component. *OCK* may help outsourcing firms to realize high technological complexity of outsourced components. Through this realization, outsourcing firms may refrain from prescribing detailed procedures and focus on practical and effective monitoring criteria to mitigate exchange hazards.

Hypotheses

In this study, *outsourced component knowledge (OCK)* is defined as the knowledge possessed by the outsourcing firm related to an outsourced component (Brusoni et al., 2001, Takeishi, 2002). This knowledge is not usually related to the core business of the outsourcing firm, for instance, the digital electronic circuits related knowledge possessed by jet aircraft engines manufactures (Brusoni et al., 2001), and satellite navigation systems related knowledge possessed by auto manufacturers (Takeishi, 2002) are typical examples of OCK. The purpose of possessing *OCK* is to avoid exchange hazards (Park et al., 2018) and to facilitate the integration of new and existing knowledge (Cohen and Levinthal, 1990).

Much of the prior literature on *OCK* has underscored its positive aspects, particularly in reducing exchange hazards (Brusoni et al., 2001, Kapoor and Adner, 2012, Park and Ro, 2013, Takeishi, 2002), absorbing new knowledge (Cohen and Levinthal, 1990) and reconfiguring organizational routines (Abecassis-Moedas and Benghozi, 2012, Jaspers et al., 2012, Park and Ro, 2011). However, Tiwana and Keil (2007) have termed *OCK* as a double-edged sword. They suggested that while beneficial most of the time, *OCK* could potentially undermine the outsourcing performance. The latter situation emerges when firms with *OCK* tend to prescribe the methods and procedures that the supplier should follow (Lacity, 2002, Levina and Ross, 2003). This situation is in line with agency theory that suggests that the supplier (the agent) should act according to guidelines and in the best interests of the outsourcing firm (the principal). However, these additional methods and procedures prescribed by outsourcing firm can reduce the supplier's autonomy, which may lead to a situation that promotes dysfunctional behaviour, and thus, negatively affects performance. These additional methods and procedures may also be incompatible with idiosyncratic practices and routines followed by the supplier (Mcafee, 2003). Since supplier performance is judged on the basis of the procedures prescribed by the outsourcing firm, the employees of the supplier firm may refrain from utilizing the best of their technical expertise and skills in order to avoid any possible deviation from the prescribed procedures.

According to its definition, *OCK* is normally of a generic nature and incapable of encompassing technical details at the micro level. However, the need to avoid exchange hazards encourages an outsourcing firm to dictate detailed procedures and methods the supplier should follow (Lacity, 2002, Park and Ro, 2011, Park and Ro, 2013, Ulrich and Ellison, 2005). Therefore, firms with greater *OCK* are more likely to provide suppliers with the procedure and methods to be followed. The suppliers, while abiding by these prescribed procedures and methods, may fail to provide superior quality solutions.

In response to such inferior quality performance outcomes, outsourcing firms can either relax the methods and procedures by allowing the supplier to fully utilize its technical expertise to enhance performance or redefine terms with the supplier, based on updated knowledge. In both cases, the outsourcing firm adjusts its relationship with the supplier in order to enhance performance. Similar to Mayer and Argyres (2004), in their case study of a computer software firm and its contractor found that rather than anticipating exchange hazards or important contingencies likely to arise in contracts, it was only after disputes arose that both parties addressed the contingencies in subsequent contracts. In a similar vein, after realizing the inferior quality solutions, outsourcing firms are more likely to take corrective actions. This postulates the main argument of the current study suggesting that the performance benefits of *OCK* would be greater at the later stage of the new product's life cycle than of the early stage. This reasoning leads to the first hypothesis of this study:

> *Hypothesis 6: The effect of outsourced component knowledge on product quality performance will be greater in the later-stage of the new product life cycle than of at the early-stage.*

This study postulates that the negative effect of *OCK* on early-stage quality performance will decrease when the technological complexity of the outsourced component is high. The technological complexity of a component is a function of 1) technological novelty 2) number of subcomponents involved and 3) interactions between subcomponents (Simon, 1962). Firms with more *OCK* are more likely to realize and understand the technological complexity of outsourced components. This awareness can help them establish more practical and effective monitoring criteria to mitigate exchange hazards. This situation lies between the two extreme conditions in which, on the one hand, firms without *OCK* are unable to control and monitor suppliers, and on the other hand, when technological complexity of the outsourced component is low, firms tend to prescribe procedures and methods the supplier must follow (Lacity, 2002, Park and Ro, 2011, Park and Ro, 2013, Ulrich and Ellison, 2005). Given that both of these extreme conditions undermine outsourcing performance, a more viable solution is proposed by suggesting that technological complexity of outsourced components positively moderate the relationship between *OCK* and the early-stage product quality performance. This leads to the second hypothesis of this study:

> *Hypothesis 7: The weak (or negative) effect of outsourced component knowledge on the early-stage product quality performance is positively moderated by the component technological complexity.*

Method

U.S. Hybrid Electric Vehicle Market

To investigate the above hypotheses, examine the U.S. hybrid electric vehicle (HEV) market from 1999 to 2017. The reason for selecting this market and specific period is threefold. First, differing from the dominant technology of Internal Combustion Engines (ICE), this new technology offers an additional battery-powered propulsion mechanism for driving vehicles. Thus, this technological change has turned out to be a competence destroying innovation shock for incumbent firms demanding new knowledge and capabilities to deal with this shock. Given that this study tends to explore a firm’s outsourcing performance in the face of innovation shock, examining this market would be valuable.

Secondly, the observation period of the current study provides detailed insights into this market. Innovation shock in the shape of HEV resulted in a regulatory pressure, particularly the Zero Emission Vehicle (ZEV) mandate of Californian Air Resources Board (CARB). The ZEV mandate requires automobile firms to produce vehicles that are fuel efficient and environment-friendly (Wesseling et al., 2015). In addition to the pressure exerted by the ZEV, other factors, such as technological advancements in battery technology and the global oil crisis from 2003 to 2008, have also contributed to the commercial success of the HEV market. Given that this market has emerged and enjoyed significant commercial success during this study's observation period, this investigation is thus meaningful.

Third, the focus is on *OCK* and outsourcing performance regarding the battery system which is one of the main components of HEV transmission system (Erjavec, 2013). Battery system technology has evolved rapidly over the period and a higher power-to-weight ratio is considered as a critical success factor for any HEV-based vehicle (Amine, 2010). In addition, most automobile firms pursued an outsourcing strategy regarding battery component making this market an ideal setting for investigating the argument presented. Specifically, 75% of the total firms in 69% of the total models sold in the U.S. market have relied on outsourcing strategy for the battery system. Given that this study focuses on the outsourcing strategy in the face of an innovation shock, investigating this market thus provides a good opportunity to test the hypotheses presented.

Sample and Data Collection

There are three basic conditions a firm should meet to be included in this study. First, the firm should have offered at least one HEV model in the United States market during this study's observation window. Second, the firm should have opted for outsourcing strategy regarding the battery system. Lastly, before entering the HEV market, the firm should have innovation experience in producing vehicle with other competing technologies such as E85, CNG (dedicated and Bi-Fuel), Methanol (M85), Propane (dedicated and Bi-Fuel), and Hydrogen.

The data for this study has been collected from several archival sources. The primary data source regarding outsourcing strategy is *MarkLines* database - an independent research corporation that focuses on the automobile industry. In this study, the outsourcing strategy indicates that a supplier has designed and manufactured the battery component for a given model. To identify the HEV models offered in U.S. market and to find firms having innovation experience with other competing technologies, this study relied upon *Alternative Fuels Data Centre* database.

The patent data used to measure *OCK* has been collected from the United States Patent and Trademark Office (USPTO). This study followed a four-step process for clean patent data. First, this study identified there is a separate patent class 903 in the USPTO database that *"includes all the patents relating to components, arrangements/ control systems of components specifically adapted for hybrid electric vehicles (HEVs) and related topologies"*. Under this class, a total of 2364 patents were applied and granted during observation window of this study. Second, after identification of the relevant patent class, patent-specific information such as the name of the assignee, application date, title, abstract and international classification was manually collected for all the patents of this class. Third, given that a patent may be granted for all kind of applicants, including subsidiaries and affiliates of a firm, it is important to link these subsidiaries/ affiliates to the ultimate parent firm. In order to establish this link, this study relied upon *Business Source Complete* database. In addition, patents granted to non-automobile manufacturers, such as suppliers, individual inventors, universities, government agencies, and other not-for-profit research centers/bodies were executed. Lastly, based upon the subclasses, each patent was linked to main component and, by so doing, tracked to the battery related patent *(more details about the last step are available in the measurement section).*

The data related to vehicle quality performance has been collected from *J.D. Power and Associates* database. The data related to technological changes associated with the vehicle model and battery systems have been collected from technical reports published by the *U.S. Department of Energy National Laboratory*, *MarkLines*, *Alternative Fuels Data Center*, firm's annual reports and industry news. In order to compute the control variables, in addition to the above-mentioned sources, this study relied upon *Thomson Reuters Eikon* database. This database has been utilized to obtain firm-level financial information, such as total sales, number of employees, total assets and R&D expenditure over the years.

Measures

Dependent Variables

Early-stage quality performance

This study utilized *J.D. Power and Associates* survey data to operationalize early-stage quality performance of battery system of each vehicle model. J.D. Power is an independent organization that conducts surveys from verified vehicle owners, specifically asking about the number of problems experienced by them pertaining to different components/systems of the vehicle during first 90 days of their purchase. Based upon the number of problems reported by customers, J.D. Power then gives rating scores to each vehicle model ranging from 2 to 5, where 5 is the highest score indicating “among the best” and 2 is the lowest score.

Late-stage quality performance

Similar to the measure of *Early-Stage Quality Performance*, the second dependent variable is also based on J.D. Power's rating data. The only difference here is the timing of the survey. This survey is conducted after three years of a new product launch. The customers are asked about the number of problems they have encountered with different vehicle components/systems during the first three years of purchase. Based upon their feedback, J.D. Power then assigns rating scores.

Independent Variables

Outsourced component knowledge

This study has operationalized the *Outsourced Component Knowledge* variable, utilizing patent data. Patent data was gathered from USPTO and in order to determine whether a patent is related to the battery system, this study utilized definitions provided by *World Intellectual Property Organization (WIPO)* through the *International Patent Classification (IPC)* system. After examining the definitions of each patent’s *IPC* sub-classes, this study identified the key patent sub-classes related to battery system. For example, class *H01M* is defined as "*processes or means, e.g. batteries, for the direct conversion of chemical energy into electrical energy"* and this definition clearly indicates that IPC subclass H01M is related to the battery system. After identifying all the battery related subclasses, this study *OCK* with a 5-year moving window was computed.

Technological complexity

Technological complexity of the outsourced components limits a firm's ability to dictate its suppliers regarding the specific processes the supplier should follow in component development. In battery systems, technological complexity arises in an effort to maintain a balance between battery power, drive per charge, and weight. This variable has been operationalized based upon battery type (*lead acid, nickel-metal hydride, lithium-ion,* and *lithium polymer)*, total voltage of battery pack(s), and battery specific energy (Watt-hr/kg). The underlying intuition is that batteries with high voltage, high power, and advanced type tend to be technologically complex (Kalaignanam et al., 2017).

Instrumental Variable

IV for P_ Outsourced component knowledge

This study has modelled *OCK* for the battery system as a function of successful patents a firm possesses relating to other components of HEV drivetrain system. The reason for doing so is that if a firm engages in internal R&D in related components, it will also engage in battery focused R&D (Novak and Stern, 2009). As explained in the analysis section, this study computed and incorporated the predicted values for *OCK* in the second stage models for hypotheses testing.

Control Variables

Number of suppliers

This variable represents the number of battery suppliers available each year to automobile firms. The underlying intuition of including this control is that the number of suppliers available in the market limits their opportunistic behaviour. This opportunistic behaviour can undermine outsourcing performance (Pisano, 1990, Williamson, 1985). In order to operationalize this variable, this study counted the number of suppliers reported in *Top 100 global parts suppliers list* published each year by *Autonews* magazine.

Firm age

Since younger firms are more open to new knowledge and do not have the rigid organizational routines in the old firms, this study therefore, controlled for firm age (Klepper, 2004). This variable was operationalized as the difference between the year of analysis and the year of incorporation of the firm.

Firm size

Given that large size firms have better access to resources, such firms may show superior performance in the face of an innovation shock. Despite the positive effect of firm size on performance, some studies suggest that large size firms may develop organizational inertia that adversely affects their performance(Hannan and Freeman, 1984, Klepper, 1996). Therefore, firm size was included as a control variable and operationalized it as the natural logarithm of total assets of the firm in the year of analysis.

R&D intensity

This study included R&D intensity as a control to incorporate firm tendency towards enhancing internal innovation capabilities and new knowledge development (Cohen and Levinthal, 1990, Mowery and Oxley, 1995). R&D intensity is operationalized as the ratio of the firm's R&D expenditure to the total sales in the year of analysis.

Labor intensity

Similar to R&D intensity this study also included labor intensity as a control variable in analysis and operationalized it as the ratio of the number of employees to the sales revenue in the year of analysis. The underlying intuition in controlling labor intensity is that a higher labor intensity suggests that the firm is less focused on innovative knowledge (Dewenter and Malatesta, 2001).

Product differentiation

Given that vehicle models targeting high market segments may require customized design and the manufacturing of different components, including *product differentiation* as control variable can make analysis more robust. This study utilized the natural logarithm of the model price as a proxy for product differentiation (Argyres and Bigelow, 2010).

Production capabilities

Economies of scope across other products being produced by the firm may also affect a firm's orientation in acquiring knowledge regarding outsourced components (Conner and Prahalad, 1996). Therefore, we included it as control variable and utilized the number of vehicle models produced by the firm in the given year to operationalize this variable.

Oil crisis

A global oil crisis that lasted from 2003 to 2008 created uncertainty in the auto industry. This uncertainty can affect the firms' decision to invest in acquiring knowledge regarding outsourced components and outsourcing performance (Nohria and Garcia-Pont, 1991). This study, therefore, included a binary variable taking the value 1 for the period from 2003 to 2008, otherwise the value 0.

Competitive intensity

Given that competitive intensity that indicates the number of competing products in the marketplace may influence a firm's internal decisions, this study has thus included a control *competitive intensity* in the analysis (Barnett, 1997). This variable has been measured by counting the total number of HEV -based models available in the US market during the year of analysis.

Analysis

The nature of the data in this study was unbalanced panel. Since the use of ordinary least squares (OLS) regression for panel data is inappropriate, the recommended approach for this type of data is fixed or random effects. To be more precise, this study has conducted Hausman (1978) specification test to decide between fixed or random effects and the results of this test favored random effect model

.

Endogeneity is another major concern that needs due diligence for unbiased estimations. Since, the use of interaction terms may pose problems of endogeneity and biased estimates (Mayer and Nickerson, 2005), the normative consequences of this regression may be incorrect

(Leiblein et al., 2002). This study thus, utilized the two-stage least squares (2SLS) regression method with an instrumental variable approach to address potential endogeneity bias (Wooldridge, 2002). This study used the predicted values of the first stage as instruments of the endogenous variable of the second stage.

The purpose of the first stage was to obtain predicted values of *OCK* utilizing an instrumental variable IV_OCK. This instrumental variable was computed by counting the number of patents a firm possessed in other components of the HEV transmission system in the year of analysis. The reason for using this instrumental variable is that firms that are involved in internal R&D in other components of the HEV transmission system are more likely to involve in battery-related R&D. In the previous literature, Novak and Stern (2009) used similar intuition where they showed that firms' level of vertical integration in one system was sensitive to other systems. Basically, a firm makes similar decisions for similar components. Thus, firms that possess in-house component knowledge for other components of the HEV transmission system are more likely to possess *OCK* for battery components.

Since the performance of a given battery system is unaffected by the degree of the firms' in-house component knowledge for other HEV components, incorporating the firm's in-house component knowledge for other components of the HEV transmission system (*IV for OCK*) is thus an appropriate instrument. Since autocorrelation can also lead to unbiased estimation, this study conducted Wooldridge (2002) test using "xtserial" in STATA and found evidence for the existence of first-order autocorrelation. To correct for this autocorrelation in the first stage regression 'xtregar' command of STATA was employed (Cameron and Trivedi, 2010), this regression results were then used to compute predicted values of *OCK*. The specific regression model used in the first stage is shown below in equation (1), where ***i*** denotes the battery system, ***j*** the firm, ***t*** the year, and ε_{ijt} the random error term:

$$OCK_{ijt} = \beta_0 + \beta_1 * IV\_OCK_{ijt} + \beta_2\ Control\ Variables_{ijt} \qquad \textbf{(1)}$$

The hypotheses were tested in the second stage. The predicted values for *OCK* from the first stage, technological complexity, the interaction term *(outsourced component knowledge* technological complexity),* and control variables were included in the second stage to obtain unbiased estimates. Given that the dependent variables in second stage are rank ordered, this study thus utilized random effect ordered probit model. Specifically, STATA command 'xtoprobit' has been employed for this stage of analysis. The second stage performance model is presented below in equation (2), where ***i*** denotes the battery system, ***j*** the firm, ***k*** early or late stage, ***t*** the year, and ε_{ijt} the random error term:

$$\begin{aligned} Performance_{ijkt} = \alpha_0 &+ \alpha_1 * P\_Outsourced\ Component\ Knowledge_{ijt} \\ &+ \alpha_2 * Technological\ Complexity_{ijt} \\ &+ \alpha_3 * P\_Outsourced\ Component\ Knowledge_{ijt} * Technological\ Complexity_{ijt} \\ &+ \alpha_4 * Control\ Variables_{ijt} \qquad \textbf{(2)} \end{aligned}$$

Table 6.1: Summary of Correlation Statistics – Study III

		1	2	3	4	5	6	7	8	9	10	11	12	13
1	Early-Stage Quality Performance	1.000												
2	Late-Stage Quality Performance	+0.269	1.000											
3	Outsourced Component Knowledge	+0.324	+0.644	1.000										
4	Technological Complexity	+0.003	-0.045	-0.005	1.000									
5	No. of Suppliers	-0.016	+0.003	-0.031	+0.041	1.000								
6	Firm Age	-0.046	-0.106	-0.132	+0.067	+0.050	1.000							
7	Firm Size	+0.203	+0.574	+0.734	+0.034	+0.082	-0.038	1.000						
8	R&D Intensity	-0.166	-0.107	-0.262	+0.043	+0.078	+0.366	-0.167	1.000					
9	Labor Intensity	-0.181	+0.004	-0.100	-0.229	+0.173	-0.106	+0.210	+0.571	1.000				
10	Product Differentiation	-0.129	-0.056	-0.075	+0.229	-0.069	+0.253	-0.075	+0.109	-0.150	1.000			
11	Production Capabilities	+0.142	+0.496	+0.504	-0.040	+0.113	+0.386	+0.472	-0.024	+0.081	+0.038	1.000		
12	Oil Crises-Dummy	+0.133	+0.108	-0.053	-0.002	-0.117	+0.093	-0.186	+0.096	+0.046	+0.192	+0.267	1.000	
13	Competitive Intensity	-0.111	+0.108	+0.076	+0.355	+0.026	-0.072	+0.348	-0.142	-0.113	-0.100	-0.063	-0.428	1.000
	Mean	3.627	3.714	17.504	2.043	6.960	82.018	8.300	0.044	0.002	62436.630	3.390	0.136	3.504
	S.D	1.036	1.055	18.298	0.434	2.342	18.841	0.240	0.010	0.000	55674.630	0.388	0.343	0.644
	Max	5.000	5.000	70.589	4.000	10.000	115.000	8.649	0.065	0.004	229441.000	4.277	1.000	3.892
	Min	2.000	2.000	-0.273	1.000	1.000	23.000	7.263	0.009	0.000	4900.000	1.946	0.000	0.000

Table 6.2: Estimation Results – Study III

	First-stage	Second Stage Performance Models					
	P_ Outsourced Component Knowledge	Early-Stage Quality Performance (EQP $_{t+1}$)			Late-Stage Quality Performance (LQP $_{t+3}$)		
	Model 1	Model 2	Model 3 (H1)	Model 4 (H2)	Model 5	Model 6 (H1)	Model 7
Outsourced Component Knowledge			-0.090 (0.041)**	-0.356 (0.164)**		+0.423 (0.206)**	-1.040 (0.433)**
Technological Complexity (TC)	+0.130 (0.527)	-0.830 (0.372)**	-0.850 (0.439)*	-1.635 (0.637)***	-1.146 (1.188)	-1.082 (1.181)	-7.581 (2.486)***
OCK*TC				+0.117 (0.060)**			+0.713 (0.214)***
IV for P_ Outsourced Component	+0.386 (0.008)***						
No. of Suppliers	-0.168 (0.069)**	+0.322 (0.110)***	+0.318 (0.116)***	+0.301 (0.106)***	-0.006 (0.103)	+0.078 (0.128)	-0.020 (0.123)
Firm Age	+0.070 (0.021)***	-0.016 (0.025)	-0.046 (0.024)**	-0.036 (0.024)	-0.090 (0.053)*	-0.215 (0.098)**	-0.250 (0.110)**
Firm Size	+5.493 (1.920)***	+5.182 (4.134)	+9.917 (5.430)*	+9.802 (5.688)*	+24.119 (6.439)***	+36.914 (12.732)***	+40.777 (14.033)***
R&D Intensity	-56.271 (35.302)	+94.802 (58.532)	+120.240 (64.049)*	+121.986 (67.034)*	+143.998 (53.319)***	+69.602 (56.111)	+102.285 (71.729)
Labor Intensity	+192.679 (1069.002)	-3269.674 (1895.722)*	-5097.372 (1923.721)***	-5074.041 (2015.475)**	-2369.384 (3079.414)	-4309.169 (3233.045)	-9863.719 (3682.575)***
Product Differentiation	+0.000 (0.000)**	+0.000 (0.000)	+0.000 (0.000)	+0.000 (0.000)	+0.000 (0.000)***	+0.000 (0.000)***	+0.000 (0.000)***
Production Capabilities	-3.984 (0.994)***	+1.930 (1.419)	+2.743 (1.137)**	+2.840 (1.157)**	+3.072 (1.549)**	+3.070 (1.707)*	+5.335 (2.081)***
Oil Crises-Dummy	-4.070 (2.067)**	+10.508 (2.969)***	+10.539 (2.832)***	610.540 (2.889)***	+6.700 (1.723)***	+9.205 (2.581)***	+11.176 (2.477)***
Competitive Intensity	+2.841 (1.204)**	-0.909 (1.410)	-0.778 (1.368)	-0.500 (1.508)	-2.204 (1.992)	-5.772 (1.933)***	-3.215 (2.776)
Constant	-45.323 (13.459)***						
N	211	46	46	46	36	36	36
Overall R^2	0.978						
F Statistic	4596.56	37.20	57.91	79.41	8544.28	14882.22	
Log likelihood		-47.448	-45.357	-44.909	-29.233	-26.916	-22.518

***p<0.01, **p<0.05, *p<0.1 / Robust (Cluster) standard error in parentheses

Results

Table 6.1 presents summary statistics (means, standard deviations, maximum, and minimum) and correlation coefficients for all variables in this study.

Table 6.2 presents the main regression models used to test the hypotheses presented. Model 1 presents the results of the first-stage regression. The *IV for P_OCK* was positive and significant (+0.386, $p<0.01$ in Model 1), suggesting that firms with in-house knowledge for other components of the HEV transmission system are more likely to possess *OCK* for battery components. Thus, the instrumental variable used in this study seems appropriate.

Regarding Hypothesis 6 (the effect of outsourced component knowledge on product quality performance will be greater in the later stage of the new product life cycle than the early stage), the in-house knowledge of outsourced component was negative and significant (-0.090, $p<0.05$ in Model 3) for early-stage quality performance, and positive and significant for late-stage quality performance (+0.423, $p<0.05$ in Model 6). These results suggest that the effect of outsourced component knowledge on product quality performance was greater in the later stage of the new product life cycle than the early stage. Thus, Hypothesis 6 is strongly supported.

Regarding Hypothesis 7 (the weak effect of outsourced component knowledge on the early stage of the new product lifecycle is positively moderated by component technological complexity), Model 4 display key findings. The direct effect of outsourced component knowledge on early-stage quality performance was still negative and significant (-0.356, $p<0.05$ in Model 4). However, the interaction of outsourced component knowledge and technological complexity was positive and significant (+0.117, $p<0.05$ in Model 3). These findings suggest that the negative effect of outsourced component knowledge on the early stage of the new product lifecycle was positively moderated by component technological complexity. Thus, Hypothesis 7 is also strongly supported.

Discussion and Conclusions

Main Findings

Both arguments of this study have found robust empirical support, as displayed in Table 2 and explained in the above section. The key finding is that, despite *OCK's* beneficial role in mitigating exchange hazards, its effects on outsourcing performance are different over the product's life cycle. Specifically, *OCK* is more beneficial for the later-stage quality performance than of the early-stage. This study also revealed that when the technological complexity of the outsourced component is high, the negative effect of *OCK* on the early-stage performance will be weaker.

Theoretical Contributions

These findings suggest following theoretical contributions of this study. First, it provides a novel perspective to the extant literature that focuses on the broad issue of how to effectively manage exchange hazards in the face of innovation shock (Brusoni et al., 2001, Gulati, 1995, Kapoor and Adner, 2012, Nickerson and Zenger, 2004, Novak and Stern, 2008, Park et al., 2018, Takeishi, 2002, Williamson, 1979). The existing literature has suggested different ways of mitigating exchange hazards, such as contracting with high-quality suppliers

(Novak and Stern, 2008), developing long-term relationships with suppliers (Gulati, 1995), and retaining in-house knowledge regarding outsourced component (Brusoni and Prencipe, 2006, Brusoni et al., 2001, Kapoor and Adner, 2012, Park and Ro, 2011, Park and Ro, 2013, Takeishi, 2002, Williamson, 1985, Zirpoli and Becker, 2011a, Zirpoli and Becker, 2011b). The current study has drawn upon the seminal work of Brusoni et al. (2001) and further enhances their idea of retaining in-house knowledge regarding outsourced components for effectively managing exchange hazards. However, this study is the first to link the effect of retaining in-house knowledge regarding outsourced component to the new product life cycle. Specifically, in this study it is suggested that the effect of in-house knowledge regarding outsourced component on outsourcing performance is not constant, rather it differs across different stages of the new product's life cycle. Thus, at the early stage of new product life cycle incumbent firms should first focus on new knowledge acquisition from suppliers rather than dictating to them based upon limited and generic in-house knowledge.

Second, despite the fact the most of the existing literature has highlighted the positive role of keeping in-house knowledge regarding outsourced components (Brusoni et al., 2001, Takeishi, 2002) on outsourcing performance, some studies have also suggested that this relationship could also be negative (Park et al., 2018, Tiwana and Keil, 2007). This study tends to bridge these two related arguments by suggesting that the effect of in-house knowledge regarding outsourced components at the later-stage of new product life cycle is more beneficial than of the early stage. Thus, this contributes to the understanding of positive and negative role of in-house knowledge regarding outsourced components contingent upon stages of new product life cycle.

Third, current study demonstrated that the outsourced component's technological complexity also play an important role in explaining the positive and negative role of in-house component knowledge on performance (Balakrishnan and Wernerfelt, 1986). While the notions of component, architectural and system complexity (Henderson and Clark, 1990, Simon, 1962) has received considerable attention in the literature on technology management, there are also some studies that explain the relationships between technological complexity and outsourcing performance (Helfat and Peteraf, 2015, Kapoor, 2013, Nickerson and Zenger, 2004). The prevailing argument is that outsourcing strategy is not so effective in managing complex problems. It is also found here that the direct effect of technological complexity on outsourcing performance is negative. However, it is suggested that a component's technological complexity moderates the relationship between in-house component knowledge and outsourcing performance.

Fourth, although this study is based on radical innovation, these findings can also be applied to other types of innovations (Henderson and Clark, 1990). In addition, while the focus is on the hybrid electric vehicle' battery system market, the arguments and findings presented here can also provide useful insights for future investigations in other industries.

Managerial Implications

This study also provides managerial implications on how to enhance outsourcing performance. Given that exchange hazards can undermine performance, the findings of this study suggest that managers should invest time and resources in acquiring knowledge regarding outsourced components. In addition, they should continue learning from suppliers, at least during the initial period of new product life cycle. It is also important to develop flexible relationships and be ready to change the contract terms when deemed appropriate.

Given that R&D is expensive and involves considerable financial and technical resources, managers should incorporate such expenditure while making cost-benefit analyses of different alternatives. While switching from outsourcing to insourcing poses financial and capabilities constraints, the only viable solution is in managing exchange hazards (Nickerson and Silverman, 2003). Findings of this study are thus very valuable.

Limitations

This study has some limitations that create opportunities for future research. First, focus is on outsourcing performance in the face of an innovation shock but does not provide useful guidance under stable technological environments. Second, while this study investigates the role of possessing in-house knowledge regarding outsourced component, in reality firms have different degrees of such knowledge. This study does not provide no guidance on why firms have different degrees of knowledge. Third, this study has investigated a single idiosyncratic industry. Therefore, the generalizability of this study’s findings can be problematic. Further research in a different industry can bring more useful insights and help generalize the findings. Future research can address this shortcoming.

CHAPTER 7

GENERAL DISCUSSION

Summary and Findings

The main objective of this dissertation is to answer the research question "**How firms can achieve superior performance through strategic sourcing?"**. This broader research question has been addressed through three specific research questions. Chapters 4, 5 and 6 specifically addressed the three specific research questions. On the basis of the findings of these specific questions in the examination of hybrid elective vehicle market from 1999 to 2017, this chapter aims to provide general conclusions drawn from this dissertation.

1. How market dynamics impact firms' strategic sourcing decisions?

While market dynamics is a broader term encompassing all factors of the external environment, in this dissertation I examine the impact of an important factor- competition- on strategic sourcing decisions. Although this study is not the first to propose that competition influence firms' strategic sourcing decisions, empirical evidence suggests that the technological niche width mediates firms' decisions to opt for a specific sourcing strategy (i.e. vertical integration or outsourcing). In addition, I found that firms offering products with a broader technological niche width performed better when they opted for vertical integration over the outsourcing strategy.

2. Why some firms pursuing outsourcing strategy perform better than the others?

Given that outsourcing strategy facilitates incumbent firms in acquiring new knowledge inhabited with other industries, this strategy, however, presents alteast two challenges. First, incumbent firms will have developed firm-specific communication channels and routines with current suppliers to facilitate the appropriate diffusion and transformation of current knowledge. These effective and superior communication channels with current suppliers may create a situation of lock-in, turning core competencies into core rigidities when dealing with a new innovation shock. Second, because firms lack the direct authoritative mechanisms to control suppliers when pursuing an outsourcing strategy, they cannot fully control suppliers' opportunistic behaviours (i.e., shirking and hiding information). In essence, although the outsourcing strategy is very critical in helping incumbents acquire new knowledge and capabilities required in dealing with an innovation shock, incumbents must manage these two challenges in dealing with suppliers.

Regarding the first challenge, I found that prior green innovation experiences may allow incumbents and their suppliers to avoid becoming rigidly locked into existing processes and communication routines through frequent experimentation. Regarding the second challenge, I found that in-house knowledge regarding outsourced components may help incumbents mitigate the opportunistic behaviours of suppliers. The most astonishing finding however in this study is that both the prior green innovation experience and outsourced components knowledge facilitate each other (i.e. play a complementary role).

3. How and why the performance of firms pursuing outsourcing strategy improves over time?

While study two suggests that incumbent firms can better manage the challenges associated with outsourcing strategy in the face of innovation shock through prior green innovation experience and keeping in-house outsourced component knowledge, a critical question arise what if incumbent firms do not have prior green innovation experience? How can incumbent firms manage the challenges associated with outsourcing strategy in this situation? To address this issue, I propose that in-house knowledge regarding outsourced component can still play a critical role.

The empirical data support my argument that in-house knowledge regarding outsourced component can help incumbent firms manage the challenges associated with outsourcing strategy in the face of innovation shock. However, the positive role of outsourced component knowledge is visible in the later stage of a new product life cycle. During the initial stage of a new product life cycle, outsourced component knowledge (without prior green innovation experience) may deteriorate the performance. The reason may be that incumbent firms tend to dictate suppliers on the basis of (limited) in-house component knowledge, without overhauling organizational routines. In addition, I found that this negative effect is weaker when the technological complexity of outsourced component is high. This finding is astonishing as it provides the basis of the positive and negative role of outsourced component knowledge.

On the basis of finding from three specific questions, this dissertation attempts to answer the main question: How firms can achieve superior performance through strategic sourcing?

Theoretical Contributions

This dissertation provides ten main contributions. First, this study contributes to the literature linking market dynamics and firm boundary decision (i.e. strategy sourcing decision) (Bayus and Putsis, 1999, Giachetti and Dagnino, 2014, Shugan, 1989). In particular, this study highlights the important role of market competition on firms' decision to opt for a specific sourcing strategy (i.e. vertical integration or outsourcing). While the previous literature linking the competition and strategic sourcing present conflicting arguments, this dissertation contributes to this stream of research by suggesting that technological niche width mediates firms' decisions to opt for a specific sourcing strategy (i.e. vertical integration or outsourcing). Also, an agreement is shown with scholars who suggested that firms offering differentiated products are more likely to pursue the vertical integration strategy (Argyres and Bigelow, 2010).

Second, this study contributes to the transaction cost of economies (TCE) literature that addresses a key question of whether a firm should develop components from within the firm or by outside suppliers. While the TCE literature has widely suggested that when uncertainty is high, firms should produce components internally (Leiblein and Miller, 2003, Williamson, 1981, Williamson, 1991), some scholars reported contradictory findings (Balakrishnan and Wernerfelt, 1986, Gil and Ruzzier, 2018, Park et al., 2018). This study further strengthened the argument suggesting competition prompts firms not to pursue vertical integration.

Third, this dissertation contributes to the previous literature investigating the performance benefits arising from firms' sourcing and market penetration strategies. In particular, this study highlights the important role of technological niche width. It contributes to the literature by suggesting that firms offering products with a broader technological niche width performed better when they opted for vertical integration over the outsourcing strategy. This study further strengthened the argument suggesting that firms pursuing vertical integration would show superior performance (Afuah, 2001, Baldwin and Clark, 2000, Fine, 1999, Kapoor and Adner, 2012, Park and Ro, 2013). Specifically, the current study suggests that the positive impact of vertical integration on performance is strengthened when the firm is offering products with a broad technological niche width.

Fourth, this dissertation contributes to the literature investigating the impact of firms' strategic decisions on environmental performance. While there is a burgeoning literature examining the impact of firms' strategic decisions for enhancing environmental performance (Arfi et al., 2018, Chen, 2017, Ding et al., 2017, Laari et al., 2018), there is a dearth of studies focusing on the impact of follower's strategic outsourcing decisions on environmental performance in the face of an innovation shock. In particular, this study bridges two research streams – one stream advocates learning-by-doing (e.g. *PGIE*) (Macher and Boerner, 2012, Mayer and Salomon, 2006, Mitchell et al., 1994) and another stream advocates reliance on external knowledge (Akerlof, 1970, Brusoni et al., 2001, Kapoor and Adner, 2012, Park and Ro, 2013). By suggesting complementarities between *PGIE* and *OCK* for environmental performance improvement, our conceptual argument and results provide a novel contribution to the extant literature. This study may be the first to investigate the (environmental) performance implication contingent upon the complementarity of *PGIE* and *OCK*.

Fifth, this dissertation further enhances the burgeoning literature on *OCK* and its effect on performance heterogeneity. Much of the literature suggests the positive role of *OCK* in enhancing performance by underscoring the importance of *OCK* for monitoring suppliers and reducing the chance of opportunistic behavior (Akerlof, 1970, Brusoni et al., 2001, Kapoor and Adner, 2012, Park and Ro, 2013). However, Park et al. (2018) recently suggested the possibility of a negative effect of *OCK* on performance. The current study helps in understanding how to compromise the disadvantages of *OCK* on performance. This study contributes to the extant literature by suggesting that the positive and negative effects of *OCK* may also be contingent upon firms' prior green innovation experience (*PGIE*).

Sixth, like the fifth, we contribute to the literature on performance heterogeneity due to *PGIE*. Although most of the published literature has underscored the positive role of *PGIE* on performance (Macher and Boerner, 2012), some studies have suggested otherwise (Moorman and Miner, 1997, Nerkar and Roberts, 2004). *PGIE* provides firms with an informational advantage, enhances the ability of firms to absorb relevant knowledge, and overhauls organizational routines. However, when pursuing an outsourcing strategy, the central objective is to reduce the chances of opportunistic behavior and monitoring suppliers' performance, and the mere possession of *PGIE* is not sufficient to meet this objective. This dissertation thus helps in understanding the root cause of the positive and negative effects of *PGIE* on performance by suggesting the complementary role of OCK.

Seventh, it provides a novel perspective to the extant literature that focuses on the broad issue of how to effectively manage exchange hazards in the face of innovation shock (Brusoni et al., 2001, Gulati, 1995, Kapoor and Adner, 2012, Nickerson and Zenger, 2004, Novak and Stern, 2008, Park et al., 2018, Takeishi, 2002, Williamson, 1979). The existing literature has suggested different ways of mitigating exchange hazards, such as contracting with high-quality suppliers (Novak and Stern, 2008), developing long-term relationships with suppliers (Gulati, 1995, Uzzi, 1997), and retaining in-house knowledge regarding outsourced component (Brusoni and Prencipe, 2006, Brusoni et al., 2001, Kapoor and Adner, 2012, Park and Ro, 2011, Park and Ro, 2013, Takeishi, 2002, Williamson, 1985, Zirpoli and Becker, 2011a, Zirpoli and Becker, 2011b). The current study has drawn upon the seminal work of Brusoni et al. (2001) and further enhances their idea of retaining in-house knowledge regarding outsourced components for effectively managing exchange hazards. However, this study is the first to link the effect of retaining in-house knowledge regarding outsourced component to the new product life cycle. Specifically, in this study it is suggested that the effect of in-house knowledge regarding outsourced component on outsourcing performance is not constant, rather it differs across different stages of the new product's life cycle. Thus, at the early stage of new product life cycle incumbent firms should first focus on new knowledge acquisition from suppliers rather than dictating to them based upon limited and generic in-house knowledge.

Eighth, despite the fact that most of the existing literature has highlighted the positive role of keeping in-house knowledge regarding outsourced components for superior performance (Brusoni et al., 2001, Takeishi, 2002), some studies have also suggested that it could also be negative (Park et al., 2018, Tiwana and Keil, 2007). This study tends to bridge these two related arguments by suggesting that the effect of in-house knowledge regarding outsourced components at the later stage of the new product life cycle is more beneficial than of the early stage. Thus, this contributes to the understanding of the positive and negative role of in-house knowledge regarding outsourced components contingent upon stages of a new product life cycle.

Ninth, this dissertation suggests that the outsourced component's technological complexity also play an important role in explaining the positive and negative role of in-house component knowledge on performance (Balakrishnan and Wernerfelt, 1986). While the notions of component, architectural and system complexity (Henderson and Clark, 1990, Simon, 1962) has received considerable attention in the literature on technology management, there are also some studies that explain the relationships between technological complexity and outsourcing performance (Helfat and Peteraf, 2015, Kapoor, 2013, Nickerson and Zenger, 2004). The prevailing argument is that outsourcing strategy is not so effective in managing complex problems. It is also found here that the direct effect of technological complexity on outsourcing performance is negative. However, it is suggested that a component's technological complexity moderates the relationship between in-house component knowledge and outsourcing performance.

Finally, although this study is based on radical innovation, these findings can also be applied to other types of innovations (Henderson and Clark, 1990). In addition, while the focus is on the hybrid electric vehicle' battery system market, the arguments and findings presented here can also provide useful insights for future investigations in other industries.

Managerial Implications

This dissertation provides valuable guidance to managers and policymakers on how to achieve superior firm performance. First, I suggest that when devising strategies for enhancing firm performance, managers should also consider the level of vertical integration and technological niche width. Without proper alignment between the level of vertical integration and technological niche width, efforts to improve firm performance may have limited chances of success.

Second, this dissertation suggests that firms should engage in trail and experimentation (PGIE) despite such efforts fail in the short run. The reason for continuing PGIE is that because it may open fresh knowledge gateways to facilitate the acquisition of OCK. Decision makers can better understand and justify the cost-benefit analysis of internal R&D efforts when they take into consideration the benefits of PGIE as input for OCK.

Third, this dissertation suggests that managers should invest time and resources in acquiring knowledge regarding outsourced components. In addition, they should continue learning from suppliers, at least during the initial period of the new product life cycle. It is also important to develop flexible relationships and be ready to change the contract terms when deemed appropriate.

Limitations and Further Research

The following are the main limitations of this dissertation. First, I examined a single, idiosyncratic industry that may limit the chances of generalizability of the findings. However, it should be noted that the results are normally more accurate and robust when the analysis is conducted on a single industry.

Second, I focused only on the HEV market, the level of competition, firm capabilities, and strategies regarding vertical integration and technological niche width in other technologies such as pure electric vehicles, conventional internal combustion engine-based vehicles might influence the firm's strategic decision regarding HEV.

Third, I measured the *PGIE* by counting the number of models offered in the U.S. market prior to the introduction of HEVs. I, however, did not include the relatedness of *PGIE* to HEV technology. Given the fact that the experience of some technologies might have more impact on HEV environmental performance than others, investigating the relative importance of different types of experiences can provide useful insights.

Future research may be conducted to address the above-mentioned limitations.

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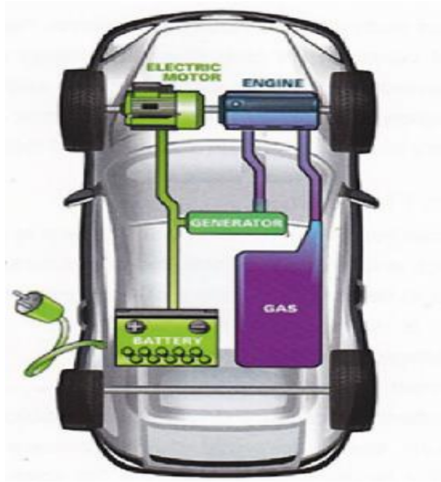
APPENDICES

APPENDIX A: Drivetrain System Comparsions of Different Vehcile Technologies

Internal Combustion Engine Vehicle (ICEV)

Hybrid Electric Vehicle (PHEV)



Plug In Hybrid Electric Vehicle (PHEV)

Electric Vehicle (EV)

Fuel Cell Electric Vehicle (FCEV)

APPENDIX B: Firms' Adoption Timeline for Green Vehicle Technologies- Industry Overview

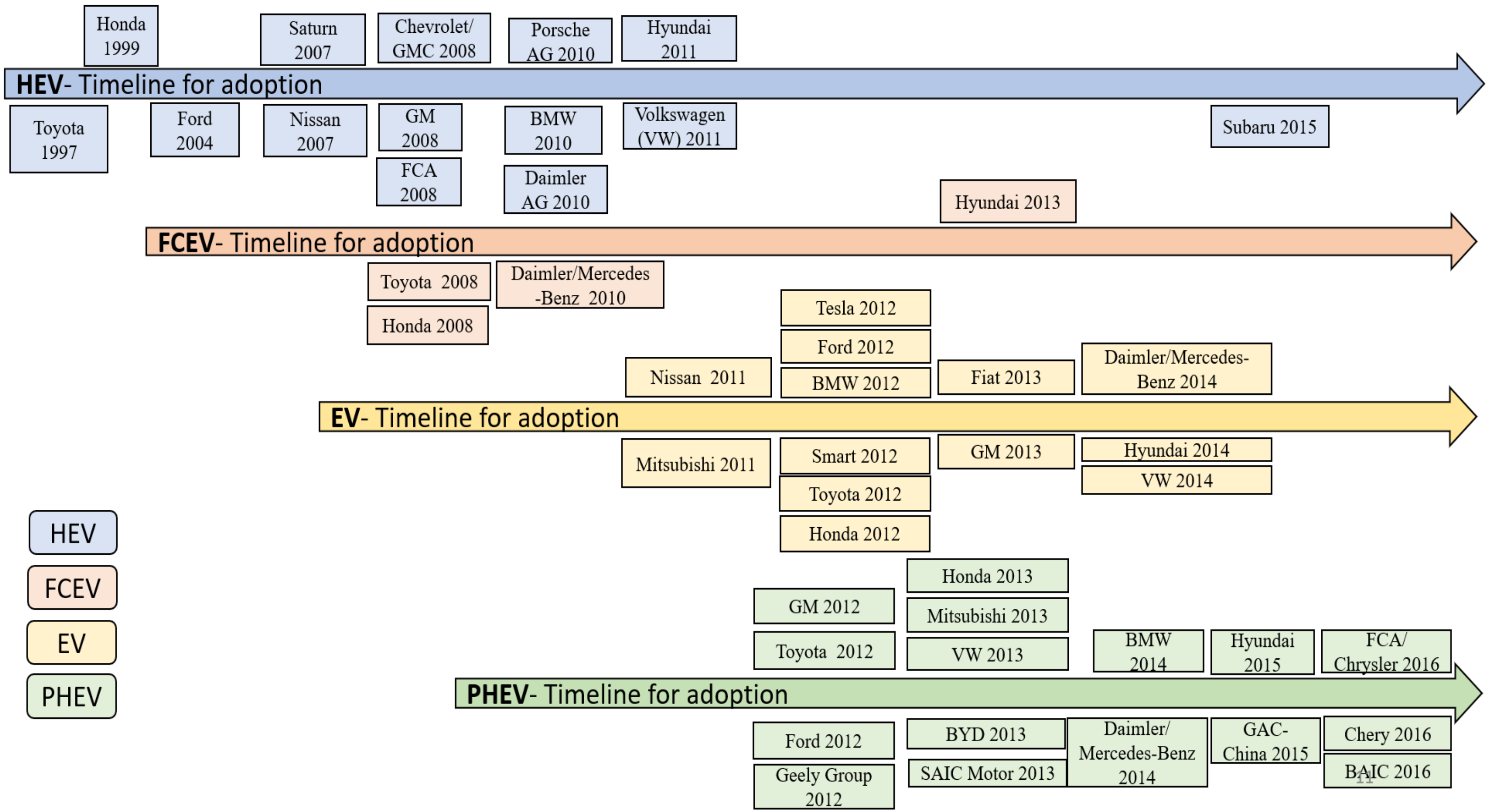


Figure B1: Firms' Adoption Timeline for Green Vehicle Technologies- Industry Overview

APPENDIX C: Major Automobile Firms’ Sourcing Strategies Regarding Drivetrain Components

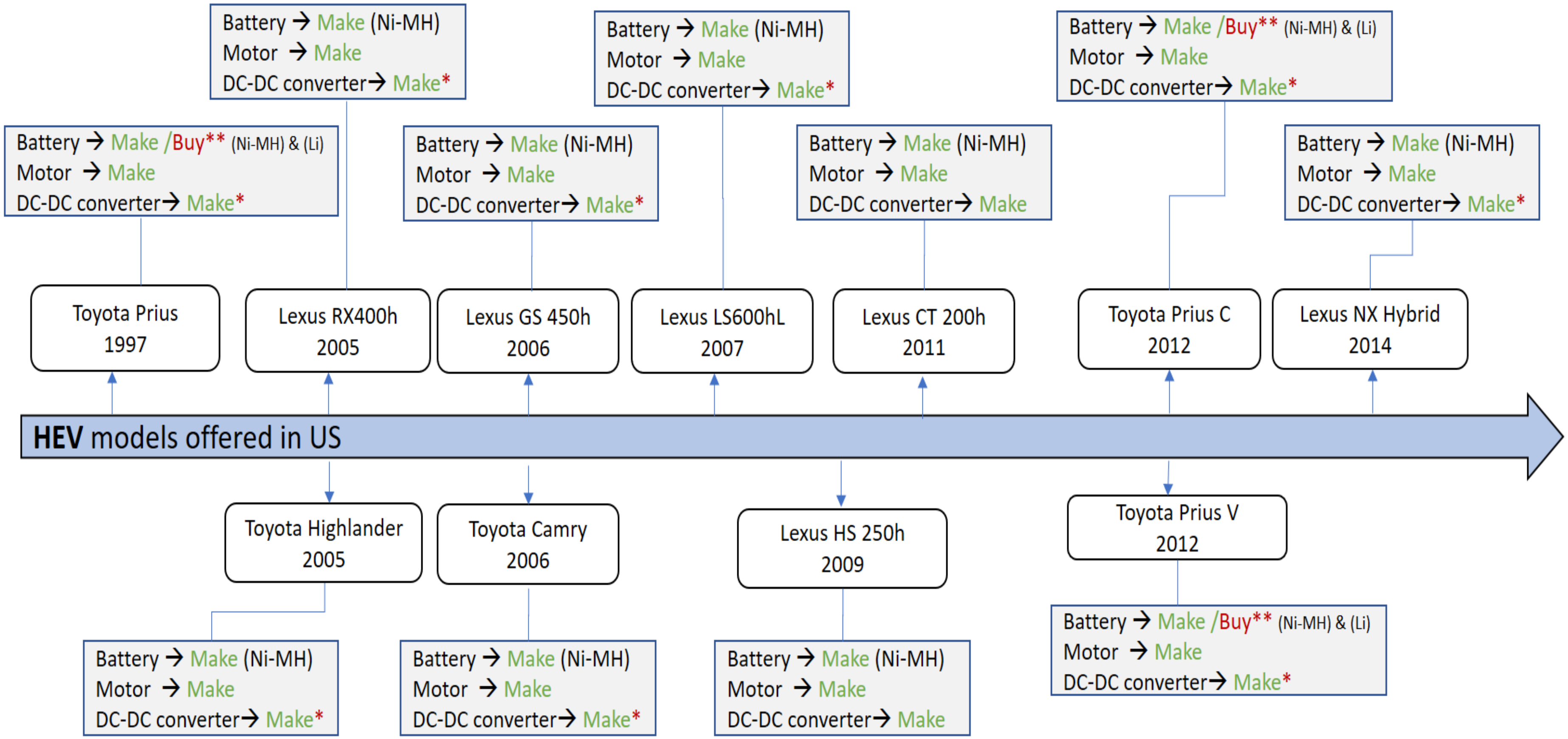


Figure C1: Toyota’s Sourcing Strategy for Drivetrain Components

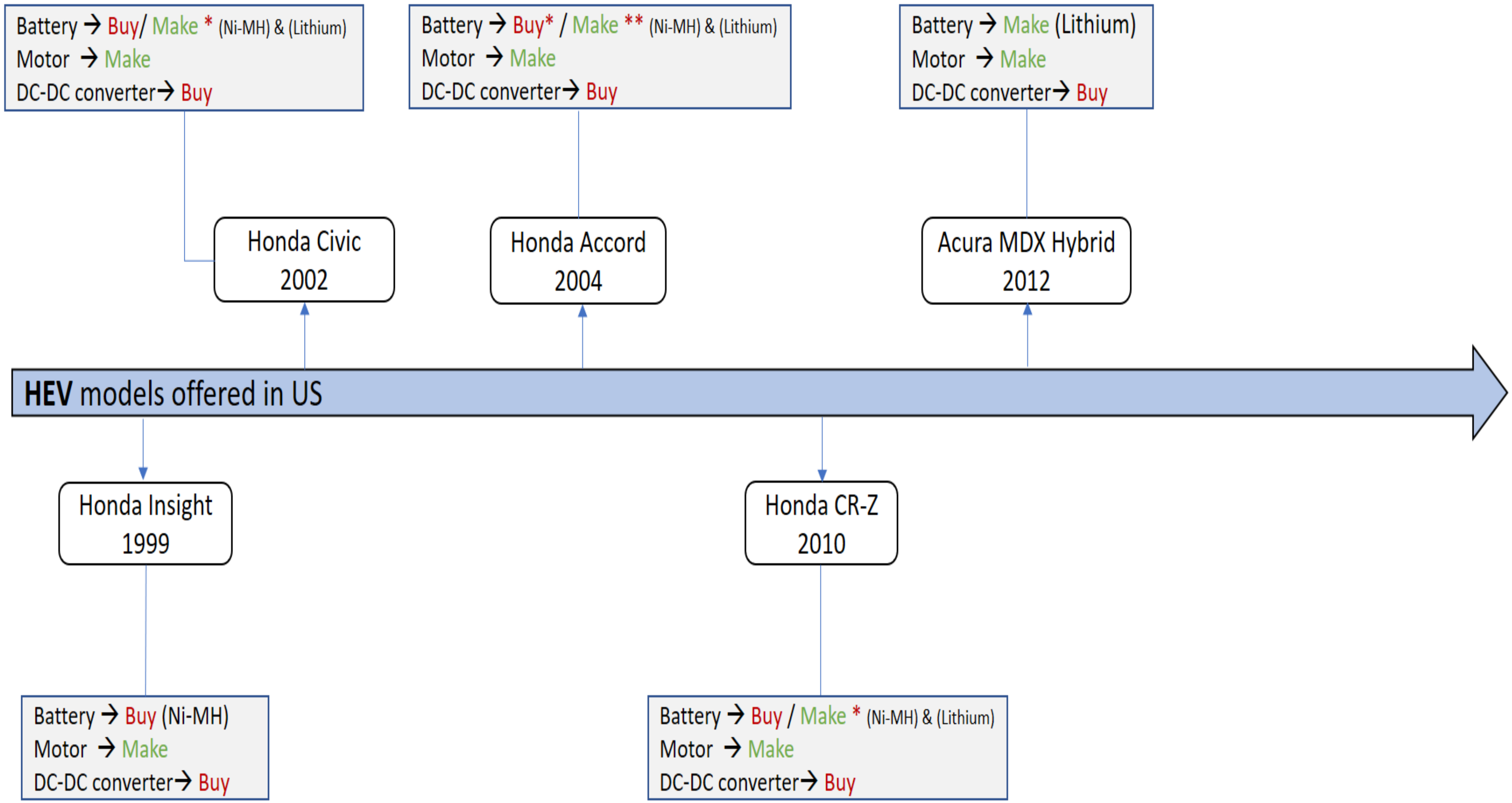


Figure C2: Honda's Sourcing Strategy for Drivetrain Components

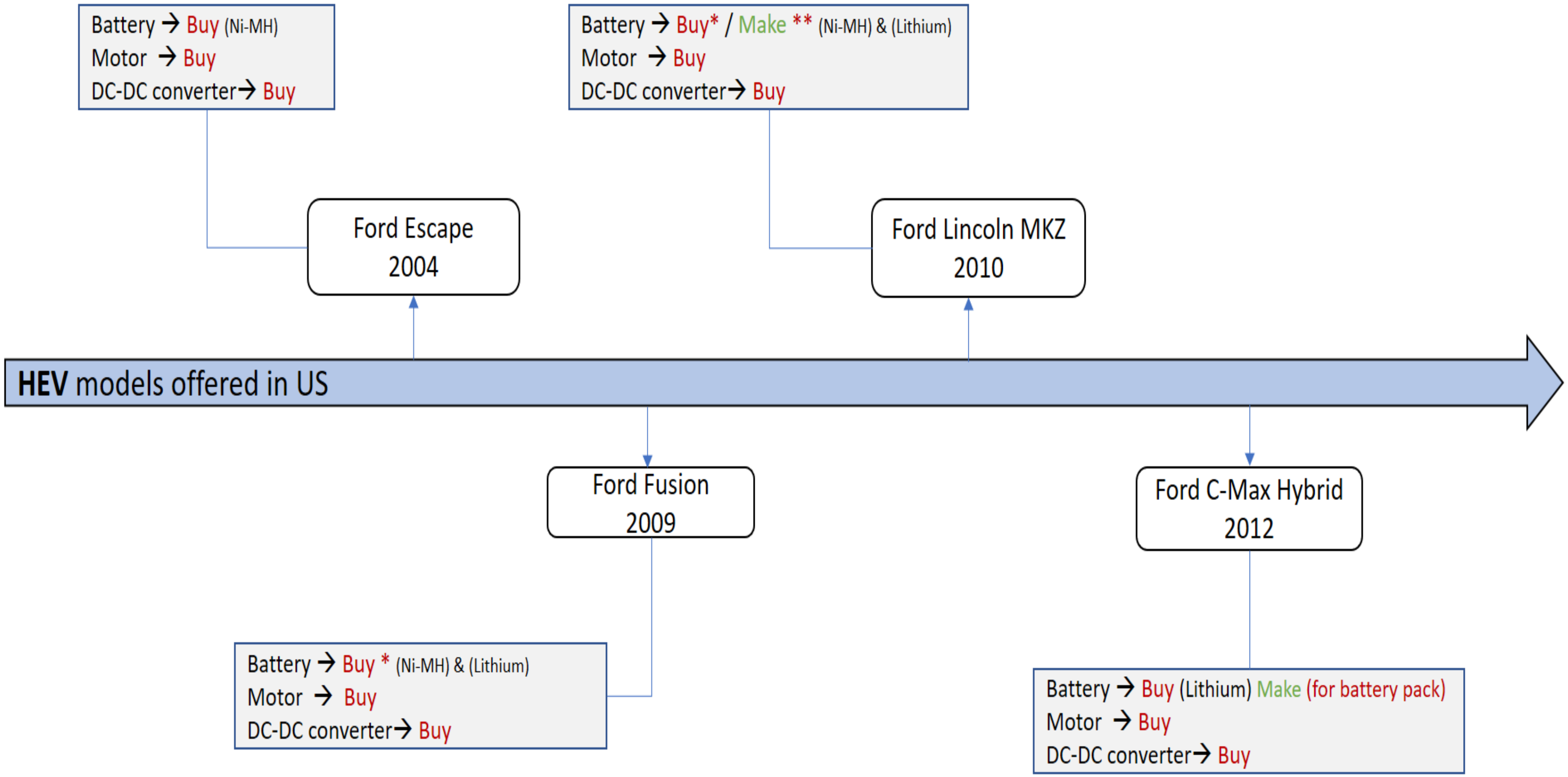


Figure C3: Ford's Sourcing Strategy for Drivetrain Components

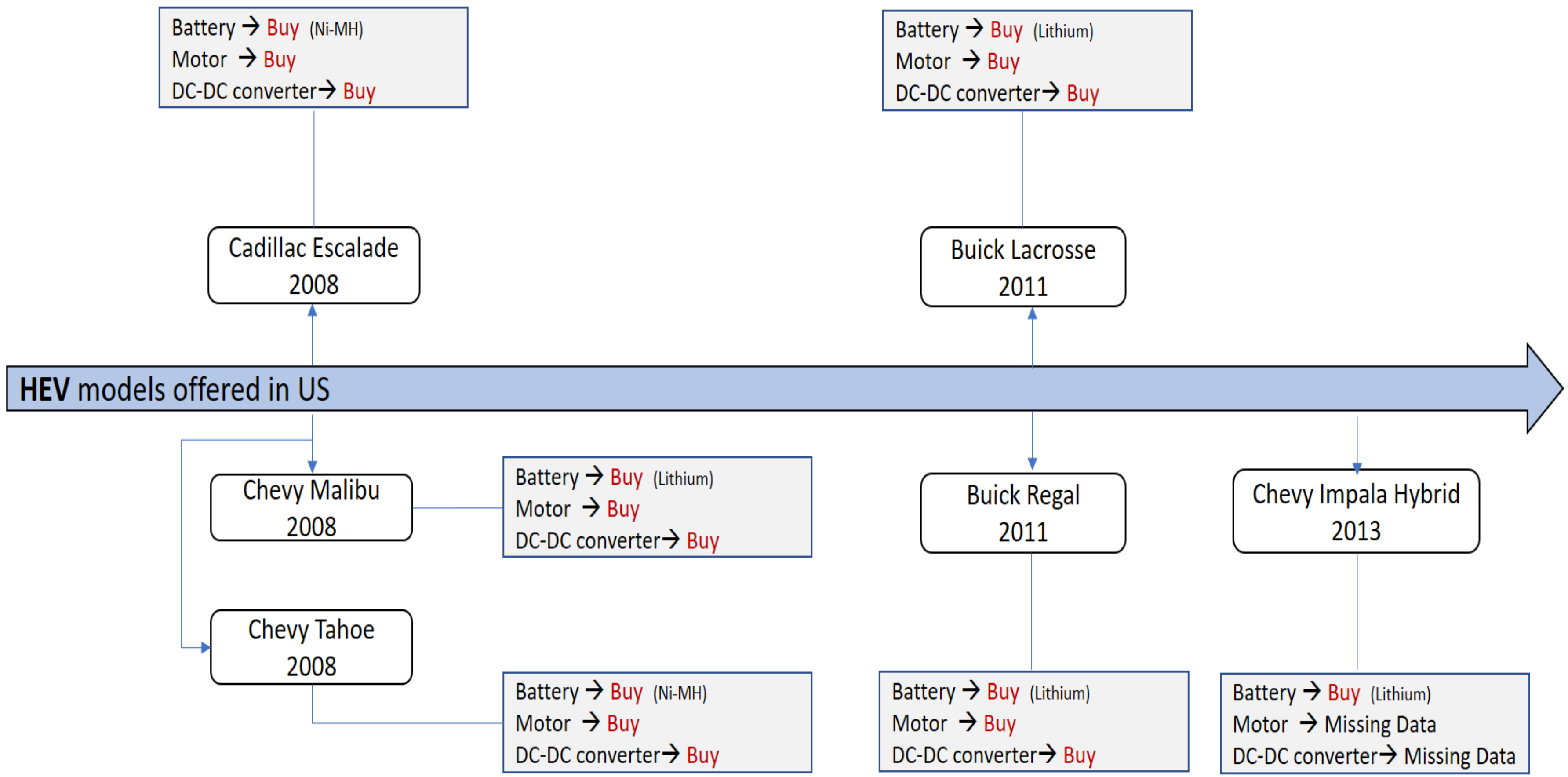


Figure C4: General Motor's Sourcing Strategy for Drivetrain Components

APPENDIX D

Table D.1: International Patent Classifications (IPC) of Major HEV Drivetrain Components

Battery (including Lead, Nickel, Lithium-ion and general)	Motor	Transmission (including gear, regenerative break, HEV architecture)	Engine	DC-DC Converter	DC-AC Converter (Inverter)
B60K 6/28	B60L011/02	B60K41/22	B60K 6/24	H02J1/00	H02M7/48
B60R16/04	B60L1/00	B60K6/36	B60K13/04		
B60S5/06	B60L50/10	B60K6/365	B60K13/06		
B60W10/24	B60L50/11	B60W10/10	B60K5/00		
B60W10/26	B60L50/13	B60W10/101	B60K5/04		
G01R31/36	B60L50/14	B60W10/105	B60K5/12		
H01M10/0525	B60L50/15	B60W10/109	B60W10/06		
H01M10/0585	B60L9/00	B60W10/11	F01N13/02		
H01M10/0587	B60L9/16	B60W30/19	F01N3/00		
H01M10/30	B60L9/18	B66D1/02	F01N3/10		
H01M10/34	B60W10/08	F01L1/047	F01N3/20		
H01M10/42	F02N11/04	F01L1/34	F01P3/12		
H01M10/44	G01N27/416	F16H1/08	F01P7/14		
H01M10/48	G01R15/20	F16H15/28	F01P7/16		
H01M10/50	G05D17/02	F16H15/52	F02B29/04		
H01M10/625	G05D29/00	F16H3/00	F02B33/00		
H01M10/637	H02K1/06	F16H3/08	F02B37/00		

Battery (including Lead, Nickel, Lithium-ion and general)	Motor	Transmission (including gear, regenerative break, HEV architecture)	Engine	DC-DC Converter	DC-AC Converter (Inverter)
H01M10/6563	H02K1/27	F16H3/091	F02B37/10		
H01M10/6566	H02K11/00	F16H3/12	F02B37/16		
H01M10/663	H02K17/42	F16H3/44	F02B37/18		
H01M16/00	H02K21/12	F16H3/64	F02B43/10		
H01M4/80	H02K21/22	F16H3/66	F02B61/00		
H02J7/00	H02K29/00	F16H3/72	F02B61/02		
H02J7/02	H02K3/12	F16H33/02	F02B61/06		
H02J7/04	H02K47/04	F16H37/02	F02B67/00		
H02J7/10	H02K49/06	F16H37/04	F02B67/04		
H02J7/14	H02K5/173	F16H37/06	F02B73/00		
H02J7/16	H02K5/20	F16H37/08	F02B75/00		
H02J7/34	H02K51/00	F16H41/28	F02B75/06		
B60L50/50	H02K7/00	F16H45/00	F02B75/18		
	H02K7/02	F16H47/04	F02D11/10		
	H02K7/09	F16H48/06	F02D13/02		
	H02K7/18	F16H48/08	F02D13/04		
	H02K9/19	F16H48/10	F02D13/06		
	H02P9/04	F16H48/295	F02D17/00		
		F16H48/30	F02D17/04		
		F16H48/40	F02D19/02		
		F16H57/02	F02D21/08		

Battery (including Lead, Nickel, Lithium-ion and general)	Motor	Transmission (including gear, regenerative break, HEV architecture)	Engine	DC-DC Converter	DC-AC Converter (Inverter)
		F16H57/021	F02D29/00		
		F16H57/022	F02D29/02		
		F16H57/023	F02D29/04		
		F16H57/025	F02D29/06		
		F16H57/029	F02D41/02		
		F16H57/03	F02D41/04		
		F16H57/033	F02D41/06		
		F16H57/04	F02D41/08		
		F16H57/08	F02D41/12		
		F16H59/14	F02D41/14		
		F16H59/24	F02D41/16		
		F16H59/38	F02D41/22		
		F16H59/42	F02D41/24		
		F16H59/46	F02D41/34		
		F16H59/56	F02D41/36		
		F16H59/68	F02D43/00		
		F16H59/70	F02D45/00		
		F16H59/72	F02G1/00		
		F16H59/74	F02G1/04		
		F16H61/00	F02M25/07		
		F16H61/02	F02M25/08		

Battery (including Lead, Nickel, Lithium-ion and general)	Motor	Transmission (including gear, regenerative break, HEV architecture)	Engine	DC-DC Converter	DC-AC Converter (Inverter)
		F16H61/04	F02M33/06		
		F16H61/12	F02M37/00		
		F16H61/14	F02M43/00		
		F16H61/20	F02N11/00		
		F16H61/21	F02N11/08		
		F16H61/32	F02N19/00		
		F16H61/66	F02N19/02		
		F16H61/664	G01M15/04		
		F16H61/68			
		F16H61/684			
		F16H61/686			
		F16H61/688			
		F16H63/06			
		F16H63/40			
		F16H63/46			
		H02P17/00			
		B60K 6/00			
		B60K 6/08			
		B60K 6/10			
		B60K 6/12			
		B60K 6/20			

Battery (including Lead, Nickel, Lithium-ion and general)	Motor	Transmission (including gear, regenerative break, HEV architecture)	Engine	DC-DC Converter	DC-AC Converter (Inverter)
		B60K 6/22			
		B60K 6/30			
		B60K1/00			
		B60K1/02			
		B60K1/04			
		B60K11/00			
		B60K11/04			
		B60K11/06			
		B60K6/02			
		B60K6/42			
		B60K6/44			
		B60K6/442			
		B60K6/445			
		B60K6/448			
		B60K6/46			
		B60K6/48			
		B60K6/485			
		B60L15/00			
		B60L15/02			
		B60L15/08			
		B60L15/32			

Battery (including Lead, Nickel, Lithium-ion and general)	Motor	Transmission (including gear, regenerative break, HEV architecture)	Engine	DC-DC Converter	DC-AC Converter (Inverter)
		B60L50/00			
		B60L50/16			
		B60L50/30			
		B60W10/00			
		B60W20/00			
		B60W30/18			
		B60L7/16			
		B60L7/20			
		B60L7/22			
		B60L7/24			
		B60L7/28			
		H02P3/14			
		B60K17/00			
		B60K17/02			
		B60K17/04			
		B60K17/10			
		B60K17/12			
		B60K17/14			
		B60K17/16			
		B60K17/24			
		B60K17/28			

Battery (including Lead, Nickel, Lithium-ion and general)	Motor	Transmission (including gear, regenerative break, HEV architecture)	Engine	DC-DC Converter	DC-AC Converter (Inverter)
		B60K17/34			
		B60K17/346			
		B60K17/348			
		B60K17/354			
		B60K17/356			
		B60K17/36			
		B60K23/08			
		B60K26/00			
		B60K28/16			
		B60K3/02			
		B60K31/00			
		B60K6/38			
		B60K6/383			
		B60K6/387			
		B60K6/40			
		B60K6/405			
		B60K6/50			
		B60K6/52			
		B60K6/54			
		B60K6/543			
		B60K6/547			

Battery (including Lead, Nickel, Lithium-ion and general)	Motor	Transmission (including gear, regenerative break, HEV architecture)	Engine	DC-DC Converter	DC-AC Converter (Inverter)
		B60W10/02			
		B60W10/04			
		B60W10/113			
		B60W10/115			
		B60W10/119			
		B60W10/12			
		B60W10/14			
		B62M23/02			
		B62M6/15			
		B62M9/08			
		B64D35/00			
		F16D13/76			
		F16D23/12			
		F16D25/0638			
		F16D25/12			
		F16D27/12			
		F16D33/00			
		F16D41/06			
		F16D41/07			
		F16D41/08			
		F16D43/04			

Battery (including Lead, Nickel, Lithium-ion and general)	**Motor**	**Transmission (including gear, regenerative break, HEV architecture)**	**Engine**	**DC-DC Converter**	**DC-AC Converter (Inverter)**
		F16D47/00			
		F16D47/06			
		F16D48/02			
		F16D48/06			
		H02K7/10			
		H02K7/108			
		H02K7/116			