Essays on Complementary Products and Strategies

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ABSTRACT

Complementary products contribute significantly to the growth and sustenance of primary products and platforms in many high technology product markets. Although different literatures have investigated issues related to complementary products, our understanding on this topic is limited. This dissertation aims to address some of the questions in the growing literature on complementary products. Following the literature review, the third chapter develops the conceptual underpinnings of product complementarity and examines commonly specified definitions to clarify the dimensions of product complementarity. The fourth chapter addresses the boundary question from the perspective of a primary product firm. The theoretical model identifies the antecedents of the internalization decision emphasizing the influence of type of product complementarity and key environmental contingences, viz., technological and market demand uncertainty.

The fourth and fifth chapters of the thesis examine the role of type of complementarity in predicting the governance choices of 31 public businesses over a time frame of 26 years in the PC industry, a setting where complementary products have significantly influenced the competitive and technological landscape. The study findings reveal that type of complementarity along with environmental contingences influence a firm's choice of internalization, alliances or complementor make. Market demand uncertainty influences the choice of strategy towards complementary product for moderately increasing levels of uncertainty while technological uncertainty predicts the governance choices for both low and moderately increasing levels of uncertainty. In

addition, in accordance with emerging literature in the Transaction Cost Economics logic (Leiblein & Miller, 2002; Jacobides, 2005) the findings highlight the role of firm capabilities. The dissertation attempts to contribute to the strategy literature by explicating the importance of nature of complementary products, so far not addressed in traditional TCE work.

CHAPTER 1: STATEMENT OF THE PROBLEM

Complementary products are seen as increasingly important in many industries. For example, computer software is complementary to hardware (Economides & Salop, 1992; Brandenburger & Nalebuff, 1997; Binken & Stremerche, 2009). The US computer software development industry involves about 50,000 companies with combined annual revenue of about $220 billion, more than half the sales of packaged products (Hoovers, 2010). Interestingly, clients using these applications particularly in the business environment source the services of information technology services companies such as IBM, Accenture and SAP. These information technology service providers are also many time producers of the prepackaged software. Thus there is a complementary relationship between the products they produce and the services they provide. Similarly, the role of complementary products was noted by Kazuo Hirai, president of Sony Computer Entertainment of America, in the context of video game systems, "Software is king. You can have the best technology, the most advanced box in the world, but without the applications, that box will only collect dust on the retail shelves."[1] Retail revenues from PDA software sales more than doubled in 2001 from 2000 to $27 million (NPD, 2002). These revenues correspond to the sale of around 900,000 units of software sold through brick-and-mortar retail channels during 2001 (versus 225,000 units in 2000)[2].

[1] HBS Case study # 9704488, 2004, *Note on Home Video Game Technology and Industry Structure,* Peter J. Coughlan

[2] ''Sales of Handheld Software Skyrocket'', Scarlet Pruitt, IDG News Service, April 08 2002, http:// www.pcworld.com/news/article/0,aid,93243,00.asp

The importance of complementary products is also witnessed in other high technology industries such as telecommunications. For instance, a recent (2009) independent Market Tools survey conducted by QuickPlay Media, a provider of mobile TV and video solutions, reveals that the number of people watching TV and video content on their mobile devices remained steady from 2008 to 2009 at 35%. The survey also suggests that multimedia-enabled phones will play a role in the growing adoption of mobile TV and video services. Specifically, the results found that while slightly less than a quarter of consumers are using a multimedia-enabled phone (24%), these devices will play a critical role in drawing consumers to watch TV and video on their mobile phone. Another 38% said that if they were considering changing wireless carriers, their ability to offer the latest multimedia-enabled PDA/smart phone would affect their decision in choosing a carrier. Thus the value of using a telephone or mobile phone today is enhanced by the extent of multimedia services/functions such as text messaging, emailing, viewing videos and movies, listening to and downloading music in addition to the core utility of using the device for communicating. The carrier service, the cellular device and the various multimedia applications complement one another. The mobile phone with apps (including OS) and the telecom carrier form the set of complements[3].

The importance of complementary products is not limited to high technology industries. In the automobile industry, a recent automobile parts industry report conducted by the US Department of Commerce (2010) suggests that value added to vehicles by suppliers will grow from 40 percent in 2002 to 55 percent by 2015. Some

[3] Mergent Industry Reports, Telecommunications, July 2009

new technologies being added or becoming standard on vehicles are safety features like blind-spot detection and side/head airbags. Navigation systems, MP3 player connections, bluetooth wireless connections and mobile video are other examples. In addition, GPS and telematics packages that connect cars to home computers will become standard within the next few years. By 2012, Original Equipment manufacturers and aftermarket suppliers are expected to create a $2.4 billion telematics market in the US and global market of $9.3billion

Literature Overview

Three lines of research, viz. in economics, marketing and strategy have focused on complementary products. We note the key lines of work in each stream of work. In the economics literature, formal models using the lens of game theory and rooted in cross price elasticity of demand have informed us about the implications and dynamics of product complementarity. First, by integrating into complementary product markets, a firm can internalize the costs of managing the development of two products externally and thereby pass on the benefits of the efficiencies gained to consumers through lower prices on the bundle of primary and complementary goods (Cournot, 1838, Economides & Salop, 1992). A monopolist could extend its market power into complementary product markets through tying and bundling as a competitive strategy (Whinston, 1990; Nalebuff, 1999; Nalebuff, Heeb, 2003; Nalebuff, 2004; Carlton & Waldman, 2002; Casadesus-Masanell, Nalebuff & Yoffie, 2007). Examples include IBM (tying tabulating machines with the purchase of tabulating cards in the past and that of its mainframe machines with its operating system, recently) and Eastman Kodak (tying products with

service). Tying not only restricts the entry of complementors into primary product markets (Choi & Stefanadis, 2001; Nalebuff, 2004), but also enables the firm to enhance its own primary product profitability by gaining access to the complementors' customers. The antitrust litigation case that has brought the focus of economic scholars to the dynamics involving complementary products is that of Microsoft tying the browser with its primary product, to mitigate the risk of the Netscape browser emerging as a potential substitute to the Microsoft operating system (Whinston, 1990; Carlton & Waldman, 2002). Such a strategy reduces the incentives for potential (i.e. firms having a new, low cost technology that may or may not be superior to the incumbent's) complementors to enter the primary product market because of the considerable costs involved in innovation (in developing a primary product) coupled with reduced possibility of consumer demand for the complement itself.

However, these arguments are contingent upon important product market characteristics or environmental conditions, the effects of which require in depth examination. For example, these arguments have been considered when network effects are relatively strong and the primary product firm has an established presence through a large installed base. Under these conditions, tying increases consumer's costs associated with switching to an alternative technology (that includes purchase and learning costs as well as the benefits from a large network of users). The superiority of a substitute technology could be a sufficient condition for switching, when the markets are not characterized by network effects and the primary product firm does not have a large installed base of users. Additionally, tying a symmetric complement to a primary product

would have a greater deterrence effect because the consumer cannot use complement without the purchase of the primary product.

Competitive strategies also influence innovation in complementary product markets (Farrell & Katz, 2000; Heeb, 2003). These models assume that the primary product firms are monopolists (or duopolies) and examine how strategies such as tying or pricing influence profitability potential. However, most high technology industries (where product complementarity is relevant) are disintegrated. Firms in one layer of the industry pursue strategies of integration into complementary product markets to increase their total share of profits (Bresnahan & Greenstein, 1999; Cheng & Nahm, 2007). While early research investigated vertical integration as a form of competitive action, several complementary product markets witness different forms of governance such as minority equity investments and different types of cooperative agreements. Thus firms pursue both competitive and cooperative strategies in high technology industries where product complementarity is important. Although integration into all complementary product markets may benefit the firm by empowering it with a high degree of control, it is yet impractical making cooperation an important aspect of dealing with its complementors.

Recently, scholars have shown interest in the coordination aspects with complementors (Gawer & Henderson, 2007; Kapoor & Lee, 2013). A complementor incurs lesser costs of making complements when the primary product firm contributes information or resources such as intellectual property or toolkits for exclusive complement development. For example, to reduce dependence on Microsoft, IBM supported the development of Linux, a substitute to the Windows based operating system

by financial investments and sharing technological know-how with Red Hat (Yoffie & Kwak, 2006). In another case, Intel subsidized the entry of complementors by sharing its IP, marketing resources for commercialization and encouraging complementary product development through free distribution of Software Development Kits. Primary product firms are also observed to enter a variety of cooperative agreements such as licensing and joint agreements for technology development, marketing, distribution with these complementors. Research is yet to investigate the mechanisms that explain the choice among these strategies.

Research in marketing has examined implications of product complementarity for consumer behavior (Sarvary & Parker, 1997; Duvvuri, Ansari & Gupta, 2007) and for a firm's marketing strategies (Sarvary & Parker, 1997; Sengupta, 1998; Noble & Gruca, 1999; Basu, Mazumdar & Raj, 2003). For instance, firms may adopt different pricing strategies when selling complementary products (Noble & Gruca, 1999), use information about consumer's sensitivities for price and promotion related to one product category to predict their purchase behaviors in a complementary product category (Duvvuri, Ansari & Gupta, 2007) and incorporate the value of complements for consumers in making forecasts for primary products positively influences technology adoption (Gupta, Jain & Sawhney, 1999).

Complementary products play an important role in the adoption of a technology such as QWERTY and VHS when competing alternatives are available (Katz & Shapiro, 1985, 1986; Farrell & Saloner, 1986; Arthur, 1994; Brynjolfsson & Kemerer, 1996; Cottrell & Nault, 2004). In high technology markets(such as video games and PDAS)

characterized by network effects, studies recommend differential pricing strategies of software (with respect to hardware) and variation in the availability of software variety over the life cycle of the hardware (Clements & Ohashi, 2005; Nair, Dube & Chintagunta, 2005). Poor availability of complementary products such as video tapes in the compatible format for VCRs and software for hardware can lead to possibility of technology lockout, where a firm is unable to compete in a product market because of technology standards (Schilling, 2002).

In two-sided markets, complementary interactions between products could be used to stimulate demand and handle competitive influences from other firms, providing a rationale for cross subsidization of products (Parker & Van Alstyne, 2005; Rochet & Tirole, 2003). Complementary products can influence whether markets with platform competition evolve to a "winner-take-all" standard, when complementors can differentiate their products and co ordinate on a standard for the platform, hardware or primary product (Rysman, 2009). Current work in this area is motivated in understanding the pricing strategies to coordinate consumers and sellers, based on cross-group effects (Rochet & Tirole, 2003; Caillaud & Jullien, 2003; Jullien, 2011; Amelio & Jullien, 2012).

There is evidence of growing interest in strategy research on the issues related to complementary products and the strategic implications (Afuah, 2000; Teece, 2007; Pierce, 2009; Adner & Kapoor, 2010; Turner, Mitchell & Bettis, 2010; Lee, Venkataraman, Tanriverdi & Iyer, 2010; Kapoor & Lee, 2013). These works also contend that complementary products and businesses are underemphasized elements of industry dynamics (Adner & Kapoor, 2010; Turner, Mitchell & Bettis, 2010). A recent

review of strategy in network industries has directed direction to this unaddressed area in the literature among others - the strategies employed by firms to create availability of complements and how product design aspects maybe critical in influencing the network intensity – the size of the network (McIntyre & Subramaniam, 2009).

Research questions

Although the importance of complementary products has been examined in different contexts, research issues remain to be addressed (Adner & Kapoor, 2010; McIntyre & Subramaniam, 2009). Although Brandenburger & Nalebuff (1997) noted – "*just as people have been playing catch-up when it comes to thinking about suppliers, there's a lot more work to be done in recognizing and benefitting from complementor relationships*", the observation is relevant. First, limited attention has been paid to the concept of complementary products. Definitions of complementary products depict different aspects of product complementarity, suggesting a need for a coherent understanding of the factors constituting product complementarity. Second, work on vertical integration strategies and the impact on product market structures, issues of competitive foreclosure and tying raise questions about the mechanisms influencing the decisions of firms in primary product markets with respect to the choice of a suitable strategy. Different forms of hold-up behavior are likely to exist in the context of complementary products (Casadesus-Masanell & Yoffie, 2006; Hogendorn & Yuen, 2009; Yalcin, Ofek, Koenigsberg & Biyalogorsky, 2013), requiring an understanding of the contextual factors and the nature of such behaviors. Finally strategies pursued by firms

have varied according to the stage of technology competition, suggesting the need to address specific market and technological factors influencing the choice of the strategy.

The specific research questions that I examine in this dissertation include -

1. What is the meaning of product complementarity?
2. What is the significance of type of complementarity for a primary product firm's governance choice? Specifically,
    i) How does type of complementarity influence complementary product internalization decision?
    ii) What are the contextual factors influencing the complement internalization decision?

Plan of the proposal

This proposal adopts a multiple essay format to address these questions. The next chapter conducts a literature review on the topic of complementary products, reviewing the definitions, findings and analyses to identify the major topics examined in the literature. The subsequent chapter develops the concept of product complementarity, by delineating aspects from a thorough review of the definitions and examples employed in the literature. Chapter 4 develops the conceptual model of the dissertation with testable propositions based on the concept of type of complementarity, product market contingences and predicting the choice of a governance strategy. Chapter 5 lays out the methodology for implementing the study and examining the hypotheses. Chapter 6 details the results from regression analyses and Chapter 7 discusses the implications of the results, and identifies limitations of the study and future research opportunities.

Contributions

The dissertation attempts to make the following contributions. First, it attempts to enhance conceptual understanding of product complementarity by identifying and describing the main dimensions and deriving a relationship between type of complementarity and firm interdependence. Second, it integrates theoretical mechanisms from the strategy literature, insights from economics and marketing literatures to explain and predict strategies pinned on type of complementarity for primary product firms competing in high technology contexts. The governance strategy is based on the recognition that complements influence sharing/execution of functions most valued by the consumer in a primary product, are a lead companion product in enabling the primary product to emerge as a strong contender in technology battles and enable maintaining a competitive edge vis-à-vis rivals in dynamic and unpredictable environments through delivery of system based products (Katz & Shapiro, 1994). Third, this thesis examines the influence of contextual factors that characterize high technology industries. In such conditions, the capability to rapidly enter new product markets, without cannibalizing current product markets can be a source of relative sustainable competitive advantage (Eisenhardt & Martin, 2000). The predictions related to complementary product governance are likely to assist managers in the decision making of firms competing in such dynamic environments.

In sum, considering the pervasive influence of complements in several aspects of a firm's primary product market outcomes - standards battles, dominant design emergence, growing market share - the thesis attempts to uncover explanations of the

influence of a key dimension of production complementarity in a firm's sourcing decisions in managing interdependence arising from complements.

CHAPTER 2: REVIEW OF THE LITERATURE ON COMPLEMENTARY PRODUCTS

Introduction

There has been a surge of interest in the technology-based competition centered on platforms and ecosystems, transcending different disciplines in business. Complementary products are an important aspect of this phenomenon. Traditional IO research and subsequent research in strategic management has examined the importance of suppliers, buyers, competitors, substitutes and new entrants in influencing the performance, innovation and survival outcomes (Porter, 1985; 2008). This research is being augmented with the activities and mechanisms involving complementors across a range of industries varying in environmental dimensions such as speed, rate of technology change and nature of products. This paper reviews the research on complementary products that has been conducted in the economics, marketing and management research streams that also includes the management of information systems and operations research. It finds that despite growing and significant strides in research in these literatures, important conceptual linkages in product complementarity have yet to be addressed. The purpose of this review is three fold; first we bring together the different assumptions, perspectives, contributions and arguments non tangentially related or involving complementary products in above literature streams. Second, we identify and describe common themes across the literatures in order and areas needing more clarification. Finally, we propose directions for future research.

The paper is structured in the following manner. First, the method used to conduct the review is described. Subsequent sections highlight the findings from the review.

Limitations and potential research possibilities are also mentioned where applicable. The review concludes by identifying potential research possibilities.

Method of Review

We conducted a comprehensive search of the economics, management and marketing literatures to identify studies that dealt with complementary products. This search was accomplished in three steps. First we developed the criteria for executing the search, including the choice of keywords. Second, based on the keywords, we analyzed the (refereed) papers that dealt with the topic of complementarity. Finally, we extended the search to incorporate influential books.

Our first task was identifying the right set of keywords for conducting an electronic search. At the outset, we searched ISI Web of Science for complementary product(s). This produced a set of 133 articles encompassing peer-reviewed articles and proceedings papers. We then read the ten most highly cited articles on this topic (Economides & Salop, 1992; Church & Gandal, 1993; Gilbert & Riordan, 1995; Lilly & Walters, 1997; Sarvary & Parker, 1997; Golder & Tellis, 1997; Parthasarathy & Bhatacharjee, 1998; Choi & Stefanadis, 2001; Carlton & Waldman, 2002). Second, we consulted some of the books published on this topic (Brandenburger & Nalebuff, 1996; Guiltinan, Madden & Thomas, 1997, Shapiro & Varian, 1998; Cusumano & Gawer, 2005; Evans, Hagiu & Schmalensee, 2006). We also consulted academic experts in the

marketing, economic and technology strategy areas on the exhaustiveness of the keywords[4].

We used the key words to conduct a second round of search in ISI Web of Science database to identify the peer-reviewed articles dealing with complementary products. Since there has been no prior review on the topic in any of the literatures and ISI allows search back until 1980, we confined our search to the period after 1980 (till Sept 2013). ISI WOS, an academic online database from Thomson Scientific has been used in the management stream for examination of literature (Bapuji & Crossan, 2004; Lane, Koka & Pathak, 2006; Crook, Ketchen, Combs, Todd, 2008)

ISI Web of Science categorizes articles into subject areas such as economics, business, management, telecommunications, computer science theory methods, surgery, biology, ecology etc. Notably, these categories are not mutually exclusive – i.e. an article categorized under "energy fuels" is also counted in the "applied chemistry" and "chemical engineering" categories. Since our interest was in identifying published work in the business literatures informing aspects of product complementarity, we applied filters to refine the above set to retrieve works in the economics and business & management categories. These categories also capture other subject areas. Thus even if we did not explicitly include categories such as "Communications", but papers published in this category have economic or management implications, they would be captured due to the inclusiveness in the categories .We excluded categories such as Biophysics,

[4] "complementary products", "complementary goods", "complementary components," "complementary markets", "indirect network effects/externalities".

Organic Chemistry, Spectroscopy etc. because, the papers in these categories dealt with subjects relating to the physical and material sciences. The search produced 665 articles. Finally, we further excluded articles in the following publications because of the irrelevance of the articles published in the journals to the focus of our interest viz., Naval Research Logistics, Group Decision and Negotiation, Journal of Forest Economics, Expert Systems with applications, Decision Support Systems, Journal of International Trade Economic Development, Journal of Sport Management, Journal of regional Science, Queueing Systems, Safety Science & Transportation Research: Policy and Practice. A list of excluded publication journals is provided in Table 1

Please insert Table 1 around here

This resulted in a set of 179 articles. A breakdown of these articles by included publication (see Table 2), year and WOS (Web Of Science) research areas/categories (see Table 3)

Please insert Table 2 around here

Please insert Table 3 around here

The literature review is structured as follows. In the first section, we note the state of the literature of the literature on complementary products. Then we review the key topics addressed, identify the conceptual aspects in the context of complementarity and the main empirical findings related to complementary products. Under each section, we summarize the analysis with the objective of highlighting the different assumptions used

in modeling (economics & marketing streams), the contexts in which product complementarity has been studied and the environmental contingencies related to product complementarity and identifying possible areas to be addressed. Finally, we identify the limitations of our review in the concluding section.

State of the literature on product complementarity

Majority of the work, specifically in the 1980s through 1990s has been primarily centered on the competitive aspect of complementary products (Carlton & Waldman, 2002; Choi & Stefanadis, 1992, Whinston, 1990) and indirect network effects. Further, since the 2000s there is a growth of interest in several areas spanning marketing, economics and management. Further the literature on product complementarity is fragmented and spans several research topics including technology strategy, competition, two sided markets and consumer behavior to name a few.

Our review suggests that there are varied conceptualizations of product complementarity, which we briefly outline in this section. The objective is to suggest the need for a clarification on the concept of product complementarity in terms of the definitions, attributes and characterizations. Based on usage, use complements are products that are consumed together, while purchase complements when they are purchased together (Mulhern & Leone 1991). The economics definition of complementary products, based on cross-price elasticity captures interdependencies in purchase behavior; strongest interdependences exist among products that are use complements (Mulhern & Leone, 1991). From a retail perspective, purchase complementarity exists for all products in a customer's shopping basket (as the consumer

may purchase two items together for several reasons such as convenience. When purchase of one product is conditional upon prior purchase of another product, they are called contingent products (Venkatesh & Mahajan, 1997). Sarvary and Parker (1997) identify situations when information goods from different sellers (selling similar products) become complements rather than substitutes as would be the case with traditional goods. When customers are faced with information that has low reliability (quality) and sources of information are independent, customers may find it beneficial to purchase from several sellers. In such a scenario, there is stronger likelihood that the information services available from the different sellers are complements. Along with cross price elasticity of demand, economic scholars also identify product complements based on product usage. Cheng & Nahm (2007, 2010) distinguish complements as symmetric and asymmetric, based on the necessity of using the complement with the primary product (Cheng & Nahm, 2007; 2010). Further, the proportion of consumption between the primary and complementary products distinguishes perfect complements and imperfect complements. Finally, the difference in timing of purchase and consumption of a pair of goods distinguishes complementary inputs from complementary goods (Fabrizio & Hawn, 2013).

To summarize, first product usage is central to conceptualizations of product complementarity. Second, there is evidence of differences in the nature of complementarity based of factors such as product durability (Bhaskaran & Gilbert, 2005), necessity of usage, component or non component (Sengupta, 1998) and proportion of use. Third, there are depictions of primary and complementarity products within a focal pair, pointing to a need for understanding the difference between primary and complementary

products. A detailed elaboration of the nature of product complementarity is taken up in the next chapter.

Market Structures

A substantial portion of the literature on product complementarity is centered on indirect network effects. The first section reviews the concepts and findings related to complementary products. The second section is devoted to reviewing the findings on vertical integration, which includes antecedents and mechanisms followed by a discussion on the category. The final section reviews the findings related to consumer purchase behavior.

Indirect network effects

In contrast to direct network effects generated from the number of users adopting the primary product, indirect network effects arise from the increase in utility from the complementary products available for the primary product, in turn influenced by the size of the network (Katz & Shapiro,1985, 1986, 1986; 1992; Farrell & Saloner, 1986; Church & Gandal, 1992; Gandal, Kende & Rob, 2000; Ohashi, 2003; Nair, Dube & Chintagunta, 2004; Schilling, Gupta, Jain & Sawhney, 1999; Basu, Mazumdar & Raj, 2003; 2002; Shankar & Bayus, 2003; Zhu & Iansiti, 2012). Further, indirect network effects in the context of informational intermediation arise, where the buyer base increases as the number of sellers registered with the intermediary increases (Caillaud & Julien, 2003). The review is categorized into the conceptual factors, antecedents, consequences and contextual aspects of indirect network effects. The section concludes with a discussion of the findings, including methodological challenges and achievements.

Concept: Three aspects are relevant, viz. a demand based perspective, a supply side perspective and attributes of the concept. The network externality argument is that consumers prefer to purchase products which have a large network size. Although this hypothesis postulates the externality that exists from the consumption perspective, increasing returns to scale in the production of complementary products is an alternative explanation for indirect network effects (Chou & Shy, 1990). I.e., consumers benefit from a large network because large networks are supported by a variety of complementary products and services. Computer software, for example, has fixed costs of development and low costs of duplication and marketing leading to increasing returns to scale in the production of software, inducing complementors to provide a variety of complementary products and services in software. Further, indirect network externalities create a two way contingency between demand (consumption) of the primary product and supply (production) of the complementary products resulting in a strategic interdependence between the strategies of primary product firms and that of the complementors. For example, indirect network effects is conceptualized as a market mediated interdependence between hardware makers and complementors, with consumer demand being influenced directly by the actions of hardware manufacturers and complementors(Gupta , Jain & Sawhney, 1999).

Attributes relevant to indirect network effects include scope, strength and variety. Scope of indirect network effects captures whether the externality is confined to consumers within a platform or across platforms, influenced by the exclusivity of software (Corts & Lederman, 2009). Strength of indirect network effects has been noted in several works intended to measure the extent to which consumers' value

complementary product variety (Corts & Lederman, 2009; Hogendorn & Yuen, 2009; Zhu & Iansiti, 2012; Dube, Hitsch & Chintagunta, 2010). Finally, consumer heterogeneity in the preference for variety, where different consumers seek distinct features provided by different formats, facilitates the survival of multiple formats in the product market (Katz & Shapiro, 1994). The importance of variety varies by industry or product type, so that the utility added by variety on books related to fishing rods is less valued than that added by supply of software for CD players (Church et. al., 2008).

Antecedents: The supply of complementary products is influenced by i) compatibility between hardware technologies and complementary products ii) primary product attributes and iii) complement attributes

Compatibility: When hardware technologies are incompatible, the decision of software developers regarding which technology to provide software is determined by the profitability of complement provision for a particular technology platform. Complementor profitability is influenced by two factors, viz., i) the value contributed by complement variety to owning a primary product and ii) competition in the complementary product market. When consumers place a high value for software variety (i.e. availability) relative to different hardware technologies so that value of a hardware technology to the consumer is determined by the number of compatible complements, greater availability of complements contributes to increased hardware sales, contributing further to greater market demand for complements. Consequently, size of complementary product market influences complementor's profitability through increased demand for the primary product. However, the downside of increased

complement supply is the impact of competition between complementors. Competition among complementors leads to a reduction in profits for a complementor, if hardware sales remain constant, but complement supply increases. De facto standardization results when the indirect network effects dominate the competitive effects. However, if sufficient complementary software are made available for the different hardware technologies, they will each have sales (Church & Gandal, 1992).

Product Attributes: In this section we review software price, hardware quality, software quality and the interaction of hardware and software attributes on complementary product availability.

Software price: Although hardware price (Nair et. al., 2004; Clements & Ohashi, 2005) and quality (Nair et. al., 2004) have informed technology competition, lack of availability of price information for complement prices has restricted the empirical impact of this attribute. The argument however is that intense competition in the software market, combined with low costs of software replication sets the stage for low prices in complements market (Shapiro & Varian, 1999; Church et. al., 2008).

Hardware quality: Quality of the primary product impacts the sales of the hardware directly through the preferences of consumers to use leading edge technology products. Important, hardware quality influences the availability of complementary products, for complementors prefer to develop complements for a system with a large installed base. Hardware quality captures the functional and performance capabilities such as speed of the processors used in the video game console. In fact significant improvement in the processor capabilities such as multimedia graphics and sound additions have led to

continuous displacement of older generations of hardware systems in the video gaming console market. In the context of the home video game industry, Gretz (2010) shows that the market share is 11.4 times more sensitive to hardware quality than network size.

Software/complement quality: The quality of software has a significant impact on consumer's choice of hardware in systems based competition. Two implications are notable in the literature. First, a complement of high quality and popularity contributes to significant network effects, regardless of the abundance in complement availability or size of complement network (Frels, Shervani & Shrivastava, 2003; Stremersch, Tellis, Franses & Binken, 2007; Hogendorn & Yuen, 2009). In the context of the home video game industry, Binken & Stremerche (2009) show that high quality "superstar" software titles have a disproportionately large effect on hardware sales. Similarly, Lotus 1-2-3 had a significant and distinct impact on the emergence of the IBM PC as the dominant design in the business segment (Carlton, 1997). Second, issues of shirking on quality (Yalcin, Ofek, Koenigsberg & Biyalagorsky, 2013), timing of product introduction (Casadesus-Masanell & Yoffie, 2006) and conflicts over pricing (Hogendorn & Yuen, 2009) arise when a complementary product gains popularity with the consumers. This in turn impacts the availability of complementary products, when the complementor may switch to producing complements for another competing primary product format.

Interaction effects: Basu et al (2003) demonstrate interaction effects between selected attributes of the hardware and software availability on hardware price so that increased software availability enhances the value of selective attributes of the CD-player. Stremerch et. al. (2007) model the takeoff between hardware and software sales in nine

markets to resolve the temporal pattern of indirect network effects, finding that hardware sales lead software availability in most markets and the reverse rarely. Further, in contrast to the well established notion that complementary product availability is critically important for hardware sales (Katz Shapiro, 1986;1994; Church & Gandal, 1992), they find that amount of software available does not significantly influence the hardware sales (in the DVD, CD-ROM & color Television markets).

Consequences: Complementary products influence de facto standardization, technology failure, technology lock out and platform dominance.

Dominant Design/Standard emergence/Technology failure: Four case studies are illustrative of the influence of complementary products in technology competition. First, the failure of various quadraphonic audio technologies is attributed to the splintering effect – availability of complements supporting different quad systems, resulting in a lack of large supply of recorded music compatible with one single format (Postrel, 1990). On the contrary, the success of Compact Digital audio system is attributed to the abundant provision of several recording artists on the CD compatible format leading eventually to the replacement of the phonograph (Church & Gandal, 1993). Second, the rise of IBM PC as the dominant design in personal computing is attested to the widespread availability of different types of complementary products (Bresnahan & Greenstein, 1999). Apple's Macintosh received lukewarm acceptance in spite of its superior computing capabilities, while IBM's open architecture strategy of sharing technical information with complementors facilitated abundant software availability. Third, in a case study examining the format competition in the US VCR market, complementary

product availability (VHS rental tapes) had a significant impact on the demise of the Beta format and the emergence of the VHS as the de facto standard (Cusumano et al., 1992; Ohashi, 2003). Fourth, in the context of the video game industry, although introductory pricing strategy positively influenced the sales of primary product in the beginning of the product life cycle, increasing availability of complements determined primary product sales later in the product life cycle (Clements & Ohashi, 2005). Finally, availability of complementary products decreases the likelihood of technology lock-out (Schilling, 2002).

Platform dominance: Recent studies begin to explore the structure of the relationship with complementors (Venkatraman & Lee, 2004; Srinivasan & Venkatraman, 2010; Afuah, 2013). First, Srinivasan & Venkatraman (2010) examine the impact of indirect network effects on platform dominance by delineating the impact of platform specific factors, viz., number and variety of complementary products and network specific factors, viz., platform overlap and complementor position in the network. In addition to reinforcing findings of prior studies on indirect network effects (Ohashi, 1986; Gandal, Greenstein & Salant, 1999; Nair, Chintagunta & Dube, 2004; Clements & Ohashi, 2005), the study highlights the importance of diversity of ties with complementors and the presence of high status complementors in the network of complementors as positively influencing platform dominance by signaling legitimacy, stability and quality of console to the end customer and access to better resources. Second, Shankar & Bayus (2003) note that a firm's network strength is a strategic asset since the social ties between its constituents make the consumer network an imperfectly imitable socially complex resource. Further, relationships with complementors benefit platform contenders because

complementors provide access to resources essential to the success of platform ecosystems and facilitate coordinated product launches (Venkatraman & Lee, 2004). Recognizing the impact of particular complementors in the network, Hogendorn & Yuen (2009) argue that market leadership in platform competition requires use of strategies based on the impact of the complementary product on indirect network effects to retain complementors producing popular complementary products.

Context: Complementary and primary product market characteristics

The market characteristics within which complementary products have been studied includes settings with i) single or multiple standards, ii) vertically integrated and disintegrated market structures, iii) multi sided markets. These factors are important because they shed light on the varying importance of complementary products based on contextual features.

Single or multiple standards competition: Technology competition in the primary product market happens through the dominance of two or more incompatible formats comparable in technological superiority. In the presence of multiple standards, consumers cannot form clear expectations regarding which technology to adopt, leading to a delay in the complementors making complements available (Church & Gandal, 1993; Rohlfs, 2001). Thus, when multiple primary product technologies compete, the complementary product market is thin particularly in the initial phases of technology competition. Case studies highlight the failure of classes of primary product technologies such as quadraphonic sound (Postrel, 1990), digital compact cassettes and minidiscs (Rohlfs, 2001, pg 101-103) or delay in the adoption of a primary product technology as in

AM stereo (Besen & Johnson, 1986) and DVD (Dranove & Gandal, 2003; Augereau, Greenstein & Rysman, 2006) due to the poorly developed complementary product market. In de facto standardization,, complementors switch to producing products for the dominant technology, with those unable to do so facing the risk of survival (Afuah, 2000). Thus, the emergence of a dominant design in the primary product coincides with competition in the complementary product market. In the absence of a de facto standard and the survival of competing technologies, such as the video game, camcorders (Srinivasan, Lilien & Rangaswamy, 2006) and flash drive markets (Liu et al, 2011), complements competition occurs across platforms, facilitating multihoming (Hagiu, 2009; Landsman & Stremersch, 2011).

Vertically integrated/disintegrated markets: Contexts include vertically disintegrated markets (Church & Gandal, 1992; Bresnahan & Greenstein, 1999; Cheng & Nahm, 2007) and integrated markets (Church & Gandal, 1993). The nature of the market structure matters for if there is an existing complementary product market at the stage of primary product development; such a case differs from one where the complementary product market structure is undeveloped. This influences the supply of complementary products, market development and the nature of the strategies towards complementors. For example, the VCR product market was vertically disintegrated and the basis of competition in the complementary product market was based on making available a large supply of movies in the VHS pre recorded format (Ohashi, 2003), with VCR makers forming strategic alliances with producers of pre recorded video (e.g. Magnetic Video) and video rental stores (Cusumano et. al., 1992). In the CD title industry large players such as Sony and Phillips were integrated into CD title production and release. Notably,

in the CD title industry production was controlled by a fairly small number of firms, who were also competing in the primary product market (Gandal, Kende & Rob, 2000). For example, the CD pressing plants were owned by Sony, Phillips and EMI.

Summary: The literature on indirect network effects underscores the dominating attention to complementary product availability, and the effect of incompatible hardware technologies and product attributes on the availability. Hardware quality and software quality are both important in influencing the network size. Complementary products have informed several contexts, notably technology competition featuring the emergence of a de facto standard, the co existence of multiple standards, platform competition and technology lockout.

Discussion: First, there exists some confusion in the use of terminology for complementary product availability and variety. Substantial portions of the literature in economics examine the importance of indirect network effects by means of complementary product availability and/or variety (Church & Gandal, 1992; Cottrell & Koput, 1998; Gandal et. al., 2000; Ohashi, 2003; Nair et. al., 2004) and a distinction between them is not made. This distinction is important because variety implies the existence of different types of complements and these differences are not accounted for in the models. For example, in the context of hardware-software systems, scholars have demonstrated that the value of hardware depends on the variety of compatible software (Greenstein, 1993; Gandal, 1994; Saloner & Shepard, 1995; Gandal, Greenstein & Salant, 1999), where variety is captured empirically as complement availability.

Second, the settings are marked by the presence of single or multiple standards. Few papers explicitly account for the differences introduced by this (for example, Church & Gandal, 1992; Basu, Mazumdar & Raj, 2003) in competition and strategies involving complements. However, recent research has begun to address aspects such as tipping (Dube et al, 2010) and multihoming (Landsman & Stremerche, 2009). Third, recent papers not only find that primary product attributes influence the price and installed base of the product, but also examine characteristics of complements not before addressed. These include features such as "superstar" titles (Binken & Stremerche, 2009), tightness of complementarity (Yalcin, Ofek et al, 2013). Further, the examples of complements in these studies is hardware-software type systems such as PDA and software, CD players and titles, video game console and title etc, pointing to the recognition of type of product complementarity .

Fourth, the differences in market structures suggest that competing firms pursue different strategies in terms of complementary product development and licensing strategies. Future studies could examine possible antecedents of these market structures and also the influence of these market structures on technology and product market outcomes. Finally, studies should also consider the influence of the technological and market environment. Since the studies formulate the models in the context of high technology product markets, there exists intense competition between the incompatible formats and/or characterized by increasing growth. So, explicitly incorporating variations from the environment will help to disentangle the effects of the technological environment from market effects such as network effects, product effects such as product attributes on outcomes such as hardware sales, technology emergence and de facto

standardization. Finally, it is interesting to examine the influence of multi platform complementary product introductions (Corts & Lederman, 2009) on both the competition between the platforms and the defensive strategies pursued by primary product firms. Future studies could examine the how these variables influence technology adoption or hardware sales.

The earliest research has been dealt with by economic scholars (Farrell & Saloner, 1985; Katz & Shapiro, 1985; Church & Gandal,1992; Matutes & Regibeau, 1992). Early marketing literature in new product adoption assume that new products are autonomous, assume a one-way contingency (where there is an impact of the hardware attributes on software availability, but not vice-versa or do not distinguish between the effects of direct and indirect network externalities (Gupta, Jain & Sawhney, 1999). Further, we also observe some differences in opinion regarding the significance of indirect network effects (Stremerch,Tellis, Frances & Binken, 2007).

While most of the extant literature in economics, marketing and strategy are primarily examining issues from the perspective of the primary product firm, Kude et al (2012) examine strategy decisions from a complementor's perspective. The setting of enterprise software industry is unique to the nature of the software, so technology based differences may influence systems that are more tightly coupled or hardware based systems. Likewise, Venkatraman & Lee (2004) examine preferential linkage from a complementor's perspective in high technology, networked industries. Their finding that complementors prefer to link with newer platforms suggests that the dynamics of environment, particularly technological uncertainty influence the received wisdom that

complementors develop products with platforms having a large installed base (Katz & Shapiro, 1985; 1986; Schilling, 2002). However, the study does not account for the influence of the nature of the game, suggesting the role of type of complementarity in preferential linkage arguments and consequent technology dominance.

Vertical Integration and Competition

This section reviews the literature on strategies of monopolist firms competing in one product market to enter into complementary product markets with the objective of preserving or extending their market power into an emerging market and eliminate potential competition from complementors. It is useful to delineate this work as strategies based on pure competitive intentions (Choi & Stefanadis, 2001; Carlton & Waldman, 2002), the boundary decision (Cournot, 1985; Gilbert & Riordan, 1995) and innovation in the product (Gawer & Henderson, 2007). We classify the review into the following categories i) Competitive intentions ii) Entry barriers and conclude with a discussion on the section.

Competitive intentions: The integration decisions into complementary product markets and associated welfare aspects have been examined when the complement is essential for use with the primary product (Cournot, 1838; Matutes & Regibeau, 1988; Economides & Salop, 1992; Gilbert & Riordan, 1995; Farrell & Katz, 2000). First, a complementor may integrate into an essential good complements market with the intention of setting lower prices on the combined product thereby increasing consumer welfare and eliminating the double mark-up problem (Cournot, 1838). Second, a monopolist in a primary product market may also have incentives to integrate into a complementary component market to

enhance its market share by driving out competition. Third, existence of independent suppliers of complementary inputs creates conditions for vertical integration. For example, in the context of the electric power sector, Gilbert & Riordan (1995) note that contracting the different complementary inputs to independent entities involved in electric utility sector is suboptimal due to the information asymmetry regarding the costs of electric power generation and transmission – i.e. this information is private to the complementors and there is a possibility of overstatement of costs to the regulator.

Entry barriers: The mechanisms examined include i) bundling (tying), ii) R & D investments and iii) compatibility.

Bundling: An incumbent can deter entry in complementary product markets by bundling the primary product with the complement (Nalebuff, 2004). Integration into the complementary product market by tying a complement to the primary product raises entry barriers in the complementary product market for two reasons. First, tying the two products makes success for the firm entering the complementary product market dependent on successful entry in the primary product market as well (Whinston, 1990; Klein, 2001; Carlton & Waldman, 2002). Second, the primary product firm's market power deters the complementor from making this move as it has to bear significant expenses to match the economies of scale and reputation to make successful entry in the main market. For example, although Netscape's browser was superior in technological attributes, it did not garner market share to survive in the browser market, because consumers could not use the browser without an operating system. Moreover, Microsoft

had a monopoly in the OS market and technologically tying the browser with the OS ensured that it captured the complementary product as well.

*R & D investment*s: Aggressive R & D investments in the complement market put competitive pressures on the non integrated complement suppliers and reduces their innovation incentives (Farrell & Katz, 2000; Heeb, 2003). Further, the presence of network externalities adds to the entry costs of a firm planning to enter a complementary product since it has to bear the costs of the installed base associated with the primary product (Carlton & Waldman, 2002). For example, in the example of tying the operating system (primary product) with Microsoft Word (the complement), users of Microsoft Windows will not only use Microsoft Word because the two sold only as a bundle, but also prefer to engage in file transactions with Microsoft Word or compatible users. Thus the installed base associated with Windows is an additional cost for the complementor planning to enter the Word product market with a superior substitute.

Compatibility: In multi component industries compatibility between components and systems reduces the competition between the firms, and each producer may adopt strategies such as setting higher prices on their individual systems and components (Economides, 1989; Einhorn, 1992) increasing the profitability for all firms involved (Economides, 1989; Matutes & Regibeau, 1992; Einhorn, 1992; Besen & Farrell,1994). Consumers benefit in the following ways. First, it permits mix and match compatibility to end consumers so that they combine components of different firms to assemble a system of their choice (Einhorn, 1992). Second, the network size increases, enabling consumers to switch between different products and also facilitating a greater supply of

complementary goods and services (Matutes & Regibeau, 1992). Thus compatibility decisions lower the entry barriers for complementors.

Summary: The research on vertical integration in the economic stream addresses issues of double mark up problem and welfare benefits to consumers, pre empting competition from complementors in multi component industries and information asymmetry (Gilbert & Rordan, 1995). Entry barriers are created through pricing, bundling (tying), R & D investments and (Choi & Stefanadis, 2001; Heeb, 2003) and lowered through compatibility decisions.

Discussion: First, the boundary question in the context of non component complements is yet to receive systematic examination, although Cournot (1838) examined this issue from an efficiency and welfare perspective. For example, the consideration of varying levels of environmental uncertainty through the evolution of the product system, difference in appropriability regime over the time period, involvement of co specialized assets (Teece, 1986; 2007) and information asymmetry between the primary product and complementors (Gilbert & Riordan, 1995) suggests the possibility of opportunism, which in turn indicates non trivial transaction costs in market based complement transactions for the primary product firm. Thus an important line of work complementing the foreclosure perspective is the application of a transaction cost lens to examine the boundary issue (Williamson, 1975; 1985; 1991). Additionally, the nature of complementarity is also likely to have an impact on these issues.

Second, although the competitive perspective has been examined incorporating network externalities, the influence of the type of complementarity is an unexplored

question. Differences in the case of essential and non essential complements arise in markets with network externalities because of market power differences based on type of complement. Particularly, certain essential complements contribute to the primary product earnings significantly (Binken & Stremerche, 2009; Hogendorn & Yuen, 2009) influencing the effectiveness of vertical integration as a competitive strategy. For example, contrary to received theory, during the VHS vs. Beta technology battle, the complementor Universal Studios filed suit against Sony, a VCR manufacturer for marketing the VCR, claiming that the latter had infringed on its rights. This case witnessed 8 years of legal wrangling, indicating that market power differences exist based on type of complementarity and other environmental aspects such as stage of the technology evolution, appropriability regime and network effects.

Third, although the assumption of the primary product firm having monopoly power facilitates inferring precise outcomes, examining the propositions in dynamic, non monopolistic settings will lend greater validity to establishing tying or vertical integration as a strategy for creating entry barriers in a wider variety of settings varying in environmental characteristics such as technological, market and competitive uncertainty. Empirical studies employing large scale archival data would also enhance the validity of these arguments.

Finally, from a methodological perspective, a substantial portion of literature uses formal modeling to address the issues of competition, and foreclosure. Assumptions regarding nature of complementarity include essential complements (Choi & Stefanadis, 2001), strict complements (Farrell & Katz, 2000) and non essential complements (Heeb,

2003). The proportion of consumption is also specified in some models as fixed (Choi & Stefanadis, 2001) and variable (Matutes & Regibeau, 1992) proportions of consumption, which have implications for the extent of R & D investments to create entry barriers. Further, most of the models assume the presence of a monopolist primary product firm - such an assumption lends the firm market power to protect its market.

Consumer Purchase Behavior

Aspects pertaining to the purchase behavior of complementary products have been examined in cross category context (Blattberg et. al., 1978; Ainslie & Rossie, 1998; Chintagunta & Haldar, 1998; Gentzkow, 2007; Iyengar et. al, 2003; Seetharaman et al , 2005; Duvvuri et. al., 2007; Sriram, Chintagunta & Agarwal, 2010, 2013). We categorize the research in this stream involving complementary products into i) Consumer heterogeneity ii) Consumer price sensitivities iii) Purchase timing related to complements iv) Brand choice

Consumer heterogeneity: Consumers differ over the usage of complementary products, such as in time (frequently, occasionally, seasonally), target market (children, women, teenagers), perceived product image (low fat foods, diet drinks), technology usage (traditional vs. new) etc (Varadarajan, 1986;Walters, 1991; Gupta, Jain & Sawhney, 1999). These differences inform the timing of purchase and purchase incidence (Xie & Sirbu, 1995; Sriram, Chintagunta & Agarwal, 2010), price sensitivities (Duvvuri, Ansari & Gupta, 2007; Liu, 2010) and quantity decisions (Niraj, Padmanabhan & Seetharaman, 2008) associated with the purchase of complementary products. For example, in the home

video game market, hard core gamers place a high value for new game consoles than casual gamers so that the latter are likely to purchase the complementary products earlier than casual gamers. Further, there are likely to be less price sensitive than the causal game player segment. Such consumer taste differences result in specific complementary products significantly heavily influencing indirect network effects (Binken, Stremerche & Tellis, 2009). For example, the strong preference for action genre games by the teenage segment of the home video game market has contributed to discrete indirect network effects, i.e. creating a large utility for consumers as compared to other complements (Hogendorn & Yuen, 2009).

Price sensitivities: Cross price, cross promotion and cross inventory variables influence the consumer purchase of complementary products (Mulhern & Leone, 1991; Walters, 1991; Chen et al, 1991; Yue, Mukhopadhyay & Zhu, 2006; Duvvuri, Ansari & Gupta, 2007; Levy, Grewal, Kopalle, & Hess, 2004). First, based on longitudinal household data on purchase incidences across 6 related product categories, Duvvuri et al (2007) find significant cross price effects, cross promotion and cross inventory effects for retail consumer purchase in most product categories. Second, consumers with strong preferences for new technology products are less price sensitive and hence choose to purchase the product when the prices are high (Karaca-Mandic, 2009; Gowrisankaran & Rysman, 2009; Lee, 2010). Third, consumers price sensitivities vary based on relative product versatility (whether it can be used with other products) and relative price (Niraj, Padmanabhan & Seetharaman, 2008). Thus, primary product firms may use the information on consumer heterogeneity in product and technology preferences to price the complementary products to maximize profits. From a retailer's perspective,

consideration of the complete basket of goods (primary and complementary products) will facilitate in setting optimum price and promotion levels (Levy et al., 2004). Specifically, they can leverage the differences among consumers by directing targeted discounts across product categories, enabling retailers to sell related products more effectively.

Purchase timing: Purchase decisions of related product categories are dependent in time (Chintagunta & Haldar, 1998; Manchanda, Ansari & Gupta, 1999; Sriram, Chintagunta & Agarwal, 2010). These include several non durable goods that are frequently purchased in comparison to the more durable goods which are comparatively less frequently purchased. Chintagunta & Haldar (1998) examine the timing of purchase based on a household panel datasets involving complements, substitutes and unrelated products. The paper finds high correlation in the timing of purchase for complementary products such as pasta and pasta sauce, washer and dryer. By controlling for the effects of inventory, marketing strategy variables (viz., price, promotions) and household demographics, they demonstrate that complementarity between products explains joint purchase behavior.

Recent works examine consumer purchase decisions in high technology contexts (Gowrisankaran & Rysman, 2009; Sriram et. al, 2010; Karaca-Mandic, 2011). Timing of purchase differs between complementary, non technology products (such as detergent & fabric softener) and durable, technology based complementary products (such as PCs & printers and PCs & digital cameras). Based on a survey of first time household level adoption that includes three related product categories, viz., PCs, digital cameras and printers, Sriram et. al. (2010) develop and test a framework incorporating aspects

distinctive to technology based purchase – viz., product quality and price, product durability, and consumer purchase in related technologies. First, since the quality of technology based products improve over time and the prices fall, consumers purchase decisions are dependent on their anticipation of the extent to which prices fall – i.e. they are likely to adjust the timing of their decision to purchase while such consideration is less likely in the case of non technology based complementary products. Thus, consumers are likely to defer complementary products purchase to a later time period for technology based durable goods or conduct them in multiple purchases unlike the case of non technology based goods, where they purchase the goods more or less simultaneously. Second, the durability of technology based products suggests that consumers need not purchase complements simultaneously.

Finally, inherent relatedness of the products influence adoption decisions across multiple product categories, so that there is less variation in purchase decisions across such product categories. For example, printer adoption is contingent on PC adoption, so that irrespective of consumer preferences purchase of such products is likely to occur closely in time. In the absence of such contingences in the adoption of two technology based products, consumer preferences determine the complementarity and the subsequent timing of purchase. Some consumers have intrinsic preference for owning a digital camera not contingent on having a PC, so that their purchase of the digital camera need not be simultaneous with PC purchase. Other consumers may prefer to own a digital camera with the PC, so that they purchase the products simultaneously or in close succession.

Brand choice: Consumer purchase decisions indicate greater likelihood of purchase incidence for complementary products with the same brand name than those with different brand names Seetharaman et al., 2005; Ma, Seetharaman, Narasimhan, 2012). Under uncertainty regarding product attributes such as quality or new product introduction, brands signal information mitigating consumer uncertainty.

Summary: Consumer price sensitivities, purchase timing and product brand choice are essential aspects of purchase decisions, influencing the sales of complementary products. Further, consumer heterogeneity in the usage of complementary products and the involvement of a technology product also influences price sensitivities and purchase timing. These have implications for the primary product firms in setting prices and promotion, which we review in the firm strategy section.

Discussion: Mulhern & Leone (1991) conceptualize retail price promotions as a form of price bundling strategy and note its different uses from a manufacturer's and retailer's perspective. Manufacturers use price promotions to encourage brand switching and increase market share, whereas retailers use of price promotions has several effects, intended to improve store profitability. They suggest that retailers can take advantage of complementary relationships by providing a low price on one product that may stimulate the sales on a higher margin use complement. Although their study is based on using data sold in grocery stores such spaghetti sauce and pasta etc., their arguments and findings are also relevant for technology complementary products. Particularly, it is interesting to examine how retail pricing influences technology based durable complements that are complements by use and those that are complements by purchase.

They suggest that product manufacturers may be able to work with retailers through cooperative strategies to design price bundling options that will enhance both manufacturer and retailer profits. In a related work, Chintagunta & Haldar (1998) argue that the nature of purchase dependence between product categories should be of substantive interest to manufacturers and retailers. The dependence could be positive (such as the purchase of the washing dryer usually follows or occurs simultaneously with that of the washing machine) or negative (such as the income constraints could lead to the delay in purchase of a PC although the TV is purchased). Separate analysis of the product categories in the positive dependence case would lead to independent promotions and pricing of the related product categories. In contrast, synergistic analysis of the products from related product categories could benefit manufacturers of these products as well as retailers involved through cooperative marketing strategies leading to reduced costs (because single category promotions would be sufficient) and/or increased sales.

An important aspect of the literature is the emphasis on leveraging complementarity from a retailer's perspective; such as complementary pricing or discount pricing, coupons and advertizing to draw sales on a complementary good to enhance store profitability. There are questions that need to be addressed- first, what are the marketing strategies that leverage complementarity from a manufacturer's or primary product firm's perspective; second, how do these questions play out in the case of technology based products; third how does type of complementarity influence the strategies.

Several asymmetric technology complements are complements in purchase rather in use. For example, printers and scanners may exhibit a negative price elasticity not

because they enhance the value of each other (as per the true definition of complementary products), but because they are complements in purchase (i.e. printers and scanners are typically available at the same location – retail stores or online retail, so consumers purchase them together). Analysis of the different characterizations suggests that the core of all of them is usage aspect, suggesting the centrality of symmetric and asymmetric characterizations of product complementarity.

A notable point that Sriram et. al. (2010) bring forth is the variation in complementarity, in the context of technology based durable products. They draw implications for retailers' product pricing; however from a primary product firm's perspective there are issues that have to yet be addressed. Since some technology products are complements by design (such as PC and printer), what factors influence firms to design products as complements by design? Second, how do firm's marketing strategies vary according to this variation in complementarity?

Summary: Thus, the review of market structures reveals that significant importance of complementary products in contributing to indirect network effects, the importance of vertical integration strategies as a competitive strategy and the efficacy of bundling (tying) and R & D investments in creating entry barriers to foreclose competition in complementary product markets. Further, consumer preferences and behaviors are influenced significantly by prices, brands and timing of purchase when complements are involved. The review thus reveals significant and important work covered in the context of market structures, and also identifies important gaps yet to be addressed in each subsection.

Firm Strategy

The second major topic related to complementary products constitutes aspects of 1) technology strategy in the context of technology competition 2) marketing strategy, primarily from the perspective of a primary product firm

Technology Strategy

A technology strategy is the set of actions taken by a primary product firm in contexts involving technology based complementary products intended to give it a unique position in technology competition. Since adaptability to changing technological conditions is also identified as an aspect of technology strategy (Pistorius & Utterback, 1997; Adner, 2002), the set of actions also include those taken by firms in response to new complementary products or technologies.

The contexts in which a actions towards complementary products are identified include technology adoption (Katz & Shapiro, 1986; Farrell & Saloner, 1986; Nair, Dube & Chintagunta, 2004; Clements & Ohashi, 2005), dominant design emergence (Suarez, 2004; Srinivasan, Lilien & Rangaswamy, 2006), technology standards (Church & Gandal, 1992; Cottrell & Koput, 1998; Shapiro & Varian, 1999; Gupta, Jain & Sawhney, 1999; Gallagher & Park, 2002; Narayanan & Chen, 2012), and platform/ecosystem leadership (Cusumano & Gawer, 2002; Gawer & Henderson, 2007; Teece, 2007; Pierce, 2009; Adner & Kapoor, 2010; Turner, Mitchell & Bettis, 2010). The decisions examined include compatibility, entry timing and complementary product development strategies.

We review the strategies, antecedents, consequences, contingences and conclude with a discussion on fruitful areas of research.

Technology adoption: A critical mass of complementary products is essential for a primary technology to establish the lead in a standards battle (Shurmer, 1993; Shapiro & Varian, 1999; Bresnahan & Greenstein, 1999; Rohlfs, 2001; Stremersch, Tellis, Franses & Binken, 2007). The existence of multiple primary product formats is a bottleneck in a technology gaining critical mass of complements, and becoming the product market standard (Church & Gandal, 1992). Multiple technologies splinter the complement development effort, so that no single technology gains leadership. The choice of strategies in product development such as compatibility, timing of entry and acquiring support from complementors influence the decision of complementors to join the focal firm's network among competing alternatives.

Compatibility decisions: There are two ways in which compatibility decisions have occurred in the literature, 1) in the primary product technology and 2) in the complementary product technology.

In Primary product technology: During the initial phases of a technology battle, there are likely to be different formats, as witnessed in high technology markets such as the CD player market and Television market (Shapiro & Varian, 1998; Rohlfs, 2001). First, to ensure consolidation in the development of complementary products, firms may pursue a strategy where they negotiate with primary product firms to converge around one format. Such coordination and adjustments take place during the design phase of the primary product even before a standards war commences (Rohlfs, 2001). For example, in

the development of the CD players, although Philips NV pioneered the laser scanning technology in 1979, competing alternatives soon were soon being designed by Sony, Telefunken & JVC in magnetic, grooving and optical scanning formats. Phillips therefore worked towards establishing a technological standard in the CD player by licensing its technology to the alternative producers and also making adjustments in its technology to incorporate attributes of the competitors' products. Such a strategy of coalescing on a single primary product design during the product design phase ensures the splintering effect is avoided from a complementary product firm's perspective and eliminates consumer uncertainty at the outset pertaining to which technology will emerge, which would have delayed adoption.

Second, if a standards war ensues de facto standardization involves significant costs associated with achieving compatibility through driving out competing formats (Farrell & Saloner, 1992) as well such as coordination between different entities in the market and involvement of institutional and government bodies (Katz & Shapiro, 1994; Narayanan & Chen, 2012).

In complementary product technology: In standards competition, the question of compatibility addresses whether different brands or technologies of the durable goods (e.g. hardware) can utilize available complementary products, viz., software (Katz & Shapiro, 1986). Two conflicting interests have to be addressed. First, compatibility in the presence of network externalities creates demand side economies of scale, allowing consumers to interchange complementary products, ease communication and benefits complementors through cost savings since interchangeability of parts facilitates mass

production (Farrell & Saloner, 1986). Second, in systems competition characterized by indirect network externalities, demand is often driven by variety in complementary products. Conversion technologies in the complementary product market allow multiple formats to persist in the complements market, leading to both greater complement availability and variety (Farrell & Saloner, 1992; Church & Gandal, 1992) without the costs involved in standardization, while also preventing the complement market from tipping to a winner-take all situation (Liu, Kemerer, Slaughter & Smith, 2012). Thus, primary product firms may encourage the development of conversion technologies in the complement market. For example, in the video game product market availability of adapters for the VCS cartridges permitted users to play Atari's game on competing consoles such as ColecoVision.

In the context of the US CD player market, Gandal, Kende & Rob (2000) examine the effectiveness of different strategies in explaining technology adoption, in the period between 1985 and 1992 - the time period when CD players showed continued improvement in technological aspects and prices declined continuously. A 10% increase in the availability of software would have as large as an effect as a 5% hardware price cut, suggesting the importance of making available a large number of complementary products. Importantly, compatibility with LPs, an alternative to CDs and a technology predating CDs would have considerably increased the speed of the technology adoption.

Entry timing decisions: The primary firm has to balance the benefits entailed in introducing the primary product early to market, to garner first mover advantages that could lead to the market tipping in its favor with the risk that consumer's delay adoption

of the primary product for lack of widespread availability of complementary products. The impasse is illustrated in two cases. First, although the US firms CBS and Sony invested several millions in the development of the Color Television sets, it was early in time because the complementary product – content was not developed enough to ensure widespread broadcasting, leading to a less than 4 percent ownership of color TV sets (Shapiro & Varian, 1998, pg 216). Second, in the CD player technology adoption, although Phillips successfully coalesced the different format CD makers such as Sony and JVC on its CD player technology, the lack of availability of pre recorded tapes in the CD format delayed adoption (Rohlfs, 2001). This in turn suggests the importance of strategies to prevent uneven entry in the primary and complementary product markets. Further early entry of both primary and complementary products enables firms to reap the gains of first mover advantage, particularly since networked markets are subject to strong irreversibilities creating path dependence in initial technology strategy decisions (Basanini & Dosi, 2001, pg 45). Schilling (2002) demonstrates that early and greater availability of complementary goods increases the associated installed base and prevents technology lock-out, when there are competing platforms. Case studies suggest that firms may pursue a strategy of internal production of complements and/or coordinating with complementors to establish support for their technologies. We examine this dimension of a firm's technology strategy in the context of technology adoption in the next section.

Complementary product development strategy: To ensure complementary product availability, firms pursue internal development of complements; coordinate with complementors to ensure timely availability of complements conforming to its product specifications or a mix of both strategies. Internal development of complements reduces

reliance on complementors on the one hand; however it also entails significant costs particularly when network effects are strong, so that widespread availability of complements significantly influences technology adoption as opposed to attributes of the primary product technology itself. Two cases are illustrative. In the context of CD players, Phillips owned 50 percent of Polygram, which ensured that pre recorded CDs were available in the market when the CD was introduced, however due to the significant dependence between the primary and complementary product such a strategy fell short in ensuring complement availability. Second in the VHS vs. Beta technology battle, Sony resorted to internal development of complementary products, which has been cited as one reason for its failure penetrating the market , as such strategies in the initial phases of technology battles create path dependences (Basanini & Dosi, 2001). In fact, had Sony pursued an aggressive competitive strategy in the first 3 years of Beta introduction in terms of complement availability it could have captured as much as 98% of the market, as compared to the actual 8.6% (Ohashi, 2003).

Studies also point to the effectiveness of strategies to coordinate complementary product development such as technology licensing agreements with complementors as in the VHS and CD player development (Cusumano, Mylonadis & Rosenbloom, 1992), investing in co production equipment and distribution networks with complementors (Rohlfs, 2001) , involving a range of cooperative forms such as minority equity investments (eg. IBM and Rolm technologies) and joint ventures (CBS Records and Sony in the making of CDs).

Platform Dominance: An industry platform involves multiple interdependent components and complements that sit on top of a core technology serving as the foundation (Gawer & Cusumano, 2002; Gawer & Henderson, 2007; Gawer, 2009). Examples include software platforms, viz., Microsoft's Windows Operating System, Linux operating system and hardware platforms viz., home video gaming console (Corts & Lederman, 2009), the Intel platform (Gawer & Cusumano, 2002) , PDA (Nair et al, 2004) and IBM PC (Gandal, Greenstein & Salant, 1999). The business ecosystem that sustains the development of such platforms constitutes platform owners (primary product firms), institutions (regulatory bodies, standard setting bodies such as IEEE, WWW), complementors, suppliers and customers, strongly functionally and market interdependent (Evans, Hagiu & Schmalensee, 2006; Teece, 2007; Piece, 2009).

In such systems, platform owners have to balance the requirements for continuous innovation in the system, at the same time maintain control over the core architecture, known as the "adoption vs. appropriability" issue (West, 2003). From a complementor's perspective, since independent complementors are not inclined to invest in a platform innovation for fears of domination (Pierce, 2009) and price squeezing by platform owners (Farrell & Katz, 2000; Choi & Stefanadis, 2001; Heeb, 2003), the platform owner has to engage in strategies signaling its commitment to complementor support and profitability (Gawer & Henderson, 2007). We review the research on platforms relating to coordination and control aspects of system evolution, involving the actions of platform owners (primary product firms) and complementors.

Coordination strategies: Coordination strategies involve actions taken by the primary product firm to ensure the availability of complements, based on type of interdependence, market and technological conditions, that involves different forms of cooperation,, negotiations and commitments (Casadesus-Masanell & Yoffie, 2006; Economides & Katsamakas, 2006; Gawer & Henderson, 2007). The research on coordination actions may be categorized into determinants and outcomes of coordination forms.

Antecedents: In high technology product markets, technological uncertainty is high due to continuous innovations by complementors in the platform ecosystem. Such markets also experience intense competitive battles. First Turner, Mitchell & Bettis (2010) argue that generational product innovations (i.e. innovations within an existing technology regime) by complementors influences release of product innovations by platform owners to realign the technological interdependences between the products. In the context of the business productivity software markets, they demonstrate that primary product firms respond with matched core product innovations in response to technological uncertainty. Specifically innovations by complementors under increasing market concentration. Such environmental contingences influence platform owner's decisions so that parallel innovations by different complementors do not compromise system stability.

Forms: Two findings are notable, viz., 1) the choice of organizational form with complementors influences the core product firm's decision to invest in an emerging technology, so that investment in a new technology is more likely when the complementors are linked in an alliance rather than arms length agreements, for an

alliance form facilitates the coordinated investment between the firms , while restraining costs involved, and 2) scope of alliance facilitates new technology investment for scope aligns incentives and facilitates cooperation (Kapoor & Lee, 2013). Specifically, they demonstrate that hospitals and physicians that formed alliances covering a broader scope of activities with complementors show greater chances of investment in new technologies such as medical imaging technologies.

Antecedents: Complementors form partnerships with platform providers having greater technological capital, reputation and the capabilities to steer system control and management of interdependences among different components, marketing and financial capabilities and the level of product complementarity (Kude, Dibbern & Heinzl, 2012). Further, motives to increase innovation in a platform, where the platform owner does not have the requisite capabilities explain some of the strategies. For example, platform owners provide access to the platform technology to complementors by pursuing open strategies to leverage the capabilities of a broader set of external complementors (Gawer & Henderson, 2007), by means of technology licensing to ensure interoperability and overall system integrity. In addition, institutional bodies such as the World Wide Web and IEEE facilitate coordination in complex open source projects (Yoffie & Kwak, 2006).

Degree of platform openness: This involves licensing the rights to use components, disclosing interfaces, providing documentation and technical support (Boudreau, 2011). Further, the platform owner may restrict access to the type of complements by a) licensing its technology to a selected number of complementors, b) retaining control of

certain complements and allowing unrestricted access to the development of other applications.

To summarize, in the post dominant design era, research focuses on the dynamics of platform performance, ecosystem management and success, emphasizing the importance of actions by complementors (Gawer & Cusumano, 2002; Turner, Mitchell & Bettis, 2010; Adner & Kapoor, 2010). The need for dealing with the challenges of managing the complex interdependences between the different components and complements, encouraging innovation to ensure platform differentiation and retaining control over system architecture so that overall system performance is not compromised dominates the nature of technology strategies in this era of technology competition. Further, these markets are also characterized by intense technological change, fierce competition and changing consumer affiliations contributing also to market uncertainty. Recent works suggest dealing these challenges with the strategies of alliances (Kapoor & Lee, 2013), opening the platform through sharing IP and seeking assistance from institutional bodies and standard setting organizations (Boudreau, 2010) and continuous platform innovation to respond to rapid technological change and market uncertainty (Turner, Mitchell & Bettis, 2010).

Discussion: First, the technology evolution paradigm suggests different environmental conditions persist through product evolution, distinguished specifically before and after the emergence of a dominant design in the technology management literature. Specifically, there are significant differences in technological and market uncertainty and

the appropriability regimes. Incorporating these dimensions in the technology strategy is likely to yield interesting results.

Second, although strategic alliances are important strategies for coordination, the strategy with complementors has not received exhaustive treatment (Kapoor & Lee, 2013). Specifically, how variations in product complementarity influence the management of interdependence requires examination of factors such as nature of interdependence adaptation required, involvement of cospecialized assets and possibility of opportunism, with the form of alliance as an outcome. For instance, managing interdependence in the complementary product design phase for an essential complement raises issues of appropriation, while coordinating in production requires significant upfront fixed costs, which may not be recoverable. In the CD player technology adoption, because of CBS records prominent role (owing to the type of complement it produced and its capabilities in producing content), it negotiated substantial equity participation through a joint venture with Sony in the production of CDs. Third, more work is needed to understand the factors influencing primary product firms decision to internalize complement development, i.e. whether there is a systematic variation in the decision to internalize complement development based on nature of product complementarity, cospecialized assets and environmental dynamism.

Fourth, the complexity of the product system also influences the coordination challenges and strategies. Greater system complexity requires coordination to be aligned in various aspects of the products (such as R & D, production and marketing) among many more actors than in the case of simpler systems (Suarez, 2004). Further, type of

complementarity is likely to influence the strategies since the needs for coordinating interface development with complements that are essential is different from that required for interface development with non essential complements, depending on the phase of the technology evolution. For example, the coordination strategies executed by PC makers towards OS and microprocessor before the emergence of the dominant design development is different compared to their strategies towards peripheral applications and products, more prominent after the dominant design. In the case of a comparatively lesser complex systems such as video gaming, the variation in coordination strategies based on type of complementarity is less evident.

From a methodological viewpoint, large scale empirical studies examine the propositions related to primary product firm strategies of coordination and their outcomes (Kapoor & Lee, 2013) , antecedents of strategies such as complementor motivations to innovate in longitudinal setting in the context of platforms and ecosystems. The settings include the health care ecosystem where the hospitals and physicians constitute the entities that are complementary and the technology investment decision pertains to new imaging technologies (Kapoor & Lee, 2013), semi conductor industry (Gawer & Henderson, 2007; Adner & Kapoor, 2010), automobile industry (Pierce, 2009) and enterprise system software industry (Kude et al, 2013).

Marketing Strategy

Marketing strategy involving complementary products addresses product pricing, distribution and promotion related factors, from a primary product firm and retailer's perspective. Importantly, it recognizes the multiproduct, multi agent nature of marketing

decisions involving complementary products. We review this literature in the following categories, viz., pricing, promotions and distribution from the manufacturer's and retailer's perspective, joint marketing strategies involving the primary product firm and complementor/retailer.

Pricing: Complementary product pricing strategies include razor-blade pricing, system pricing, bundling strategies, skim and penetration pricing (Tellis, 1986; Guiltinan, Madden & Joseph, 1997; Noble & Gruca, 1999; Venkatesh & Kamakura, 2003; Liu, 2010). We review the literature based on the type of pricing strategies from the perspective of the firms involved and the contingences.

From the manufacturer (primary product firm's) perspective: Following types of pricing strategies are noted in the literature viz.,

1) razor-blade pricing, where the core product is priced low and complementary items such as accessories, supplies, spare parts, services, etc. are priced at a higher premium. An example is Gillette's strategy of selling razors cheaply and blades at a higher markup. Further, in many industrial markets, a firm offers a wide range of spare parts, and accessories, profits from which constitute a large profit stream. Under this strategy, the main product or platform is sold for a relatively low price while complementary products carry a high margin (Guiltinan et.al.,1997).
2) in systems pricing, the primary product firm bundles the complement(s) along with the main product at a total price less than the sum of individual prices. For example, IBM's strategy of selling mainframe systems that includes the server, the client, related software, databases, punch cards and printer. Based on a survey

of 270 practicing managers from fifteen different industries, Noble & Gruca (1999) find that firms were more likely to use one of the complementary product pricing strategies when the firms also sold complements, brands were highly elastic and target high growth markets where consumers are highly price sensitive.

3) bundling is likely to be effective strategy when introducing new products if firms vary the bundling mix based on level of complementarity, i.e. consumer perceptions of the fit between the products in a bundle (Simonin & Ruth, 1995). Specifically, mixed bundling is effective for weak complements and pure bundling is effective when selling strong complements (Venkatesh & Kamakura, 2003).

Contingences: Network effects and consumer heterogeneity in product use have opposing influences on the effectiveness of pricing strategies, in high technology product competition (Xie & Sirbu, 1995; Liu, 2010). In the presence of indirect network effects, since consumer product adoption increases with installed base, penetration pricing - where the products are sold at below marginal costs - leads to faster product diffusion and first mover advantages in technology competition (Shapiro & Varian, 1998), however at the cost of initial profitability. The recognition of consumer heterogeneity in the usage of technology provides incentive for skim pricing, where the product is priced relatively high in the beginning, enabling a primary product firm to recover the costs of product development earlier, however at the cost of slower product diffusion and network growth. Typical technology product introductions follow a price skimming strategy with

a declining price trajectory by targeting the early technology enthusiasts first and then capturing the mass market through reduced pricing (Xie & Sirbu, 1995).

In a comparative study of the video game market involving competition between Nintendo and Sony, Liu (2010) shows that Sony's penetration pricing strategy gave it an early lead in the market, enabling it to win the console war for that generation..

From the retailer's perspective: Retail pricing strategy generally includes the use of price promotions (Mulhern & Leone, 1991), so we review this in the next section on promotions.

Promotions and distribution: The impact of promotional spillovers across complementary product categories examines the effect of price promotions on one product by manufacturers and retailers, display and feature advertizing activities on one product by retailers (Blattberg, Briesch & Fox, 1995; Niraj et al., 2008) and display allowances to the retailers (intermediaries), Branding and advertizing alliances on the sales of complementary products are also examined in this category (Manchanda et al, 1999; Chib et. al, 2002; Russell & Petersen, 2000; Wedel & Zhang, 2000; Song & Chintagunta, 2006; Sinitsyn, 2012). We review the promotional spillovers from the perspective of the manufacturer (primary product firm) and retailer.

From the manufacturer (primary product firm's) perspective: The importance of the brand in the promotion of complementary products is notable (Walters, 1991; Mulhearn & Leone, 1991; Ma, Seetharaman & Narasimhan, 2012; Sinitsyn, 2012). Due to the influence of the brand on consumer purchase, when complementary products sharing the same brand name go on sale simultaneously, it results in joint purchase and increased

sales of both products. In channel distribution involving complementary products and based on recent developments in technology based product markets, for e.g., the exclusive agreement between Apple and AT&T, where the iPhone was designed to be used only with the AT & T service, Cai, Dai & Zhou (2012) examine the influence of a combination of exclusive deals and revenue sharing between manufacturers and retailers, where the manufacturer sells the primary product and the retailer sells the complementary good/service at the same time. Unlike traditional revenue sharing contracts, the retailer pays a percentage of the profit from the sale of the complementary good/service rather than the sale of the primary product contingent on exclusivity with the complementor's product/usage.

From the retailer's perspective: Promotional (retail pricing) activities in the context of complementary products have been examined in terms of same store versus competing store sales, magnitude of promotional expenses across product categories, timing of promotions and the differential impact of promotions based on product attributes. First, retail price promotional activities on a product in one store, such as advertizing of price reductions on a weekly basis – positively influences sales of complements in the same store and have the reverse effect on sales in competing stores (Walters, 1991) explained by search costs and co location of complements (Guiltinan et. al., 1997). Based on scanner level data in different consumer product categories, the papers find evidence for the enhancing effect of retail price promotions for complementary products within the store. Second, the allocation of promotional expenditures with consideration of complementarity effects positively influences sales (Mehta & Ma, 2012). Higher promotional discounts lead to higher profits for complementary product pairs as

compared to non related or substitute products (Mulhern & Leone, 1991), emphasizing the following implications viz., the importance of strategic co location of complementary products from a retailer's perspective, retailer power in channels, opportunities for cooperative strategies between the manufacturer and retailer to improve primary product market share, from a primary product firm's perspective.

Third, coordinating timing of promotions influences retail sales of related product categories such that simultaneous promotion has a stronger effect. Finally, complementary product promotional spillovers are asymmetric in that retailers profit more when the prices of one product in a pair are reduced as compared to the other product (Niraj, Padmanabhan & Seetharaman, 2008), determined by relative price sensitivities and product versatility.

Co-marketing: Co-marketing alliances are contractual relationships between firms producing complementary products, for the purpose of coordinating marketing strategies including building product complementarity usage awareness, advertizing, promotion and branding (Bucklin & Sengupta, 1993; Son, Hahn & Kang, 2006). We categorize this research into the i) antecedents and types of co marketing alliances , viz., advertizing, joint sales promotion and brand alliances ii) challenges in co-marketing alliances

Antecedents and types of co marketing alliances: Antecedents include consumer brand perceptions, product complementarity, cost efficiency, reputation considerations and the stage of the product in its life cycle, informing the type of alliance. Samu, Krishnan & Smith (1999) shed light on the factors influencing effectiveness of advertizing alliances. Specifically, brand-awareness and brand -beliefs (consumer's perception of the

association between product category and brand) influence the effectiveness of the type of advertizing strategy based on product complementarity. For example, a top-down advertizing strategy where the relatedness between the two products is highlighted is likely to be effective when consumers are unfamiliar with the nature of complementarity between the products, a bottom-up advertizing strategy where the advertisement's headline focuses attention on the attribute linking the advertized products is likely to be effective when a new non essential complementarity is being advertized. For the primary product firm, forming an alliance with an established brand of a highly complementary product would result in consumers readily perceiving the complementarity between the products and increased purchases.

Cooperative sales promotion involves the pool of promotional resources by two or more complementary product manufacturers formed to capitalize on joint opportunities for sales growth by promoting trial, large quantity purchase etc. In fact complementarity between the product lines of two distinct firms has been suggested as a motivation for joint promotion programs (Varadarajan, 1986). Joint sales promotions also confer greater cost efficiency and promotion effectiveness due to collective sales effort. Brand alliances are joint alliances involving one firm with higher reputation formed to enhance the perception of product quality of the one of the firms involved, particularly when the quality of the product cannot be observed (Rao & Ruckert, 1994). Finally, stage of the product life cycle influences the decisions of firms to co promote their products with complementors in other industries by discriminating between price sensitive and insensitive segments (Son, Hahn & Kang, 2006).

Challenges in co-marketing alliances: First, joint marketing programs tend to be prolonged due to the negotiations required to reach shared objectives. Second, possibility of conflict exists when firms also compete in other product categories, with disagreements over product launch dates, production delays value chain leading to shortages at the retail level for one of the products (Varadarajan, 1986; Bucklin & Sengupta, 1993). Finally, possibilities of opportunistic behavior exist. As we identify in the next section.

To summarize, marketing strategy has addressed aspects of pricing and promotion related to complementary products from a manufacturing and retailing firm's perspectives. The work on co-marketing alliances examines motivations and types of agreements, along with the challenges involved.

Discussion: Substantive research in marketing examines cross category purchase behavior for non technology based products. It is interesting to examine if similar findings can be generalized to technology based complements. Specifically, how do firms change/adapt their marketing strategies with factors such as interoperability, firm technological and marketing capabilities influencing decisions of firms to brand and promote complementary products? Particularly, there is evidence of a notable difference in the context of consumer based products that have informed the context of marketing research (for complementary products) in pricing, advertizing and promotions. Further, several high technology product markets are also characterized by network effects, so that the relevance of the marketing strategies in the context of network externalities and

platforms/ systems competition is likely to provide better understanding about the associated challenges.

Second, an unaddressed area is how firms respond to the cross pricing, promotion and distribution strategies for the differences in product complementarity based on the nature of use. Particularly, the issues of shirking on quality and competition in the distribution channels are likely to have differential impact on the partner's incentive to cooperate and impact the distribution of profits.

Co-marketing alliance represent a dimension of a primary product firm's strategy involving complementary products that have a significant impact on increasing joint sales (Bucklin & Sengupta, 1992; Son, Hahn & Kang, 2006). There is a lack of research examining the nature of these co-marketing alliances in the context of complementary products involving technology based products and the changing market and technological conditions (Venkatesh, Mahajan & Muller, 2000). Relatedly, existing frameworks for co promotion agreements involving complementary products do not examine the influence of different kinds of complementary products (such as usage, timing, image, occasions etc).

Opportunism

This section reviews some of the opportunistic concerns identified in the literature, viz.,

1. Joint distribution of complementary products could also result in loss of profits from potential complements that are not part of the agreement (Xia, Xiao, Zhang, 2013),

mainly from competition from their complementors. For example, although Lexmark made additional revenues from the sale of its printers through Dell's distribution channels, it also led to increased competition when Dell introduced its own brand of printers and started selling printer cartridges, reducing sales of complements for Lexmark (Bulkeley, 2005).

2. Since consumers are more strongly influenced by the dominant or well established brand among complements sold as a bundle, from a primary firm's perspective, partnering with a well established brand entails appropriation of rents through bargaining. A survey based study by Venkatesh & Mahajan (1999) reveals that consumers perceived Intel as the dominant brand in the PC-microprocessor product category. The implication is that Intel could potentially bargain for a higher share of the profits, when the firms conduct joint marketing activities that involve revenue sharing. The possibility of bargaining over the distribution of revenues has been noted in recent joint marketing activities involving complementary products (Cai, Dai & Zhou, 2012).

3. Certain complementary products contribute to large indirect network effects because of their superstar status (Binken & Stremercxhe, 2007) and the nature of the relationship with the primary product (Hogendorn & Yuen, 2009; Yalcin et al, 2013). Such indirect network effects are a form of asset specific investment for the primary product firm. (Hogendorn & Yuen, 2009). Contractual instruments such as royalty rate or revenue sharing agreements lead to two issues. First, the complementor may bargain for a higher share of the profits, threatening to defect to another network if the bargaining

requirements are not met. Second, the complementor may shirk of quality and deliver an inferior complement.

From a primary product firm's perspective, the risks associated with opportunism not only increases the ex ante partner search, contract specification and monitoring costs, but also ex-post transaction costs in contract enforcement, renegotiation, and appropriation of proprietary know-how and loss of rents, particularly if asset specific investments are involved. The primary lens used to examine opportunism concerns has been transaction cost economics (Williamson, 1975, 1976), which posits the use of hierarchical governance structures to shield the firm from opportunistic concerns. The next chapter uses this lens to propose governance structures in the context of the governance choice involving complementary products.

CHAPTER 3: CONCEPT OF PRODUCT COMPLEMENTARITY

Introduction

The literature review on complementary products indicates that that the term complementary product masks the variety discussed in the current literature. Although the idea of cross price elasticity of demand underpins all streams of research, somewhat different facets of the concept have also been attended to. For instance, nature of consumer usage (Sengupta, 1998; Wedel & Zhang, 2004; Duvvuri, Ansari & Gupta, 2007; Song, Parry & Kawakami, 2009), perceived usefulness (Chintagunta & Haldar, 1998; Samu, Krishnan & Smith, 1999), value chain related dependences (Teece, 1986; Adner & Kapoor, 2010) and technological aspects (Cusumano & Gawer, 2002; Gawer & Henderson, 2007) inform aspects of product complementarity. Further we observe variations in the types of complementary products, such as hardware & software, or components as complements that vary by context in which they are studied.

Even though recent work addresses the differences between components and complements based on value chain related factors (Adner & Kapoor, 2010) and the necessity of complement usage (Cheng & Nahm, 2007), there is a lack of adequate attention in explaining this variation and the dimensions of product complementarity, i.e. the meaning of product complementarity. Delineating the different aspects of the concept is fruitful both from an academic and practitioner perspective. First, it will enhance our understanding of technology related outcomes such as dominant design emergence (Suarez, 2004) , platform leadership (Cusumano & Gawer, 2000) and de facto standardization (see Narayanan & Chen, 2012 for a review) by identifying the components of product complementarity contributing to value creation in the different

contexts. High technology markets are characteristically different from others, for instance - the mechanism of indirect effects operates through complementary products. But the literature gives little guidance in terms of which complements to pay attention to, under which context, for it treats indirect network effects and complementary products fundamentally in a unitary fashion.

The Profiting from Innovation framework (Teece, 1986; Pisano & Teece, 2007) emphasizes the importance of the appropriability regime, types of complementary assets and technology change in influencing firm strategies, in turn determining the distribution of rents from innovation. In spite of the widespread attention to complements in general, not much has been written about how the nature of product complementarity influences the sharing of rents in several high technology product industries with horizontal architectures. Further, the increasing dependence of products and services and parallel innovations by multiple firms in different layers of the architecture prompts the examination of factors influencing technology leadership, the evolution and control of the system architecture (Gawer & Cusumano, 2002). Since different types of complementary products contribute to the performance and innovation in the platform, guidance for managers regarding the adoption of strategies in accordance with the interdependence between the complements in different layers will facilitate decision making in the context of platform leadership.

The primary goal of this paper is to develop the concept of complementary products by addressing three related issues, viz., the dimensions of the relationship between primary and complementary products, the different types of complementary

products, and the variation in the different types of complementary products, by analyzing the definitions employed in the extant literature. The definitions employed in the literature are summarized in Table 4. The next section delineates the dimensions, distinctions and the variation in the concept.

Please insert Table 4 around here

Meaning of Product Complementarity

The first subsection begins by identifying clusters of definitions, followed by a description of each cluster and ends with a discussion on the clusters.

Definitions

We group the definitions into different clusters (see Table 4 for a detailed list) based on1) cross price elasticity of demand 2) consumer usage and 3) functional interdependence, the factors noted in the definitions.

Definitions based on cross-price elasticity of demand reflect sales interdependence between the products include "*Two goods xi and xj are said to be gross complements if* δ *xi/* δ *pj* < 0*, i.e. they are gross complements if a rise in the price of one good causes less of the other good to be purchased"*(Nicholson, 2005), "*we define substitutability and complementarity from the firms' point of view by referring to the sign of the cross-price elasticity of demand. If it is positive, products are substitutes; in the opposite case they are complements"* (Sarvary & Parker, 1997) and "*Complementary*

products are those products (or services) that experience a sales increase when related products experience an increase in support" (Guiltinan, Joseph & Gordon, 1997).

Technological and functional interdependence between the products are another aspect defining the nature of complementary products. "*A product maybe one component of an evolving technological system and exhibit strong functional interdependence with other components in such a system"* (Gawer & Henderson, 2005), "*Many products are complex, specified by a long array of characteristics (i.e. interdependent functions). A firm may choose to decompose this integrated set of features into two or more smaller parts……. These smaller parts correspond to components or complements*" (Economides, 1 989), "*Systems are composed of complementary and interdependent products, such as hardware and software" (Binken & Stremerche, 2009)*. Similar implications are also made by other papers (*Church & Gandal, 1992; Katz and Shapiro 1994).*

From a consumer usage point of view, definitions of product complementarity highlight the value derived. "*Complementary product is one that enhances the value of a focal product when the two are used together by end users"* (Sengupta, 1998) , "*a complement to one product or service is any other product or service that makes the first one more attractive*" (Brandenburger & Nalebuff, 1996), "*complements are goods that go togethe*r" (Guiltinan, Joseph & Madden, 1996), "*complementary products add value to the primary product beyond the basic functionality*" (Sengupta, 1998), "*Consumers receive a positive benefit from consuming a system where a system consists of one primary unit and one complementary unit* " (Carlton & Waldman, 2002). Some of the

definitions emphasize the relative benefit derived from using the products jointly in comparison to benefits from using them separately as in "*complementary products are those for which a consumer's utility derived from using both the goods together is greater than the sum of the utilities that the consumer would have derived by using them separately*". Consumers may also benefit from indirect network externalities, i.e., the value the products contribute to the consumer in using the primary product when a large number and variety of complements are available (Katz & Shapiro, 1985; Afuah, 2000; Shankar & Bayus, 2003; Clements & Ohashi, 2005). In this context, "*Systems are composed of complementary and interdependent products such as hardware and software* (Farrell and Saloner 1986; Katz and Shapiro 1986; Binken & Stremerche, 2009).

We analyze these clusters to derive the underlying dimensions of the concept of product complementarity in the following section.

Product Complementarity: Underlying dimensions

Sales interdependence: suggests greater sales of one product (by reduction in its price) increases demand for the other product (Cournot, 1838; Economides & Salop, 1992; Brandenburger & Nalebuff, 1996; Sarvary & Parker, 1997). In two sided markets, complementarity between products stimulates demand, generating externalities across the markets (Parker & Van Alstyne, 2005). As an example, consider Television and programming (Bhaskaran & Gilbert, 2005). A decrease in the price of Television will likely lead to greater purchase of TV sets and a corresponding increase in the availability of programming content. Further, increase in programming variety and bandwidth is likely to spur demand for newer television sets. Further, the cross price elasticity is

reciprocal, although the magnitudes may not be proportional. For example, between detergent and softener, price changes in detergent had a larger effect on softener purchase than the other way (Manchanda, Ansari & Gupta, 1999). These differences may be explained by factors such as the primary product, nature of functional interdependence, and consumer usage.

Functional interdependence: Different types of product systems are involved, viz., multi component systems (Economides, 1988; Matutes & Regibeau, 1988), two product systems (Bhaskaran & Gilbert, 2005; Duvvuri, Ansari & Gupta, 2007), product-service system (Guiltinan, Madden & Joseph, 1997; Costa & Dierickx, 2005), platforms (Gawer & Cusumano, 2002), industrial and business ecosystems (Gawer & Henderson, 2007; Teece, 2007) and two sided markets (Parker & Van Alstyne, 2005), there is considerable difference in the nature of functional and technological interdependence between the core and the complementary products. Examples of complementary product pairs illustrating the different type of product systems include CD player and titles (Basu et. al., 2003), computer hardware and software (Shankar & Bayus, 2003; Chou & Shy, 1989) and Wintel platform (Casadesus-Masanell & Yoffie, 2006). Variation in functional interdependence implies that the performance of one product is differently influenced by the performance of another in the context of the systems considered. For example, the platform/ecosystem based definition incorporates the complexity of functional and technological interdependences (Evans et al., 2006; Gawer & Henderson, 2007; Pierce, 2009), while the CD player and CDs encoding the software are relatively separable and modular systems, although they closely related in function.

Consumer usage: Definitions based on consumer usage indicate variations in the concept from two aspects, viz., nature of use and enhancement in the value of a primary product. Variation in usage arise from the fact that they are inherently used in conjunction (Guiltinan, Paul & Madden, 1996) such as computer and printer, there is greater value from using the products together than using them individually (Bhaskaran & Gilbert, 2005) or there is increase in the value of a basic product beyond that provided by supplies and components (Sengupta, 1998).

Further, there are differences in how the value of a primary product is enhanced, i.e. by attainment of the basic product functionality, improvement in product quality (Costa & Dierickx, 2005), product features (Guiltinan, Madden & Joseph, 2007) or addition of new functions desirable to the end user (Heeb, 2003; Cheng & Nahm, 2007; Gawer & Henderson, 2007). The following examples are illustrative. The video game console and video game are product complements that have to be used together to be of any value to the consumer. On the other hand, bread and butter are complements sometimes used independent of each other and at other times jointly and each usage behavior provides its own distinctive value. The PC and printer exhibit a different usage pattern where the PC is used by itself or with a host of other complements; the printer on the other hand renders minimal value without the PC. Definitions also suggest possible variations in the nature of use, such as the proportion in which the complementary products may be consumed – i.e. whether the primary and complementary products are used in the same or different proportions.

Summary: First, there is variation in the nature of the interdependence and the variations arise from the nature of usage, and how value is derived (i.e., value enhancement and functional interdependence). Thus sales interdependence, value enhancement and functional/technological interdependence form the dimensions of product complementarity. Second, sales interdependence is a fundamental aspect of all complementary products since products that enhance the value of a primary product and are functionally interdependent are sales interdependent.

Finally, although product complementarity has been defined from the consumer usage perspective, intermediate products have also been considered complementary as when they are inputs to an assembly sector (Carr & Karmarkar, 2005) or components in a multi component product system (Matutes & Regibeau, 1988). This distinction maybe important because 1) complements from a firm's perspective relevant to a consumer purchase decision yet hold strategic relevance for the firm and 2) certain other complements are important for a consumer's use (such as roads and cars or bread and butter), yet not impact a firm's strategy significantly. This in turn suggests the importance of the following

i. The distinction between the primary and complementary product, noted in some of the definitions is relevant for further examination, for there is a need for clarity in making this distinction.
ii. the need for a typology of complementary products to capture the variation in the different examples of complementary products.

A typology of product complementarity

I classify the examples of different complementary product pairs into different clusters, then identify and describe the common and varying attributes, based on which I propose a useful typology of complementary products viz., type of complementarity.

i. Components and systems: Components have been defined as complements, for the functionality they contribute to the multi component product system. For instance, the stereo system may be broken down into its components - amplifier, receiver and speaker; photography where the typical product line includes cameras, lenses, film and film processing services (Matutes & Regibeau, 1988; Matutes & Regibeau, 1992; Economides, 1989).

ii. Durable goods and services: Many durable goods and services are complementary. Examples include cell phone and service; television and programming; paper making machines and pollution control devices, airplane purchase and servicing contracts among others (Bhaskaran & Gilbert, 2005; Aribarg & Foutz, 2009; Costa & Dierickx, 2005; Economides, 1989). Financing, homeowner's insurance, furniture, lawn mowers, grass seed as a partial list of complements to residential houses (Porter, 1985). Similarly, product and training courses, manuals and books are complementary (Schumer, 1993).

iii. Hardware and software: Hardware and software based systems are complementary (Casadesus-Masanell & Yoffie, 2007; Sengupta, 2008; Binken & Stremersh, 2009; Gupta, Jain & Sawhney, 1999) primarily through the mechanism of indirect network externalities. Examples include CD player

and CD titles, PDA and software; DVD player and DVD title, game console and video games, HDTV & programming among others.

iv. Information goods: Bundles of information products have been considered complementary based on the quality and reliability of information (Sarvary & Parker, 1997) and the functional interdependence between the products (Carlton & Waldman, 2002; Heeb, 2003; Nalebuff, 2004; Turner, Mitchell & Bettis, 2010). Particularly, under market uncertainty, since information regarding product quality is not perfectly reliable, consumers are likely to treat information based substitute products as complementary. For example, online databases, valuation of firm targets, professional opinions given by medical, engineering, accounting/financial, and legal professionals, are characterized by low reliability so that information goods from competitors behave as complements rather as substitutes (Sarvary & Parker, 1997). The functional relationship between applications software and operating system leads to a value adding complementary relationship (Heeb, 2003; Turner et. al., 2010).

Varying attributes: First, product durability as an attribute of complements (Bhaskaran & Gilbert, 2005) explains some of the variety in complementary products, however is not common to all complementary product clusters, i.e. durability, by itself is a not a factor that sufficiently captures the variation in the types of complements. Second, the component or non component attribute places the complement in the perspective of the complete product system, as an input to the primary product (Matutes & Regibeau, 1988; Sengupta, 1998; Carr & Karmarkar, 2005) or consumed alongside the primary product (Adner & Kapoor, 2010). Like durability, it addresses some of the observed variety in

complementary products, but does not do so exhaustively for all the clusters. Similarly, hardware and software as a criterion sheds light on a substantial amount of variation in complementary products viz., video games and console, PC and application software; however falls short of being a universal attribute to all the product categories.

Common attribute: The nature of usage dependence is a central feature of all the complementary product clusters and explains the variation in types, and is in alignment with product durability, component, non component or service and hardware-software differences. Based on the dependence of one product on another for use or fulfilling a set of functions in a product architecture, there are two distinct types of complementary products, viz.,

1. Symmetric complementarity, where both the products – the primary product and complementary product are essential for value enhancement (or value attainment) for the user and there is a reciprocal functional interdependence between the two products,
2. Asymmetric complementarity, where the primary product provides stand-alone functionality and using the complement with the primary product provides additional value to the user.

In asymmetric product complementarity, one of the products maybe used independently, while the other is dependent on the first or both products may be used independently, but is value enhancing when used together. Type of complementarity is a defining aspect in all examples of complementary product pair categories (component-non component,

component-component, hardware-software, durable-non durable, IS-IS). The next section elaborates the conceptual distinction between primary and complementary products.

Summary: Product complementarity maybe conceptualized in terms of sales interdependence, functional interdependence, value enhancement and type of complementarity.

Some definitions of product complementarity refer to primary and complementary products (Sengupta, 1998; Carlton & Waldman, 2002; Clements & Ohashi, 2005; Binken & Stremerche, 2009) or core product and complementary product (Gallaher & Park, 2002; Nambisan, 2002), indicating the importance of some products as complements. This topic is examined in the next section.

Distinction between primary and complementary products

A scheme to distinguish primary and complementary products enhances our understanding of the concept of product complementarity. Specifically, how is a complementary product differentiated from a primary product by sales, functional, value enhancement and type of complementarity? This section first suggests the importance of such a distinction and then develops a set of heuristics.

Importance of the distinction: Complementary products have received selective attention from scholars and businesses alike, i.e., not all complements that are value enhancing or functionally interdependent have received attention and some complements that are stand-alone have received more attention. Examples of technology based complements that have received attention include the operating system and

microprocessor related issues since the beginning of the PC Industry (Teece, 1986; Bresnahan & Greenstein, 1999; Casadesus-Masanell & Yoffie, 2006; Lee, Venkatraman, Tanriverdi & Iyer, 2010), however the power supply or resistor although essential for use have not received as much attention. The video gaming industry has been the context for research from the outset (Economides & Salop, 1992; Gallager & Park, 2002; Shankar & Bayus, 2003; Hogendorn & Yuen, 2009; Liu, 2010; Zhu & Iansiti, 2012), however the attention related to VHS tapes, complement to the VHS recorder declined after the emergence of the dominant design (Cusumano, Mylonadis & Rosenbloom, 1992). Moreover, issues related to asymmetric complements, such as the browser, add-on complements to the PC have informed scholarly interest (Whinston, 1990; Sengupta, 1996; Carlton & Waldman, 2002; Choi & Stefanadis, 2003; Heeb, 2003; Cusumano & Gawer, 2002). Further, in the business arena, the selective attention is witnessed in the tying strategies of IBM and the court battles involving Microsoft over its strategies pertaining to the browser.

Rules of distinction between primary and complementary products

Add on: The nature of dependence between the products: Among a pair of products, one of them provides a basic value and hence can be used as a stand-alone product, but an add-on product is useful only if consumed with the basic product (Cheng & Nahm, 2007; 2010; Chou & Shy, 1990, IJIO; Gaudet & Salant, 1992). In such a case, the basic product is the primary product and the add-on product is the complement. The rule is relevant for most asymmetric complements. For example, in the case of PC and printer, the PC is the primary product while the printer is the complement.

First in time: Product that is developed first is the primary product, when identification of such a separation in time is possible (Shapiro & Teece, 1992). For example, between airplane manufacturing and servicing contracts, the airplane is the primary product and the service is the complement (Costa & Dierickx, 2005). The next set of rules is relevant for symmetric complements when a basic product cannot be identified.

Durability: The product that is more durable of the two is the primary product (Bhaskaran & Gilbert, 2005). For example, between TV and programming, TV is the primary product while programming is the complement.

Magnitude of cross price elasticity: Complementary products are reciprocally interdependent in sales, i.e. a reduction in price of one product in a pair, increases demand for that product as well as for the other product; likewise when the price is reduced for the second product in the pair, the first product experiences increase in demand. The magnitude of cross price elasticity among a pair of products is uses an indicator of the primary product (Manchanda et al., 1999). The price change in a primary product has a larger impact on the purchase of the complementary product.

Hardware & software: In a system made of hardware and software goods, hardware products are primary products while software goods are complementary. For example, between CD player and titles, CD player is the primary product.

Exceptions: There are also situations where a primary product cannot be identified. In examples of weak complements, such as bread and butter, spaghetti and sauce the primary product cannot be determined based on heuristics that are entirely detached from consumer preferences. As another example, the case of cell phone and landline maybe

complements for a particular consumer because it allows him to conference call or transfer address books from one to other, providing enhanced functionality. The primary product is determined largely by the consumer preference. Adner & Kapoor (2010) make a distinction between components and complements based on the location of the primary product in the value chain context– components are bundled upstream by the primary product firm and complements are bundled downstream by the consumers along with the primary product. A key difference between component based components and non component based complements is that non component based complements are extrinsic to the primary product.

Summary: Thus, a primary product is determined by the ability of the consumer to use it independent of the complement, relative magnitudes reciprocal sales interdependence, occurrence in time, durability and hardware technology. Further, since symmetric complements cannot function independently, the relevant heuristics include relative magnitudes of sales interdependence, occurrence in time, durability and hardware technology. Finally, the section also identifies cases where we cannot unambiguously make a distinction between primary product and complement.

The literature review points to the importance of strategies related to complementary products from a primary product firm's perspective in domains such as technology adoption (Katz & Shapiro, 1985, 1986, 1992; Shapiro & Varian, 1999; Ohashi, 2003) competitive battles (Casadesus-Masanell & Yoffie, 2007; Turner, Mitchell & Bettis, 2010) supply chain coordination (Carr & Karmarkar, 2005; Nagarajan & Sosic, 2009), innovation, ecosystem control and dominance (Adner & Kapoor, 2010; Pierce, 2009),

technology lockout (Schilling, 2002) and two sided markets (Landsman & Stremersch, 2011). Based on our conceptual development of the different dimensions of product complementary, it is essential to analyze the implications for a primary product firm's strategies. Considering the centrality of type of complementarity, we elaborate the influence of this dimension in the next section.

Strategic importance of complementary products: The importance of a complement to a firm is influenced by the impact of the complement on its product's performance and market share. The more strategic the complement is to the primary product functionality, the more likely it is to impact the sale of the firm's focal product. The factors determining complement specificity may be categorized into two broad factors, viz., product level and market level factors. Product level factors include i) Type of complementarity ii) Product functional, physical and technological interfaces and market level factors include i) Substitute availability and ii) Competitive supply iii) network effects iii) product variety and iv) bargaining power

Product level factors: Type of complementarity directly influences the performance of a primary product by being essential for use of the primary product and by contributing or enabling the core functionality of the product. Asymmetric complements do not impede core product performance and hence are peripheral in the sense of directly impacting the primary product use and sales. Second, the physical, functional and technological specifications influence complement specificity based on whether they are standardized or not standardized. i.e., whether modularity has enabled complement functionality encapsulation and separation (Baldwin & Clark, 2001) and technology standardization

has resulted in interface compatibility. Specifically, the more non standardized specifications closely influence primary product performance (functionality), hence its use and purchase. The Nintendo's video game cartridge is essential for using the game console and the functionality is reciprocally shared between the cartridge and the console. Further, the physical design permits use only with Nintendo's machine (unlike a CD). These factors make the console usability closely dependent on the availability of cartridges.

Market level factors: Although product level factors influence the usability of primary product, availability of substitutes for the complement functionality and the complementary product market structure influences the specificity of the complement, i.e. how closely it impacts primary product's performance and market sales. Availability of substitutes reduces the dependence of the primary product's performance (functionality) on the complement and hence reduces the dependence of product use on the complement. Similarly, a competitive supply of complementary products ensures that product related dependences do not mitigate the availability of complements and purchase or primary product. For example, although VHS tape is a symmetric complement to the VCR, the large scale availability of compatible tapes in the VHS format reduces the impact of complement specificity on VCR purchase and sales. In contrast, the less developed complements market (cells) in the hybrid cars market makes the purchase of hybrid cars closely dependent on complementary product level factors, such as type of complementarity and functional specifications.

Complement specific network effects: A complementary product has significant network effects associated with its usage (Carlton & Waldman, 2002). Importantly, network effects associated with a symmetric complement can closely impact the sales of the primary product. For example, purchase of the video game console is influenced by the number of other users of the same format console as consumers derive greater value by the ability to exchange games with other users. Users of Microsoft Word (complementary application to the OS/PC) could exchange files with other users have the same format complement, increasing the value of owning a Microsoft OS based machine (Carlton & Waldman, 2002).

Bargaining power: Type of complementarity, technological interoperability and market factors (differences in the primary and complementary product market characteristics), may create differences in advantage based on the ability to control primary product architecture evolution and influencing timing of primary product introduction and pricing. These differences in turn influence the bargaining power between primary and complementary product firms when there are conflicts over decisions related to product architecture evolution, introductions and pricing. Bargaining power of primary and complementors influences the distribution of profits (Brandenburger & Nalebuff, 1997; Gal-or, 2004; Yoffie & Kwak, 2006; Casadesus-Masanell & Yoffie, 2006; Nagarajan & Bassok, 2008). Microsoft and Intel differ in their motivation in making R & D investments; timing of product introductions and pricing, primarily from Microsoft have a higher edge in the relationship due to the nature of interdependence between the operating system and microprocessor (Casadesus-Masanell & Yoffie, 2006; Yoffie & Kwak, 2006).

Product variety: After the emergence of the dominant design, if the interoperable interfaces with complements are standardized, economies of specialization favor the complement development and manufacturing by complementors (Church & Gandal, 1992; Farrell & Saloner, 1992; Economides & Salop, 1992), as evidenced in the stereo systems and PC product markets. Product variety enables a primary product selling firm to introduce differentiated products, when the existing product market becomes highly competitive so that profitability is marginal (Langlois & Robertson, 1992; Sanchez, 1995; Ulrich, 1995; Uzimeri & Sanderson, 1995; Garud & Kumaraswamy, 1995; Cottrell & Nault, 2004). A complementary product provides the opportunity for continued returns from its primary product by adding value enhancing complements, i.e. increasing primary product variety. For example, when the PC product makers lost their leadership due to low barriers to entry in the PC market and horizontal specialization of the industry (Langlois & Robertson, 1992; West, 2003; Heeb, 2003), HP attempted to re-assert leadership by entering the printer product market. The Windows based Operating System continues to offer enhanced value through the integration of complements ranging from the browser, Office suite and Media Player.

Summary: Type of complementarity influences the importance of complementary products with symmetric complements closely impacting the sales of the primary product, through the reciprocal nature of functional, usage and sales interdependence. Moreover, market factors such as availability of substitutes and competitive supply also determine the importance by influencing the specificity associated with the development of the complement. Further, the contribution of a complementary product to the network effects associated with a primary product and the increase in primary product variety

increase the switching costs associated with the primary product system, deterring entrants in the primary and complementary product markets.

This is illustrated by the operation of firms in the video game industry, where firms such as Nintendo and Sony continue to make profits on their consoles from a continuous stream of a variety of complements (in genres such as sports, action, mythology etc) delivered by a growing number of complementors (Binken & Stremerche, 2009). Nonetheless, asymmetric complements contribute to increased value in the usage of the primary product through variety by satisfying latent needs (Uzumeri & Sanderson, 1995; Schilling, 2000) and new market opportunities to the firm. The next section synthesizes the scheme from the literature review on complementary products to distinguish primary and complementary products, sorted on the basis of their importance from a primary product producing firm's perspective.

Conclusion

Managing interdependence is important because firms can derive a basis for differentiating from competitors by harnessing the strategic interrelatedness between the value chains (Brandenburger & Nalebuff, 1996). In markets characterized by network effects, volume sales strongly influence the emergence of a dominant design (Suarez & Utterback, 1995) as well as continued growth in the product market; support from complementors influences the size of the installed base (Katz & Shapiro, 1985; Schilling, 2000; Srinivasan & Venkataraman, 2010). Differences in managing the interdependencies identified earlier influences the outcomes related to the primary product.

Furthermore, post standardization, the basis for competitive advantage shifts to innovation in complements markets, leading to systems based or platform competition (Katz & Shapiro, 1994; Shapiro & Varian, 1998). This is witnessed in the computer, mobile phone and video gaming product markets and information technology product markets, where consumers value a system of primary and complementary products more than a standalone product (Lee, Venkatraman & Tanriverdi, 2010). A greater number of complements co-evolving and functionally interdependent with the primary product increase the complexity of the primary product, transforming it into a platform, introducing different coordination challenges and need for control (Gawer & Cusumano, 2002). Consequently, firms that adopt varying strategies depending on the technological and market conditions are likely to see a longer endurance in their primary product life. From the perspective of a primary product firm, its strategies in coordination, control and system growth could potentially enhance its product market position primarily by increasing barriers for entry and imitation and increasing switching costs.

Although scholars have emphasized the need for coordination among activities with complementors (Brandenburger & Nalebuff, 1997; Iansiti & Levien, 2004; **A**dner & Kapoor, 2010; Kapoor & Lee, 2013), there has been little academic working examining the mechanisms that constitute a firm's strategies to manage the interdependence in the various activities. In the subsequent chapters, I examine how firms manage interdependence with complementors through internalization and coordination strategies based on type of complementarity and market characteristics in the subsequent chapters.

Discussion

This chapter was devoted to explaining the concept of product complementarity, based on interdependences associated with product, consumer and firm factors. Further, it suggests the role of type of complementarity and the significance of this dimension for firm strategy, particularly in determining the boundaries of the firm. The primary theoretic lens used to examine boundary decisions is Transaction Cost Economics (Williamson, 1976, 1981, 1991). Although significant work has examined the governance structures employed by firms when it comes to sourcing of component complements (Klein, Crawford & Alchian, 1991; Masten & Meehan, 1991; Oxley, 1997, David & Hand, 2004; Hoetker, 2005) research in non component complements has only started to take off (Adner & Kapoor, 2010). Further, the contexts that TCE has been traditionally employed have not considered the contextual aspects relevant to technology adoption. Having elaborated upon the dimensions of product complementarity, the next chapter builds on this conceptual development to develop firm boundary decisions from a primary product firm's perspective for non component complements.

CHAPTER 4: COMPLEMENTARY PRODUCT GOVERNANCE CHOICE: THEORETICAL MODEL

Introduction

Several aspects of firm interdependence have been examined in the literature in the context of components or inputs to a system. The design, production and sale of components constitute the vertical scope of the primary product manufacturing firm. The boundary question receives continued attention in the literature based on opportunism, asset specificity and uncertainty in the TCE logic (Williamson, 1975; Klein, Crawford & Alchian, 1978; Monteverde & Teece, 1982; Walker & Weber, 1987; Leiblein & Miller, 2003; Colombo, 2003; Geyskens et al., 2006) competence based perspectives (Kogut & Zander, 1996; Conner & Prahalad, 1996, Silverman, 1999; Leiblein & Miller, 2003; Jacobides & Hitt, 2005) relational views of strategy (Dyer & Singh, 1998; Gulati & Singh, 1998; Chung, Singh & Lee, 2000; Hoetker, 2005), real options (Chi & McGuire, 1996) and game theoretic lens(Parkhe,1993).

Relatively little has been written in the strategy literature examining the mechanisms and factors that influence the boundary question of non component complements (that are not inputs to the production of the primary product). Differences in strategies in managing the interdependence influence primary product market related outcomes such as market share and a primary product firm's competitive advantage. The objective of this chapter is to examine how the boundary decision is informed by TCE arguments, based on different contextual and product complementary related factors. The chapter is structured as follows. First, I review the tenets of Transaction Cost Economics,

viz., technological uncertainty, market demand uncertainty and opportunism. Then, I review the different governance modes employed in the TCE literature. Finally, I develop a conceptual model for the governance choice for complementary products from a primary product firm's perspective incorporating the conceptual aspects of type of complementarity.

Overview of Transaction Cost Economics

The theory identifies characteristics of a transaction that suggests a better fit of internal organization or markets, based on a comparison of the costs in conducting a market exchange and in house development. Costs of an external transaction include ex-ante search, writing and enforcing contracts, monitoring performance and dealing with contingences arising from opportunistic behaviors resulting in negotiating or bargaining with partners (Williamson 1975, 1985, 1991, 1996; Klein et al., 1978; Joskow, 1987). The assumption of bounded rationality makes contracts incomplete and does not rule out the potential for opportunistic behavior from one of the partners involved in an exchange (Williamson, 1985). Importantly, involvement of asset specific investments in an exchange creates the opportunity for hold-up. The risks of opportunistic behavior add to ex-ante transaction costs in the form of specifying and incorporating extensive contractual safeguards if the firm. The central argument is that if the characteristics of the market exchange increase the costs considerably, firms are better off adopting a more hierarchical form of governance and internalizing aspects of the problematic market exchange. Internalizing the transaction with involvement of specific assets is the best defense again opportunism due to i) superior monitoring of the transaction facilitated by

internal controls of firms relative to markets and ii) since employees do not have a direct claim on the distribution of profits, there is no loss of profits from opportunistic behavior

Although traditionally researchers in transaction cost economics have focused on the dichotomy between markets and internal organization, alliances have emerged as a feasible alternative to internal organization, particularly when the risk of opportunism is non negligible, but not high enough to require internalization. Contractual clauses in alliances facilitate coordination, reduce information asymmetry between partners and prevent unexpected events such as production scheduling delays, etc. (Mayer & Argyres, 2004). Thus, hybrid modes have also since been folded in the TCE governance framework (Pisano, Russo & Teece, 1988; Williamson, 1991; Oxley, 1997; Robertson & Gatignon, 1998; Gulati & Singh, 1998, Colombo, 2003), where the firms make a choice between equity forms such as joint ventures, minority equity holdings or bilateral exchanges involving exchange of technology and non equity based agreements such as franchising, long term supply and distribution contracts. Scope of activities and involvement of technology component (Oxley, 1997; Gulati & Singh, 1998), determine extent of damage from opportunism, in turn influencing the choice of an equity or non equity based alliance.

The governance question has been examined in the R&D (Pisano, 1989; Sampson, 2004), production (Monteverde & Teece, 1982; Walker & Weber, 1987; Leiblein & Miller, 2003) and marketing contexts (Anderson & Schmittlein, 1984; Dutta, Heide & Bergen, 1999).

Asset specificity

Asset specificity captures the extent to which the current assets in an exchange are redeployable in an alternative transaction. Four types of asset specific investments, viz., site specificity, physical asset specificity, human asset specificity and dedicated asset specificity are identified (Williamson, 1975, 1981, 1985) the characteristics of these are described in Table 5. Asset specificity creates opportunities for quasi-rents to be held up by opportunistic exchange partners by creating a situation of mutual dependence (Williamson, 1975, 1987; Robertson & Gatignon, 1998). Asset specific investment(s) is a condition for market failure, where a partner gets locked into a relationship creating a small-numbers situation with limited or no resource deployment alternatives ex-post the transaction.

Please insert Table 5 about here

Studies have shown that firms choose to vertically integrate under the following conditions, viz., 1) specialized human assets in the form of tacit engineering know-how in the context of R&D or technology development (Pisano, 1990; Robertson & Gatignon, 1998) because such specialized assets create the threat of small numbers bargaining hazard in R& D markets, 2) sourcing of specialized components (Monteverde & Teece, 1982;Masten, Meehan & Snyder, 1989) requires transfer of the transaction specific know-how to the supplier, in turn creating high switching costs for the assembler and 3) sales personnel with know-how specific to the products were involved (Heide & John, 1988; Anderson, 1985) or specialized distribution equipment (John & Weitz, 1988) made

the relationship with an intermediary vulnerable to opportunism. Klein et al (1990) examine different forms of hierarchical exchange include markets, alliances and integration.

Frequency of exchange: This attribute to whether a transaction is one-time or recurrent. Recurrent transactions create a condition for internalization due to scale effects as well as reputation effects (Williamson, 2002). This factor has received less empirical attention as compared to asset specificity and uncertainty (Geyskens et. al., 2006).

Opportunism

Table 6 lists some of the opportunistic behaviors identified in the TCE literature, the types of asset specific investments and their impact.

Please insert Table 6 about here

Conditions of information asymmetry, where one of the parties to an exchange does not have information about the efforts or committed involvement of the other and lock-in, where a partner cannot leave the transaction without incurring significant losses contribute to the increased risk of opportunistic behavior. Information asymmetry is acute under uncertainty when external commotion makes it even more difficult to accurately assess the information coming from the partner. Lock-in typically arises owing to asset specific investments (Anderson & Schmittlein, 1984). Opportunistic behavior manifests in the form of hold-up (Klein, 1996) where unanticipated events lead the opportunistic partner to appropriate quasi-rents associated with asset specific investments, moral hazard which is essentially non-performance and could be avoided

were a perfect contract written (Klein, 1996). Moral hazards include shirking where there the opportunistic party withholds efforts or involve product deviance from quality. Opportunism maybe classified based on the manner in which profit distribution is affected (Wathne & Heide, 2000) and can occur in passive forms as shirking. The involve instances where a partner fails to deliver a quality product in accordance with the expectations of the sourcing firm, evading obligations, refusal to adapt in the face of new circumstances, for the opportunistic partner may enjoy short term gains. Active forms of opportunism include more explicit forms where the contract terms are violated or involve significant losses from asset specific investments. One such example involved in technology based transactions are the rents from technology appropriation (Oxley, 1997; Gulati & Singh, 1998). Further, differences in market conditions requires adaptation, specifically when there is long-term bilateral dependence and renegotiation in contractual clauses, at which point the partner may refuse to change leading to bargaining over terms of execution and profit, which imposes costs (Williamson, 1991, pg 279).

Due to the variation in complementary products, opportunistic behaviors differ based on type of complementarity, the environmental factors and the contexts. Table 7 describes different forms of opportunistic behaviors possible in the context of complementary product development.

Please insert Table 7 about here

Environmental Uncertainty

Two types of uncertainty have been widely used in TCE work - demand uncertainty and technological uncertainty. The assumption of bounded rationality in TCE limits the ability of firms to specify all the contingencies related to an exchange in a contract. Environmental uncertainty increases the possibility for opportunistic appropriation of rents especially occur when asset specific investments are involved (Klein, Crawford & Alchian, 1978), by 1) contract renegotiations may be required to adapt to changing circumstances and 2) the opportunistic firm may refuse to alter the terms of the contract, leading to bargaining and enforcement - these factors increasing the costs of carrying out the transaction. I review the major arguments and findings related to the influence of the two types of uncertainty. Demand and technological uncertainty are relevant to the topic complementary products because the contexts where complementary products are important, viz., technology adoption or leadership contexts are characterized by variations in technological and demand uncertainty in the related product markets.

Market demand uncertainty: Market uncertainty reflects the fluctuation and unpredictability in demand in the market for the final good. Firms incur high transaction costs in high volatility markets arising from the need to monitor and enforce a workable contract (Balakrishnan & Wernerfelt, 1986; Teece,1986). Such a situation is also captured as volume uncertainty (Walker & Weber, 1984; Geyskens et al, 2006) where it becomes difficult for the firm(s) to accurately predict the volume requirements in a relationship. Under these conditions, the suppliers may experience unexpected strain on their production lines or land up with excess capacity. The buyers on the other hand, may

either face shortage of critical resources or have to bear the costs of excess inventory. Thus, increasing demand uncertainty may call for dealing with a number of contingencies ex-post and firms have to incur costs in renegotiations and also deal with problems of frequent information co ordination (Heide & John, 1990). In the context of technology development, Robertson & Gatignon (1998) increasing demand uncertainty to predict internal technology development than a technology alliance (externalize) since disagreements are likely to arise on different critical aspects of technology development due to several contingences in high demand uncertain conditions, reducing the efficacy of alliances. The likelihood of internalization of the production decision under uncertainty has received support in the production decision (Walker & Weber, 1984; MacMillan, Hambrick & Pennings, 1986). Increasing uncertainty has been associated with the likelihood of direct channel rather than intermediaries for distribution (Anderson & Schmittlein, 1985; John & Weitz, 1988; Klein et al, 1990). Such conditions may need renegotiations and refusal on the part of the partner firms to adapt.

Technological uncertainty: Technological uncertainty makes it difficult to predict the technical requirements in a relationship (Walker & Weber, 1984). It is created by technological changes, such as rapid obsolescence of current technologies, changes in standards, specifications of components and end products that make current efforts in capability building subject to rapid obsolescence (Robertson & Gatignon, 1998; Geyskens et al, 2006). Two different sets of theoretical arguments leading to different predictions have been employed. One line of argument suggests that in industries characterized by short product development cycles and rapid product obsolescence, if innovations are to be introduced at a faster rate, externalization provides greater

flexibility in rapid product introduction. The transaction costs associated with market contracting or alliances are likely to be offset by the benefits offered by timely market entry (Robertson & Gatignon, 1998). External modes render firms the flexibility to terminate the contract or relationship and switch to partners that have the requisite capabilities or resources (Balakrishnan & Wernerfelt, 1986; Geyskens et al, 2006; Klein et al, 1990). The second line of argument is that the risk of opportunism and needs for communication during product design changes leads to the choice of internalization (Hoetker, 2005).

Internal/behavioral uncertainty: Although the two types of uncertainty that has been frequently used in the TCE literature is external uncertainty, early work also examines the impact of uncertainty that arises within the context of the exchange itself (John & Weitz, 1988; Klein et al, 1990). This refers to the difficulty of assessing the performance of the partner, which in turn can lead to false claims by the partner (such as an intermediary in the channels context) about the use of committed resources.

Summary: Vertical integration eliminates the issues out of opportunism by means of fiat through 1) the provision of extensive administrative rules and procedures to help reconcile differences among the parties in an exchange and specifically for problems aggravated by uncertainty 2) the need for restructuring contracts (Williamson, 1975, 1991). Thus vertical integration is posited as a viable solution to the problems posed by high uncertainty. Both lines of arguments have found empirical support. In fact, studies have shown that under technological uncertainty, the likelihood of firms sourcing the components from the market is higher when there are numerous upstream suppliers in the

automotive industry (Walker & Weber, 1987). On the other hand, firms in the computer industry vertically integrated into the making of displays for the laptops, under increasing technological uncertainty (Hoetker, 2005). Interestingly, Poppo & Zenger (1998) found no relationship between increasing technological uncertainty and the outsourcing of information services by large American firms. More recent advancements of TCE posit that increasing uncertainty will conditionally affect vertical integration decisions. Uncertainty is a stronger predictor of the vertical integration decision when asset specific investments are involved (Leiblein & Miller, 2003). Market exchange is not hazardous in uncertain environments because it is more costly to write complete contracts in uncertain environments per se, but uncertain environments facilitate subsequent contractual renegotiation that can be costly in the presence of specific investments.

Governance choices

Table 8 summarizes the governance choices in the TCE literature

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Please insert Table 8 about here

Governance choices in the TCE work considers arms-length licensing contracts, tightly coupled co development partnerships and joint ventures, and vertical integration. Scholars in the TCE lineage have treated the limiting points (of the sourcing mode) in the decision to internalize or not. For example, Schilling & Steensma (2002) focused on the two extremes in this continuum, market contracting through licensing and the use of firm hierarchy through acquisition. Robertson & Gatignon (1998) focused on the choice between technology development partnerships and internal development. Pisano (1990)

examined the internal R & D decision versus market contracting for technology development. Hybrid modes, such as alliances with varied degree of control and equity are more suitable for transactions that involve a technology component (Columbo, 2003). The equity modes permit greater incentive alignment through the mechanisms of shared ownership, superior monitoring and control. JVs are a preferred and commonly used form of equity alliance involving an autonomous formal managerial hierarchy (see, Pisano et al, 1988; Pisano, 1989; Osborn & Baughn, 1990; Gulati, 1995; Garcia Canal, 1996; Gulati & Singh, 1998; Oxley 1997; 1999a). A continuum of governance modes, that can be addressed through the TCE lens and addresses different opportunistic concerns that arise in the transactions associated with a primary product firm's activities related to complement development, is illustrated in figure 1a and 1b.

Please insert figure 1a & 1b about here

In the next section, I examine the firm's strategy for complementary product development, reflected in the degree of internalization.

Hypotheses development

Figure 2 illustrates the conceptual model for this chapter. Using transaction cost economics as the theoretical lens, I propose type of complementarity as influencing the decision of the primary product firm to make or externalize the development of complements. Importantly, the governance decision is influenced by technological and market demand uncertainty.

Direct influence of type of complementarity

A significant stream of work in network economics emphasizes the importance of complementary product availability on the market share of the primary product firm (Katz & Shapiro, 1985; 1986; Farrell & Saloner,1986; Church & Gandal, 1993; Gandal; 1993; Ohashi, 2003; Nair et al, 2004). The literature however does not address how variation in the type of complementarity influences firm decisions. Functional interdependence is stronger in symmetric than asymmetric complements, influencing extent of asset specific investments needed. Due to the bilateral dependence, greater asset specific investments are needed in aspects of product architecture such as interoperability, partitioning of functions and overall system reliability. Assets such as i) proprietary information exchange to develop interfaces and internal common modules or shared components and ii) hardware tools and components, software to ensure inter product compatibility iii) human and financial resources. The process of preproduction heuristic development generates design as well as production know-how that is specialized and may be non-patentable (Monteverde & Teece, 1982). For example, the first generation video game was wired to the game console, requiring tight coordination in the development of both products.

Further, there are likely to be fewer providers of complements with the capabilities to deliver the symmetric product, particularly when the primary product market is not developed. These aspects increase the chances that the investments between the firms become specialized to the relationship and are not easily redeployable in alternative transactions. The know-how becomes specialized to the primary product

over time, making replacement of the complement developers difficult. Hold - up in the form of delays in product releases by the complementor, primary product technology appropriation or deviance from the agree upon terms of a contract such as withholding information pertaining to common components or module development can lead to a setback for the primary product firm in competitive battles. Early and synchronized product release enables the primary product firm to 1) create a reputation for products 2) allows time to experiment with the different combinations of the primary and symmetric complements, adapt them to suit consumer tastes and re introduce the products before competitors. The importance of entry timing has been noted in technology related contexts, such as the battle for dominant design (Suarez, 2004), standards creation (Narayanan & Chen, 2012) and preventing technology lock out (Schilling, 2002). Similarly, alignment in product design decisions, production schedules, and marketing activities are important in giving primary product firms an early lead in competition for market share or technology dominance. For example, consumers are likely to perceive the products as part of the system when pricing, advertizing and distribution between primary product and symmetric complement is coordinated.

In asymmetric complementarity, consumer may use the primary product independent of the complement. Due to reduced functional interdependence, product design, production, product introduction and marketing of the primary product can be carried out independently. Development of asymmetric complements benefits the primary product firm once the primary product technology itself has been accepted by the consumer. This also increases the willingness of a larger number of complementors developing asymmetric complements. So the primary product firm is likely to have more

control over its technology and its relationship with the asymmetric product complementors, reducing the impact of opportunistic behaviors in contractual relationships with complementors. Hold-up in the form of product introduction delays, withholding of information related to asymmetric complement development or lack of coordination in aspects related to asymmetric complementary product development and selling is less likely to impact the delivery of the primary product to the market

Type of complementarity thus influences the potential for opportunistic behavior through the involvement of asset specific investments and the small numbers condition. Specifically, the primary product firm risks losing its advantage to a complementor or its primary market competitor if it shares its technology through contractual agreements, the complementor does not deliver the complements on time or appropriates the technology and becomes its competitor. Internal organization reduces transaction costs as compared to external modes by eliminating potential for hold up behaviors (Williamson, 1975, 1987; Walker & Weber, 1987), reducing a need for bargaining with complementors, and enabling coordination through internal organizational controls (Williamson, 1979; Novak & Eppinger, 2001). Hierarchical controls in internal organization offer superior information processing mechanisms arising from the increased division of labor, creating cooperation and coordination among organizational teams involved in the development of the primary product and complementary product.

Hypothesis 1a: Symmetric product complementarity is positively associated with higher degree of internalization

Hypothesis 1b: Asymmetric product complementarity is negatively associated with higher degree of internalization

Two environmental factors, viz., technological uncertainty and market uncertainty are notable in contexts involving complementary products. Next, I consider the influence of technological uncertainty, a predictor of firm governance structure in the context of complementary products.

Moderating influence of technological uncertainty

In contexts characterized by increasing technological uncertainty, there is a lack of clarity and knowledge regarding technology evolution and change, the length of time a technology and product will survive. In early stages of primary product development and technological changes, there is increasing uncertainty regarding the technology trajectory evolution and outcome of the primary product and symmetric product development. Similarly, when the pace of technological change is rapid, it creates unpredictability in the value of long term investments in research and development. There may exist a limited number of complementors with capabilities in symmetric complement technology development or complementary assets such as stock of patents and software modules, particularly when there is information asymmetry regarding the nature of primary product technology evolution.

The uncertain nature of technology evolution requires greater levels of communication, information exchange, personnel involvement to facilitate and coordinate the closely interdependent phases of product design, development and testing of commonly shared modules and interfaces due to the tight nature of interdependence

between the primary product and the symmetric complement, without loss of system integrity. In contexts where technology change is rapid, sharing the information with all the teams involved in the wake of new developments is critical for rapid product introduction. Specifically, such contingences may require modifications to commonly shared modules, changes in production engineering processes and design advancements. For example, RCA was not only involved in the design and production of the Television, but also integrated into programming through ownership of NBC studios. Such tight interdependence introduces potential for opportunism due to the co specialization in knowledge assets and proprietary production equipment that are specialized to the product pair.

Although a milder form of opportunistic behavior, complementor shirking on optimal commitment of resources, refusing to commit to a different technological design in the context of new information from the development process or changing market conditions impacts the prospects of the primary product. Such conditions are difficult to anticipate and specify at contract formulation stage and leads a situation for bargaining on pricing and sharing of profits or disputes, contributing to transaction costs (Williamson, 1991; Casadesus-Masanell & Yoffie, 2006). This impacts production schedules and timing of product releases which have to adapt as well. The primary product firm may thus incur ex-post transaction costs from renegotiation, revision of formal agreements between independent partners or involving a third party to settle irresolvable disputes (Williamson, 1985, 1991; Walker & Weber, 1984; Anderson & Schmittlein, 1984; Pisano, 1990; Schilling & Steensma, 2002). TCE based explanations of governance structure provide evidence of increasing governance costs under

technological uncertainty in several components industries (Masten, 1984; Globerman, 1980; Anderson & Scmittlein, 1984; Hoetker, 2005).

Internal development of symmetric complements enables the primary product firm to deal with the contingences in product development rapidly, eliminate the inefficiencies from technological uncertainty and prevent any severe forms of opportunism such as technology appropriation, which can severely impact the firm's competitive position. This facilitates synchronized product market entry, an advantage when the focus of competition is on establishing the leadership of the primary product design, for which symmetric complements are essential.

The purchase of asymmetric complements is guided more by the choice and needs of the consumer. Due to the nature of the relative functional and technological independence, the primary product maybe developed independent of the asymmetric complement. Particularly, the firm has greater flexibility in implementing primary product design changes in the wake of unanticipated technological developments or in introducing new versions of its products, regardless of the changes in complements. Further, the primary product firm is less likely to incur costs on technologies and products that are not directly related to the primary product until the uncertainties in the primary product technology are resolved.

However the development of asymmetric complements is beneficial to the primary product firm, for greater complement variety is valued by consumers, increasing the market share and complement development by external players sends signals of primary product credibility to consumers. Although the demands on the primary firm are

considerably less for rapid investments in asymmetric complement technology development, changing technological and prevailing market factors such as network effects have emphasized the role of asymmetric complements. The benefits of having a greater supply of asymmetric complements are likely to influence the primary product firm strategies. However, exchange of intangible knowledge assets, required during update of product architecture involving primary product and asymmetric complement does not rule out technology appropriability concerns by the complementor. Thus, under high levels of technological uncertainty, the primary product firm is likely to opt for a governance strategy which allows it some degree of control in asymmetric complement development.

***Hypothesis 2*:** Technological uncertainty moderates the relationship between type of complementarity and degree of complement internalization such that

2a) (+): Higher internalization is more likely in high technologically uncertain environments than in low technologically uncertain environments for symmetric complements,

2b) (-): Higher internalization is more likely in high technologically uncertain environments than in low technologically uncertain environments for asymmetric complements.

Moderating influence of market demand uncertainty

Market demand uncertainty reflects the fluctuation and unpredictability in the level of demand in the market for the final good - arising from factors such as consumer product demand variations and competitive dynamics. The source of market uncertainty in the TCE literature is demand unpredictability, so in this dissertation I examine how fluctuations in demand influence the primary product firm boundary decisions for complementary products. To deal with demand uncertainty, the firm has to adopt a two pronged approach of i) allaying consumer expectations of primary product decline or stagnation and ii) minimizing forms of opportunistic behavior.

Since consumers' value variety in complementary products, firms deal with the consumer demand expectation contingency by adopting tactics that facilitate complement variety in the market. Contractual agreements involving technology licensing, sharing of APIs, etc. encourage entry of complementors in the complements market, who develop have the capabilities to develop superior quality complements compatible to the primary product (Gawer & Henderson, 2006; Binken & Stremerche, 2009). This in turn contributes to increasing installed base of the primary product (Ohashi, 2003; Nair, Chintagunta & Dube, 2004).

Opportunistic behaviors such as increasing prices or delaying the complementary product development by symmetric complementors impact the primary product sales more than similar hold-up actions by asymmetric complementors. In symmetric product complementarity, arms length contracting may not be the ideal choice for the main reason that the primary product is always dependent on its symmetric counterpart, irrespective of

the product market structure changes (such as market separation after technology standards and modularity developments) although the market for symmetric complement suppliers is unlikely to be thin (Hogendorn & Yuen, 2009). In general, TCE researchers have found that the transaction costs to specify, monitor and enforce a workable contract are higher in high volatility markets than in low-volatility markets (Balakrishnan & Wernerfelt, 1986; Teece, 1988), making internalization the transaction-efficient governance structure. However, the contexts are different mainly in the need for variety in complement availability and internalization does not address the need. Consequently, I argue that the primary product firm will opt for a governance choice that gives it greater control in its relationship with symmetric complementors than with asymmetric complementors. Alliances with involvement of different levels of equity facilitate or non exclusive contractual agreements provide the firm with more security in dealing with opportunism in the case of symmetric complementors.

The technologies and products that maybe used independent of the primary product, but yet enhance its value are not known to the primary product firm. The relative functional independence of the primary product on any one asymmetric complement is an incentive for the primary product firm to encourage availability of several complements, particularly when market uncertainty is high. The likelihood of primary product-complement adoption is greater if consumers have the option to mix and match a primary product with a number of other complements, which address different needs of consumers. This in turn will permit several system configurations to co-exist (Baldwin & Clark, 1994; Sanchez, 1995) lending the choice to the consumer to adopt a system that suites their requirements the best (Matutes & Regibeau, 1988).

The impact of opportunistic behaviors such as pricing issues or product quality degrades in asymmetric complements are lesser than in the case of symmetric complementary product development since the primary product firm has the resources to deal with such contingences. The choice of the external market of complementors increases the chances of availability of a wide variety of complements in the market place as the external players have greater diversity in resources and capabilities than the focal firm alone. Further, non equity forms of cooperative relationships such as licensing contracts provide a way of sharing information and commit complementors to complementary product development. Complementors benefit from developing complements compatible with the primary product as they can reap the advantages of an already installed base of consumers devoted to the primary product.

***Hypothesis 3*:** Market demand uncertainty moderates the relationship between type of complementarity and degree of complement internalization such that

3a) (-): lower degree of internalization is more likely in high demand uncertain environments than in low demand uncertain environments for symmetric complements,

3b) (+): lower degree of internalization is more likely in high demand uncertain environments than in low demand uncertain environments for asymmetric complements.

Conclusion

Based on the tenets of Transaction Cost Economics, this chapter examines the influence of type of complementarity on the boundary question. I detail the opportunistic behaviors relevant under changing market and technological conditions and formulate hypotheses regarding the governance mode. Specifically, primary product firms choose between hierarchy, different hybrid forms, and external modes (which include market contracting

and letting complementors make the complements). Type of complementarity has a different influence on the governance mode, moreover the technological and market conditions before and after dominant design emergence have different influences on the governance choice. The flexibility to adapt to changing circumstances is a determinant of opportunistic behavior (Williamson, 1991; Wathne & Heide, 2000). This aspect has different influences before and after the emergence of the dominant design on the governance decision.

Limitations

The dissertation does not address two aspects of technology battles that are likely to have an influence on the boundary question, viz., i) appropriability regime ii) firm competence

Appropriability regime: The efficacy of legal mechanisms of protection prevailing in the industry provided by patents, trademarks and copyrights is likely to influence the primary product firm decisions and complementor decisions in terms of which platform to collaborate with or produce complements for. The stage of technology development also determines the efficacy of these mechanisms - for example, patenting has its limitations in protecting technology appropriation in the early stages of technology development (Teece, 1986) and the effectiveness of the public institutions in establishing and enforcing the rights of the inventor (primary product firm) is stronger in later stages of the technology battle. Although this dissertation does not address the influence of these mechanisms, the nature of opportunistic behaviors in dealing with complementors is unlike those of other technology based transactions. First, not all know-how can be

patented, such as specific assets based on experience or unstructured technical dialogues in design and production (Monteverde, 1995).

Second, the consideration of this factor only reinforces the arguments proposed in this thesis. For instance, in the context of technology life cycle, the early stages of the symmetric product development are characterized by weak appropriability since there are few standard enforcing institutions. Consequently, the threat of technology appropriability and its impact on the primary product firm's prospects are even stronger, increasing the likelihood of internalization. However, in the later stages of the product life cycle, the appropriability regime is likely to provide safeguard against active forms of opportunism such as technology appropriability and violation of contracts, so that governance choices with lower hierarchy and control enable firms to increase their market share by encouraging complement variety.

Competence based explanation: A firm may internalize a transaction associated with a complement because it represents the firm's core competence (Prahalad & Hamel, 1990; Murray & Kotabe, 1999). Thus, firms with greater capabilities in production tend to perform this activity internally rather than choosing the markets (Jacobides & Hitt, 2005). Other works demonstrating support for the capabilities driven explanation of vertical scope include capability differences between suppliers and buyers (Hoetker, 2005), licensing of technology that is rare, unique and valuable (Schilling & Steensma). Further, in the context of choosing external modes of governance such as equity or non equity forms of alliance, technology capability differences and similarities inform the decision logic (Colombo, 2003).

The theoretical mechanisms for the influence of appropriability regime and firm competences are not clarified in this dissertation. However, I account for the influence of these factors in the empirical study based on the selection of the sample and research design, as detailed in chapter 6. In the next chapter, I detail the methodology to empirically validate hypothesis for the complement internalization.

CHAPTER 5: RESEARCH DESIGN

This chapter describes the steps in the methodology I followed to test the propositions in the theoretical model. The research design is organized under the following framework 1) Sampling strategy 2) Data collection 3) Analytical model.

Sampling strategy

The sampling strategy is discussed in 5 steps:

I. *Identifying the primary product market*. The choice of the primary product is critical because the predictions in the model are from the perspective of a primary product firm, and the nature of product complementarity is defined with the primary product as the reference product. The choice of the primary product was made based on following criteria 1) variation in type of complementarity with known availability of different types of complements of 2) variation in technological and market uncertainty – the moderator variables in the study. A comparison of complements in the some high technology product markets (see Appendix I: section A) suggests the prevalence of a greater number of different type of complements in the PC product market than others. Consequently, firms from SIC codes 3570 (Electronic and Office Computers), 3571(Electronic Computers) from COMPUSTAT formed the sample of primary product firms. Several product categories are complementary to the computer viz,

i. Microprocessor, operating system, motherboard which are essential to the use of the PC (Matutes & Regibeau, 1988; Economides, 1989).

ii. Desktop monitor and computer terminals

iii. Different storage drives such as removable tape drive, disk drive, cartridge, flash/zip drive.

iv. Services such as internet connectivity, IT services (Costa & Dierickx, 2005)

v. Peripherals such as modems, fax, scanners, printers and network connectivity products (Sengupta, 1998).

vii. A range of application software for video streaming, security, back up and recovery, remote desktop management, file management, PC protection, database and business productivity software, games etc (Heeb, 2003).

viii. Other electronic products such as TV, video camera, digital camera, portable music systems, projectors etc with HDMI interface or Firewire port or USB.

Thus the PC and related product markets allows examination of the dynamics between primary product firms and complementors making different types of complements including component, non component, service, symmetric and asymmetric. I test the hypothesis based on hardware based complements only, since the software based complements involve different consideration of different factors in terms of technological interdependence, product deployment and copyright aspects. Further, there is variation in the PC market for the following reason.

II**:** *Identifying the list of primary and complementary product pairs*. All possible pairs of hardware based complements to the PC were identified (PC, desktop and laptops) from the following sources, viz., i) Technical/academic books on computers and ii) Trade publications in the computer industry, validated with two librarians, knowledgeable on the industry and Examples of complements in the strategy, economic & marketing

literatures. The list of trade journals and books referred to are listed in the Appendix I: (section A, B).

III**:** *Categorizing the primary and complementary product pairs.* The product pairs were categorized using the assistance of four industry experts[5] into three distinct categories viz., symmetric complements, asymmetric complements and not sure according to the sorting technique often used in management research (Anderson & Gerbing, 1991; Nadkarni & Narayanan, 2007). The initial rate of inter coder agreement was 88%. The "cannot decide" categories were re coded after they were provided with a definition of the products and thereafter the agreement was above 90%.

IV**:** *Identifying announcements for the primary product category*. First, a dictionary of complementary product keywords was derived based on literature review on complementary products, dictionary meaning search and synonyms and *consultation* with industry experts in the information services sector to validate the keywords[6]. This list of keywords include *complement(s),Complementary product(s),Complementary good(s), Complementary market(s), Complementary part(s), Complementary component(s), Complementary module(s),Complementary gadget(s),Complementary package(s), Complementary system(s), Peripheral(s),Peripheral good(s), Peripheral product (s),Peripheral component (s),Peripheral part (s),Peripheral gadget(s),Peripheral module(s),Peripheral market(s),Peripheral system(s),Add-on(s),Add-on good(s),Add-on*

[5] Deepa Mundewadi, Manager, Accenture,India Sunder Siva, Systems Architect at PTC,PA Sandeep Chandak, Senior Architect at Sasken Technologies, Pune Mitul Patel, Systems Integration Consultant, Appirio,TX

[6]Chanda Jackson, Business Analyst, BSCI; Mike Betschart, Business Analyst, BSCI; Mike Schary, Project Manager, PTC, Baburaj Panicker, Software Architect, PTC

product(s),Add-on component (s),Add-on part (s),Add-on gadget(s),Add-on module(s),Add-on package(s),Add-on system(s),Accessories, Feature enhancement(s),Consumable(s),Synergistic product(s), Synergistic module(s), Synergistic system(s), Synergistic market(s), Synergistic part(s), Synergistic component(s), Synergistic complement(s). Second, I searched search the newswire database for all computer related complementary product category announcements, in the *Businesswire* based on these keywords and applying different criteria between 1980 – 2010. Firms disseminate information on actions related to primary product and the information is visibly captured in the business press announcements (Westphal & Zajac,1998). Prior research in management has referenced these databases (Kalaignanam, Shankar & Varadarajan, 2007; Lavie & Rosenkopf, 2008).

Figure 3 shows the steps involved in the data collection process

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Please insert Figure 3 about here

Figure 4 shows the flowchart for the selection of announcements

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Please insert Figure 4 about here

V: *Identifying the sample of product pairs with primary product firm and their strategies.* The resulting final set of documents is fed to a software program I developed to match primary product firms with those from COMPUSTAT, identify complementors and identify the governance strategies. Although historically action coding in texts such as news documents has been done manually by coders trained to conduct such activity, recently software packages are replacing this manual intensive effort. Studies provide

evidence of the comparable accuracies in coding done manually and that by a computerized effort (Laver et al, 2003; Uotila et. al., 2009). I developed a custom software package to identify the strategies for a particular primary product-complementary product pair in an announcement on a sample of announcements. The strategy identification involved the following steps.

i. A set of keywords for the different strategies proposed in the theoretical model was derived, based on a review of the academic literature and consultation with business and academic experts. The set of keywords included *release(s/ed), debut(s/ed), introduce(s/ed) new, unveil(s/ed), launche(s/ed), ship(s/ed), announce(s/ed) new, deliver(s/ed), extend(s/ed) support, offer(s), produce(s), present(s), manufacture(s), develop(s), reveal(s/ed), acquire(s), purchase(s), takeover, buyout, merger, consolidation, subsidiary, syndicate, hostile, absorb, parent, white knight, suitor, integrate, acquire, purchase, buy, merge, equity stake, equity position, agreement, alliance, ally, allies, signs pact, sign pact, signs deal, sign deal, pact, collaboration, collaborates, jointly develop, joint development, jointly developed jointly market, joint market, joint marketing, joint production, joint R & D, joint R&D, co-brand, co-develop,co development, co produce ,co production, co-market, co-marketing, co-branding, cross license, cross-licensing, cross licensing, joint distribution, joint advertizing.*

ii. The announcements were searched to locate a match between the primary product-complementary product pair in the set of announcements. The matched set of announcements was then selected for further processing.

iii. The subset of announcements from step ii) above was examined for a match of the primary product firm in the title and/ (or) header of each announcement with the master list of all primary firms from SIC 3570 (Computer And Office Equipment) and 3571(Electronic Computers).

iv. The set of announcements with a primary product firm were matched for identifying a match with validated strategy keywords[7] (see Appendix I: section F) for internalization, alliance and complementor make by the software program. The flowchart for the software program and criteria used in programming are listed in the Appendix I (see section G). I also did manual verification checks to improve the accuracy of the software program (Appendix I: see section H).

Data

Data Source

The data sources for creating the list of complementary products include the trade journals in the PC industry, academic books on computers and peripherals, industry reports on computer peripherals, review of the academic literature and industry experts. Technological, market demand uncertainty and control variables data are from COMPUSTAT, firm annual reports and the Almanac of Industry ratios. Patents data are from USPTO (http://www.uspto.gov). Governance strategies data is from Lexis Nexis Academic, specifically announcements reported in the Business Wire and SDC database. Availability of data restricts data clection to primary product firms and their activities headquartered in the United States.

[7] with two academic experts

Business Wire disseminates full text news releases from thousands of companies worldwide to several audiences including news media, financial markets, market research firms, investors and databases. To deliver accurate and fast reporting, it has carriage agreements with several premier news agencies such as AP, Dow Jones, Reuters, and Thomson One. Business Wire research polls and surveys have been cited in academic work (Filson, 2004; Houde, 2012). COMPUSTAT for sales, assets and expenditures (viz., R & D, advertizing).

Data Description

		Observations
Total Product pairs	108	696
Primary product firms	31	
Product pairs associated with a primary product firm	88	307
Symmetric product pairs	56	112
Asymmetric product pairs	32	195

The sample consists of 88 pairs of primary product-complementary product pairs. The complements are hardware based such as CPU, monitors, disk drives, scanner, printer, digital camera, camcorder, projector, keyboard and mouse. Strategies pertaining to 31 primary product firms are captured in the sample, between 1982 and 2010, which were in the PC market for all or some period, generating a total of 307 pooled observations.

Measurement of variables

Dependent variable*: Degree of complement internalization*

This variable captures the choices of the primary product firm conducting the complementary product development within the boundaries of the firm, or outside its boundaries. Vertical integration and markets, including long term contracts are the two basic forms of organization examined in the TCE literature. Hybrid governance structures that include joint ventures, relational contracts and bilateral arrangements are located between the markets and hierarchy spectrum. From a transaction cost perspective, equity form of governance structures including JVs and partial equity investments relationships are subject to the transaction hazards of both markets and hierarchies as they are located intermediate between hierarchy and markets (Park & Russo, 1996). Consequently, I coded degree of internalization involving complementary products as a variable with three distinctive, non overlapping values

1. Complementor make: These include complementary product development by complementors. Product announcements by complementors for a particular primary product were coded in this category.
2. Alliances: Agreements involving primary and complementary product firms such as jvs, minority or partial equity, supply contracts, OEM agreements and retail contracts between primary and complementary product firms were also coded in this category (Oxley, 1999; Columbo, 2003).
3. Vertical integration: Complementary products developed internally by the primary product firm were captured by complement announcements from primary firms.

Independent variables

1. *Symmetric and asymmetric complementarity:*

The development of the measure required industry expert validation and categorization. First, two experts validated the definitions for symmetric and asymmetric product complementarity, specifically that the distinction in the type of product complementarity was clear (see Appendix –Section C, D). Examples include

Symmetric Complementarity		**Asymmetric complementarity**	
PC	Microprocessor	PC	Printer
PC	keyboard	PC	scanner
PC	power supply	PC	web camera
PC	RAM chipset	PC	videophone
PC	motherboard	PC	DVD player
PC	OS	PC	digital camera

Second, four industry experts categorized the product pairs into two categories. The extent of agreement in the categorization was significant enough to proceed with the coding of the construct into two distinct categories (see Appendix – Section E).

Third, since these are distinct and identifiable usage behaviors from a usage perspective of a primary product, I it as coded as a dichotomous variable, i.e. a product pair is either symmetrically or asymmetrically complementary. For this study, it is coded as:

TOC =0; asymmetric complement

TOC =1; symmetric complement

2. *Primary product market technological uncertainty:*

In the TCE literature, technological uncertainty is operationalized as the frequency of changes in product specification, the probability of technological improvements (Walker

& Weber, 1984; 1987; Shelanski & Klein, 1995), frequency of new product introductions, the frequency of technological change (Lazzarini, Claro & Mesquita, 2008; Ragatz et. al, 2002) and the change in product configurations resulting from frequent technological change (Poppo & Zenger, 1998). Firms are likely to respond to frequent and unpredictable product or technology developments influencing the primary product functions with investments in new technology development. Further, technological developments involving process innovations (such as the fabrication equipment in CPU manufacture) require investments in capital equipment. Technological uncertainty is measured as the average ratio of the sum of research and development expenditures and capital expenditures averaged for all firms in the primary product market (Snyder & Glueck, 1982).

3. *Primary product market demand uncertainty:*

Product market uncertainty reflects the unpredictability in sales in the corresponding product market (Dess & Beard, 1984; Bergh, 1998). I calculated volatility for the current year as the standard error of the regression slope coefficient, where past 3 previous years' net product market sales were used in the regression equation. Sales data pertaining to the relevant product market was obtained through Compustat Segment data to include only those data relevant to operations for the primary product (i.e. BUSSEG, OPSEG). The volatility is an indicator of the unpredictability of product demand, user needs, pricing and distribution.

Controls

Diversification motive, core competence or past alliance experience may be suggested as an explanation for a particular governance choice. Prior research in transaction cost economics has identified the influence of asset specificity, firm size, experience and capabilities as influencing the firm's decision to internalize. Since the study is focused on the choice of governance strategy from a primary product firm's perspective, I use the following primary product firm level controls.

1. *Primary product firm size*:

Larger firms are more likely to have the resources essential to conduct the complementary product activities internally as compared to smaller firms. Firm size has been used a measure of the scale of operations which influence the decision to choose the governance strategy (Gatignon & Anderson, 1988). Larger firms could leverage the existing production and marketing assets as compared to smaller firms who are likely to seek external complementors in producing or marketing the complements. Further, small firms are likely to be more nimble in terms of the choosing strategies such as Similar to prior research, size is measured as the natural logarithm of the number of employees (Gatignon & Anderson, 1988; Brouthers, Brouthers & Werner, 2003).

2. *Primary product firm age*:

Older firms are likely to have more complementary product related activities in progress as they have had more time for planning the activities, assessing the competitive environment and implementing different strategies. Further, older firms are also more likely to have to have entered more alliances than younger firms (Sorensen & Stuart, 2000). Younger firms are unlikely to know how to manage subjectively, monitor and

assess the performance of partners or markets (Gatignon & Anderson, 1988). It is measured as the number of years in the industry since date of founding.

3. *Primary product firm technological capability:*

Arguments based on the resource based view of the firm in the context of buyer supplier make or buy decisions supports the likelihood of internalization as being influenced by the technological capabilities of the firms (Argyres, 1996; Hoetker, 2005). Technological capabilities encompass trade secrets, know-how generated by R & D and technology intellectual capital (Dollinger, 1995; Lee, Lee & Pennings, 2001; Carlsson, Jacobsson, Holmen & Rickne, 2002). Firms may not involve another partner or have to depend on markets if it has the essential set of capabilities in development, production and marketing to make complements. Technological knowhow embedded in patents reflects the primary product firm's ability to innovate and develop complementary products related to its primary product technology. Technological capability is measured as the count of patents held by the primary product firm. Such a measure has been used in prior research, reflecting the firm's ability to innovate (Shan, Walker & Kogut, 1994)

4. *Primary product firm R & D Intensity*

Asset specificity, a determinant of a firm's decision to conduct product development within its boundaries has been measured in terms of the firm's R & D Intensity (Gatignon & Anderson, 1988; Henisz, 2000). Higher R & D intensity is a proxy for intangible assets such as engineering personnel know-how and technology assets whose value is difficult for outsiders to assess and difficult to redeploy (Balakrishnan & Fox, 1993), influences the choice of a governance form that gives the firm greater control over the assets.

5. Firm Capital Intensity

Firms with large fixed assets dedicated to the development of its primary product line have lesser flexibility in realigning their production line, technology laboratories and personnel in the development of newer product lines without significant costs or time delays, in turn influencing their decision to internalize other product lines. It is measured as the ratio of capital expenses to sales for each year.

6. Firm alliance experience

Prior sourcing relationships enable firms to develop capabilities in identifying partners and better implement the phases of a transaction, viz., negotiating, monitoring and enforcing the terms of a contract (Gulati, 1995; Hoetker, 2005). Firms with greater experience are likely to choose alliances for implementing the phases of complementary product development as compared to other modes since they provide firms with greater flexibility in scaling up the commitment or reversing the transaction. Similar to prior research, I control for past experience in alliances with a count variable (Oxley, 1997; Rothaermel & Deeds, 2004).

7. Time controls

The computer product market has undergone growth and downturn due to business cycle effects, macroeconomic factors such as recessions, and other factors that cannot be explained by technological or demand uncertainty over the study period. For example, the Y2K scare[8] around 1998-2001 caused an increased demand in the sales of the computers,

[8] The computers were so designed to function (due to the software) that it would not be able to make a difference between the year 18**00** and the year 20**00**, for many of them used only two digits for the year field as opposed to four.

where the sales of computers were influenced by a need to ensure Y2K compliance. This was followed by a decline in sales as computer orders declined, firms had invested in machinery and equipment and the limited shelf life of the equipment in a rapidly changing technology market. To account for the impact of the broader economic fluctuations and time related variations in the dependent variable, year dummies $t_{1.....}t_{26}$ were included.

Model specification

The unit of analysis is the product pair. The governance choice in this study takes distinct and non substitutable values, viz., the markets option includes complementor making the complement, unilateral licensing or contracting agreements such as supply contract, distribution contract or non exclusive technology licensing as the default choice (0); alliances as the second and vertical integration as the third choice.

Specification1: The multinomial probability that the governance strategy is *i* for the j^{th} observation is expressed as –

$$P_{ij} = Pr(GS_j=i) = \frac{1}{1 + \sum exp(x_j\beta_m)}, \text{ if } i = 0 \qquad \text{---------(1)}$$

$$P_{ij} = Pr(GS_j=i) = \frac{exp(x_j\beta_i)}{1 + \sum exp(x_j\beta_m)}, \text{ if } i \neq 0 \quad (i=1,2) \qquad \text{--------(2)}$$

where x_j is the vector of observed values of independent variables for the *j*th observation and β_m is the coefficient vector for outcome *i*, such that

$$\sum \exp(x_j\beta_m) = \beta_{1\text{-}34}\text{Controls} + \beta_{35}\text{TypeofComple}_{it,j} + \beta_{36}\text{TechUncertainty}_{it,j} + \beta_{37}\text{MktUncertainty}_{it,j} + \beta_{38}\text{TypeofComple*TechUncertainty} + \beta_{39}\text{TypeofComple*MktUncertainty} \quad (3)$$

for the governance choice for symmetric *or* asymmetric complements,

where $\beta_{1\text{-}34}\text{Controls}=\beta_1\text{FirmSize}+\beta_2\text{Firmage}+\beta_3\text{FirmTechCapability} + \beta_4\text{FirmAllianceExperience} + \beta_5\text{FirmR\&DIntensity} + \beta_6\text{FirmCapitalIntensity} + \beta_7\text{Industry} + \beta_8 t_{1\ldots} \beta_{34} t_{26}$

Specification 2: The make vs. buy literature has largely employed binary choice models to test the relationship between a set of predictors and the governance decision (Monteverde & Teece, 1982, Pisano, 1990; Poppo & Zenger, 1998; Leiblein & Miller, 2003). Based on the firm's decision to internalize or not, the analytical model is expressed as:

$$GS_{it,j} = \alpha_j + \lambda_{t+} \beta_{1\ldots x}\text{FirmControls} + \beta_7\text{TypeofComp}_{1,2it,j} + \beta_8\text{TechUncertainty}_{it,j} + \beta_9\text{MktUncertaintyit,j} + \beta_{10}\text{TypeofComp}_{1,2}\text{*TechUncertainty} + \beta_{11}\text{TypeofComp}_{1,2}\text{*MktUncertainty} \quad (4)$$

where $GS_{it,j}$ indicates the choice of governance strategy for a pair of products *i* at time *t* *for* primary product firm *j*, α_j captures subject specific heterogenerity(firm/product pair) and λ_t captures the variability introduced by time. Control variables include primary product firm size, firm age, firm technological capabilities, firm alliance experience , firm R&D intensity firm capital intensity.

A pooled model specification for the binary choice is expressed as

$$GS_{it,j}=\beta_{1\ldots x}\text{FirmControls} + \beta_{6\ldots 32}\text{TimeControls} + \beta_{33}\text{TypeofComp}_{1,2it,j} + \beta_{34}\text{TechUncertainty}_{it,j} + \beta_{35}\text{MktUncertainty}_{it,j+}\beta_{36}\text{TypeofComp}_{1,2}\text{*TechUncertainty} + \beta_{37}\text{TypeofComp}_{1,2}\text{*MktUncertainty} \quad (5)$$

CHAPTER 6: RESULTS

The chapter discusses I) correlations, II) multinomial logit regressions, II) Logistic model regressions. The analyses were conducted using Stata 10 as the statistical software.

I. Correlations

The pair wise correlations are in Table 9.

Please insert Table 9 about here

Type of complementarity, the main predictor variable is correlated with R&D intensity ($p<0.1$) suggesting involvement of asset specific investments for symmetric complements. Strategy is correlated with firm technological capability ($p<0.1$), in line with prior research findings based on the resource based logic that firms are likely to internalize with increasing stock of valuable technological resources. Technological uncertainty, one of the moderator variables is positively associated with R&D intensity ($p<0.05$) and firm technological capability ($p<0.05$) in accordance with past findings that firms increase investment in research and development, when technological environment is unpredictable due to frequent technological change (Zhou & Wu, 2010). Technological uncertainty is also positively associated with strategy ($p<0.05$), suggesting the use of higher governance modes with increasing uncertainty, in line with arguments on the influence of technological uncertainty in transaction cost economics (Walker & Weber, 1984). Finally, market uncertainty is not significant but shows a negative association with strategy suggesting lower equity governance choices with increasing uncertainty.

II. Multinomial logistic regressions

Governance strategy values viz., complementor make, alliances and internalization are non substitutable alternatives, making multinomial logit a suitable analytical model for testing the hypotheses. The iia test does not suggest significance in the interdependence of the alternatives. To check for multicollinearity between the study variables, I conducted OLS regression. The VIFs for the main predictor variables viz., type of complementarity, technological uncertainty and market uncertainty were below 10. Further, the likelihood ratio test and Wald tests indicate that the individual effects of the independent variables, viz., type of complementary, technological and market uncertainty are distinct. Since the data contain multiple observations for the same firm across years, to address the problem of unobserved heterogeneity, I used the multinomial logit model with robust standard errors, along with clustering. To account for interdependence between observations within a firm, product pair and firm product pair, I performed the analysis by clustering on these three factors that accounts for interdependence within each of 31, 88 and 207 clusters.

1. Full sample multinomial logit regressions: I conducted multinomial logit regressions employing the full sample (Table 2 – Models 1 & 2). To address issues of heterogeneity introduced by repeated alliance or internalization strategies by a particular primary firm, I used dummy variables that indicate repeat alliance or internalization strategies by the same firm, similar to prior research (Wang & Zajac, 2009). I did not account for interdependence among observations where the strategy was *complementor make* because the analysis is focused from the primary product firm perspective. *Complementors make*

strategies involve decision logic from a complementor's perspective as well and this study does not address those mechanisms. The results are reported in Table 2 - Model 3 & 4.

Summary of results:

Please insert Table 10 about here

Hypotheses 1 predicts a direct effect of type of complementarity on the governance choice of a primary product firm for complementary products. The models do not support this prediction. Hypothesis 2a and 2b predict an interactive effect of technological uncertainty and type of complementarity on the primary firm's governance choice. This hypothesis is not supported in the full sample multinomial logit model analysis. Technological uncertainty has a direct impact on the likelihood of alliance formation as well as the internalization decision, suggesting that rapidly changing technologies influence the firm strategy. Hypothesis 3a and 3b predict an interactive effect of market demand uncertainty and type of complementarity on the primary firm's governance choice. This hypothesis is not supported in the multinomial logit model analysis.

Primary product firm variables, firm technological capabilities and alliance experience are significant in explaining the choice of alliance over complementor make and the choice of internalization over complementor make. Further, the alliance governance choice is also influenced by prior alliances involving the same primary product firm and product pair influence ($p<0.05$) (Table 2 – model 4a). Thus, the

significance of both overall alliance experience and product pair specific past alliances indicate the possible role of i) alliance capability in firm's preference of choice of alliance (Kale & Singh, 2007) and ii) complementary product specific factors influencing .the choice of alliance strategy over others. In conjunction with the finding that technological uncertainty is also significant ($p<0.05$), it is likely that firms on the one hand adopt strategies which give them flexibility at the firm level, and on the other hand identify and develop competence in a strategy that fits a particular primary product-complementary product pair in dynamic environments (Eisenhardt & Martin, 2000).

To test the influence of varying levels of uncertainties on the governance choice of the firm, I split the sample by different levels of technological and market uncertainty, viz., low, moderate and high.

Impact of Technological Uncertainty

Please insert Table 11 about here

Low levels of technological uncertainty: The relative risk of the choice of alliances relative to complementor make is higher for symmetric complements as compared to asymmetric complements and the relative risk of the choice of internalization relative to alliances for symmetric complements decreases at lower levels of technological uncertainty. On the one hand, this supports the prediction that primary product firms are likely to opt for higher modes of governance for symmetric as compared to asymmetric complements. It also shows that the propensity for internalization is lower at low levels of technological uncertainty. However, the results do not provide evidence of the

predicted choice of complementor-make at low levels of technological uncertainty for asymmetric complements.

Moderate technological uncertainty: The relative risk of the choice of internalization relative to complementor make for symmetric complementarity increases by a factor 6.976 times as compared to asymmetric complements at moderate levels of uncertainty ($p<0.05$) and the relative risk of the choice of internalization relative to alliances increases by a factor 3.851 times as compared to asymmetric complements at moderate levels of uncertainty ($p<0.05$). The results support the idea of a strong choice of internalization for symmetric complements relative to asymmetric complements at moderate levels of uncertainty.

High technological uncertainty: The moderating effect of increasing technological uncertainty on the predicted relationship between type of complementarity and the governance choice diminishes at high levels of technological uncertainty. The results indicate that firm technological capabilities and firm age are only significant in explaining the choice of internalization over other governance strategies for symmetric complements. However the magnitudes of the coefficients still indicate a stronger choice for internalization than other modes for symmetric complements.

Impact of market demand uncertainty

Please insert Table 12 about here

Low demand uncertainty: The results do not provide a discerning effect of type of complementarity at low levels of market demand uncertainty. The magnitude of the coefficients suggests that symmetric complements are less associated with alliances than internalization or complementor make.

Moderate market demand uncertainty: The relative risk of the choice of internalization for symmetric complements relative to complementor make decreases by 0.546 ($p<0.1$) and the relative risk of the choice of internalization relative to alliances decreases by 0.396 ($p<0.05$) as compared to asymmetric complements. Further, the results also show that firms are more strongly likely to choose alliances ($p<0.05$) as compared to complementor make ($p<0.1$). This result provides support to the moderation hypothesis that primary product firms are more likely to choose alliances as a governance strategy under increasing levels of market demand uncertainty for symmetric complements. Firm age is also significant in explaining the choice of alliances relative to other governance modes for symmetric complements.

High level of market demand uncertainty: There is no effect of demand uncertainty on governance choice of the primary product firm at high levels of demand uncertainty. The magnitude of the coefficients however indicates that symmetric complements are less associated with internalization or complementor make and more likely associated with alliances.

III. Logistic regressions

Research in the TCE lineage has traditionally examined the boundary question with two choices viz., make or buy and has employed binary choice models (Monteverde & Teece, 1982; Walker & Weber, 1984; Safizadeh, Field & Ritzman, 2008). To examine whether type of complementarity and the primary product market contingences predict the internalization vs. not internalize decision, I performed following analysis. I conducted logistic regressions (pooled and panel regressions) for predicting a firm's choice between a) alliance and internalize b) internalize and complementor make (excluding complementor make) and c) alliance and complementor make (excluding internalize). I explain the results next.

Summary of results in the pooled logistic regression models: The results are reported in Table 13, Models, 1 to 3.

Please insert Table 13 about here

Although the main explanatory variables (type of complementarity, interaction variables technological uncertainty*type of complementarity, market uncertainty*type of complementarity) are not significant, firm controls and technological uncertainty are significant. Specifically, primary product firm technological capabilities is significant in explaining the firm's choice of alliances over complementor make and internalization over complementor make (please see Table 13 - models 1 & 2 respectively). Further, firm R & D intensity ($p<0.1$) and alliance experience ($p<0.05$) are significant in explaining internalization over complementor make (please see Table 13 – model 1). Technological uncertainty is significant in explaining the firm's choice of alliances over

complementor make and internalization over complementor make (please see Table 13 - models 1 & 2).

Summary of results in the panel logistic regression models: The results are reported in Table 14 - Models, 1 to 6.

Please insert Table 14 about here

Fixed effects model (Table 6 – Models 1, 2, 3): Firm technological capabilities ($p<0.01$), alliance experience ($p<0.05$) and technological uncertainty are significant ($p<0.1$) in explaining firm's choice of alliance over complementor's strategy to make (model 1). The other explanatory and control variables, except technological uncertainty ($p<0.05$) were non significant in explaining the firm's decision to internalize (Table 14 - model 2). Interestingly, primary product firm capital intensity is significant in explaining the firm's choice of internalization over alliance.

Random effects model (Table 14 – Models 4,5,6): Primary product firm's technological capabilities and alliance experience are significant in explaining alliance over complementor make (Table 14 - model 4), technological uncertainty and technological capabilities are significant in explaining internalization relative to complementors' making the product.

Conclusion

The data analysis provides partial support for the hypothesized effect of type of complementarity that symmetric complements are generally associated with higher

modes of governance as compared to asymmetric complements. The results however are evident at moderately increasing levels of technological and market demand uncertainty than at very high levels of uncertainty. At low uncertainty, primary product firms are likely to rely less on internalization for symmetric as well as asymmetric complements. Further, the dominant choice of strategy for symmetric complements at low levels of technological uncertainty is alliances, higher than that for asymmetric complements. At moderately increasing levels of technological uncertainty, the results indicate that firm's choice for internalization increases for symmetric complements, and for asymmetric complements the overall preference (split sample results by type of complementarity) is alliances with increasing technological uncertainty. At very high levels of technological uncertainty, the results are not clear.

Further, market demand uncertainty also moderates the relationship between symmetric complementarity and governance choice, mainly at moderately increasing levels of uncertainty. The results indicate a greater likelihood of firm's adopting strategies that enable them to have greater flexibility in the development of complementary products. In contrast to increasing likelihood of internalization with increasing technological uncertainty, symmetric complementarity is associated with a propensity for alliances with increasing demand uncertainty.

CHAPTER 7: DISCUSSION

I discuss the results in the context of the supported and not supported hypothesis. The thesis proposed to examine the following hypotheses:

Hypothesis1a: Symmetric product complementarity is positively associated with higher degree of internalization and

*Hypothesis1b**:*** asymmetric product complementarity is negatively associated with higher degree of internalization

Hypothesis 2: Technological uncertainty moderates the relationship between type of complementarity and the governance choice of a primary product firm such that

> Hypothesis 2a) higher internalization is more likely in high technologically uncertain environments than in low technologically uncertain environments for symmetric complements and
>
> Hypothesis 2b) higher internalization is more likely in high technologically uncertain environments than in low technologically uncertain environments for asymmetric complements

Hypothesis 3: Market demand uncertainty moderates the relationship between type of complementarity and the governance choice of a primary product firm such

> Hypothesis 3a) lower internalization is more likely in high demand uncertain environments than in low demand uncertain environments for symmetric complements and
>
> Hypothesis 3b) lower internalization is more likely in high demand uncertain environments than in low demand uncertain environments for asymmetric complements.

The study finds partial support for the moderating influence of technological uncertainty and market demand uncertainty. The results indicate that primary product firms are more likely to internalize symmetric complementary product development at moderately increasing levels of technological uncertainty and likely to form alliances at low levels of technological uncertainty. Further, the results indicate that firms are more likely to internalize the symmetric complementary product development at moderately increasing levels of market demand uncertainty than at low or high levels of market demand uncertainty. Thus, overall the results support the general direction of the association between type of complementarity and governance choice, contingent on different levels of technological and market uncertainty.

I. Hypothesis supported

The technological uncertainty moderator hypotheses predict the influence of technological uncertainty between type of complementarity and the governance choice of the primary product firm such that internalization is more likely at higher levels than at lower levels of technological uncertainty for symmetric complements and externalization (specifically alliances) is more likely at higher levels than at lower levels of technological uncertainty for asymmetric complements. The split sample multinomial regression analyses reveals that at low and moderate levels of technological uncertainty, firms are more likely to adopt alliances and internalization for symmetric complements respectively. Further, the likelihood of the firms adopting alliances and internalization are also higher for symmetric than asymmetric complements at low and moderate levels of technological uncertainty.

The increasing propensity to internalize symmetric complements at moderately increasing levels of technological uncertainty may be attributed to the fact that, although the technological developments in the PC industry do not classify as significant during the study period, the nature of technological development in the all the symmetric complement markets has been quite to the contrary. Significant advancements characterize memory chips and display panel technologies. Although primary product firms lost control of the critical complement markets, they have adopted strategies that permit them to retain control over other essential complement markets. Thus, firms have been involved in the making of several symmetric complements such as keyboards, chipsets, displays and internal disk drives, even though there has been a competitive complementor market. This provides support to the arguments made in the dissertation that firms anticipate some level of opportunism in these markets and one way of ensuring control over these markets is by also making these complements.

Further, the results suggest that firms are less likely to internalize symmetric complements at low levels of technological uncertainty as compared to making a choice between alliances or letting complementors make the products. Thus, when technological development path is relatively known or the nature of technological breakthroughs is minor or predictable in the industry, the threat of possible opportunistic behaviors is minimal, and nature of functional interdependence does not provide a basis for internalization. However, the increasing propensity for alliances (involving technology licensing, co-marketing, production , distribution and minority equity agreements) over complementor make for symmetric complements even at low levels of technological uncertainty suggests that firms may not completely relinquish control of

symmetric complements. These inferences have to be however be considered in the context of the PC and related product markets as well as I explain the result for high technological uncertainty (Section II).

The market demand uncertainty moderator hypotheses predicts the moderating impact of market demand uncertainty between type of complementarity and the governance choice of the primary product firm such that alliances is the preferred choice at higher levels than at lower levels of market demand uncertainty for symmetric complements and externalization (specifically letting complementors make complements) is more likely at higher levels than at lower levels of technological uncertainty for asymmetric complements. The results provide evidence of a moderation effect of market demand uncertainty at increasing levels of uncertainty over a specific range. The choice of alliances for symmetric complements lend support to the following arguments put forth in the study –

i) Firms deal with demand fluctuation in the primary product market by encouraging growth in the complementary product markets. Internalizing in such conditions restricts the ability of the firm to reach a broader market audience and tap into the needs of different customers who have varying needs from complementary products. Specifically, the innovations in the complement markets including the plug and play capabilities facilitated by innovations in the operating system, the increasing processing power of the microprocessor and the growth of the internet opened new consumer markets as well as expanded the composition of existing consumer segments. Moderately increasing uncertainty could also coincide with growth phase of the primary product and growing

opportunities in related product markets. Forming alliances with complementors enable the primary product firms to better understand the needs of the complement markets and co-develop or co-market the products

ii) The results indicate that firms are not likely to choose the complementor make option in comparison to the choice of strategic alliances for making symmetric complementary products. This supports the main idea for the need for some level of control in symmetric complementary product development to minimize opportunistic concerns. Bargaining over pricing (Yalcin et al, 2013) or delays in complement introduction and innovation (Casadesus-Masanell & Yoffie, 2006) impair the ability of the primary firm to capture a greater market share, more harmful in the context of symmetric complements than in asymmetric complements.

II. Hypothesis not supported

First, there is no evidence of a direct effect of type of complementarity (in the absence of product market contingences). Second, at high levels of technological uncertainty, the firms do not show a greater propensity for internalization of symmetric complements as hypothesized by moderator effect of technological uncertainty. Further, the findings do not support the prediction that alliances are the preferred governance choice at high levels of market demand uncertainty. I suggest possible reasons for these results.

The following reasons may explain the lack of significance for a choice of symmetric complement internalization at high levels of technological uncertainty. First, the study does not take into account variations in the structure of the complementary

product markets. IBM's open architecture policy influenced subsequent complementary product market structures, with the critical components being in the control of external firms (West, 2003). In the case of the PC and related markets, the rapidly increasing installed base of users committed to the DOS and Windows operating systems served as a strong deterrent for PC manufacturers to make this complement. Similarly, the control of the microprocessor rested with Intel. Second, it is useful to understand the sources of high levels of technological uncertainty in the data, occurring between 1985 and 1995. Significant innovations occurred in the operating system and the microprocessor, from the release of the Windows 1.0 to the release of the Windows 95; matched with upgrades in the CPU processing power and RAM capacities.

These innovations had remarkable impact on the PC architecture as well because the innovations spelled the beginning of fax/modems, email, the new online world, and multimedia games and educational software. For instance, Windows 95 has built-in Internet support, dial-up networking, and new plug and play capabilities. To keep pace with these developments and to ensure overall system integrity and interoperability, it is likely that primary product firms may have made significant investments in research and development. Thus, i) a separation of control from the primary product firm to a limited set of symmetric complementors for the critical components in the PC in conjunction with ii) rapid technological developments in these complement markets during the time period of high technological uncertainty may be reasons why the results do not support the prediction at high levels of technological uncertainty. In order to verify these inferences, however it is essential to also examine in detail the technological developments in the different complementary product markets associated with the PC;

specifically, whether the pace of innovation in the complement markets is largely restricted to the operating system and microprocessor markets (during the period of high technological uncertainty).

I suggest following reasons may explain a lack of support for the preferred governance mode of alliances for symmetric complement development at high levels of market demand uncertainty

i) High demand instability maybe a transient state, so that firms are likely to adopt a wait and watch approach before formalizing a strategy. Investing in alliances to capture broad sections of the market may be futile, if the sources of uncertainty are independent of the type of complementarity or immediate product market contingences. For example, the periods of dot com boom and bust and the Y2K eras (1999-2001) are periods where firms may have delayed adopting a specific strategy. I.e. it is not evident whether the fluctuations in demand during this time period are caused by real, lasting changes in consumer needs or changes in consumer demographic segments. A sudden increase in the demand for PCs may not be driven by a need for greater needs for data storage, but rather by an increase in the new PC purchases by small businesses who cannot afford the large investments needed to correct the problem imposed by the Y2K issue in older machines

ii) Technology life cycle: The technology life cycle models suggest that high levels of market uncertainty characterize the period around the acceptance of a dominant design (Abernathy & Clark, 1985; Tushman & Anderson, 1986; Anderson & Tushman,1990). There is significant uncertainty regarding the consumer adoption of competing technologies until a dominant design emerges (Katz & Shapiro, 1985; 1986). Market

demand instability in the initial period of the study (between 1981-1986) could be attributed to the reason that the PC market was relatively new. During this period, the primary product firms are less likely to adopt specific strategies targeting complementary products. They are likely to develop strategies to deal with rivals in their primary market first before focusing on complement markets.

The results do not support the prediction for the direct effect of type of complementarity on the governance choice, when the varying levels of technological and market demand uncertainty are not included in the models. The types of opportunistic behaviors in the complement markets are slightly different from issues of technology appropriability, as discussed in the TCE literature include delays in complement innovations, delays in complement releases, bargaining over pricing terms and switching to another primary product firm with a larger installed base of users. One possible reason is that anticipation of such concerns may not be sufficient for firms to invest in internalization. Second, the structure of the PC product market and the related complement markets pre empted possibilities of opportunism that require internalization based on type of complementarity alone.

III. Limitations and future research

First, although the dissertation examines the strategy at the level of the primary product class, it also points to the importance of firm factors giving pointers to the possible differences in strategies related to complements. Specifically, since the study examines the governance decisions over a long time period, it is likely that firms have adopted different strategies along the time period. Thus, although firms such as IBM, HP

and Dell are in the same product market, firm competences and weaknesses are likely to influence the nature of the decisions, relating to complements. Most of the large firms have moved away from vertical integration to outsourcing in relation to component development, few works have examined the structure of the industry and firm strategies with respect to complementary products. The data suggests that IBM pursued a strategy of internalization in the first decade of the study period (1980-1990), with a mix of complementor-make and alliances in the second decade of the study period (1990-2000) and fewer appearances in the last decade. In this direction, comparing the resource profiles of the firms over the longitudinal time frame may give insights into differences in strategies pursued.

Second, since the dissertation is focused on identifying strategies from a primary product firm's perspective, it does not take into account the non specific complementor product introductions. The substantial number of these product introductions, is suggestive of a complementor firm strategy. Recent research provides some evidence of the antecedents of such a strategy (Kude, Dibbern & Heinzl, 2012). Since platform dominance involves competition and collaboration among the different primary firms and complementors (Gawer & Cusumano, 2002; Brandenburger & Nalebuff, 1996; Yoffie & Clark, 2006), future research could examine decisions from a complementor's perspective.

Third, some methodological limitations are also likely to explain the nature of the findings viz.,

i) The sample consists of 307 observations. Limitations of the software program in terms of the number of parsers that can be included to correctly identify the exact match between primary product and complementary product, in the context of a primary product firm involvement limits the ability to capture all relevant announcements. Increasing the robustness of the software program to process more complex textual parsers would allow a greater number of announcements to be captured and hence increase the accuracy of the findings.

ii) The nature of the primary product market: This study is limited to the PC product market. Although the setting is ideal for the variation in type of complementarity, and the variation in environmental contingences, the complementor strategies of two important complements – viz., microprocessor and operating system have tended to dominate the nature of strategies of all other players in the PC ecosystem. Examining the hypothesis in other high technology product markets is needed for improving the validity of the study findings.

iii) Inclusion of other primary product firms: This study includes only public, US based firms. Several primary product firms in the last decade (2000-2010) include firms that are headquartered in China, Taiwan, Japan & South Korea. Firms such as Toshiba, Sony, Acer and Samsung are on the one hand highly diversified, yet have contributed significantly to the nature of both primary and complementary product development. Moreover, the study considers only those firms that have survived the different events in the PC industry. Inclusion of both private firms and diversified non US firms may give different results.

iv) The sample includes only hardware product complements. Several complements are software complements and future research could examine the antecedents of a primary firm involving these complementors to get a complete picture of a primary firm's strategy towards complementors. The features of software raises issues such as appropriability involving patenting and licensing aspects (Arora & Ceccagnoli, 2006; MacCormack & Iansiti, 2009), product design aspects such as modularity (Nambisan, 2002) and complementary capabilities, viz., software production and deployment.

Finally, this dissertation has attempted to examine one aspect of a primary product firm's strategy towards complementors. Several other factors govern the evolution of a technological system. For instance, research examines how the market perception of a complement, viz., and "superstar software" strongly influences the sales of a primary product (Binken & Stremerche, 2009). Second, differences in retail strategy such as promotions and pricing influence the consumer's purchase choices among competing complementary product pairs (Lam & Mukherjee, 2005).

IV. Implications

From a theoretical perspective, the findings contribute the broader discussion of the role of transaction cost mechanisms, firm capabilities and inter organizational relationships in dealing with complementary products. First, the significance of firm capabilities suggests that firm specific factors, related to complementary products are an alternative explanation for the choice of a governance strategy. Since system based capabilities provide a competitive edge against rivals, incumbents are likely to build a portfolio of

patents and modules that are closely related and in turn, are likely to opt for internalization to build a set of value chain competences in the technological system. Second, the significance of alliances suggests that coordination is a relevant decision making factor when choosing a complement strategy. The role of coordination mechanisms may be further examined by considering how equity involvement is related to the types of activities governed in the alliance (Gulati & Singh, 1998).

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Table 1: List of excluded publications

Source Titles
NAVAL RESEARCH LOGISTICS
MANCHESTER SCHOOL
APPLIED ECONOMICS
INFORMATION ECONOMICS AND POLICY
ELECTRONIC COMMERCE RESEARCH AND APPLICATIONS
EUROPEAN ECONOMIC REVIEW
EUROPEAN JOURNAL OF OPERATIONAL RESEARCH
EXPERT SYSTEMS WITH APPLICATIONS
INFORMATION SYSTEMS RESEARCH
INTERNATIONAL JOURNAL OF TECHNOLOGY MANAGEMENT
R D MANAGEMENT
ASIA PACIFIC JOURNAL OF OPERATIONAL RESEARCH
CONTEMPORARY ECONOMIC POLICY
DECISION SUPPORT SYSTEMS
GROUP DECISION AND NEGOTIATION
JOURNAL OF FOREST ECONOMICS
JOURNAL OF INTERNATIONAL TRADE ECONOMIC DEVELOPMENT
JOURNAL OF MATHEMATICAL ECONOMICS
JOURNAL OF REGIONAL SCIENCE
JOURNAL OF SPORT MANAGEMENT
JOURNAL OF SYSTEMS SCIENCE AND SYSTEMS ENGINEERING
MANAGING SERVICE QUALITY
NATIONAL TAX JOURNAL
POLITICKA EKONOMIE
QUEUEING SYSTEMS
REVIEW OF FINANCIAL STUDIES
REVIEW OF MANAGERIAL SCIENCE
SAFETY SCIENCE
SINGAPORE ECONOMIC REVIEW
SOUTHERN ECONOMIC JOURNAL
STUDIES IN NONLINEAR DYNAMICS AND ECONOMETRICS
TRANSPORTATION RESEARCH PART A POLICY AND PRACTICE
TRANSPORTATION SCIENCE

Table 2: Breakdown of articles by WOS category &year

WOS Research Categories	**count**
MANAGEMENT	79
ECONOMICS	76
BUSINESS	66
OPERATIONS RESEARCH MANAGEMENT SCIENCE	35
ENGINEERING INDUSTRIAL	19
ENGINEERING MANUFACTURING	11
BUSINESS FINANCE	6
INFORMATION SCIENCE LIBRARY SCIENCE	6
COMPUTER SCIENCE INFORMATION SYSTEMS	6
LAW	4
ENGINEERING MULTIDISCIPLINARY	4
PLANNING DEVELOPMENT	2
SOCIAL SCIENCES MATHEMATICAL METHODS	2
COMPUTER SCIENCE INTERDISCIPLINARY APPLICATIONS	2
HISTORY OF SOCIAL SCIENCES	1
MATHEMATICS INTERDISCIPLINARY APPLICATIONS	1
*there are overlaps in research areas, so the count does not add up to 179	

Year	**count**
1992	2
1993	2
1994	1
1995	2
1996	3
1997	4
1998	3
1999	5
2000	2
2001	5
2002	9
2003	7
2004	5
2005	8
2006	9
2007	10
2008	14
2009	21
2010	19
2011	14
2012	21
2013	7

Table 3: Breakdown of research articles by included publication journals

Publication	**count**
MANAGEMENT SCIENCE	14
INTERNATIONAL JOURNAL OF INDUSTRIAL ORG	13
MARKETING SCIENCE	11
JOURNAL OF PRODUCT INNOVATION MANAGEMENT	10
JOURNAL OF ECONOMICS MANAGEMENT STRATEGY	8
JOURNAL OF INDUSTRIAL ECONOMICS	6
PRODUCTION AND OPERATIONS MANAGEMENT	6
RAND JOURNAL OF ECONOMICS	5
ECONOMIC LETTERS	5
STRATEGIC MANAGEMENT JOURNAL	5
JOURNAL OF COMPETITION LAW ECONOMICS	4
JOURNAL OF ECONOMIC BEHAVIOR ORGANIZATION	4
B E JOURNAL OF ECONOMIC ANALYSIS POLICY	3
HARVARD BUSINESS REVIEW	3
JOURNAL OF MARKETING	3
JOURNAL OF RETAILING	3
MIS QUARTERLY	3
REVIEW OF NETWORK ECONOMICS	3
TECHNOVATION	3
B E JOURNAL OF THEORETICAL ECONOMICS	2
CALIFORNIA MANAGEMENT REVIEW	2
DECISION SCIENCES	2
ECONOMIC INQUIRY	2
IEEE TRANSACTIONS ON ENGINEERING MGMT	2
INDUSTRIAL MARKETING MANAGEMENT	2
INDUSTRY AND INNOVATION	2
INFORMATION SYSTEMS RESEARCH	2
INTERNATIONAL JOURNAL OF TECHNOLOGY MGMT	2
JOURNAL OF BUSINESS	2
JOURNAL OF BUSINESS RESEARCH	2
JOURNAL OF ECONOMIC DYNAMICS CONTROL	2
JOURNAL OF MARKETING RESEARCH	2
M SOM MANUFACTURING SERVICE OPERATIONS MGMT	2
MARKETING LETTERS	2
OPERATIONS RESEARCH	2
RESEARCH POLICY	2
SMALL BUSINESS ECONOMICS	2
ACADEMY OF MANAGEMENT JOURNAL	1
ADVANCES IN CONSUMER RESEARCH	1

ADVANCES IN STRATEGIC MANAGEMENT A RESEARCH ANNUAL	1
AMERICAN ECONOMIC REVIEW	1
AMERICAN ECONOMIC JOURNAL OF MICRORCONOMICS	1
APPLIED ECONOMICS LETTERS	1
BUSINESS HISTORY REVIEW	1
ECONOMIC POLICY	1
ECONOMIC JOURNAL	1
ENTREPRENEURSHIP THEORY AND PRACTICE	1
GAMES AND ECONOMIC BEHAVIOR	1
HISTORY AND STRATEGY	1
INFORMATION SYSTEMS AND E BUSINESS MGMT	1
INTERNATIONAL JOURNAL OF COMPUTER INTEG MANUF	1
INTERNATIONAL JOURNAL OF ELECTRONIC COMMERCE	1
INTERNATIONAL JOURNAL OF RESEARCH IN MARKETING	1
JOURNAL OF BUSINESS ETHICS	1
JOURNAL OF BUSINESS VENTURING	1
JOURNAL OF CONSUMER RESEARCH	1
JOURNAL OF ECONOMIC THEORY	1
JOURNAL OF ECONOMICS	1
JOURNAL OF FORECASTING	1
JOURNAL OF MANAGEMENT INFORMATION SYSTEMS	1
JOURNAL OF MANAGEMENT INQUIRY	1
JOURNAL OF MANAGEMENT STUDIES	1
JOURNAL OF MATHEMATICAL ECONOMICS	1
OMEGA INTERNATIONAL JOURNAL OF MGMT SCIENCE	1
ORGANIZATION SCIENCE	1
QME QUANTITATIVE MARKETING AND ECONOMICS	1
REVIEW OF INDUSTRIAL ORGANIZATION	1
SLOAN MANAGEMENT REVIEW	1

Table 4: Definitions of complementary products

No.	**Definition**	**Literature Origin**	**Categorization**	Citation
1	Complements are goods that "go together" such as coffee and cream, fish and chips, or brandy and cigars. Two goods xi and xj are said to be gross complements if δ xi/ δ pj < 0, i.e. they are gross complements if a rise in the price of one good causes less of the other good to be purchased. The "gross" definition includes both inc income and substitution effects that arise from price changes.	Economics	Sales interdependence	Walter Nicholson, 2005
2	Product complements are products that are used in conjunction with one another to satisfy some particular need	Marketing	Usage interdependence	Walters, 1991
3	Complementary product is one that enhances the value of a focal product when the two are used together by end users We distinguish between components and supplies on the one hand and value-adding complementary products, on the other hand. Without all the components and supplies the primary product cannot function and has no value to an end-user. Complementary products add value to the primary product beyond the basic functionality provided by the components and supplies	Marketing	Usage interdependence, Functional interdependence	Sengupta, 1998
4	A complementary product is one that enhances the value of a focal product when the two are used together	Marketing	Usage interdependence	Nambisan, 2002
5	Complementary products are those for which a consumer's utility derived from using both the goods together is greater than the sum of the utilities that the consumer would have derived by using them separately	Marketing	Usage interdependence	Bhaskaran & Gilbert, 2005
6	We use the term "complementor" in the sense defined by Brandenburger and Nalebuff (1997), as a short-hand for "the developer of a complementary product" where two products are complements if greater sales of one increase demand for the other. Formally, A and B are complements if the valuation by consumers of A and B together is greater than the sum of the valuation of A alone and of B alone. $Va+b = (1 + \delta) (Va + Vb)$, $\delta > 0$.	Economics, Management	Sales interdependence, Usage interdependence	Gawer & Henderson, 2005
7	Complementary products are those products needed to maximize the utility of the core product	Management	Usage interdependence	Gallagher & Park, 2002
8	A complement to one product or service is any other product or service that makes the first one more attractive. A player is your complementor if customers value your product more when they have the other player's product than when they have your product alone.	Economics	Usage interdependence	Brandenburger & Nalebuff, 1997

Table 4 (continued)

9	We define substitutability and complementarity from the firms' point of view by referring to the sign of the cross-price elasticity of demand. If it is positive, products are substitutes; in the opposite case they are complements.	Marketing	Sales interdependence	Sarvary & Parker, 1999
10	Systems are composed of complementary and functionally interdependent products, such as hardware and software	Marketing	Functional interdependence	Binken & Stremersch, 2009
11	Many multiproduct firms sell systems - lines of products (components), where each good cannot, or usually is not, used separately but might still be purchased separately. Components are complements	Economics	Usage interdependence	Matutes & Regibeau, 1988
12	A number of strongly complementary components are used together in a system to provide consumer benefits;Components A & B are valuable only when used together; there are independent suppliers of A & B (A may supply B as well)	Economics	Usage interdependence	Farrell & Katz, 2000
13	As viewed by customers, high-technology 'products' are often systems. These systems consist of interdependent components resting on 'platforms'. There is strong functional interdependence amongst components of the system. Complements often sit on top of what might be thought of as 'platforms', which are managed by an incumbent enterprise	Management	Functional interdependence	Evans et al., 2006.
14	Model: One of the two firms develops a complementary product, that when used with the homogeneous basic product produced by both firms in the model, results in an enhanced, higher quality product XE. Specifically, one unit of the enhanced product XE consists of one unit of the basic product XB plus one unit of the innovation y. Complementary product/service maybe sold as an add-on/upgrade to the main product	Management	Usage interdependence	Costa & Dierickx,2005
15	Perfect (strict) symmetric complementarity: Consumers cannot get any utility from one product unless they use both Asymmetric complementarity: The relationship between the basic product and the CP is such that a basic product provides its own functions , but an add-on product is useful only if consumed with the basic product	Economics	Usage interdependence, Functional interdependence	Cheng & Nahm, 2010
16	Complementarities are present whenever having a bundle of goods together provides more value than the total value of having each of the goods separately	Management	Usage interdependence, Functional interdependence	Amit & Zott, 2001

Table 4 (continued)

17	The outputs of upstream suppliers serve as inputs to the focal actor. We refer to such inputs, which are bundled by the focal actor into its product, as components. A customer may also need to bundle other offers alongside the focal actor's product in order to utilize it. We refer to such offers, which are bundled downstream by the customer, as complements. Thus, components and complements are defined according to where elements are bundled in the flow of activities relative		Usage interdependence	Adner & Kapoor, 2010
18	Complementary products are those products (or services) that experience a sales increase when related products experience an increase in support. Products that are used together or purchased together and serve related needs are complements	Marketing/ Economics	Sales interdependence	Guiltinan, Gordon & Madden, 1997
19	"complementary products" refer to unfinished goods that are inputs to the same assembly sector.	Management	Functional interdependence	Carr & Karmarkar, 2005
20	Products that depend entirely on the availability of another product are called contingent products ; In the contingent diffusion model, the purchase of one product (the "contingent product") is conditional on the prior purchase of another product (the "primary product").	Marketing	Functional interdependence	Peterson & Mahajan, 1978
21	Indirect network effects arise when the benefit of using a good increases with the use of a complementary set of compatible goods.	Marketing, Economics	Usage	Nair, Dube, Chintagunta, 2004
22	Consumption benefits rise in markets where a large customer network leads to increases in complementary goods and services, which in turn leads to increased consumer utility (Farrell & Saloner, 1985; Katz & Shapiro, 1985)	Management	Usage	Shankar & Bayus, 2003
23	The greater the availability of complementary products (the "software"), the more attractive the capital good (the "hardware") for consumers (based on Church & Gandal, 1992)	Marketing	Usage	Gupta, Jain & Sawhney, 1999
24	We say that A and B are complements if $V_{a+b} = 1+\delta\ (V_a + V_b)$, $\delta > 0$. If $\delta < 0$, then A and B are substitutes. When the complementarity is not symmetric: $V_{a+b} = (V_a + V_b)$ if the two goods are purchased together, but $V_b = 0$ if good B is purchased alone	Economics	Usage	Nalebuff, 2004
25	The greater the variety of compatible complementary goods, the "software," the greater the value of the services rendered by the capital good, the "hardware," and hence the greater the willingness of a consumer to pay for the hardware good.	Economics	Usage	Church & Gandal, 1992

Table 4 (continued)

26	Two software products are defined to be complementary when changes in the activity levels of one of the products (e.g., sales, functionality & ease of use) affect marginal returns to changes in the activity levels of the other software product as well	Management	Sales interdependence, Functional interdependence, Usage	Lee, Venkatraman et al., 2010
27	We define product level complementarity as the relative distance of two products within a layered software stack model	Management	Functional/ Technological interdependence	Kude et al, 2012
28	Complementary inputs are consumed are purchased and consumed at the same time as the focal good	Management	Usage	Fabrizio & Hawn, 2013,
29	With strict complementary products, a consumer derives positive utility only when both products are used together	Marketing	Usage	Yalcin, et al, 2013

Table 5: Asset specificity in TCE

Type	**Definition**	**Examples**	**Source of transaction costs**
Physical asset specificity	The manufacturer and supplier/distributor make investment in plant and machinery dedicated to producing or selling the products of the firm(s)	1.Component maker invests in specialized component manufacturing & tooling equipment (Monteverde, 1995; Klein, 1991) 2.Distributors invest in facilities or train sales employees specifically for a particular product (Heide & John, 1988)	Use in alternative transactions requires significant retooling or adaptation
Site specificity	firms or production plants/distribution channels/inventory storage maybe located in close proximity to minimize costs of transportation. The importance of locating upstream operations in proximity to subsequent stages of the manufacturing process (Masten, Meehan & Snyder,1989)	Mine-mouth coal generating plant (Joskow, 1985)	Immobility of the asset
Human asset specificity	Human capital investments where there is a learning-by-doing component (Williamson, 1983; Joskow, 1985) or product development requirements unstructured technical dialogue (Arrow, 1974; Monteverde, 1995) between the firms involved in the design and production or production and marketing or any two adjacent operations related to the product	1.Applications engineering effort in the development of a component (Monteverde & Teece, 1982) 2. face-to-face discussion and unstructured, undocumented communication between the product design and production engineers in the semiconductor manufacturing (Monteverde, 1995) 3. Customer specific knowledge and product specific knowledge when salespeople interact with customers (Anderson & Schmittlein, 1985)	Specific components manufacture involve greater engineering know-how than generic components, Tacit know how, relation specific (such as between (manufacturer & supplier for a specific component or sales team and customers for a specific product- related to use, features, service, installation etc)
Dedicated assets	Investments made for a particular customer that their release on the market would depress the market value of assets (Williamson, 1985)	Specialized distribution facilities such as refrigeration (Hennart, 1988)	

Table 6: Opportunism in TCE literature

Opportunistic behaviors	**Description**	**Value chain**	**Asset specificity**	**Gains for the opportunistic firm**	**Losses for the primary product firm**	**Example**
Appropriability problems	1.In R & D projects or those involving a technology component involving different firms, contractor sells the know-how arising from the project to the other firm's product market rivals, mainly due to the nature of the R & D process and difficulty in specifying tacit know how components in contract (Pisano, 1990; Pisano, Russo & Teece, 1988; Gulati & Singh, 1998) 2. Holder of the technology may use or modify the technology in ways that were not intended in the contract (Oxley, 1997; Anand & Khanna, 1997)	Product design/Technology development	Human asset specificity	Profit gain from sale/appropriation of IP	Loss from proprietary technology, Imitation	1.In the 1960s, RCA licensed its color television technology to Japanese companies, they reversed engineered the technology and entered the US market
Shirking	With-holding expected or committed efforts (Wathne & Heide, 2000) Poor quality of resources in the production Delay in schedules (Masten, 2000)	Production	Physical assets such as production equipment, raw materials for manufacturing; Intangible assets such as production know-how	Cost saving from diverting the efforts to the firm's product line Delay may be an effective strategy for eliciting price concessions (Masten, 2000)	Difficulty of arranging an alternative at short notice , especially when timing is critical (Masten, 2000)	

Table 6 (continued)

Shirking	Non performance (Klein, 1996), (Wathne & Heide, 2000) primarily 1)contract does not specify it 2)not monitored 3)Could involves misrepresentation of skills 4)Delivery of inferior product/technology (Oxley, 1997)	Marketing	May or not be involved, although the problem is serious if asset specific investments are involved	Cost saving, Sort term improvement in profits	1.Customer dissatisfaction, if product quality is compromised 2. Costs incurred by the primary product firm/manufacturer if shirking on internal, unobservable aspects (such as production, marketing) that are specialized to the exchange	1.Retailers withhold the display of promotional materials, but take allowances from manufacturers (Murray & Hiede, 1998) 2.Shirking on quality inputs in franchising (Lafontaine, 1992)
Hold-up	Involves appropriation of quasi-rents by the trading partner, particularly when unanticipated events occur (Monteverde, 1995; Wathne & Heide, 2000)	Production	Physical asset specificity, Site specificity	Profit gain that actually belonged to the other firm	Loss of profits from asset specific investments	In the face of *increased demand*, Fisher Body adopted a highly inefficient production process and located its plant far away from GM's assembly plant. Ex-ante contractual commitment required GM to source the component from Fisher exclusively for 10 years (Klein, 1996)
		Product Design & Production	Human asset specificity (between the main firm and the production firm)			With the technology specifications known to the production firm, it can begin selling what it has been making (Monteverde, 1995)

Table 6 (continued)

		Marketing				Taco Bell introduced a new food concept which led to the appropriation of rents from its franchisees who introduced a similar concept in the first place(Wathne & Heide, 2000)
Free riding	A trading partner acting in a manner as to derive the benefits without incurring the associated costs (Anderson & Gatignon, 1986; Anderson & Gatignon, 1988)	Marketing	Physical assets Dedicated assets	A lesser known brand or new entrant benefits from association with an established firm and may dilute the value of the brand by supplying lower quality products than what consumers associate with the brand		1. A GM dealer cutting service to the bone and advertizing new GM cars slightly above wholesale 2. In selling of complex products, extensive upfront investment in educating the consumers is needed , so that some distributors reduce the expenses (Dutta, Heide, Bergen, 1999)
Breaching of contract violations	Deviating from clauses specified in the contract				Higher costs to incorporate monitoring and	Violation of exclusive dealing contracts (Heide, Dutta & Bergen, Wathne & Heide)

Table 7: Opportunism in the primary product firm – complementor context

Opportunism	Assets	Description	Impact	Example
Technology appropriability	Common modules, proprietary knowledge assets such as patents, software packages	If a complementor is licensed to develop complementary products through simple contract, it may appropriate the proprietary technology. It may either develop a primary product or incorporate the technology in other products that is not covered as part of the agreement. Proprietary primary product information may also be inadvertently leaked to a complementary product design engineer during joint product development, which may be required when complement interfaces and product functionality boundaries have not yet clearly evolved.	In early stages of the technology battle, when there are several competing technologies, appropriability regime is weak and threat of imitation is high, it can lead to loss of market share, technology lock out or primary product failing to emerge as the winner in technology battles	Lotus Inc did not honor a licensing agreement with Verity Inc , a complementor for sharing Verity's products such as- its "concept-based-retrieval add-on" , a text retrieval module to some of Lotus' products and "topic agent" – an electronic information locator on a Lotus Notes Network (1992,1995). Apparently, Lotus Inc deployed Verity's products in several its other products not covered within the scope of the agreement (1998). *Source- Business Wire News Announcements. Lexis Nexis Academic*
Shirking/ hold-up	Interdependent functions	i. With holding of information related to product development ii. Delays in product introduction: A complementor may not share the incentives of a primary product firm to introduce a new complement to support a new primary product introduction/innovation (Bucklin & Sengupta, 1993).	Product failure, Delays in introduction of a complement impact the size of the primary product firm's installed base, detrimental to primary product adoption/market growth in markets with strong indirect network effects.	Poor quality games developed for Atari's game console, led to insufficient time for Atari to make market entry for the new versions of its console

Table 7 (continued)

Free-riding		In high technological environments, continuous product upgrades are required to reinforce the installed base and to add new consumers. For a primary product upgrade to be successful the must-have component or symmetric complementor likely requires similar product or interface changes. This creates a potential for hold-up problems, particularly when there is a misalignment of incentives due to one of the parties being at an advantage. The opportunism manifests as bargaining for improvement of product pricing, refusal or intentional delays in committing to product development decisions	Simple contracts or markets option, where the complementor makes the products and pays a royalty fee to the primary product opens the possibility of bargaining, that come to the forefront when product upgrades or pricing requires coordination among the firms. Such bargaining is costly (Williamson, 1991), as there are no clear guidelines for profit sharing	Microsoft benefits from existing installed base of users, while Intel derives its profits primarily from releasing new product versions. However, the firm cannot release the upgrades without corresponding changes in the operating system. Thus Intel loses profits on potential innovations were it not locked in with Microsoft because of the dedicated installed base of users, which is a form of asset specific investment (Casadesus-Masanell & Yoffie, 2006)
Free-riding	reputation/ brand	Compromising on product quality: When the efforts of the complementor cannot be monitored, it may release complements that are not reliable or fail to comply to the quality standards of the primary product firm: Complementors may intend to free ride on the reputation of the primary product firm and introduce complements with less reliable performance, saving on costs.	Loss of reputation and market share for the primary product firm, critical when the complement is relevant to the success of the primary product and there are only a few complementors producing it	Eastman Kodak Company had to voluntarily recall 120,000 AC adapters that were sold for use with certain Kodak digital cameras (1999) because the batteries in the camera overheated when the connector plug of the AC adapter was not properly inserted into the camera. They were made by an independent complementor and sold separately as optional accessories, however were authorized for use by Kodak. Kodak incurred significant expenses on account of this complement interface malfunction in the form of adapter replacement charges and recalls in electronic, computer, camera stores and web retailers.

Table 8: Governance structures in TCE

Context	**Hazards (of markets/contracting)**	**Governance form in Market Hierarchy Continuum**	**Governance attributes**	**Mechanisms**	**Degree of control**	**Applicability to Type of Complementarity**
Technology development Weak Appropriability regime (Teece, 1986)	1.Leakage	Full ownership			Highest	Symmetric complements When: In the early stages of product evolution, typically before dominant design
Technology development/transfer transactions (major technology updates such as generational innovation) 1.Level of difficulty involved in transferring tacit know-how that determines extent of intimate personal contact, teaching, demonstration and participation, prolonged collocation of participants (Polanyi, 1962; Kogut, 1988)	When contracts are incomplete because of gaps in specification, moral hazard risks are high from both partners. 1. It may later find a better partner and so deliver an inferior product/technology to its partner than promised in the original document. 2. The complementor may use or modify the technology in ways that were not intended in the contract and which may hurt the other firm's profitability (Oxley, 1997; Anand & Khanna, 1997)	Joint Ventures	1.creation of separate entity, where each partner owns a portion of the equity 2.a distinct hierarchy of managers	Incentive alignment: mutual hostage by shared equity Command structure and authority system: a distinct hierarchy of managers Exchange of resources: autonomous entity	High	Symmetric complements When: In the early stages of product evolution, typically before dominant design

Table 8 (continued)

1. Involvement of a technology component (such as technology upgrades/exchanges) 2. Technological interdependence requires collaboration 3. there could be a divergence in interests 4.Involvement of transaction specific assets 5. Firm lacks the capabilities to develop the technology itself (due to difference in technologies, industries) 6. Emerging technologies (Nichols-Nixon & Woo, 2003)		Minority equity agreements (Pisano, 1989; Gulati & Singh, 1998; Teece, 1986; Steensma & Corley, 2000; Nichols-Nixon & Woo, 2003)	1.One partner takes a minority equity position in the other (less that 50%) 2. investing partner joins the board of directors of the partner that received the investment (control & authority, dispute resolution through board member intervention) 3.concern for value of equity (incentives for investor) 4. regular information exchange & decision sanctioning through board (in place of SOPs)	Incentive alignment: mutual hostage by shared equity Command structure and authority system: a distinct hierarchy of managers Control of resources: autonomous entity	Moderate	After the emergence of dominant design: Asymmetric complementary product development Interoperability collaboration with symmetric complementor for primary product upgrades
New technology development , there is less know-how related to its application, making contract specification incomplete	ex post contract disturbances are not expected to be too severe defection is likely in the event of highly consequential disturbances, leading to the problem of dispute resolution in court	Bilateral contract Examples: cross-license, technology sharing agreement, joint research agreements, exclusive agreements		Mutual hostage by way of commitment of technology on both sides or exclusivity	Moderate-low	After the emergence of dominant design: Asymmetric product development, Symmetric complementary product development

Table 8 (continued)

Age of technology: "Routine" technology transfer – both partners share information about the application of the technology making contract specification relatively detailed		Unilateral contract Examples: unilateral licensing agreements, long-term supply, distribution agreements, contracts, R&D contracts	1. Similar to arms' length market exchanges 2.No shared ownership or administrative structure 3. Almost no command structures, authority systems, incentive systems, SOPs, dispute resolution procedures, pricing systems- i.e. members of the partner firms work directly from their own organizational confines 4. New decisions are jointly negotiated	Markets and prices	Lowest	After the emergence of dominant design

Table 9: Pair wise correlations between study variables

	Mean	S.D.	Min	Max	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
TypeCmp(1)	0.365	0.482	0	1	1										
Age(2)	34.3	25.21	0	91	0.039	1									
					(0.501)										
Size(3)	4.392	0.867	1.146	5.608	-0.001	0.797***	1								
					(0.982)	0									
CapInten(4)	0.062	0.031	0.011	0.265	0.068	0.331**	0.311*	1							
					(0.238)	0	0								
R&Dinten (5)	0.062	0.027	0.015	0.255	0.153*	0.11**	-0.013	0.081	1						
					(0.007)	(0.053)	(0.825)	(0.158)							
TechCap(6)	4282.645	6867	1	35228	0.022	0.717***	0.569*	0.304*	-0.084	1					
					(0.696)	0	0	0	(0.14)						
AlliExp(7)	149.013	192.1	1	1400	0.007	0.655*	0.534*	0.21*	-0.054	0.889*	1				
					(0.903)	0	0	0	(0.346)	0					
TechU(8)	0.265	0.061	0.12	0.331	0.075	-0.031	-0.09	-0.054	0.238**	0.31**	-0.272*	1			
					(0.191)	(0.584)	(0.114)	(0.342)	0	0	0				
MktU(9)	0.027	0.016	0.011	0. 058	-0.009	-0.011	-0.021	0.296*	-0.112*	0.112*	0.075	-0.262*	1		
					(0.881)	(0.848)	(0.717)	0	(0.05)	(0.049)	(0.192)	0			
Strtgy(10)	0.909	0.807	0	2	-0.015	0.089	0.061	0.054	0.004	0.143*	0.065	0.124**	-0.005	1	
					(0.794)	(0.121)	(0.285)	(0.343)	(0.939)	(0.012)	(0.257)	(0.029)	(0.925)		
Ind(11)	0.945	0.229	0	1	-0.024	0.025	-0.047	0.091	-0.016	0.072	0.058	-0.035	0.057	-0.027	1
					(0.68)	(0.663)	(0.412)	(0.111)	(0.78)	(0.208)	(0.308)	(0.546)	(0.322)	(0.633)	

Table 10: Multinomial logit results – full sample, all governance choices.The likelihood of a) alliance vs. complementor make b) VI vs. buy

	Model1		**Model2**		**Model3: with repeat strategy dumies**		**Model4: with repeat strategy dumies**	
	a: Alliance	b:Internalize	a:Alliance	b:Internalize	a:Alliance	b:Internalize	a:Alliance	b:Internalize
Type of complement	-0.411	-0.123	-0.411	-0.123	-0.411	-0.123	-0.411	-0.123
	(1.721)	(1.760)	(1.834)	(1.623)	(1.781)	(1.780)	(1.755)	(1.781)
Firm age	-0.0117	-0.0139	-0.0117	-0.0139	-0.0117	-0.0139	-0.0117	-0.0139
	(0.0151)	(0.0168)	(0.0215)	(0.0138)	(0.0123)	(0.0166)	(0.0123)	(0.0166)
Firm size	0.0556	0.0845	0.0556	0.0845	0.0556	0.0845	0.0556	0.0845
	(0.321)	(0.323)	(0.451)	(0.420)	(0.267)	(0.340)	(0.267)	(0.340)
Firm CapIntensity	-4.782	0.132	-4.782	0.132	-4.782	0.132	-4.782	0.132
	(5.636)	(5.407)	(8.223)	(5.492)	(4.984)	(4.644)	(4.882)	(4.642)
Firm R&Dintensity	5.128	-0.371	5.128	-0.371	5.128	-0.371	5.128	-0.371
	(5.506)	(8.054)	(6.594)	(9.089)	(7.177)	(8.172)	(7.205)	(8.170)
FirmTechCapability	0.000205***	0.000218***	0.000205**	0.000218***	0.000205***	0.000218***	0.000205***	0.000218***
	(6.73e-05)	(6.40e-05)	(8.33e-05)	(7.83e-05)	(5.28e-05)	(6.11e-05)	(5.28e-05)	(6.11e-05)
Firm AllianceExp	0.00350*	-0.00412**	0.00350	-0.00412*	0.00350*	-0.00412*	0.00350*	-0.00412*
	(0.00208)	(0.00194)	(0.00233)	(0.00227)	(0.00202)	(0.00242)	(0.00205)	(0.00243)
TechUncertainty	10.77***	8.069**	10.77***	8.069	10.77***	8.069**	10.77***	8.069**
	(3.269)	(3.878)	(3.211)	(4.941)	(3.294)	(4.016)	(3.299)	(4.016)
MktUncertainty	4.164	2.796	4.164	2.796	4.164	2.796	4.164	2.796
	(12.53)	(12.95)	(11.91)	(12.61)	(9.035)	(13.43)	(9.029)	(13.43)
typeXtechU	1.662	-0.267	1.662	-0.267	1.662	-0.267	1.662	-0.267
	(5.504)	(5.562)	(4.980)	(5.387)	(5.678)	(5.726)	(5.648)	(5.733)
typeXmktU	-0.584	-0.941	-0.584	-0.941	-0.584	-0.941	-0.584	-0.941
	(18.26)	(20.87)	(22.51)	(18.98)	(15.92)	(20.96)	(14.72)	(20.94)
Industry	-1.042	-0.437	-1.042	-0.437	-1.042	-0.437	-1.042	-0.437
	(0.680)	(0.763)	(0.696)	(0.711)	(0.640)	(0.634)	(0.640)	(0.634)
fm_ad1 (repeat alliance, repeat prd pair)							-1.268	-1.221
							(2.245)	(1.439)
fm_ad2(repeat alliance, firm)							72.91***	-1.443
							(14.86)	(0.967)

Table 10 (continued)

fm_i3 (repeat internalize)							2.516*	40.46
							(1.366)	(0)
Constant	-2.269	-2.134	-2.269	-2.134	-2.269	-2.134	-2.269	-2.134
	(1.758)	(1.923)	(1.728)	(2.272)	(1.660)	(2.029)	(1.660)	(2.030)
Observations	307	307	307	307	307	307	307	307

Table 11: Multinomial logit regression results for different levels of technological uncertainty

	Technological Uncertainty=low						**Technological Uncertainty=moderate**					
	base strategy=0		base strategy=2		base strategy=1		base strategy =0		base strategy =1		base strategy =2	
Predicted strategy	1	2	0	1	0	2	1	2	0	2	0	1
Type of comp	0.95	0.4*	5.4	6.71**	0.811	0.148**	1.811	6.976**	0.552	3.85***	0.14**	0.26***
	(0.454)	(0.218)	(7.637)	(6.281)	(0.635)	(0.138)	(1.406)	(6.671)	(0.429)	(1.979)	(0.137)	(0.1)
Market Unc	2.3e+63***	6.49E+36			0	0	6.3e+12	1.1e+27	0	1.8e+14	0	0
	(1.12E+65)	(4.8E+38)			(0)	(0)	(4.9e+14)	(7.8e+28)	(0)	(1.414e+16)	(0)	(0)
Firm size	0.821	1.316	1.052	0.768	1.370	1.302	3.169*	1.874	0.316*	0.591	0.534	1.692
	-0.389	-0.864	(1.183)	(0.704)	(1.322)	(1.194)	(1.898)	(1.327)	(0.189)	(0.396)	(0.378)	(1.134)
Firm age	1.01	0.988	1.027	0.901	1.140	1.110	0.963	0.952	1.038	0.988	1.051	1.012
	-0.0326	-0.0418	(0.04)	(0.088)	(0.0961)	(0.109)	(0.0366)	(0.0410)	(0.0394)	(0.0355)	(0.0453)	(0.036)
Firm Cap Intensity	0***	0**	0***	6.2e+07	0***	1.6e-08	2.3e+06	3.347e+11	4.26e-07	142,472	2.7e-05	1,717
	0	0	(0)	(2.1e+09)	(0)	(5.4e-07)	(6.8e+07)	(8.483e+12)	(1.24e-05)	(3.608e+06)	(0.0005)	(24,75)
Firm R&D Intensity	6.705e+30*	4.07E+23	1.8e+89***	0	3.23e+114*	1.80e+25	6.3e+07	37,128	1.57e-08	0.000582	0	7.2e-06
	-2.596E+32	-2.1E+25	(8.56e+90)	(0)	(3.3e+116)	(1.7e+27)	(1.39e+09)	(604,997)	(3.43e-07)	(0.00840)	(7.5e-11)	(0.002)
Firm TechCapability	1.000*	1.000**	0.999***	1.000	0.99***	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	-0.00015	-0.00012	(0.0001)	(0.0003)	(0.00028)	(0.0003)	(0.00042)	(0.000356)	(0.000402)	(0.000257)	(0.0004)	(0.003)
AllianceExp	0.998	0.997					0.986	0.990	1.014	1.005	1.010	0.995
	(0.006)	(0.004)					(0.0116)	(0.00974)	(0.0120)	(0.00696)	(0.0093)	(0.007)
rdixmktu	0***	0	***	0	***		0	0		0	1.1E+163	
	0	0		(0)			(0)	(0)			(8.81E+163)	
Industry	-1.042	-0.437	-1.142	-0.437	-1.042	-0.437	-1.002	-0.437	-1.032		-1.011	-0.4
	(0.680)	(0.763)	(0.680)	(0.763)	(0.680)	(0.763)	(0.680)	(0.763)	(0.680)	(0.763)		
Constant	0.522	0.0751	0***	0***	1.5e+17**	1.4e+33*	0.01	0.0248	65.20		40.2	0.618
	-1.486	-0.288	(0)	(0)	(1.1e+18)	(1.2e+34)	(0.05)	(0.05)	(229.0)	(5.519)		
Observations	84	84	84	84	84	84	120	120	120	120	120	120

*** p<0.01, ** p<0.05, * p<0.1

Table 12: Multinomial logit regression for different levels of market demand uncertainty

	Market uncertainty=lo		Market uncertainty=moderate						Market uncertainty=hi	
	base strategy =0		base strategy =0		base strategy =1		base strategy =2		base strategy =0	
Predicted strategy	1	2	1	2	0	2	0	1	1	2
Type of Complement	0.732	1.087	1.377	0.546*	0.726	0.396**	1.832*	2.524**	1.099	0.924
	(0.409)	(0.501)	(0.632)	(0.199)	(0.333)	(0.184)	(0.670)	(1.171)	(0.783)	(0.782)
Firm age	1.090**	1.123***	0.982	1.011	1.018	1.030***	0.989	0.971***	1.007	0.963***
	(0.0445)	(0.0321)	(0.0135)	(0.0119)	(0.0139)	(0.0108)	(0.0116)	(0.0102)	(0.0196)	(0.0128)
Firm size	0.821	1.316	1.052	0.768	1.370	1.302	0.534	1.692	1.052	0.768
	-0.389	-0.864	(1.183)	(0.704)	(1.322)	(1.194)	(0.378)	(1.134)	(1.183)	(0.704)
Firm CapIntensity	5.489e+22**	4.581e+34***	1.00e-10	5.88e-11*	9.986e+09	0.587	1.700e+10*	1.703	0.00102	0.824
	(1.237e+24)	(7.914e+35)	(1.53e-09)	(7.17e-10)	(1.521e+11)	(9.724)	(2.072e+11)	(28.18)	(0.00809)	(3.743)
Firm R&D Intensity	3.30e-10*	0***	67,271	947.0	1.49e-05	0.0141	0.00106	71.04	3.80e-06	2.24e-07
	(4.30e-09)	(0)	(514,305)	(6,638)	(0.000114)	(0.0653)	(0.00740)	(329.4)	(4.73e-05)	(4.51e-06)
Firm TechCapability	1.000	0.999**	1.000***	1.000***	1.000***	1.000	1.000***	1.000	1.000	1.000**
	(0.000501)	(0.000237)	(0.000113)	(0.000105)	(0.000113)	(0.000113)	(0.000105)	(0.000113)	(0.000103)	(9.64e-05)
Tech Uncertainty	1,222	49.80	1.093e+07***	116.3*	9.15e-08***	1.06e-05***	0.00860*	93,997***	1.280e+06**	91,048*
	(9,746)	(572.4)	(5.529e+07)	(333.9)	(4.63e-07)	(3.99e-05)	(0.0247)	(352,584)	(7.400e+06)	(593,742)
Firm AllianceExp	0.992	1.003	0.986***	0.984**	1.014***	0.997	1.016**	1.003	1.004	1.000
	(0.0140)	(0.00888)	(0.00463)	(0.00728)	(0.00476)	(0.00661)	(0.00752)	(0.00665)	(0.00291)	(0.00221)
	0.0273	0.0209	(0)	(0.724)	(1.939e+09)	(0)	(2.763)	(0)	0.0292	0.101
Industry	-1.002	-0.437	-1.042	-0.437	-1.142	-0.437	-1.002	-0.437	-1.042	-1.002
	(0.680)	(0.763)	(0.680)	(0.763)	(0.680)	(0.763)	(0.680)	(0.763)	(0.680)	(0.680)
Constant	(0.0795)	(0.0879)	0.0354*	1.397	28.25*	39.45***	0.716	0.0253***	(0.0656)	(0.204)
			(0.0717)	(1.789)	(57.25)	(55.84)	(0.917)	(0.0359)		
Observations	93	93	110	110	110	110	110	110	104	104

Robust standard errors in parenthesis: *** p<0.01, ** p<0.05, * p<0.1

Table 13: Logit Pooled Regressions results: a) alliance vs. complementor make b) internalize vs. complementor make c) alliance vs. internalize (rrr).

Variable	**Model1: alliances** vs. **complementor make**	**Model2 : internalize** vs. **complementor make**	**Model3: internalize** vs**. alliance**
Type of complement	1.187	0.680	1.352
	(2.087)	(1.099)	(2.768)
Firm age	0.985	0.989	1.001
	(0.0242)	(0.0129)	(0.0173)
Firm size	1.130	0.980	1.006
	(0.535)	(0.442)	(0.299)
Firm CapIntensity	0.0115	2.855	1,278
	(0.0985)	(13.84)	(8,362)
Firm R&Dintensity	149.6	0.254*	0.00825
	(1,244)	(2.501)	(0.0418)
FirmTechCapability	1.000*	1.000***	1.000
	(0.000126)	(0.00006)	(5.23e-05)
Firm AllianceExp	0.996	0.996**	0.999
	(0.00376)	(0.00176)	(0.00107)
TechUncertainty	8.168***	2.078***	0.00998
	(254,432)	(9,709)	(0.0422)
MktUncertainty	499.5	0.0366	0.0327
	(5,981)	(0.469)	(0.372)
typeXtechU	1.052	0.997	0.141
	(5.130)	(5.356)	(0.770)
typeXmktU	0.0132	116.8	0.556
	(0.313)	(2,340)	(15.51)
Industry	0.356	0.628	1.791*
	(0.262)	(0.441)	(0.582)
Constant	0.0666		1.804
	(0.123)		(3.078)
Observations	220	202	192
Robust std errors in parenthesis: *** p<0.01, ** p<0.05, * p<0.1			

Table 14: Logit panel regression results - Choice of 1) alliance vs. compl make 2) VI vs. compl make 3) alliance vs. VI

	Logit -fixed effects			Logit -random effects		
Variable	Model1	**Model2**	Model3	Model4	**Model5**	Model6
Type of complement	0.8730286	0.2080057	0.721	13.21	0.653	1.076
	(1.770709)	.4315838	(1.627)	(45.64)	(1.411)	(2.332)
Firm age	0.991	0.999	1.019	0.992	0.990	1.003
	(0.0158)	(0.0146)	(0.0160)	(0.0269)	(0.0141)	(0.0132)
Firm size	1.042	0.852	0.655	1.129	0.887	0.935
	(0.343)	(0.322)	(0.235)	(0.616)	(0.312)	(0.288)
Firm CapIntensity	0.00110	19.76	219,100*	3.39e-06	5.413	13,492
	(0.00659)	(105.0)	(1.564e+06)	(3.92e-05)	(32.65)	(88,706)
Firm R&Dintensity	421.6	10.96	0.00122	16.51	0.131	0.00144
	(2,881)	(75.09)	(0.00762)	(200.7)	(0.969)	(0.00853)
FirmTechCapability	1.000***	1.000**	1.000	1.000**	1.000***	1.000
	(0.000101)	(7.52e-05)	(6.14e-05)	(0.000156)	(0.00086)	(5.84e-05)
Firm AllianceExp	0.994**	0.997	1.000	0.994*	0.995*	1.000
	(0.00282)	(0.00224)	(0.00183)	(0.00406)	(0.00243)	(0.00174)
TechUncertainty	3.532*	2.799	0.00214	6.8807***	1.169*	0.00828
	(15,498)	(1,033)	(0.0108)	(267340)	(4,670)	(0.0364)
MktUncertainty	0.537	0.000795	0.0752	2.510e+09	0.0224	0.00335
	(8.307)	(0.0118)	(1.264)	(5.565e+10)	(0.332)	(0.0474)
typeXtechU	7.326	86.37	0.967	1.092859	1.686	0.286
	(47.32)	(581.7)	(6.718)	(6.537185)	(11.97)	(1.925)
typeXmktU	8.715	1.330e+06	1.192	.0192036	84.29	15.30
	(195.5)	(2.980e+07)	(28.03)	(0.3917242)	(1,933)	(329.7)
Industry	0.854	0.832	1.060	0.403172	0.608	1.567
	(0.594)	(0.668)	(0.807)	(0.2734)	(0.526)	(1.080)
Constant						
Observations	204	186	174	220	202	192
Groups	18	17	19	28	77	29
Robust std errors in parenthesis *** p<0.01, ** p<0.05, * p<0.1						

Figure 1a: Hybrid forms of governance

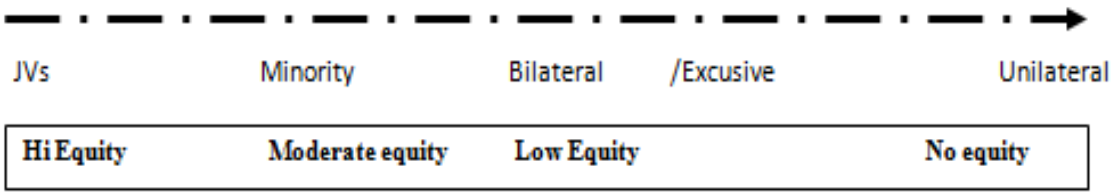


Figure 1b: Complementary product governance structure (Degree of internalization)

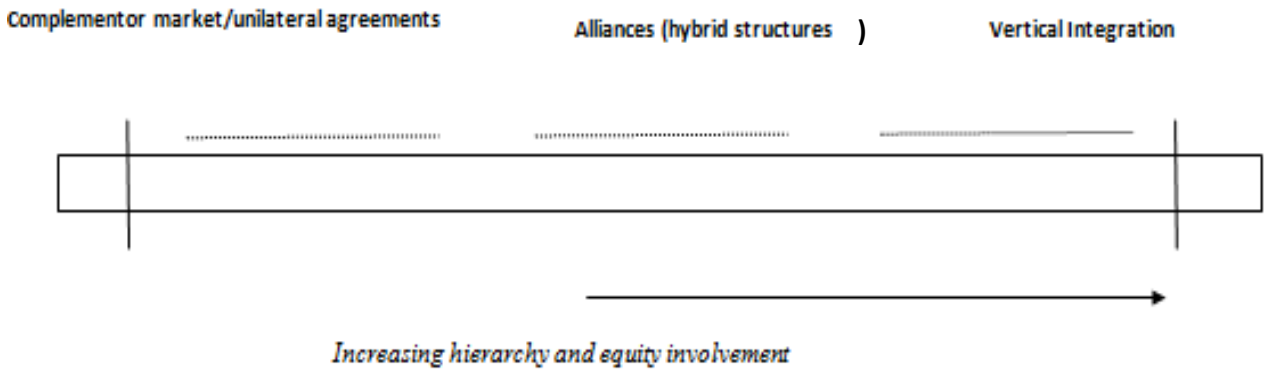


Figure 2: Conceptual Model for primary product firm's governance strategy

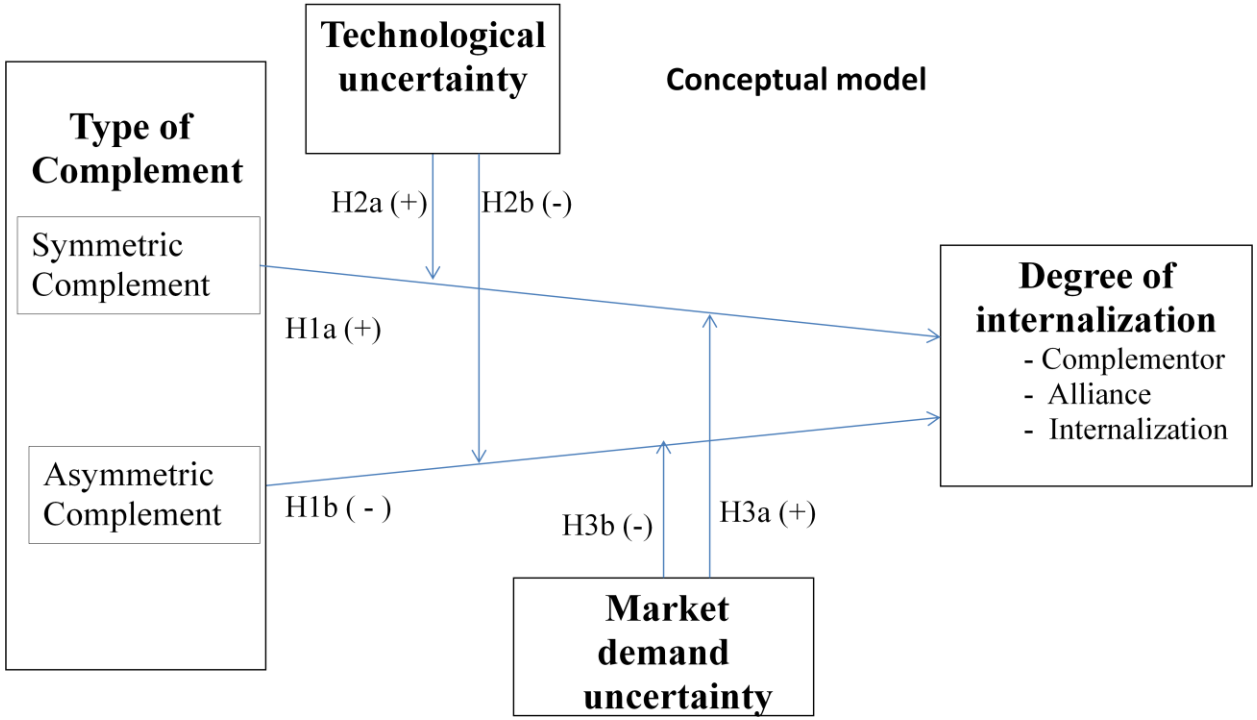


Figure 3: Data collection steps

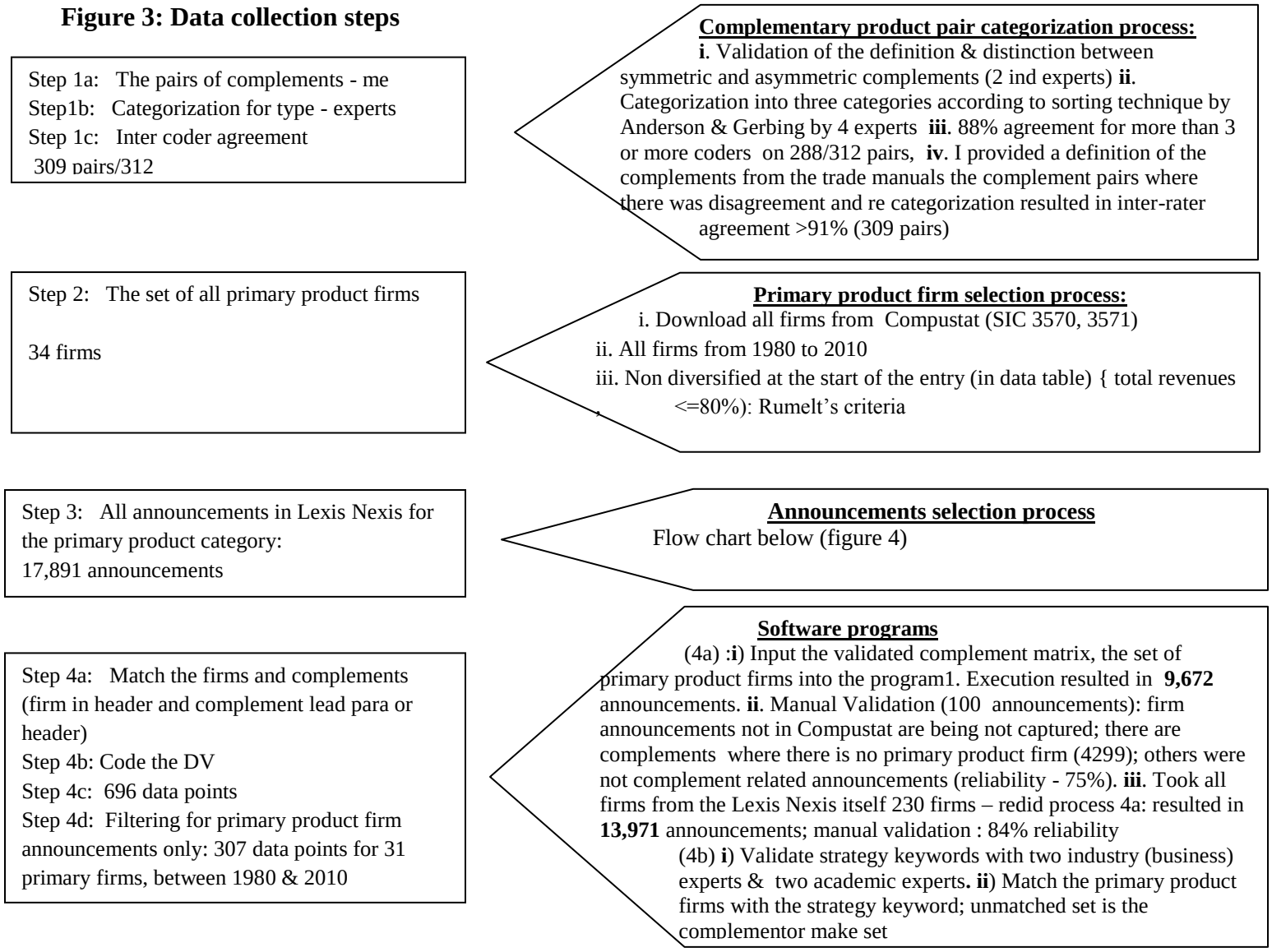
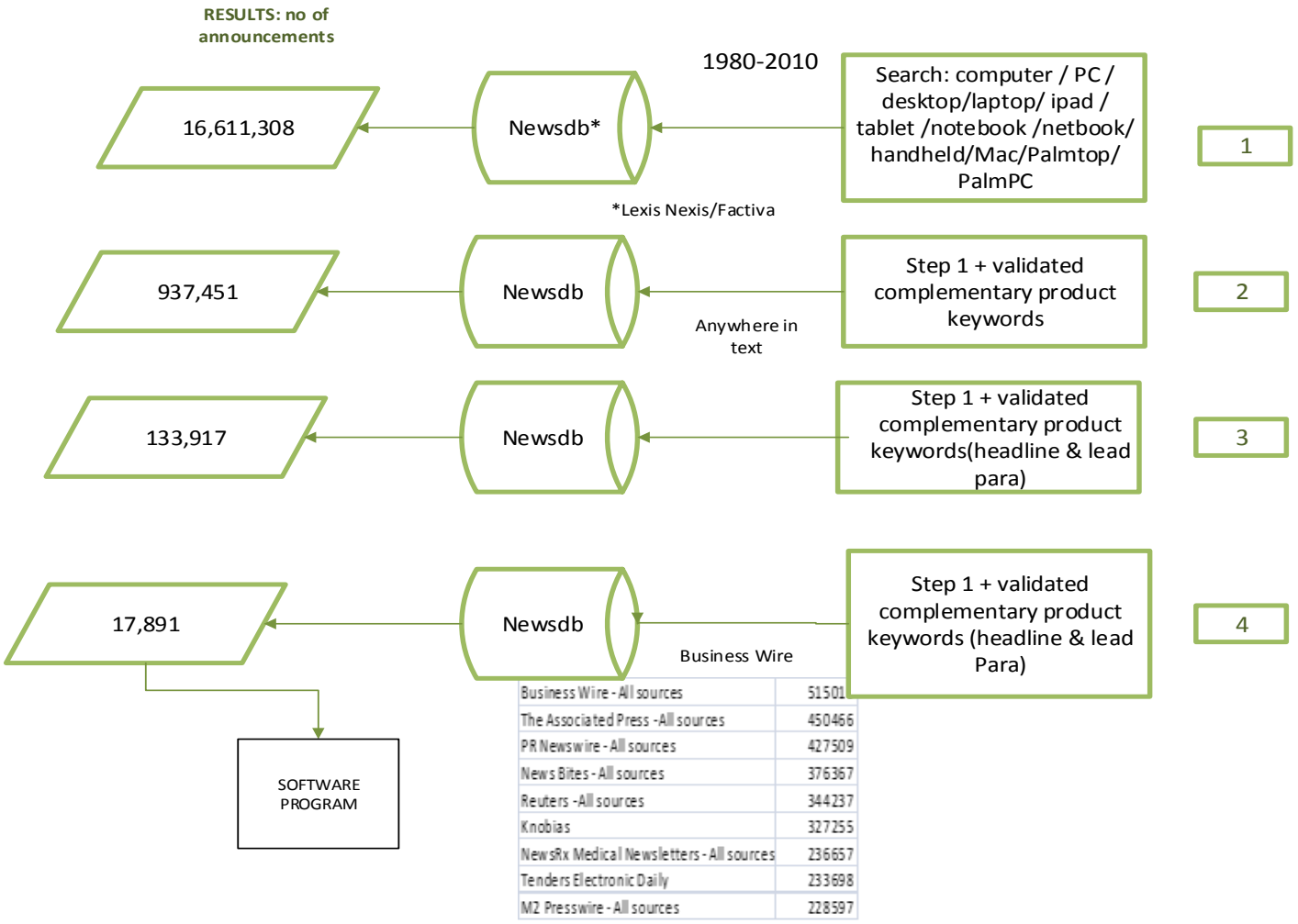


Figure 4: Process model for selection of announcements



APPENDIX

A. Comparison of primary products for the number of complementary products between different primary product markets

Primary product	Symmetric	Asymmetric	Hardware (non components)	Software(non components)
PC (Kottrell & Coput, 1998; Bresnahan & Greestein, 1999; Sengupta, 1998; Nambisan, 2002; Evans et al., 2006)	OS, CPU, adapter, monitor, motherboard, chips, bus, controller, graphics card, sound card, clock, RAM, keyboard, host adapter, sound card, video adapter	External hard disk, printer, scanner, mouse, DVD drive, GPS, camera, Bluetooth, email, search, games, social networking, UPS, fan cooler, screen, webcamera, docking station, cover/case/bag, digital camera, modem, fax, USB hub, port replicator, video capture device, trackball, plug add-on controller, internet phone/radio/TV	Monitor, mouse, keyboard, printer, flash drive, external hard disk, flash drive, speakers, headphones, UPS, webcamera, docking station, cover/case/bag, digital camera, PC lamp, microphone, RAM, screen pen, USB hub, keyboard vacuum, USB cable, videocam, cooling stand, locking kit, SSD drive, floppy drive, modem, fax, host adapter, video card, sound card, heat sink, wrist rest , port replicator, video capture device, trackball, add-on controller, USB based internet phone/radio/TV …..	Anti virus, disk check, printer driver, games, range of business productivity software such as Word, Excel, powerpoint…..
Video game console (Clements & Ohashi, 2005; Dube, Hitsch et al., 2010)	Games, gamebox, controller, joystick, cartridge/CD,	Speakers, Controller, cartridge, charger, gaming headset, gaming mouse	Speakers, Controller, cartridge/CD, charger, gaming headset, gaming mouse	Games

Television (Gupta, Jain, et al., 1999)	TV set, cathode ray tube, programming service,	DVD player, CD player, headphones , mounting kit, cover, remote controller, antenna, viewing glasses, video capture device	DVD player, CD player, headphones , mounting kit, cover, remote controller, antenna, viewing glasses, video capture device	programming
VCR (Cusumano & Mylonadis, 1999)	VCR box, CDs, movies, Television	Headphones	VHS tapes	Movies
Smartphone	Handset, service, graphics chip, OS,, CPU	GPS, camera, Bluetooth, email, search, games, social networking , range of application software , protector, case, docking station, earphones, video capture device	Earphones, adapter, video capture device	Variety of application software…..

B. Sources for list of complementary products for the computer product category

I. Academic and manufacturer provided technical and non technical books

1. IBM Dictionary of Computing
2. Wilkinson, Barry, 1987. *Computer Peripherals*, Inc. Upper Saddle River, NJ
3. Thorne, Julie. 1992. *Computer Peripherals.*
4. Stallings, W. 2006. *Computer Organization & Architecture – Designing for Performance.* Pearson Prentice-Hall, Inc
5. Hennessy, & Patterson, 2006. *Computer Architecture: A quantitative approach*, Morgan-Kaufman
6. Grattan, Nick. 2002. *Pocket PC*, *Handheld PC - Developer's guide*. Prentice-Hall, Inc. Upper Saddle River, NJ

II: Trade Publications (Computer hardware)

Trade Journal	Website	Links	Description
APPLIANCE Magazine	http://www.appliancemagazine.com/	Supplier Solutions Market Research Whitepaper library	a premiere electronic industry information source
Automation World	http://www.automationworld.com	Products Networking	Industrial automation, including latest trends in computer networking
BusinessWeek	http://www.businessweek.com/	Technology companies & Industry	
BYTE	http://www.informationweek.com/personal-tech/	Security Mobility Big Data Tablets Wireless technology Desktop PCs Home Automation Gaming	News, analysis , discussions and expert reviews on product releases, product comparisons and analysis of firm strategies
Chip Design Magazine (FPGA Developer e-Newsletter)	http://chipdesignmag.com/		Targeted towards integrated circuit designers, it includes news and analysis of product introductions on EDA development and tools, chip architecture, test& verification, tool interoperability and power regulation
CNET News	http://news.cnet.com/		One of best unbiased reviews of *computers*, digital electronics products delivering the consumer reviews of technology *products* on the Web.
Communications Engineer	http://digital-library.theiet.org/content/journals/ce		this magazine provided in-depth coverage in the area of communications, including the design, development, operations and application of systems for communication and information networking
CRN Magazine	*www.crn.com*		leading advertising medium for the IT industry targeted mainly to computer resellers

Trade publications (continued)

Computer Shopper Magazine	*http://www.computershopper.com/*		Computer buyer's source for labs-based reviews of laptop computers, desktop computers, tablets, and related computer products. Provide ratings, rankings, and pricing to help find the top computer products and best computer deals.
Computer Technology Review Magazine	*http://www.wwpi.com/*	Data Centers Security Data Protection Data backup White Papers	Covers enterprise storage and networking, connectivity, tape and optical media and the Internet.
ComputerWorld	*http://www.computerworld.com/*	covers a wide range of technology topics, including software, security, operating systems, mobile, storage, servers and data centers	leading source of technology news and information for IT influencers worldwide for over 40 years, having won more than than 100 awards in the past five years alone
Digital Trends	www.digitaltrends.com		
Data Storage Review	*http://www.storagereview.com/*	Consumer reviews Enterprise reviews	offers in-depth news coverage and detailed reviews for **hard drives, SSDs, NAS units, other storage hardware,** and software for enterprise and consumer markets
Electronic Engineering Times	www.eetimes.com	Power Management Wireless & Networking	News source for resource for *news*, analysis, design ideas & solutions, *products*, education, & engaging for the *electronic engineering* community.
Handheld Computing Magazine	http://hhcmag.com/	Pen computing Rugged PCs Tablet PC Personal Media	A consumer's guide to mobile electronics – features latest product releases including updated features, market forecasts and expert product reviews
IEEE Spectrum	*http://spectrum.ieee.org/*	Reports Archives Topics: robotics, electronics, computing, energy, biomedical devices	A flagship monthly publication of the IEEE, the world's largest professional technology association exploring future technology trends and the impact of those trends on business.

Trade publications (continued)

Laptop Magazine	*http://www.laptopmag.com/*	Laptops Tablets Ultrabooks	Reviews of latest product releases, pricing of mobile computers that benefits consumers and small and medium enterprises
MacWorld	*http://www.macworld.com/*	Macs MobileEntertainment	Review of Apple based product introductions
Microprocessor report			publication for engineers and other industry professionals on microprocessors. The publication is accessible only to paying subscribers.
MIT Technology review	*http://www.technologyreview.com/*	Magazine – Current Issue/Past Issues/Business reports	Targeted towards business leaders and early adopters, the news analysis and reviews covers technology areas in various aspects of computing and the reports are freely accessible online
Network Computing	*http://www.networkcomputing.com/*	Backup & recovery Cloud Storage Data Center Data protection Networking &Mgmt Servers & Storage Storage & Mgmt WAN & App Acceleration Wireless	Focused towards product architecture information seekers, it provides expert reviews, analysis and blogs on enterprise technologies, such as back-up and recovery, data center architecture and technologies, data protection, network and storage management, unified communications, virtualization, wan acceleration, and wireless networking.
PC World	*www.pcworld.com*		Test and review *computer*- and Internet-related *products* and services, report technology *news* and trends, and provide shopping advice and price comparisons
Printweek	*http://www.printweek.com/*		Publishes reviews and analysis in the printer industry
PC Magazine	*www.pcmag.com*		Test and review *computer*- and Internet-related *products* and services, report technology *news* and trends, and provide shopping advice and price comparisons

Trade publications (continued)

InfoWorld	*www.infoworld.com*		
Silicon Valley Journal	*http://www.bizjournals.com/sanjose/*		
Smart Computing	*http://www.smartcomputing.com/*	PCs/Drives/Accessories Printers/Shredders/Machines	Hardware and software reviews related to computing
Wall Street Technology	http://www.wallstreetandtech.com	Data Security Data Management IT infrastructure	News, analysis , discussions and expert reviews on product releases, product comparisons and firm strategies
Webcom Communications	*http://www.webcomcommunications.com/category/magazines*	E Drive Electronics protection Battery Power	
Zdnet	*www.zdnet.com*		A business technology news website published by CBS Interactive

C: Validation with industry experts for the type of complementarity between given two products

Validation of conceptual definition (2 industry experts)

Definition: In symmetric complementarity, the primary product is functionally dependent on the complement and the two products are always used together to provide value to a user of the primary product.

In asymmetric complementarity, the primary product maybe functionally independent of the complement, but joint use of the two products provides additional value to a user of the primary product.

Please indicate the extent to which you agree (or disagree) with the definition based on the following scale:

1. Completely agree 2. Moderately agree 3. Not sure 4. Moderately disagree 5. Completely disagree

D. Examples included along with definition of type of complementarity for industry expert validation

Symmetric Complementarity		**Asymmetric complementarity**	
PC	microprocessor/chipset	PC	printer
PC	keyboard	PC	scanner
PC	Batteries/power supply	PC	web camera
PC	host adapter	PC	videophone
PC	Internal hard disk drive	PC	earphones
PC	OS		

E. Complementary product list categorization summary

Agreement on	**Type of complementarity**			**Agreement on**	**Type of complementarity**		
	Agreements	Not known	Disagreements		Agreements	Not Known	Disagreements
Expert1 (product pairs)	320,322	2,0	0,0	Expert3	286 , 309	29,0	8, 12
Expert2 (product pairs)	232, 310	90,0	2,12	Expert4	235, 286	5	12, 0
IRR_1	0.990430622,1.00			IRR3	0.870813397, .96		
IRR2	0.818181818, .97			IRR4	0.813397129		
IRRavg	**0.89; 0.95**[9]			**IRRavg**	**0.87; 98**[10]		

[9] : the disagreement (the first time) occurred for the following reasons-

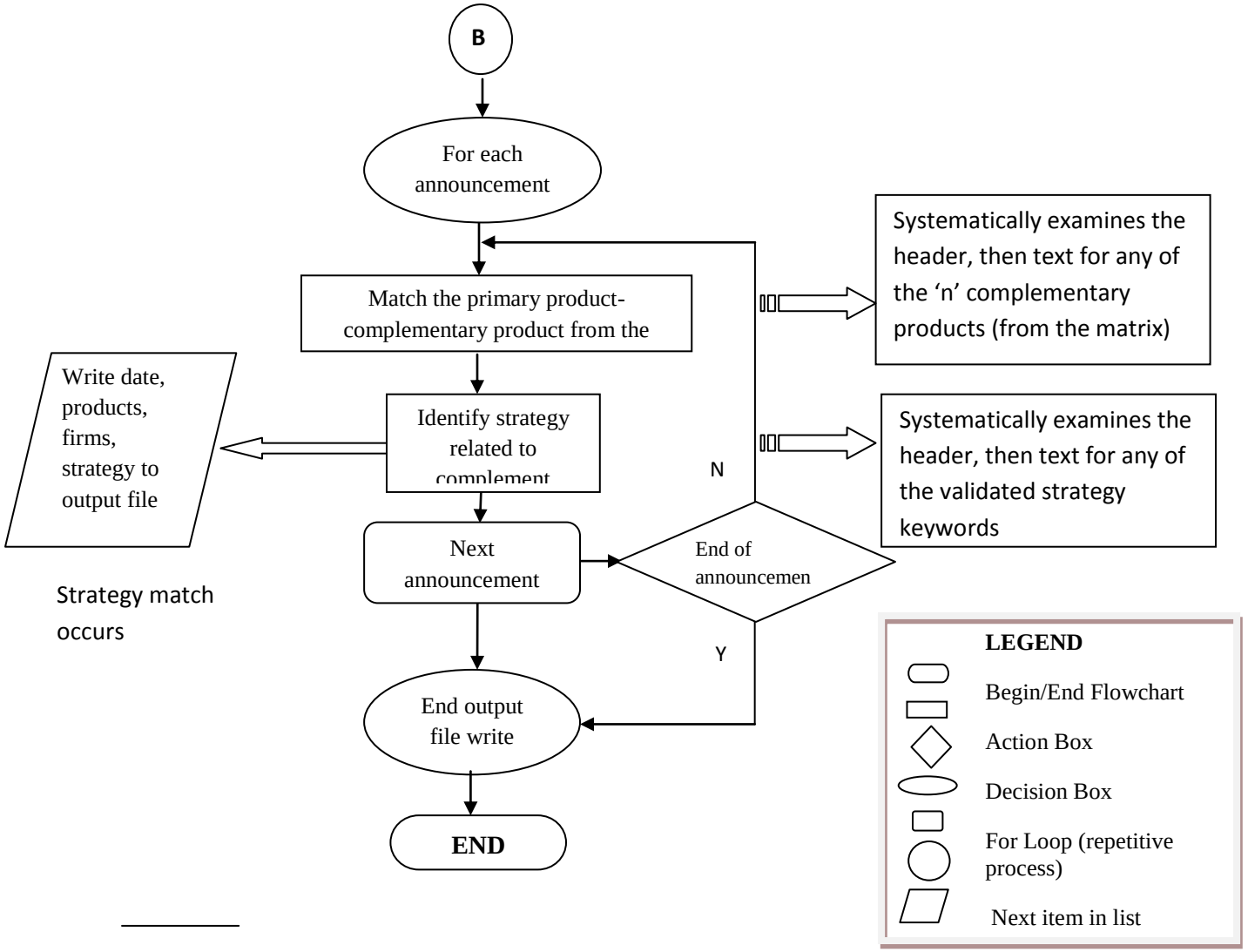
i. Some of them were unfamiliar enough to evaluate the complementarity,

ii. The assumptions experts formed in the context of larger systems as opposed to the given primary product led them to categorize some complements as asymmetric as opposed to symmetric. Subsequent clarification improved the agreement on categorization

F. Strategy Keywords

Make	Hybrid	Let them make	
Release(s/ed), debut(s/ed), introduce(s/ed) new, unveil(s/ed), launche(s/ed), ship(s/ed), announce(s/ed) new, deliver(s/ed), extend(s/ed) support, Offer(s), Produce(s), Present(s), manufacture(s), develop(s),reveal(s/ed) Acquire(s), purchase(s), Takeover, Buyout, Merger, Consolidation, Subsidiary, Syndicate, Hostile, Absorb, Parent White Knight Suitor, integrate acquire purchase buy merge equity stake equity position	Agreement alliance ally allies signs pact sign pact signs deal sign deal pact collaboration collaborates jointly develop joint development jointly developed jointly market joint market joint marketing joint production joint R & D joint R&D co-brand co-develop co development co produce co production co-market co-marketing co-branding cross license cross-licensing cross licensing joint distribution joint advertizing	Release(s), debut(s), introduce(s) new, unveil(s), launche(s), ship(s), announces new, delivers, extends support, announces & availability offers, Produce(s), Present(s), manufacture(s), develop(s) Acquire(s), purchase(s), Takeover, Buyout, Merger, Consolidation, Subsidiary, Syndicate, Hostile, Absorb, Parent White Knight Suitor, integrate acquire purchase buy merge equity stake equity position	joint sales joint technology join forces join together join hands work together relationship strategic relationship joint venture JV partnership partner team

Figure 2: SOFTWARE PROGRAM FLOWCHART[11]



[11] A high level description of the flow of logic

G. Brief description of different scenarios handled in the software program:

The content analysis program primarily does a headline analysis, but also incorporates certain document level analysis as described below for the different use cases.

Internalization decision: On encountering any of the validated keywords for internalization, *the* program checks for the occurrence of the primary product

Case1: The firm name, primary product and complement and strategy keyword appear in the headline

For example: Starfish Announces REX Synchronization for Microsoft Outlook 98 and Other Popular Organizers; Essential REX Accessory Works Directly With Most Popular Organizers or

HP Announces Ultimate Desktop-Replacement Notebook PC With New Intel Mobile Pentium II Processor

The program compares the master list of complements with the complement in the header, viz. "processor". Upon encountering the appropriate primary product- complementary product entry in the master list, it moves on to examine the strategy keyword in this case "announces" combined with "new". Then the program compares the primary product firm master list with the company name in the headline. Since it finds a match, viz., "HP" it compares the primary products viz., desktop and notebook with the strategy keyword and is programmed to recognize that the primary product firm is not introducing the product, but is a complementor make. So it lists the strategy, the primary product firm, primary product and the complement correctly, but does not fill in the complementor name – viz., Intel. *This needs to be complete manually*.

Case 1.1: New HP OmniBook 7100 Notebook PC Delivers High Level of Processor and Graphics Performance (Products in headline)

The program compares the master list of complements with the complement in the header, viz. "processor". Upon encountering the appropriate primary product- complementary product entry in the master list, it moves on to examine the strategy keyword in this case "delivers" combined with "new". Then the program compares the primary product firm master list with the company name in the headline. Since it finds a match, viz., "HP" it compares the primary product viz., notebook PC with the strategy keyword and is programmed to recognize that the primary product firm is introducing a primary product and so skips the announcement altogether

Case 2: The firm name, complement and strategy keyword appear in the headline

For example: Kensington Unveils Mouse-in-a-Box Scroll; New Input Device Makes Scrolling Simple and Affordable

The program compares the master list of complements with the complement in the header, viz. "mouse" . Upon encountering the appropriate primary product- complementary product entry in the master list, it moves on to examine the strategy keyword in this case "unveils". Then the program compares the primary product firm master list with the company name in the headline.

Since it does not find a match, it lists the strategy as "complementor make" and the company. *Sometimes the company is not accurately captured by the program because of the high level of complexity in program needed to incorporate the occurrence of the company anywhere in the headline.*

Case 3.1: Firms and strategy in headline (no products in headline)
For example: nStor Signs Distribution Agreement with PTG, Inc.

The program checks for the occurrence of all the possible pairs of primary and complementary product pairs contained in the master list in the header paragraph of the text document. Further it checks for the keywords as well. It encounters "information storage solutions" and extracts the primary product-complementary product into the output file.

Case 3.2: Firms and strategy in headline (no products in headline)
For example: Technitrol To Acquire GTI Corp.

The program checks for the occurrence of all the possible pairs of primary and complementary product pairs contained in the master list in the header paragraph of the text document. Further it checks for the complementary keywords as well. *Either the complementary keyword or the complement may only be found in the lead paragraph. Then the output prints the names of the firms and the strategy word. I have to manually fill in the rest of the information. Programmatically retrieving the information from the rest of the document when there is little information relating to the products in either the headline or lead paragraph gives results to high percentage of spurious results.*

Case 3.3: Firms and strategy in headline (no products in headline)
For example: Electro-Sensors Announces Dividend

The program checks for the occurrence of all the possible pairs of primary and complementary product pairs contained in the master list in the header paragraph of the text document. Further it checks for the complementary keywords as well. *Neither the complementary keyword nor the complement is found in the lead para.* In such a case the program skips the line.

Case 3.4: Complementary product not in master list

Maxwell Technologies to Acquire Unit of Primex Physics International; Solidifies Global Leadership in Pulsed Power Technology

This is a limitation of the software program.

Validity of the content analysis program

The threats to the validity of the program arises from

i. inaccurate classification of individual announcements either from a mismatch of the primary product-complementary product pair
ii. from the inaccurate classification of the strategies with the primary product-complementary product pair
iii. Inadequate vocabularies in identifying the complementary products. Such a threat has been noted in prior research employing custom programs for content analysis of archival text documents in strategy research (Uotila et al., 2009).
iv. the order to ensure that software program errors did not impact the reliability of the data, I adopted the following procedure

To address reliability issues arising from the above threats, I performed the following checks.

Correcting for Program errors:

Procedure: I manually examined the first 100 lines of output from the program and detected few inconsistencies, reasons for which are stated below. Subsequently, I examined 75 lines of output and did not encounter a different issue. Additionally, I randomly examined 50 lines of the output. After accounting for the discrepancies in the software program and re execution of the program, I examined 75 lines of the result set and did not find any different errors in the program output. I further examine 50 lines and reached the same conclusion at which point I stopped the manual validation of the program results.

Errors in results set (19 errors out of 225 examined)

1. Announcements where multiple complementary products appear in the same announcement such as – "*AIWA launches data products line; company announces series of computer peripherals including CD-ROM drives, fax/modems, and PCMCIA cards*", listed only the first complementary product, viz., CD-ROM drives.

2. Distinction between standard and product: Some vocabularies needed to be defined more specifically. For example, USB 2.0 and USB 2.0 terminal or USB 2.0 port.

For example, *Sealevel Systems, Inc. Introduces 16-Port **USB to Serial Servers**, Silicon Laboratories Introduces Complete 8-Bit MCU Evaluation Tool in a **USB Stick**; ToolStick Demonstrates Easy-to-Use MCU Development Tools; SMSC Provides Industry's First ULPI Stand-Alone Transceiver for Hi-Speed **USB Industry Specification**; Newly Released ULPI Interface Promotes Stand-Alone PHYs*

Program correction: Code for not "USB Industry Specification" or USB standard

3. If the complement is introduced by a primary product firm, then I code it as make strategy. Specifically, I examine the firm in the announcement whether it is part of the list of firms compiled from Computat which are single business/dominant business firms (in the primary product line). The program codes the product introduction as a "Make" if the match with any of the firms from Sic code 3570 or 3571 is found.

Bias: If the firm is a multiproduct firm (such as Sony, Mitsubishi, Toshiba), then it will not be recognized by the program as a primary product firm.

Program Correction: Consider the set of all firms in the corresponding SIC codes from Compustat.

4. 17 announcements were coded as part of the alliance agreement, when it was not to be considered. Manual validation revealed that although these agreements involved the development/distribution of the complementary product, a primary product firm was not involved.

For example –

"Imation and Panasonic Announce Joint Development of SuperDisk Drive For USB Interface Availability To Coincide With First Shipments Of New Apple iMac"

Such errors cannot be eliminated programmatically without significant complexity into the program.

To establish the validity of the content analysis software program, I also conducted a manual procedure for identifying the strategy.

Manual Validation results: Summary of manual validation by another individual (with a non computer background) not involved in the data collection process is provided below

H. Manual validation checks conducted for the accuracy of the software program

	No of lines examined	Missed cases	Reasons	Correction procedure
Sequential checking	100	4	*2 cases: Complement was not part of the master list* ⇒ *2 cases: program cannot handle, too complex- identified above* ⇒	Complements were verified with two industry experts and added to the master list Cannot be handled by the program
	75	3	*Errors by coder : (due to unfamiliarity/insufficiency of coding rules)* a. identified software as complement, but there was no product associated with the release ⇒ b. identified back-up technology agreement as a strategy, but it was not directly related to any complement c. mistake	Coder was informed of the errors and asked to code the next set of lines accordingly
	50	4	*1 case: complement was not part of the master list* ⇒ *3 cases: program cannot handle, too complex- identified above* ⇒	Complement was verified with two industry experts and added to the master list Cannot be handled by the program
Random checking:	100	3	3 cases: program cannot handle, too complex- identified above ⇒	Cannot be handled by the program
	50	2	: program cannot handle, too complex- identified above ⇒	Cannot be handled by the program

VITA

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Dissertation Committee

Dr. V.K. Narayanan (***Chair***), Dr. Sucheta Nadkarni, Dr. Donna DeCarolis Dr. Konstantinos Serfes, Dr. Daniel Tzabbar, Dr. Susan K. Cohen (University of Pittsburgh)

Bachelor of Engineering (Electronics & Telecommunication), June 1998*, Shivaji University, Maharashtra, India*

RESEARCH

1. Dissertation

Essays on Complementary Products and Strategies, Defended on June 03, 2014

2. Conference Presentations

"Team Mental Model Characteristics and Performance in a Simulation Experiment (with Yang, Y., Narayanan, VK & Swaminathan, S." Presented at the Academy of Management Conference. Boston, MA, August 2012.

"The Cognitive Architecture of Innovation" Presented at the PDW "Cognition in the Rough" at the Academy of Management Conference. Montreal, Canada, August 2010.

"Relational and Legitimation Perspectives on the Alliance Management Function" (with De Carolis, D.) Presented at the Academy of Management Conference. Anaheim, California, August 2008.

"The Impact of Social Networking Technology on Information Seeking for Entrepreneurs." (with Tribbitt, M. & Anandarajan, M) Presented at Drexel University Research Day, Drexel University, Philadelphia, April 2009.

3. Manuscripts

Baburaj, Y., co-authored with Yang, Y., Narayanan VK & Swaminathan S., "Team Mental Model Characteristics and Performance in a Simulation Experiment"

Baburaj, Y., Narayanan V.K., & Tzabbar D. "A conceptual framework for Product Complementarity"

Baburaj, Y., co-authored with Narayanan, VK., "Five Forces Framework", *Palgrave Encyclopedia of Management, 2013*.

TEACHING

1. Course Taught

Strategy and Competitive Advantage (MGMT 450)
Course Evaluation: 3.09/4.0; 3.14/4.0; 3.32/4.0

Management Simulation (MGMT 451)
Course Evaluation: 3.40/4.0; 3.47/4.0

2. Manuscripts

Strategy Toolkit for MBA students, co-authored with Tribbitt M.

SERVICE

Academy of Management Reviewer for the TIM and BPS divisions for 2008, 2009, 2010, 2011, 2012, 2014

Organizer at the Eastern Academy of Management, 2012, Philadelphia, PA.

Session coordinator for Business Professor Teaching Summit, 2012, Drexel University, Philadelphia, PA.

PROFESSIONAL WORK EXPERIENCE

Sept 2004 to June 2006

Senior Software Engineer, *IBM Global Services India Ltd, Pune, India*

Sept 1998 to June 2004

Senior Software Engineer, *Patni Computer Systems Ltd, Pune, India*