The Adoption of New University Technology for Product Innovation: A Core Competence Perspective

by

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A thesis

presented to the University of Waterloo

in fulfillment of the

thesis requirement for the degree of

Doctor of Philosophy

in

Management Sciences

Waterloo, Ontario, Canada, 2001

0-612-65266-1

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ABSTRACT

Firm-university relationships tend to develop when universities are considered as sources of technological innovation or sources of R&D assistance to innovative activities taking place in industry. These relationship have tended to be examined from a public policy perspective with the aim of understanding the motivations driving them and understanding how to improve the mechanisms involved in the transfer of technology.

Little is known, however, about the firm's perspective on the adoption of new university technology for product innovation. This research addresses this gap by examining the strategic contribution made by new university technologies to firms' product innovation. Building on strategic management and innovation theory, this work evaluates the degree of association between the new technology and a firm's core competencies. A new construct, core competence association, is defined and measures developed to evaluate the degree to which new university technology is associated with a firm's core competencies. In addition, platform product orientation, future market orientation, tacitness of technological knowledge and technology lifecycle stage have been measured. Using a survey instrument, data have been collected for 65 examples of product innovation within the information and communications technology sector.

The results indicate that firms are two times more likely to adopt new university technology that is closely associated with their core competencies than technology that is not. It is also found that the degree of association with core competencies is positively related to platform product and future market orientations, tacitness of knowledge and infancy in the technology lifecycle stage. By establishing empirical linkages between core competencies and product innovation, the research provides fresh support for the resource-based view of the firm. It also contributes to public policy by highlighting the efficacy of new university technology in platform product innovation and in building core competencies.

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Dr. Paul Guild, for his mentoring and guidance on both small and big issues of this research. He has always been a motivator and encourager – both essential factors needed to keep this work on track.

Thank you to the members of my committee, Dr. J. David Fuller, Dr. John Michela and Dr. James Brox, for offering constructive comments that helped spur me along a path of research plausibility and academic rigour.

Behind the scene, Marion Reid, Lynne Wight, Kimberley Dunne and Pat Anderson have always been ready to do the necessary stuff required to keep the process of administration going. Thanks.

A number of my graduate student colleagues provided helpful and stimulating discussions from time to time and generally made the research task more pleasurable. Doug Sparkes, Enrique Diaz De Leon and John Jordan stand out in this regard.

The biggest thank you goes to my wife, Janette, for allowing me to pursue this goal and for being prepared to move to yet another new country with all the risks, trials and hardships that entails. My children, likewise, deserve a special thanks for enduring all the upheavals.

Finally, I gratefully acknowledge the financial support provided for this research by the Natural Sciences and Engineering Research Council through its Post Graduate Scholarship, the Ontario government through its Graduate Scholarship for Science and Technology, the University of Waterloo through its Graduate Scholarships and lastly the NSERC/SSHRC/CIBC/Nortel Chair in Management of Technological Change.

DEDICATION

To my wife Janette,

and to my children Shane, Matthew and Elissa;

and to the Lord for his grace and provision.

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1.0 INTRODUCTION

1.1 Introduction to the Problem

This research examines the role of new university technology as an external source of technological knowledge for product innovation. Recent findings indicate that Canadian universities do 30% of all national research, with a portion of it being financed by industry. The resulting stream of new ideas and technologies translates into appreciable economic growth and accelerates the development of new products (Martin 1998).

Achieving and sustaining a competitive advantage is an enduring challenge for firms (Black and Boal 1994; Collis and Montgomery 1995; Barney 1997). Firms tend to specialize in selected business activities in order to become very competitive. These have been called distinctive or core competencies (Selznick 1957; Andrews 1971; Prahalad and Hamel 1990). Remaining competitive requires firms to take a dynamic approach to building and enhancing these competencies (Teece, Pisano and Shuen 1997). Early studies have already provided some empirical support for the resource-based view of the firm (Collis 1991; Harrison, Hall and Nargundkar 1993; Henderson and Cockburn 1994; McGrath, MacMillan and Venkataraman 1995; Maijoor and Van Witteloostuijn 1996; McGrath, Tsai, Venkataraman and MacMillan 1996; Miller and Shamsie 1996). However, further support is still needed (McGrath 1996).

Innovation plays a vital role in maintaining the flow of products with differential advantage (Porter 1983). The firm's strength in innovation is dependent on its internal technological knowledge base. Since this is a limited resource, firms often rely on inter-firm relationships, such as strategic alliances, joint ventures and networks, as a means of accessing external technological knowledge for innovation. This has proven to be a fruitful area for strategy research (Hagedoorn and Schakenraad 1994; Kotabe and Swan 1995; Steensma 1996; Dutta and Weiss 1997).

Another approach is for firms to adopt new technologies from the public sector (Leonard-Barton 1995). Universities, as sources of new technology (Grigg 1994), are of particular interest because they are not in direct competition with other firms. In addition, new university technologies are likely to be radical in nature because of their respective science bases (Betz 1994). Acquiring and commercializing new university technologies (NEUT) for the first time is therefore an important means of staying current with technological advances in an environment of rapid technological change (Dosi 1982; Tushman and Anderson 1986; Granstrand, Patel and Pavitt 1997)[1].

Firm-university linkages occur in a wide variety of forms (Bonaccorsi and Piccaluga 1994) and appear to be an increasingly important phenomenon. Most academic literature focuses on improving the quality of these relationships from a public policy perspective (Grigg 1994; Lee 1996; Shohet and Prevezer 1996; Leoncini 1998; Martin 1998). One recent study has examined the contribution of public sector scientific and technological knowledge to the firm (Faulkner and Senker 1995), yet there remains an absence of theoretical and empirical work that examines the adoption of new university technology in the context of product innovation and firm performance. This, therefore, is an area ripe for investigation.

1.2 Problem Statement

Past research on external technology adoption has focused on comparing internal development with external sourcing. This "make-vs-buy" literature and associated core

[1] The reader is referred to Appendix G for a discussion of science, technology and innovation, and Appendix H for a discussion of firm-university relationships.

competence framework suggests that firms must focus their scarce resources on the internal development of core competencies while sourcing non-core items and services from outside.

This highlights a lack of current understanding concerning the nature of the adoption of NEUT for product innovation and whether or not it is strategically associated with firms' core competencies. In other words, it is not a question of whether or not to adopt external university technology, but whether or not it should be linked with building core competencies. This research, then, is a comparitive study of two "buy" alternatives rather than the traditional "make-vs-buy" alternatives and can be summed up in the following research question:

Research Question 1

"When NEUT is adopted by firms for use in product innovation, is there a preference between NEUT that is associated with the firm's core competencies and NEUT that is not?"

Closely linked to the above is the issue of differences between these two situations. This can be examined in a number of ways, such as by looking for differences in the characteristics of new technology used in the two alternative situations or by examining the resulting application of the products that arise from these new university technologies. This leads to the second research question:

Research Question 2

"When NEUT is adopted by firms for use in product innovation, are there differences in the characteristics of the NEUT between instances where it is associated with the firm's core competencies and instances where it is not?

1.3 Focus of the Study

This study is conducted within the context of the information and communications technology (ICT) sector. The focus of the research is the adoption of new university-based technologies for product innovation by established Canadian firms. Other forms of firm-university links such as multi-party collaborations, consulting, use of facilities, and R&D not related to product innovation are outside the scope of this study.

2.0 THE RESEARCH MODEL

2.1 The Core Competence Framework

2.1.1 The Resource-based View of the Firm

The fundamental strategic challenge for managers is how to achieve and sustain competitive advantage leading to superior performance (Porter 1985; Amit and Schoemaker 1993). Superior performance, or above normal economic return (Porter 1985), is achieved when the rate of return on the resources controlled by the firm is greater than what was needed to attract them. In other words, the return is greater than what was expected by the original owners (Barney 1994, p. 116).

According to the industrial organization analysis approach, the firm's organizational competencies and resources are evaluated in terms of strengths and weaknesses and matched appropriately to environmental opportunities (Andrews 1971; Porter 1985; Mahoney and Pandian 1992). The resource-based perspective complements this by viewing firms as bundles of resources that yield competitive advantage. It maintains that superior returns are generated from internal resources and capabilities that are rare, inimitable, non-substitutable and valuable (Wernerfelt 1984; Aaker 1989; Barney 1991; Barney 1992, p. 44; Peteraf 1993). Put another way, the "type, magnitude, and nature of a firm's resources and capabilities are important determinants of its profitability" (Amit and Schoemaker 1993, p. 35). Thus resources and capabilities are a source of uniqueness for the firm and are heterogeneously distributed across firms (Penrose 1959, p. 25, 75; Barney 1991; Peteraf 1993). A key dimension of strategy formulation, then, may be identified as the task of making appropriate choices about expenditures with a view to accumulating the required resources (Dierickx and Cool 1989).

This approach goes back to the original work of Penrose (1959) and later developed by Wernerfelt (1984; 1995) and various other scholars (Lippman and Rumelt 1982; Nelson and Winter 1982; Teece 1982; Barney 1989; Dierickx and Cool 1989; Teece, Pisano and Shuen 1990; Barney 1991; Conner 1991). The firm is looked upon as "a collection of productive resources the disposal of which between different uses and over time is determined by administrative decision" (Penrose 1959, p. 24). These productive resources give rise to services that are the inputs to the production process (Penrose 1959, p. 25). When resources are valuable, rare, difficult to imitate, and without substitute, they are potential sources of sustainable advantage since they result in resource barriers that other firms find too costly to imitate (Wernerfelt 1984; Barney 1994, p. 119).

Resources have been described as stocks of assets (Dierickx and Cool 1989), both tangible and intangible, which are tied semi-permanently to the firm (Caves 1980); stocks of available factors that are owned or controlled by the firm (Amit and Schoemaker 1993, p. 35); or "anything which could be thought of as a strength or weakness of a given firm" (Wernerfelt 1984, p. 172). They may be tangible physical and human resources such as capital equipment and the skills of individual employees (Penrose 1959, p. 24) or intangible resources such as patents and reputation (Black and Boal 1994).

Capabilities may be viewed as the various ways in which resources are put to productive use (Amit and Schoemaker 1993, p. 35) or the capacity for a set of resources to perform a task or activity (Schulze 1994, p. 130). They are the glue that brings resources together and enables them to be deployed advantageously (Day 1994, p. 38).

2.1.2 Core Competencies

At a higher level of abstraction, a competence is "a set of differentiated skills, complementary assets, and routines that provide the basis for a firm's competitive capacities and sustainable advantage in a particular business" (Teece et al. 1990, p. 28). It is viewed as a bundle of skills and technologies rather than a single discrete skill or technology that enables a company to deliver value by providing a particular benefit to the customer. Competencies represent the synthesis of a variety of skills, technologies, and knowledge streams (Prahalad and Hamel 1990; Hamel 1991; Hamel and Prahalad 1994).

Those fundamental abilities that the firm is uniquely good at in a competitive sense have been called distinctive competencies (Selznick 1957; Andrews 1971, p. 47). They enable the firm to perform business activities particularly well compared to its competition (McKelvey and Aldrich 1983) and are sources of competitive advantage leading to superior performance (Mahoney and Pandian 1992, p. 364; Peteraf 1993, p. 185). These competencies evolve as the firm discovers more valuable ways of using its resources and capabilities compared to its competition (Penrose 1959, p. 24; Barney 1994, p. 118), either by producing more economically and or by better satisfying customer wants (Peteraf 1993, p. 180).

Similarly, "core competencies" define the absolute minimum resources and value-added skills that are at the very core of the business (Prahalad and Hamel 1990; Quin and Hilmer 1994; Quin 1999). They make a significant contribution to customer-perceived value and contribute to the competitiveness of a range of products or services. They last longer than individual products or services, do not diminish with use, but are enhanced as they are applied and shared (Prahalad and Hamel 1990; Hamel 1991; Hamel and Prahalad 1994). Firms must perform them better than their competitors, strive to maintain world leadership in them and maintain control over their development by deploying internal resources (Hamel and Prahalad 1989; Welch and Nayak 1992; Lei 1997; Petts 1997; Tidd and Trewhella 1997).

Lei defines a core competence as "the bundle of firm-specific knowledge, skills, technological capabilities and organisation that form the basis of the firm's ability to create value in ways that other competitors cannot do so easily" (Lei 1997, p. 211). Core competencies can also be thought of as "consisting of bodies of technological expertise (both product and process) and organisational capacity to deploy that expertise effectively" (Coombs 1996, p. 346). They have an internal structure that is composed of a number of capabilities that are mapped more closely onto technologically defined domains of knowledge and expertise. It is this ability to combine appropriate capabilities into specific competencies that is embodied in the organisational dimension of a core competence (Coombs 1996). Thus core competencies are the collective learning of the organization that relates to harmonizing multiple streams of technology and coordinating diverse production skills (Prahalad and Hamel 1990; Hamel and Prahalad 1994).

Leonard-Barton uses the term "core capability" synonymously with core competence. She defines it as "the knowledge set that distinguishes and provides a competitive advantage" (Leonard-Barton 1992, p. 113). The knowledge set is core if it "differentiates a company strategically" (Leonard-Barton 1992, p. 111). There are four dimensions to this knowledge set: the employee knowledge and skills in which the contents are embodied; the technical systems in which the contents are embedded; the managerial systems that guide the processes of knowledge creation and control; and the values and norms which are associated with the various types of knowledge and control processes. Knowledge and skill sets (Quin and Hilmer 1994) encompass both firm-specific techniques and scientific understanding. Knowledge embedded in technical systems results from the accumulation, codifying and structuring of tacit knowledge and includes both information and procedures. Managerial systems represent the formal and informal ways of creating knowledge. The interaction between product development projects and core capabilities is affected by how well aligned are the values, skills, and managerial and technical systems required by the project with those currently prevalent in the firm (Leonard-Barton 1992).

In order to be core, competencies must meet at least three distinguishing criteria (Prahalad and Hamel 1990). First, they should exhibit extendibility by providing potential access to a wide variety of markets. Thus they are the gateways to tomorrow's markets. Second, they should provide customer-perceived value by delivering a significant contribution to the perceived customer benefits of the end products. Likewise, core competencies should produce value at a best-in-class standard (Coyne, Hall and Clifford 1997). Third, core competencies should be difficult for competitors to imitate, and will be so if they are a complex harmonization of individual technologies and production skills (Prahalad and Hamel 1990; Hamel and Prahalad 1994). Thus they should be distinctive relative to competitors' competencies (Gorman and Thomas 1997). Building on the above works, we define core competencies as follows:

> "Core competencies are those combinations of complementary knowledge and skill bases that are difficult for competitors to imitate; they enable the firm to execute one or more critical processes that create substantial customer value in a wide variety of ways and at a best-in-class standard. Core competencies are embodied within the firm's personnel, are embedded within the technical and managerial systems and are shaped by the firm's culture."

The core competence concept, though widely discussed in the literature and adopted by practitioners to varying degrees, (Petts 1997) is not without its difficulties. At the conceptual level, it is mainly descriptive rather than analytical since its origins lie in early exploratory case studies (Prahalad and Hamel 1990; Unland and Kleiner 1996). At the language level, the various meanings associated with terms and symbols such as skills, abilities, capabilities and competencies make precise definitions more difficult (Prahalad and Hamel 1990; Leonard-Barton 1992; Hamel and Prahalad 1994; Coombs 1996; Javidan 1998). This has resulted in cross-industry variation in the meaning of core competence, how core competencies should be identified and how the concept might best be implemented (Unland and Kleiner 1996; Coyne et al. 1997). Thus the core competence concept does not render easily to empirical testing although there is a small but growing work in this area (McGrath 1996). Finally, initiatives for integrating the resource-based stream with the positioning stream of strategy is ongoing, but lagging behind practice (McKiernan 1997). Thus, for the practitioner, the core competence concept has not provided an easily assimilated framework for managers to use (Coyne et al. 1997; Petts 1997). Nonetheless, core competence is an important concept for the firm and has implications for firm-university innovation.

2.1.3 Building Core Competencies

This study is concerned with core competencies that are technological in nature, such as Honda's expertise in engines or Canon's competence in miniaturisation (Prahalad and Hamel 1990). The work of natural selection forces results in a dynamic environment which affects these core competencies (Nelson and Winter 1977; Porter 1980; Porter 1985). For example, the perceived-value that customers associate with a core competence may change over time (Collis 1994; Petts 1997; Mascarenhas, Baveja and Jamil 1998).

From the 1970s to 1980s, Japanese car producers were differentiated by their superior reliability: an important value element for customers of motor vehicles at that time. But by the mid 1990's Western car manufacturers had closed the quality gap and reliability had become a prerequisite for every car manufacturer (Hamel and Prahalad 1994, p. 211). Consequently, a competence may gradually *evolve* from core to non-core as its importance decreases due to the changing external environment or from non-core to core as its importance increases.

Since core competencies are such an important source of competitive advantage (Hamel 1991; Day 1994; Hamel and Prahalad 1994; Marino 1996; Granstrand et al. 1997), firms need a dynamic approach to managing their changing effectiveness (Leonard-Barton 1992; Teece et al. 1997). One way is to strengthen *existing* core competencies through improvements or additions to underlying resources and capabilities, thus maintaining superiority over competitors' competencies in terms of uniqueness, inimitability and customer value generation (Prahalad and Hamel 1990; Hamel 1991; Hamel and Prahalad 1994; Cravens, Greenley, Piercy and Slater 1997; Gorman and Thomas 1997). Consider, for example, if Honda had acquired a NEUT related to improved engine vibration cancellation. If this technology enabled engine speeds to increase by 50% while limiting increases in vibration levels to only 10%, then it would clearly fall within the expertise of designing high revving, vibration free engines. The outcome of this is that Honda could produce cars that are more powerful and faster, yet remain smooth and comfortable for the driver. Thus it enhances the specific customer-perceived value for which Honda is noted.

Other situations might require the creation of *new* core competencies (Petts 1997; Javidan 1998; Mascarenhas et al. 1998). This happens when a decision is made to build a new core competence with new abilities that do not currently exist, or the decision is made to re-configure existing abilities into a new core competence.

Building core competencies may be viewed as an investment mode of R&D (Coombs 1996). It is concerned with the accumulation over time of selected stocks of assets (Dierickx and Cool 1989) that results in a portfolio of technological capabilities which feed into core competencies. This accumulation may be through internal development or through selective acquisition from external sources. Technologies, however, vary in their degree of strategic value. "Enabling" technologies, for example, are essential to the quality and efficiency of the design, manufacture and delivery of the company's products or services. They are, however, broadly available to members of the industry and therefore offer little strategic value (Whelan 1989; Przybylowicz and Faulkner 1993, p. 33). "Strategic" or "key" technologies, on the other hand, differentiate the firm from its competition by enabling it to provide greater value to its customers. They are proprietary to some degree and firms seek to control them (Whelan 1989; Welch and Nayak 1992; Przybylowicz and Faulkner 1993, p. 33; Tidd and Trewhella 1997, p. 370).

This research focuses on the adoption by firms of new external technologies developed by universities. It is concerned with understanding whether these technologies are associated with the core competencies of the firms that adopt them. A new construct, "Core Competence Association," has been developed to measure the contribution made by NEUT to enhancing existing or building new core competencies. For example, a new technology that enhances an existing customer-perceived value or enhances an existing reputation of the firm would be considered to be closely associated with the firm's core competence. Likewise, a new technology that strengthens an existing technology capability that is strategic to the firm or one that distinguishes the firm from its competitors would be considered to be closely associated with the firm's core competence (Prahalad and Hamel 1990; Hamel and Prahalad 1994). The following sections advance a theoretical framework for understanding why firms would or would not adopt NEUT as part of a core competence building agenda.

2.1.4 The Strategic Outsourcing Perspective

The outsourcing or make-vs-buy literature has been developed considerably during the last decade. It has been addressed largely by two theoretical views, namely, transaction cost analysis and strategic behaviour. Transaction cost analysis is concerned with organisational efficiency (cost plus benefits) and short-term tactical considerations (Williamson 1989), whereas a strategic behaviour perspective focuses on organisational effectiveness and the longer-term competitive considerations (Andrews 1971).

The main stream of this literature focuses on the manufacturing sector in the context of Western companies that have often lacked competitiveness. Thus, external sourcing of high quality components for manufacturing was viewed as a way of reducing cost and thereby increasing competitivness (Venkatesan 1992). This approach assumed that competitive position was the primary deteminant of competitive advantage (Porter 1980).

This assumption, however, has been called into question by proponents of the resource-based view of the firm who argue that competition is as much a "race to learn" through the accumulation of skills and competencies as it is a battle for product-market position (Hamel 1991; Bettis, Bradley and Hamel 1992, p. 14; Sako 1994). The improper use of outsourcing, it was argued, could lead to a decline in competitiveness and a "hollowing out" of the corporation through the erosion of core competencies (Bettis et al.

1992, p. 7; Miles and Snow 1992). In response to this criticism, outsourcing proponents have embraced the strategic concepts of long-term capability or competence building as necessary to competitive advantage. The traditional cost analysis rationale for make-buy decisions was augmented with the need to maintain and build in-house the technological competencies. These were the core activities that provided value for the customer, which were done better than the firm's rivals and which were the main source of competitive advantage in the present and projected future. Thus the outsourcing decision involved a strategic process requiring the identification of core or strategic components that render crucial differential advantage to a product (Murray and Kotabe 1999). These must be sourced internally while non-critical components could be outsourced (Venkatesan 1992; Welch and Nayak 1992). Strategic outsourcing frees the firm to redirect valuable internal skills and capabilities to high value-added areas (Murray and Kotabe 1999), thus achieving a balance between the required skills and competencies from internal and external sources (Venkatraman 1997).

This meant that even licensing agreements that allowed "unique access to a particular technology" might not be considered part of core competencies (Hamel and Prahalad 1994, p. 208). Instead, leveraging core competencies against externally available technologies presents an appropriate means of addressing immediate and specific market competition (Venkatesan 1992; Welch and Nayak 1992; Quin 1999). This synthesis of outsourcing and core competence concepts has produced a strategic oursourcing approach that continues to receive support and formalisation through decision making models (Quin and Hilmer 1994; McIvor, Humphreys and McAleer 1997; Quin 1999).

In the context of this research, the above argument supports the view that since

NEUT is an external source of technology, it would only be acquired if it was non-strategic and not associated with the firm's core competencies. Consider again, the case of Honda's competence in engine design and manufacture. If Honda were to acquire a NEUT for enhanced plastic moulding techniques, this would not be related to the firm's core competence of engine design. The effect of this NEUT on firm performance (such as increased sales) may not be significant since it does not enhance the specific customer-perceived value for which Honda is noted. The foregoing discussion may be expressed in propositional form:

Proposition 1a: When NEUT is adopted by firms for product innovation, NEUT that is not associated with the firm's core competencies is prefered over NEUT that is.

However, the strategic outsourcing model may not provide the best framework for explaining the external sourcing of technological capability. For example, the assumptions in manufacturing such as continuous sourcing of quality components at cost effective prices may not apply directly to the acquisition of technological knowledge. The former involves technology embodied in artefacts whereas the latter involves technological knowledge yet to be embodied and applied (Kurokawa 1997). Because of the difficulty identifying and calculating actual costs involved in R&D, transaction cost analyses need to be modified to include benefits such as expected reduction in development cost and shortened development periods (Kurokawa 1997). For example, time to market has often been found to be the overriding factor in determining external technology acquisition for core technologies (Tidd and Trewhella 1997). This leads to an alternative perspective on the adoption of external technologies for core competence building: the technological accumulation view of strategic behaviour.

2.1.5 The Technological Accumulation Perspective

The resources required for innovation are becoming increasing complex and multi-disciplinary (Rosenberg 1976; Rosenberg 1982; Arora and Gambardella 1990). As a result, firms may not be fully self-contained in the knowledge base they need to produce their products or services (Ziman 1991; Grigg 1994). External technologies, therefore, are attractive to firms that do not have the internal capacity or time to develop them or when they are more economical to acquire from external sources (Arora and Gambardella 1990; Atauhene-Gima 1992; Pennings and Harianto 1992; Tidd and Trewhella 1997). Furthermore, the need for complementary external technologies appears to increase as the number of component technologies in products increases (Granstrand and Sjolander 1990; Granstrand, Bohlin, Oskarsson and Sjoberg 1992; Granstrand et al. 1997). For example, Tidd and Trewella (1997) found that some pharmaceutical firms acquired technologies that could be bolted onto existing products.

A technological accumulation approach enables the organisation to respond quickly to inevitable changes in product and process technology taking place in industry, and it provides a rational basis on which to build or sustain a competitive advantage over a period of years (Bettis et al. 1992). Consequently, some argue that firms can look externally to acquire core capabilities if they are available from non-competing sources (Kurokawa 1997; McIvor et al. 1997). Grandstrand and Sjolander (1990) noted, for example, the increased tendency of Swedish companies to use technology acquisition to build their base of technology and meet competition (cited in Green, Welsh and Dehler 1996).

Similarly, the focus of the Japanese industry on the manufacture of quality products and the achievement of success in the market place resulted in an emphasis on buying and assimilating technology from any available source (Prahalad and Hamel 1990; Rothwell 1994a). Japanese firms often bought new technology from elsewhere and integrated it with their own technology to produce new products, processes and applications (Bowonder and Miyake 1988; Bowonder and Miyake 1990). Their technological advance was due to the intense efforts to import and assimilate technology, and wherever possible, to improve on the best available technology in the world (Freeman 1987; Freeman 1987; Bowonder and Miyake 1990).

During the 1970s to 1980s NEC built up competencies in semiconductors rapidly and at low cost through strategic alliances aimed at the acquisition of foreign technologies. As NEC's Director of Research summed up: "From an investment standpoint, it was much quicker and cheaper to use foreign technology. There wasn't a need for us to develop new ideas" (Prahalad and Hamel 1990, p80). Similarly, Sony licensed the new transistor technology from Western Electric in 1953 and proceeded to improve its performance to a level adequate for the pocket transistor radio[2]. Furthermore, a recent Industrial Research Institute's survey confirmed that Japanese companies gained far greater benefits from university programs in terms of research collaboration to build technological capability than their US or European counterparts (Roberts 1995).

These observations agree with product innovation theory that high innovation performance is characterized by proactive new technology acquisition (Cooper 1984). The technology accumulation view of strategic behaviour, therefore, offers considerable support for building core competencies with external technologies.

[2] From a case study on Sony in course T841 by The Open University, UK, 1997

This leads to an alternative research proposition:

Proposition 1b: When NEUT is adopted by firms for product innovation, NEUT that is associated with the firm's core competencies is prefered over NEUT that is not.

2.2 Characteristic Differences in NEUT

This section explores four characteristics related to NEUT that may be expected to differ between those situations where NEUT is associated with core competencies and those where it is not. Two of these, platform product orientation and future market orientation, relate to the application of NEUT in the product. The other two, tacitness of knowledge and technology lifecycle stage are characteristics of the NEUT itself.

2.2.1 Platform Product Orientation

Classical product life cycle theory considers market-related influences on product category as it progresses through the stages of introduction, growth, maturity and decline (Levitt 1965; Cox 1967; Polli and Cook 1969). Product/process life cycle theory extends this by considering product and process technology influences throughout the product life cycle. It argues that there is more product technology innovation early in the lifecycle when market uncertainty is high. In the later stages as market uncertainty diminishes there is more process technology innovation and the focus shifts to cost and production economies (Utterback and Abernathy 1975; Hayes and Wheelwright 1984). Thus "major systems innovations" are "followed by countless minor product and system improvements" (Abernathy and Utterback 1978, p. 41). These are represented by platform family products on one hand and product extension or derivative products on the other (Wheelwright and Clark 1992; Tatikonda 1999). Thus product/process life cycle theory suggests that new platform family products are more likely to occur early in the life cycle, and derivative products are more likely to occur later in the life cycle. Thus product/process life cycle theory might help to explain that NEUT will more likely be used to create future platform family products when it is associated with core competence than when NEUT is not associated with core competencies. Thus,

Proposition 2: Products based on NEUT will tend to be more like platform family products when NEUT is associated with the firm's core competencies than when NEUT it is not associated with the firm's core competencies.

2.2.2 Future Market Orientation

Corporate strategy attempts to define "what business" the firm is in or ought be in (Andrews 1971, p. 28). One approach to corporate strategy assumes that the superior profitability is achieved primarily by linking the firm to its environment in such a way as to establish a competitive position. This "outside-in" process (Javidan 1998, p. 60) involves identifying industry structure, addressing the five competitive forces and developing a defensible market position often referred to as product-market positioning (Porter 1980). The technology development decision is then made based on an evaluation of the strengths and weaknesses of the firm in response to threats and opportunities presented by the environment (Porter 1980).

Management by core competence, on the other hand, is an "inside-out" process (Javidan 1998, p. 60) that requires firms to identify core competencies and develop strategic architectures based on a strategic intent (Hamel and Prahalad 1989; Prahalad and Hamel 1990). This process involves identifying streams of technology and market evolution resulting in a foreseeable pattern of industry evolution. Core competencies thus identified and developed are the well springs of new business development and the gateways to creating new markets where competitors do not already exist. They influence the selection of markets, guide patterns of market entry and enable businesses to adapt quickly to changing opportunities (Prahalad and Hamel 1990; Przybylowicz and Faulkner 1993; Hamel and Prahalad 1994). This is the leveraging side of core competencies which exploits economies of scope, i.e., using core competencies as "the platform from which innovation can jump into new projects" (Prahalad and Hamel 1990; Unland and Kleiner 1996, p. 8; Mascarenhas et al. 1998).

The over-reliance on product-market positioning and subsequent failure to manage by core competencies has been the focus of recent academic debate (Porter 1991; Bettis et al. 1992; Prahalad 1993; McKiernan 1997). Since core competencies are sources of long-term competitiveness, management by core competence should be seen as a supplement rather than an alternative to product-market positioning (Javidan 1998). The above suggests that a competence-based corporate strategy might help explain why firms would acquire NEUT for building and leveraging their core competencies in order to address new future market needs. Thus,

> **Proposition 3:** Products based on NEUT will tend to address new future markets more when NEUT is associated with the firm's core competencies than when NEUT it is not associated with the firm's core competencies.

2.2.3 Tacitness of Knowledge

The concept of absorptive capacity may offer an explanation for when NEUT might be associated with core competencies. Absorptive capacity is the ability of a firm to recognise the value of new, external information, assimilate it, and apply it to commercial ends (Cohen and Levinthal 1990). It is largely a function of the firm's level of prior related knowledge. Since the firm focuses its scarce resource on its core competencies, it is expected to have a higher degree of absorptive capacity in areas related to its core competence and a lower degree of absorptive capacity in areas outside of its core competence. This means that the firm is better able to assimilate new technological knowledge in its core competence areas (Veugelers 1997). For example, some firms have been found to use external sources of technology to "fill gaps" in their current in-house competencies (Tidd and Trewhella 1997, p. 369; Lowe and Taylor 1998). Likewise, "when research results can be used within an existing technological system, the research has often been rapidly and successfully transferred" (Betz 1994, p. 789).

A higher degree of absorptive capacity also implies an increased ability to absorb knowledge. Tacit knowledge is more difficult to transfer than explicit knowledge. Tacit knowledge may be identified with *knowing how* as distinct from *knowing about* facts and theories identified as explicit knowledge (Grant 1996). It resides within the individual researcher and cannot easily be codified or written down (Polyani 1958)[3].

Tacit knowledge is revealed through its application by oral transmission or repeated observation of practice (Bettis et al. 1992; Bonaccorsi and Piccaluga 1994; Grant 1996). Since science is largely person-embodied (Pavitt 1991), NEUT often comprises knowledge having a large degree of tacitness (Nelson and Winter 1982) requiring extensive oral transmission or personnel mobility. The transfer of tacit knowledge between people is slow, costly and uncertain (Kogut and Zander 1992; Zander and Kogut 1995).

[3] See Nonaka (1994) and Zander and Kogut (1995) for reviews of the dimensions of knowledge.

As Nelson and Winter (1982, p. 82) point out, "whether a particular bit of knowledge is in principle articulable or necessarily tacit is not the relevant question in most behavioural situations. Rather …whether the costs associated with the obstacles to articulation are sufficiently high so that the knowledge in fact remains tacit." This suggests that tacit knowledge will be transferred more readily in regimes characterised by high absorptive capacity such as within the firm's core competence. For example, Merck's success in pharmaceuticals is often attributed to its legacy of superb medicinal chemistry (Henderson and Cockburn 1994; Mowery, Oxley and Silverman 1996).

Finally, increased tacitness of knowledge also results in increased causal ambiguity (Nelson and Winter 1982) which in turn increases resistance to imitation (Lippman and Rumelt 1982; Peteraf 1993). Thus when NEUT is associated with core competence it is expected to be more resistant to imitation than when NEUT is not associated with core competence. This can be summed up in the proposition:

Proposition 4: NEUT associated with core competencies will tend to have a higher degree of tacitness than NEUT not associated with core competencies.

2.2.4 Technology Lifecycle Stage

Another explanation for when NEUT would be associated with core competencies might be given by innovation theory. The technology lifecycle or s-curve (Foster 1986) can be used to describe the stages of maturity of the technology. New university technologies emerging from the early stage of the s-curve and entering the application stage of rapid growth and adoption represent potentially valuable resources for product innovation (Twiss and Goodridge 1989).

However, such technologies often result from scientific advances in forms not directly useable by industry (Betz 1997). Firms must then apply additional resources to further develop the technology or improve it, often resulting in new innovations and patents (Mazzoleni and Nelson 1998, p. 278). This favours the acquisition of early lifecycle technology for core competence, since the firm's scarce resources, already focused on the core competence, can be readily applied to improving a technology related to the core competence.

For example, a recent study identified one pharmaceutical firm which licensed-in basic cephalosporin technology and used its internal skills to produce a range of these antibiotics, hence adding value to the licensed technology (Tidd and Trewhella 1997). This requires a long-term strategy for technology development with eventual embodiment of the technology in future product innovation. Since development of core competencies is a long-term strategy, innovation theory favours NEUT acquisition for core competence when the technologies are very new and embryonic.

This highlights that early lifecycle technology, when further developed, may emerge in a considerably different form. This process also increases the degree of causal ambiguity (Lippman and Rumelt 1982) which, in turn, helps to prevent would-be imitators from knowing exactly what to imitate or how to go about it (Peteraf 1993). This increasing resistance to imitation offers greater competitive advantage. Thus, since core competencies should be distinctive and hard to imitate, innovation theory helps to explain the adoption of early lifecycle NEUT for core competencies. Conversely, when the new technology is not associated with core competence, less internal resource is available for further development and the new technology should be further along the technology lifecycle and more ready for product application. Thus,

Proposition 5: NEUT associated with core competencies will tend to be less mature in its lifecycle than NEUT not associated with core competencies.

2.3 Conclusion to Chapter 2

Two alternative situations exist when firms adopt NEUT for product innovation. The first is when the NEUT is associated with the firm's core competencies and the second is when it is not. The strategic outsourcing perspective suggests the latter while the technological accumulation perspective suggests the former. These two scenarios have been cast as alternative competing propositions. One aim of this research is to determine which, if any, of these alternatives plays the dominant role.

Four propositions have been offered in relation to the characteristics and application of NEUT. Firstly, when NEUT is acquired in situations where it is associated with the firm's core competencies, the resulting product will tend towards the platform family category. Secondly, when NEUT is acquired in situations where it is associated with the firm's core competencies, the resulting product will be intended to address new future markets. Thirdly, when the transferred technological knowledge is highly tacit in nature, the NEUT will be acquired in situations where it is more closely associated with the firm's core competencies so that regimes of high absorptive capacity are at work. Finally, when the NEUT is in an early stage of its technology lifecycle, it will tend to be acquired in situations where it is more closely associated with the firm's core competencies so that scare and focussed resources can be applied for its further development.

A framework that depicts the constructs discussed above is shown in Figure 1. The next chapter turns to a description of how these constructs can be measured and how the propositions can be tested.

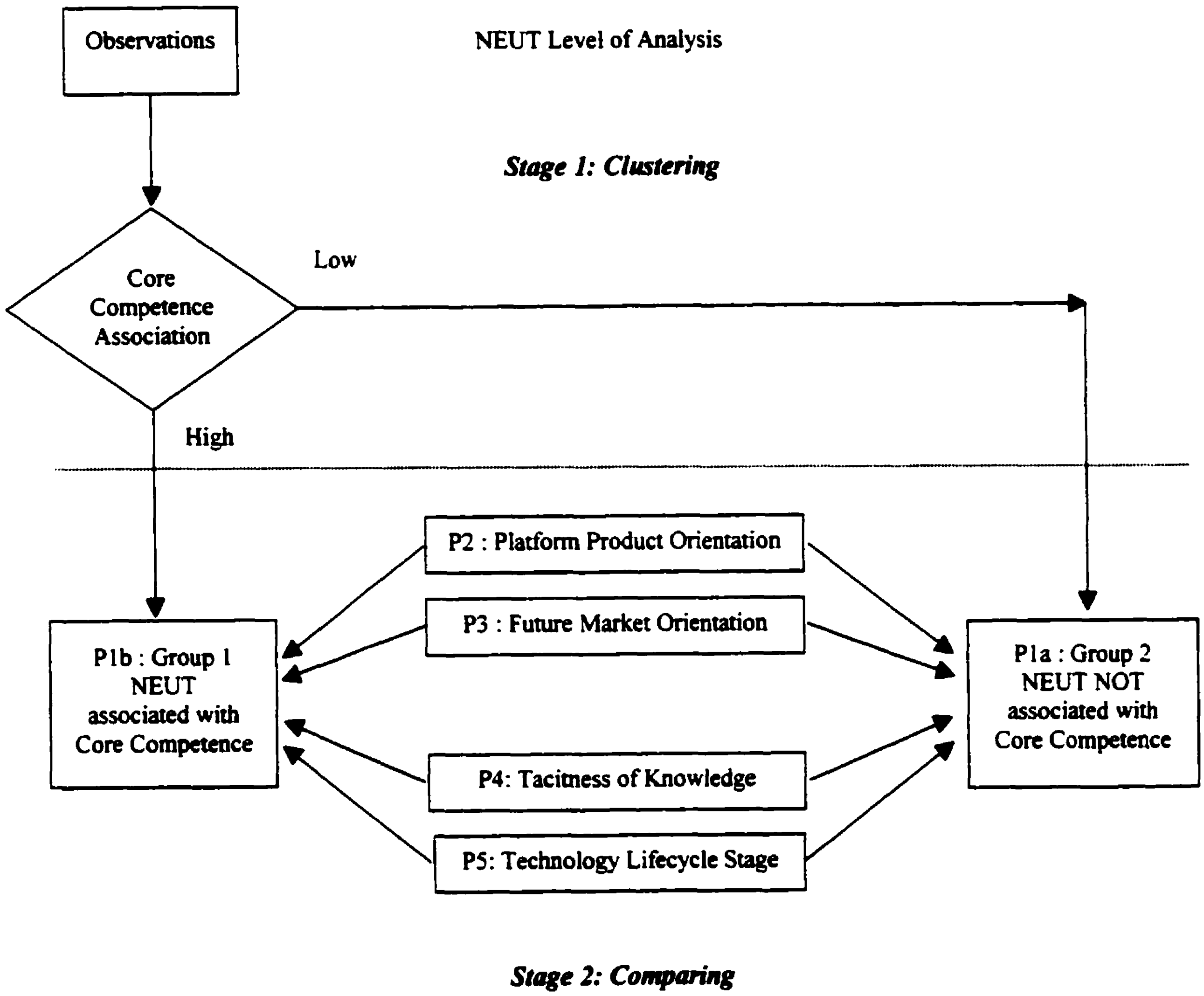

Figure 1: The Research Model

3.0 THE RESEARCH DESIGN

3.1 Description of the Study

This study is conducted in the context of the information and communication technology industry sector (ICT) of Canada. The unit of analysis is the project involving the adoption of a specific NEUT and its application by the firm in the improvement or creation of a new product.

A two-part empirical field study was conducted using survey instruments to collect measures of the research variables and test the propositions. The first part involved a telephone survey of managers in ICT firms that had used NEUT in product innovation. The telephone survey was used to identify projects that matched the research framework and collect categorical data to examine Proposition 1. This yielded a research sample size of 91. A subset of these projects were then selected for participation in the second more detailed web-based survey to collect data to test all the propositions. This yielded a research sample size of 65.

Prior to the empirical study, preliminary fieldwork was performed to help construct the measures and provide support for the theoretical framework. The fieldwork comprised multiple interviews with two firms conducted along the lines of a case study methodology (Yin 1994). An interview protocol was developed beforehand using open and closed-ended questions to collect data about the characteristics and application of NEUT and its relationship to the firm's core competencies. The use of the protocol provided a structure for conducting the interviews in a systematic and objective manner, thus increasing confidence in the reliability and robustness of the information (Yin 1994, p. 36).

The first round of interviews examined the commercialisation of the "hypercube network switch technology" developed at the University of Saskatchewan and adopted by PMC-Sierra Inc. A total of six interview sessions, each of approximately 1.5 hours duration, were conducted with two PMC-Sierra senior staff at the Saskatoon Design Centre. The results were recorded in the interview protocol and a report describing the commercialisation process was written. The report was reviewed by the interviewees and approved by the firm for publication in this dissertation (see Appendix A).

The second round of interviews examined the commercialisation of the "Always-on" DSL technology developed at the University of Saskatchewan and Telecom Research Laboratories and adopted by Critical Control Corporation. A total of three interview sessions, each of approximately 2 hours duration, were conducted with the firm's Chief Technical Officer. The results were recorded in the interview protocol and a report describing the commercialisation process was written. The report was reviewed by the interviewee and approved for publication in this dissertation (see Appendix B).

The studies provided an opportunity for exploring if and how NEUT might be associated with firms' core competencies. Because they were firm specific, it was possible to discuss how the interviewees perceived their firms' core competencies and the relationship with the NEUT. The studies also provided an opportunity to explore proposed research model relationships related to tacitness, technological lifecycle, platform product orientation and future market orientation. In this way the studies provided background support for and confidence in the proposed theoretical framework. Data collected during the interviews also helped to refine some of the measures used. The case reports have been included in the dissertation as examples of how NEUT has been used by firms in developing and shaping their core competencies.

3.2 Data Collection

The recruitment phase of this study posed two major challenges. The first was to identify specific cases of university to industry technology transfer and the second was to determine whether the technology was actually used in product innovation. The search was focussed on the ICT sector of Canada.

The initial step was to contact university technology transfer offices directly and ask for information regarding the licensing of their technologies to industry. Although some information was received, this proved to be relatively unsuccessful since most officers were unwilling to release information citing the confidential nature of license agreements.

It was then decided to use a multi-source approach to identify potential research subjects. The first involved using the NSERC awards listing to identify collaborative R&D research grants. This is a public database that lists the grant details including the topic, researcher, institute and collaborating firm's names. Using a software version of this database for the years 1990 to 1998, search queries were used to identify grants for collaborative R&D research, industrially oriented research, Micronet partnerships, industrial research chairs and strategic projects as well as segregating them according to industry sector, application and firm. The combination of these powerful search queries resulted in identifying over 376 potential university-industry projects out of a database of 80,526 grant records. Further investigation and screening resulted in a pool of 192 potential subjects.

The original 372 potential subjects included 85 project grants associated with the ICT sector giant Nortel. However, it was decided to exclude these 85 from further investigation following discussions with a number of external network contacts. These discussions suggested that it would be quite difficult to confirm whether NEUT adopted by Nortel was used specifically for product innovation and, if so, into which product it was included. One reason cited was that the size and dynamics of the organisation might result in frequent changes to individual responsibilities. Another reason was the complexity of their products making it difficult to pinpoint exactly how the NEUT was used. Thus, the task of tracing the outcome of NEUT could be a difficult and potentially unproductive activity.

The next approach involved tapping into the various science and technology networks and centres of excellence. Using the internet as the data medium, a range of networks were investigated to identify member companies in the ICT sector. The web-sites of potential companies were then researched to gather information about R&D activities, products, senior executives and contact information. The contact person selected was usually a senior executive such as the President. CEO, CTO, Vice-President of R&D or Engineering. The networks and other sources that were investigated are shown in Table 1 below. Using these sources, a combined database of 342 potential projects was created involving 150 firms. This procedure took approximately six months to complete.

The next step involved sending an email invitation to the appropriate executive at each firm informing them of the research and inviting them to participate in a telephone interview. Each email was customised to the individual firm and included information about their NSERC collaborative R&D grants and their membership in science and technology networks. An example email is shown in Appendix C.

BC Advanced Systems Institute (BC-ASI)
CANARIE
Communications and Information Technology Network of Ontario (CITO)
Canadian Institute for Telecommunications Research (CITR)
Canadian Institute for Photonic Innovations (CIPI)
Institute for Robotics and Intelligent Systems (IRIS)
NSERC Awards listing
Mathematics of Information Technology and Complex Systems Network (MITACS)
Micronet Network
Strategic Microelectronic Consortium (SMC)
Synergy University-Industry Awards for R&D Partnerships
Telelearning Network of Centres of Excellence
TRLabs

Table 1. Data Sources Used to Identify Subject Companies and Adoptions of NEUT.

The email was followed by a telephone call within a few days. In most cases, repeated calls were made and messages left before the person could be contacted. The telephone interview had several objectives. The first was to screen the potential projects as research subjects or to identify other projects more suitable. The second was to collect provisional data about the project and the firm and, in particular, the association of the NEUT with firm's core competencies. This information was considered critical to the research in the case of a low response rate to the main survey. The third objective was to invite the person to participate in the more detailed web-based survey. The interviews typically ranged from ten to twenty minutes in duration. In most of the interviews where suitable projects were identified, the person agreed to participate in the main survey. The telephone survey script is shown in Appendix D.

A second email was then sent to the person as a formal invitation to participate in the web-based survey. This included a reference to the specific project that was agreed during the interview, instructions for completing the survey and a hyperlink to the survey web-site. An example invitation email is shown in Appendix E and the web-based survey instrument is shown in Appendix F. After completion of the on-line survey form, each respondent was presented with a new web-page offering a courtesy thank you message. For those who did not respond to the web-based survey within a week, repeated follow-up calls were made and messages left until the survey response was received, or the person declined to participate or the recruitment phase ended.

Responses to the telephone survey were captured during the interview and entered into a custom software database for analysis. Responses to the web-based survey were received as coded email messages. These were compiled into a separate database using the web-based survey software. This database was then imported into a statistical analysis software package.

The active phase of this recruitment began on 19th October 2000 when the first preliminary invitation email was sent and finished on 31th January 2001 when the last survey response was received. During this stage a total of 816 outgoing telephone calls were made and 500 correspondence emails were sent or received.

Of the 342 potential research subjects, 37 cases did not proceed to the telephone interview stage after preliminary invitations were sent either due to difficulty in making contact or the recruitment phase was drawn to a close. Another 212 were screened out as unsuitable as a result of the telephone interview or based on new information prior to the interview. Of the remaining 93 subjects, research data were collected for 91 subjects during the telephone survey of which 80 cases were specific examples of NEUT that was embedded into a product and 11 were cases of design related tools specifically for developing new products. Because these tools resulted in embedding new or improved technological features into the products, the subjects were pooled together with the other 80 cases creating a research sample size of 91. The data covered a time period from 1991 to 2000.

From 91 subjects, 75 were selected for participation in the web-based survey and agreed to do so. Of the 75 invitations to the web-based survey, 67 responses were received achieving an 89.3% response rate for the main survey. Of the 67 responses, one was subsequently found not to fit the research model and one was unuseable due to too much missing data resulting in a final tally of 65 useable responses. Of the eight non-responses, only two executives refused to participate citing insufficient time and four did not respond despite repeated calls and reminders. Two non-responses were associated with second projects from respondents who had already submitted a response to one project.

Most of the subjects were cases of NEUT developed in Canadian universities and used by established Canadian firms. Eight cases differed slightly from this model. These comprised five examples of new technology from non-Canadian universities and used by Canadian firms, one involving Canadian university technology used by a non-Canadian firm, and two involving early stage companies.

3.3 Variables and Measures

The constructs and the research variables used to tap them are listed and described in Table 2 below and in the following sections.

Variable Symbol	Construct Name	Description
CCA	Core Competence Association	The degree to which the NEUT is associated with the firm's core competencies.
PLATF	Platform Product Orientation	The degree to which the new product created from the NEUT was a new platform product.
DERIV	Platform Product Orientation	The degree to which the new product created from the NEUT was an improvement to an existing product line.
FUTMKT	Future Market Orientation	The degree to which the new product created from the NEUT was intended to address a new market in the future.
TACIT	Tacitness of Technological Knowledge	The degree to which the new technological knowledge was tacit in nature.
LIFECYC1	Technological Lifecycle	The degree to which the NEUT had progressed along the technology lifecycle at the point of transfer to the firm.
LIFECYC2	Technological Lifecycle	The perceived amount of future development work needed to be done on the NEUT by the firm to make the product ready for the market.
CLUS1ST	Cluster Case Number	Dichotymous variable used to identify the cluster group membership, i.e., group 1 or 2.
CONTROLS		
FSIZE	Firm Size	The number of people in the firm's division at the time of the technology transfer.
RD	R&D Percentage	The percentage of revenue spent on R&D in the last fiscal year.
DIST	Geographical Proximity	The proximity of the firm to the university.
TTIME	Travel Time	The number of hours taken to travel from the firm to the university.

Table 2. Research Constructs and Their Related Variables

An important consideration during research design was to keep the completion time of the web-based survey instrument to between fifteen and twenty minutes. Since most of the respondents to the survey were senior executives, it was felt that keeping the survey short would increase the participation rate. This proved to be supported during the telephone interview when executives expressed concern over the time the survey might take. By offering a streamlined instrument, almost all invitations to participate were accepted.

The constructs were operationalised as multi-item summative scales where each item taps into a particular attribute of the construct. Seven-point Likert-type scales were used to capture subjective responses, allowing a wide range of perceptions to be measured. Self-assessment measures are a commonly used form of performance assessment in strategy research since senior executives are typically the respondents with the greatest knowledge of their own business and performance (Gatignon and Xuereb 1997). Also, perceptions, rather than objectively measured factors, often determine strategy policy (Bourgeois 1980; Lowe and Taylor 1998) and several studies have demonstrated the convergent validity of such scales (Dess and Robinson 1984; Venkatraman and Ramanujam 1986; Gatignon and Xuereb 1997). Special attention was nonetheless given to reduce potential sources of bias, such as demand characteristics and social desirability response. These included careful ordering of questions to avoid sending cues about the relationships under investigation, constructing questions that do not have socially desirable responses and using reverse-coded items where possible.

Scale reliability was also an important concern. Internal reliability, as measured by Cronbach's coefficient alpha, increases with the number of response alternatives and the number of items in the scale. As noted earlier, the number of measure items was constrained to reduce demands on executives' time and to increase the likelihood of their participation. The number of items per scale in this study ranged from two to eleven as shown in Tables 2 to 6. In a recent study by Murray and Kotabe (1999), scales with only two items and five response alternatives achieved Cronbach's coefficient alpha's of 0.78 and 0.83., However, to facilitate improved reliability, seven response alternatives were used (Cox 1980). This is the modal number of response alternatives for scales reviewed by Peter (1979) and has been used in recent management research (Zander and Kogut 1995; Tatikonda 1999).

The measures were constructed using a multi-step process. The first comprised a review of empirical literature to identify concepts that tapped into the constructs and relevant measures that have been used successfully in past research. The field interviews were then used to provide additional support for the measure items. This included testing provisional measure items with the interviewees. Next, careful wording was chosen to create measures which were as concise as possible. For example, measures were often worded as short half-sentence phrases that could be used with a leading phrase. This allowed several ending phrases to be grouped with one leading phrase as shown in Table 2. In addition, the Likert-scale anchors were worded so as to help focus the respondent's attention. This was done with the aim of improving the reliability of the respondent's perceptions. For example, the scale anchors "does not describe this new university technology at all" and "describes this new university technology exactly" focuses the respondent's attention onto evaluating the new university technology.

The instrument was pre-tested to help identify potential sources of ambiguity, ensure ease of completion and determine the length of time to complete the questionnaire. Pre-testing included internal departmental and external reviewers. In addition, an on-line pilot test of the web-based questionnaire and domain server was carried out to ensure that responses were correctly captured and that the constructed database could be analysed using a statistical package.

After data collection, pre-selected measure items were summed into their representative scales and tested for reliability using Cronbach's coefficient alpha The general procedure for including measure items in the scale was as follows. The coefficient alpha was first determined using all the pre-selected measures. If the alpha was acceptable, (e.g., greater than or equal to 0.7 as suggested by Nunnally 1978), all items were included in the scale. If the alpha was not acceptable, the contributions from individual measures were examined to identify which items degraded the alpha value. Such items were removed one-by-one starting with the item whose exclusion resulted in the greatest increase in alpha. The procedure was stopped when the desired limit was achieved or a maximum value of alpha was obtained. The resulting coefficient alphas are reported in Chapter 4.

3.3.1 Core Competence Association

The core competence association scale taps the degree to which the NEUT is associated with the firm's core competencies. Measure items for this variable were posed in question blocks Q12 and Q13 of the survey (see Appendix F). Respondents were asked to answer the questions from the corporate level perspective. In the instrument, "customers" were defined as the buyers of their firm's products; and "key technologies" as those that are proprietary to some degree and which their firm seeks to control; they differentiated their firm from its competition by enabling it to provide greater value to their customers. Respondents were asked to indicate how well each item described their situation on a seven point scale ranging from (1) "does not describe this new university technology at all" to (7) "describes this new university technology exactly." The higher the score the greater the association between the NEUT and the firm's core competencies.

These items were combined to measure core competence association in two different ways. Initially, the measure items were used as cluster variables in a multivariate cluster analysis, described later in this chapter. During this procedure, only those measure items that resulted in a reliable and robust cluster model were selected. This selection of items, shown in Table 2 below, was then combined into the multi-item scale (denoted CCA) and tested for internal reliability as reported in Chapter 4.

Core competence association was also measured during the telephone survey. Participants were asked to rate the association of NEUT to their core competencies by selecting one of the following three response alternatives:

- unrelated to our firm's existing core competencies
- helps strengthen our firm's existing core competencies
- helps build a new core competence for our firm.

MEASURE ITEMS	REFERENCE
12.1 Controlling this new university technology will be very important to our competitiveness.	(Przybylowicz and Faulkner 1993, p33; Hamel and Prahalad 1994, p. 210; Quin and Hilmer 1994, p. 47; Tidd and Trewhella 1997, p. 370)
12.2 We would have a distinct advantage if our competitors did not have access to this new university technology.	(Prahalad 1993, p. 45; Hamel and Prahalad 1994, p. 205; Tidd and Trewhella 1997, p. 370)
12.3 We will continue to invest in this new university technology for a significant period of time.	(Prahalad and Hamel 1990, p. 89; Mascarenhas et al. 1998, p. 125)
This new university technology ...	
13.1 ... will be useful for a significant period of time.	(Prahalad and Hamel 1990, p. 82; Hamel and Prahalad 1994, p. 200, 206; Quin and Hilmer 1994, p. 45, 47)
13.3 ... will increase the value our customers perceive of our products.	(Prahalad and Hamel 1990, p. 84; Prahalad 1993, p. 42; Hamel and Prahalad 1994, p. 204, 205; Quin and Hilmer 1994, p. 45; Cravens et al. 1997, p. 497)
13.4 ... is likely to be deployed across a range of our products.	(Prahalad and Hamel 1990, p. 89; Hamel and Prahalad 1994, p. 198, 206)
13.5 ... has exceptional synergy with our existing strategic capability.	(Unland and Kleiner 1996, p. 8; McIvor et al. 1997, p. 172; Tidd and Trewhella 1997, p. 369)
13.6 ... will help build a new strategic capability.	(Prahalad and Hamel 1990, p. 80; Hamel and Prahalad 1994, p. 214; Lei 1997, p. 221; Petts 1997, p. 554)
13.8 ... will improve one of our existing key technologies.	(Przybylowicz and Faulkner 1993, p. 33; Betz 1994, p. 789; Lei 1997, p. 220; Tidd and Trewhella 1997, p. 370)
13.10 ... is likely to replace one of our existing key technologies.	(Przybylowicz and Faulkner 1993, p33; Betz 1994, p. 789; Lei 1997, p. 220; Tidd and Trewhella 1997, p. 370)
13.12 ... is likely to become a key technology some time in the future.	(Przybylowicz and Faulkner 1993, p. 33; Tidd and Trewhella 1997, p. 371)

Table 3. Measures Items Used as the Cluster Variables and in the Variable: CCA

3.3.2 Platform Product Orientation

The platform product orientation was represented by two scales. PLATF taped the degree to which the new product created from the NEUT was a new platform product. DERIV taped the degree to which the new product created from the NEUT was an improvement to an existing product line. Measure items for these variables were posed in question block Q14 of the survey. Respondents were asked to indicate how well each item described their situation on a seven point scale ranging from (1) "does not describe our new product at all" to (7) "describes our new product exactly." The higher the score the greater the product resembles platform or derivative characteristics. Items 14.1 and 14.7, shown in Table 4a below, were *a priori* assigned to the scale PLATF and tested for reliability as reported in Chapter 4.

MEASURE ITEMS	REFERENCE
Our new product ...	
14.1 ... marks the beginning of a new platform family / product line for our firm.	(Song and Montoya-Weiss 1998, p. 126; Tatikonda 1999, p. 4,11)
14.7 ... is unlike anything seen in the marketplace before.	(Gatignon and Xuereb 1997, p. 89; Song and Montoya-Weiss 1998, p. 126; Tatikonda 1999, p. 20)

Table 4a. Measures Items Comprising the Variable: PLATF

Items 14.2 to 14.6 were selected for the scale DERIV and tested for reliability. Item 14.6 was found to degrade the coefficient alpha and was therefore excluded from the scale. The remaining items used are shown in Table 4b below.

MEASURE ITEMS	REFERENCE
Our new product ...	
14.2 ... is an extension of our existing platform family / product line.	(Song and Montoya-Weiss 1998, p. 126; Tatikonda 1999, p. 4,11)
14.3 ... adds new functionality to our existing product line.	(Gatignon and Xuereb 1997, p. 89; Song and Montoya-Weiss 1998, p. 126)
14.4 ... substantially increases the performance level of our existing product line.	(Song and Montoya-Weiss 1998, p. 126)
14.5 ... substantially increases the level of functional integration of our existing product line.	Appendix A

Table 4b. Measures Items Comprising the Variable: DERIV

3.3.3 Future Market Orientation

The future market orientation scale (FUTMKT) taped the degree to which the new product created from the NEUT was intended to address a new market in the future. Measure items were posed in question block Q15 and in question Q16 of the survey. Respondents were asked to indicate how well each item described their situation on a seven point scale ranging from (1) "does not describe our new product at all" to (7) "describes our new product exactly." The higher the score the greater the product is intended to serve new future markets.

Only items 15.3 and 15.4, shown in Table 5 below, combined to provide an adequate coefficient alpha. Items 15.1 and 15.2 were reverse coded measures intended to be combined with items 15.3 and 15.4. However, 15.1 and 15.2 resulted in significant degrading of coefficient alpha and were thus excluded from the scale. Similarly, question 16 was intended to measure the future market orientation of the product but failed to combine reliably with 15.3 and 15.4 and was therefore excluded.

MEASURE ITEMS	REFERENCE
15.3 We expected our new product to serve a market need not addressed by our competitors at that time.	(Hise and Groth 1995, p. 38; Tatikonda 1999, p. 6, 22)
15.4 We expected our new product to address the needs of a newly emerging market.	(Hise and Groth 1995, p. 38; Christensen 1997, p. 19, 24, 41, 44; Gatignon and Xuereb 1997, p. 81)

Table 5. Measures Items Comprising the Variable: FUTMKT

3.3.4 Tacitness

The tacitness scale (TACIT) taped the degree to which the new technological knowledge was tacit in nature. Measure items for this variable were posed in question blocks Q10 and Q11 of the survey. Respondents were asked to answer the questions with respect to the time when the university technology was being transferred to the firm. They were asked to indicate how well each item described their situation on a seven point scale ranging from (1) "does not describe the transfer of this technology at all" to (7) "describes the transfer of this technology exactly." The higher the score the greater the tacitness of the new technological knowledge.

Items 10.1, 11.2 and 11.3 were found to degrade the coefficient alpha and were therefore excluded from the scale. The remaining items, shown in Table 6 below, combined reliably to provide an adequate coefficient alpha.

MEASURE ITEMS	REFERENCE
10.2 To assist with the technology transfer, the university researchers spent an extended period of time at our firm.	(Polyani 1958; Winter 1987; Lei 1997, p. 216; Leonard 1998)
10.3 To assist with the technology transfer, university students who worked on the technology spent some time at our firm.	(Nonaka 1994, p. 19; Lei 1997, p. 216)
10.4 To further develop this new technology, we hired some of the university researchers.	(Nelson and Winter 1982, p. 124; Grigg 1994, p. 295; Teece et al. 1997, p. 525, 526)
11.1 Our technical staff are very knowledgeable in disciplines closely related to those of the university researchers.	(Cohen and Levinthal 1990, p. 128; Saviotti 1998, p. 848, 849)
11.4 Our technical staff needed frequent discussions with the university researchers to fully understand this new technology.	(Polyani 1958; Reed and DeFillippi 1990; Kogut and Zander 1992, p. 389; Nonaka 1994, p. 25; Lei 1997, p. 216; Tidd and Trewhella 1997, p. 372)

Table 6. Measures Items Comprising the Variable: TACIT

3.3.5 Technology Lifecycle

The technology lifecycle scale (Foster 1986) taped the degree of maturity of the technology. University technologies often result from scientific advances in forms not directly useable by industry (Betz 1997). Firms must therefore apply additional resources to further improve or develop the technology (Mazzoleni and Nelson 1998, p. 278).

The measure items used for this construct were posed in question blocks Q8 and Q9. Respondents were asked to answer the questions with respect to when the university technology was being transferred to the firm. They were asked to indicate how well each item described their situation on a seven point scale ranging from (1) "does not describe this new university technology at all" to (7) "describes this new university technology exactly" and (8) "not applicable." Subjects that responded in the "not applicable" category were excluded from the analysis.

Two sets of measures were developed. The first set, represented by the scale LIFECYC1 and posed in question block Q8, taped degree to which the NEUT had progressed along the technology lifecycle at the point of transfer to the firm. Increasing scores represent further progress along the lifecycle curve and increasing readiness of the new technology for application. Item 8.1 was excluded from the scale due to low reliability. Items 8.2 to 8.4, shown in Table 7a below, combined reliably into the scale.

MEASURE ITEMS	REFERENCE
When we received this new technology, the university provided us with ...	
8.2 ... a simulation model or software program that enabled us to evaluate it.	(Betz 1994, p. 792)
8.3 ... a prototype that demonstrated the general principle or concept.	(Betz 1994, p. 793) Appendix B
8.4 ... a prototype that demonstrated the functions of the technology as it should perform in the final product.	(Betz 1994, p. 793)

Table 7a. Measures Items Comprising the Variable: LIFECYC1

The second set of measures, represented by the scale LIFECYC2 and posed in question block Q9, taped perceived amount of future development work needed to be done on the NEUT by the firm to make the product ready for the market. Items 9.1 to 9.5 were reverse-coded. All the items, as shown in Table 7b, combined reliably into the scale.

MEASURE ITEMS	REFERENCE
In order to meet our new product requirements, we changed this new technology by ...	
9.1 ... adding more functions.	(Dosi 1982, p. 153; Foster 1986; Twiss and Goodridge 1989; Faulkner and Senker 1995, p. 145)
9.2 ... improving the performance level.	(Dosi 1982, p. 153; Foster 1986; Twiss and Goodridge 1989)
9.3 ... making major changes to the technical concept.	(Faulkner and Senker 1995, p. 145; Betz 1997, p. 9) Appendix B
9.4 ... making major changes to the physical implementation (such as circuits or software.	(Betz 1997, p. 9)
9.5 ... significantly re-engineering it for production.	(Betz 1997, p. 9)
9.6 We made no major changes to the technology.	

Table 7b. Measures Items Comprising the Variable: LIFECYC2

3.4 Clustering Methodology

The first step in the data analysis stage of this research was to classify the data according to whether or not the NEUT was associated with the respective firm's core competencies. These two groups were not identifiable *a priori*, i.e., membership of each subject could not be known a priori by some categorical variable. Cluster analysis was therefore the appropriate statistical technique to group the subjects according to a set of similar characteristics, i.e., groups that exhibit high internal (within-cluster) homogeneity and high external (between-cluster) heterogeneity.

Cluster analysis applications in strategic management research have been subject to some criticism concerning over-reliance on researcher judgement (Ketchen and Shook 1996). This is especially the case when using hierarchical techniques to identify and select the number of clusters and when clusters are formed without any adequate underlying theoretical rationale. A similar concern lies with the selection of clustering variables. For example, when an exploratory classification is performed, neither the clustering variables or the number and nature of resultant groups are tightly linked to deductive theory (Ketchen and Shook 1996, p. 443).

The research method used here sought to avoid these shortcomings by using a deductive approach that closely tied the categories (CCA=Low/High) to explicit theory as outlined previously in Chapter 2. Likewise, the clustering variables used to create the membership assignments were chosen from operation definitions that theoretically taped into the categorical construct. In addition, objective tests were used wherever possible to minimize reliance on researcher judgement.

A non-hierarchical clustering method was used since the number of clusters (two) was predetermined according to prior theory. The clustering process began with partitioning observations into clusters based on initial cluster seeds. Using the *K*-means algorithm[4], cases were reassigned by moving them to the cluster with the closest centroid. These centroids were then recalculated and the cases reassigned once more. This iterative process continued until every case was assigned to the cluster with the closest centroid resulting in a minimum within-cluster variance (Punj and Stewart 1983). By using multiple passes through the data, the final solution optimizes within-cluster homogeneity and between-cluster heterogeneity (Ketchen and Shook 1996). In addition, by allowing observations to switch cluster membership through subsequent passes, the results were less impacted by outlier elements (Hair, Anderson, Tatham and Black 1992).

[4] The Quick Cluster function in the SPSS statistical software package was used.

The first step in ensuring the cluster solution is useful for research was to demonstrate that the solution was statistically different from a random solution (Punj and Stewart 1983), i.e., that the observations did not come from the same population. This was determined using the Wilks' lambda statistic to test the equality of the vectors of means of cluster variables across the two groups.

3.5 Reliability

A number of steps were also been taken to ensure that the cluster solution was reliable. Firstly, the operational definitions for the variables were chosen on the basis of explicit theory to represent differing attributes of the construct core competence association. This helped ensure that the cluster variables were uncorrelated thus avoiding overweighting the cluster solution. Secondly, all variables were given the same range based on the number of response alternatives ensuring that they contributed equally to the clustering process. Thirdly, the contribution of variables to cluster discrimination was examined in order to reject those that did not provide significant differentiation. This was done by comparing the cluster mean values of each variable using the F statistic. A high level of significance is associated with high discriminatory power (Hair et al. 1992). Cluster variables that did not have mean differences significant to the $p < 0.05$ level were rejected. A step-wise procedure was used for this culling starting with using all potential cluster variables in the analysis. After clustering, the variables that were not statistically significant at the $p < 0.05$ level were identified and ordered according to their level of significance. The variable that was the least significant was removed and the cluster procedure repeated with the remaining variables. The results were examined again and any non-significant variables were identified and ordered according to their significance level. The culling process was repeated until the cluster solution contained variables that were all significant. As a result, two items were rejected as described later in Section 4.4.

Next, a split sample replication method was used to test for stability of the cluster solution (Morris, Blashfield and Satz 1981; Speece, McKinney and Applebaum 1985). In this method, cluster analysis was performed on a randomly selected two-thirds subset of the observations. Agreement of membership assignments with the original solution was then tested as an indication of stability of the original cluster solution. This was performed using the kappa coefficient of agreement (Cohen 1960). Cohen's kappa provides an objective measure of the chance-corrected percentage of agreement between the two assignments (Howell 1997). This random selection procedure was repeated five times and an average value of kappa determined as evidence of convergence. A final test for reliability of the *k*-means algorithm was then performed by clustering using three different initial cluster seeds and comparing the resulting cluster centres for agreement (Cormak 1971).

3.6 Validity

In addition to reliability discussed above, the research results must be valid. Two kinds of validity checks have been incorporated into the research design. Face validity is a judgement of whether an item appears to measure what the investigator assumes it measures (i.e., the phenomenon at issue) or said another way, whether it measures what its name suggests (Bailey 1987; Judd, Smith and Kidder 1991). Face validity, particularly in regard to the topic of core competencies, has been addressed by an extensive review of extant literature and received theory in order to select cluster variables that appear closely tied to the theoretical attributes of the constructs of interest. Where possible, measure items have been taken from the literature so that this research is cumulative with previous work. Face validity was also built into the research through the detailed interviews with staff in PMC-Sierra and Critical Control Corporation. These helped affirm the proposed relationships and identify items that taped the constructs.

Criterion validity was also addressed. Criterion validity refers to the extent to which independent measures of key constructs are correlated with measures used in the study. The comparison variables, TACIT, LIFECYC1, LIFECYC2, FUTMKT, PLATF, and DERIV, were used as the external criterion to demonstrate that the clusters differed on conceptually similar variables independent of the measures used for cluster formation (Speece et al. 1985). Wilks' lambda was used to test for equality of the vectors of means of these variables between the two groups. The resulting significance provided a measure of criterion validity.

3.7 Generalisability

Despite the difficulty in recruitment, considerable effort has gone into ensuring that the research sample is a diverse and representative one. By tapping into many different science and technology networks, a broad range of firms in the ICT sector have been included so as to provide variability in the research sample. Also, by undertaking a thorough search for firms with visible university-industry links, the pool of firms is considered to comprise most of those that have active and relevant university-industry linkages and thus adequately represents the phenomenon under study. Furthermore, it could be argued that the research sample size is large in proportion to the size of the available population of adoptions of NEUT for product innovation in the ICT sector for the period of 1991 to 2000. This serves to increase the generalisability of the sample findings to the industry population. In addition to the above, care has been taken to ensure that the projects included in the sample offer the potential to control for effects which otherwise might confound the results. These control variables are discussed below.

3.8 Control Variables

Four variables have been selected as potential sources of contextual factors that might have an impact on the association of NEUT with the firm's core competencies. The variables and their definitions are shown in Table 2. The first, firm size, may be related to association of NEUT with the firm's core competencies. Larger firms are more established in their technological capabilities, are more likely to have a core competence and thus more likely to acquire NEUT for their core competence. They also have more senior management resources and are able to apply them to the development of new future markets. Firm size was operationalised using the variable FSIZE which measures the number of employees in the firm's division at the time it adopted the NEUT.

Likewise, firms with larger R&D budgets have greater technical resources that allow them to adopt external technologies (Veugelers 1997) which might then be used to build core competencies. It also enables them to more readily develop new platform products. R&D was operationalised using the variable RD which measures the percentage of revenue that was spent by the firm in research and development for the most recent fiscal year. This time period was adopted because of the difficulty in obtaining historical R&D expenditure data and because expenditure tends to be relatively consistent in established firms. Data for both FSIZE and RD were collected during the telephone survey.

Finally, the distance from the firm to the university might have an adverse effect on the adoption of NEUT for building core competencies. Distance creates barriers to communication that require additional resources to overcome. It is therefore a detractor to adopting external technology that might be strategically important to core competencies. Barriers due to distance might also inhibit the adoption of NEUT that is very tacit in nature or NEUT that is at a very early stage in the technology lifecycle. Distance was operationalised using the variables DIST and TTIME. DIST is a five-level categorical variable that measured the proximity of the firm to the university. An increasing score indicates a greater distance. The levels used were: same city, same province, neighbouring province, distant province and outside Canada. TTIME measured the number of hours taken to travel from the firm to the university by the most appropriate means. Data for these variables were collected using Q4 and Q5 in the web-based survey.

3.9 Proposition Testing

Using the cluster analysis procedure, the data were partitioned into two heterogeneous clusters exhibiting maximum between-group variance and minimum within-group variance. The eleven measure items used to tap the CCA construct were used as individual cluster variables. The resulting groups represent relatively high and relatively low values of NEUT association with core competence respectively. They formed the basis for testing Proposition 1 using the chi-square goodness of fit test and for testing Propositions 2 to 5 using independent sample t-tests.

In addition, the eleven measure items used to tap the CCA construct were combined into a single scale and used to evaluate the correlation between CCA and the variables across the entire data set. The CCA scale was validated by using it to cluster the data into a second set of two groups and comparing the cluster assignments with those from the multi-variate clustering. The kappa coefficient of agreement was used as an objective measure of consistency. A correlation matrix was then created and support for the propositions was evidenced by the sign of coefficients being in the correct direction and significant.

4.0 RESULTS

This section presents the results of the research undertaken using the methodology described in Chapter 3. First, the descriptive statistics and scale reliabilities are presented for the entire data set. This is followed by a detailed report of the cluster analysis which is provides the basis for proposition testing. The final part presents the results of the tests for Propositions 1 to 5. All statistical results are reported at the two-tailed level of significance unless otherwise stated.

4.1 Scale Reliability – Cronbach Coefficient Alpha

The Cronbach coefficient alpha was used to test for internal reliability of the scales. Cronbach alpha is a measure of the inter-item correlation of items in a scale. Alphas for each scale were calculated and items that significantly degraded the value of alpha were rejected from the scale. The final alpha values for each scale associated with the measures in Tables 2 to 6 are shown in Table 8. In four cases the alphas were above the conservative limit of 0.7 level advocated by Nunnally (1978). Two scales, TACIT and FUTMKT, have alpha's of 0.68 and 0.63 respectively and are above the cutoff value of 0.6 which is still considered acceptable (Bagozzi and Yi 1988; Zander and Kogut 1995). The scale PLATF has an alpha of 0.56. Although this is a poorer value, the two items seem logically to belong together as indicators of the construct. Also regression analysis showed that R-squared went up with their combination and the combination related to the predictors in the same manner, though more strongly, than each of the individual items. The above factors were considered to outweigh the poorer alpha and pointed to combining the items into the scale[5].

[5] I would like to thank Dr. John Michela for his guidance in resolving this issue.

Variable	Sample Size (N)	Number of Items	Coefficient Alpha
CCA	65	11	0.90
TACIT	65	5	0.68
LIFECYC1	56	3	0.72
LIFECYC2	59	6	0.88
FUTMKT	64	2	0.63
PLATF	64	2	0.56
DERIV	64	4	0.72

Table 8. Cronbach Coefficient Alphas for the Variable Scales
(See Table 2 for variable descriptions)

4.2 Descriptive Statistics

The descriptive statistics for the main variables are shown in Table 9. Missing item values were excluded resulting in a loss of one subject for FUTMKT, PLATF and DERIV. For LIFECYC1 and LIFECYC2, the sample sizes were reduced to 56 and 59 respectively. The variables were comprised of two or more items each having a response alternative ranging from 1 to 7. The multi-item scores are calculated by summing the responses for each item in the score. For example, the CCA variable consists of 11 items and has a possible range of 11 to 77. All variables have means close to the centre of the range. The range of variable scores lies between 3.1 and 4.3 times the respective standard deviation indicating that the distribution of scores has adequate variability. The skewness of each variable does not exceed two times the standard error of the statistic and therefore are considered to be only mildy skewed. The kurtosis of each variable is also mild. Therefore, assumptions of normality are not unreasonable for these variables.

Variable	N	Possible Range	Mean	Std. Dev.	Skewness	Std. Err.	Kurtosis	Std. Err.
CCA	65	11-77	47.77	15.26	-0.43	0.30	-0.63	0.59
TACIT	65	5-35	21.51	7.07	0.28	0.30	-0.92	0.59
LIFECYC1	56	3-21	11.75	5.86	0.18	0.32	-1.16	0.63
LIFECYC2	59	6-42	21.74	9.98	0.44	0.31	-0.76	0.61
FUTMKT	64	2-14	8.62	3.38	-0.14	0.30	-0.65	0.59
PLATF	64	2-14	8.38	3.81	-0.22	0.30	-1.03	0.59
DERIV	64	4-28	15.34	6.50	-0.48	0.30	-0.90	0.59

Table 9. Descriptive Statistics for the Variables
(See Table 2 for variable descriptions)

4.3 Correlation Matrix

Table 10 shows the correlation matrix for the model variables. Since the variables are near normal, Pearson correlation coefficients were calculated. The propositions are supported to the extent that the correlation coefficients are significant and of the predicted sign.

Table 10. Correlation Matrix (See Table 2 for variable descriptions)

		CCA	TACIT	LIFECYC1	LIFECYC2	FUTMKT	PLATF
TACIT	Pearson r	.348**					
	Sig.	.004					
	N	65					
LIFECYC1	Pearson r	-.015	-.016				
	Sig.	.903	.901				
	N	65	65				
LIFECYC2	Pearson r	-.228^{+}	-.460***	.147			
	Sig.	.083	.000	.266			
	N	59	59	59			
FUTMKT	Pearson r	.321**	.266*	-.173	-.244		
	Sig.	.010	.034	.173	.065^{+}		
	N	64	64	64	58		
	N	64	64	64	58		
PLATF	Pearson r	.455***	.211^{+}	-.015	-.291*	.621***	
	Sig.	.000	.094	.909	.026	.000	
	N	64	64	64	58	64	
DERIV	Pearson r	.074	.067	.229^{+}	-.040	.044	-.082
	Sig.	.560	.598	.068	.763	.728	.520
	N	64	64	64	58	64	64

+ significant at the 0.10 level
* significant at the 0.05 level
** significant at the 0.01 level
*** significant at the 0.001 level

4.4 Cluster Analysis

The cluster analysis of the cases was performed in order to create two heterogeneous groups representing low and high association of NEUT with core competencies. The resulting structure formed the basis for comparative tests. Following the method described in Chapter 3, the first step was to apply a non-hierarchical cluster analysis to the data set. The analysis was performed with the SPSS statistical package using the k-means algorithm and specifying two clusters. The cluster variables were the 11 items defined in Table 2 of Chapter 3. The labels for these variables, as shown in Table 14. are given as 12_1, 12_2. 12_3, etc., representing the question items 12.2, 12.2, 12.3, etc.

The initial cluster seeds were automatically assigned by SPSS with a distance between clusters of 18.466 as shown in Table 11. The cluster solution converged after 14 iterations of the algorithm at which point no more re-assignment of cases took place. The final distance between clusters was 8.528.

Number of Iterations	Initial Distance Between Clusters	Final Distance Between Clusters
14	18.466	8.528

Table 11. Initial and Final Cluster Centres

Out of 65 valid cases, 44 were assigned to cluster 1 and 21 were assigned to cluster 2 as shown in Table 12. The resulting case assignments (cluster 1 or 2) were stored as the dichotomous effect variable CLUS1ST.

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	44	66.7	67.7	67.7
	2	21	31.8	32.3	100.0
	Total	65	98.5	100.0	
Missing	System	1	1.5		
Total		66	100.0		

Table 12. Cluster Number of Cases

To verify that the cluster result was statistically different from a random solution a MANOVA was performed to test the equality of the vectors of the means of the cluster variables across two groups as shown in Table 13. The value of Wilks' Lambda was 0.258 with an F-value of 13.84 at a significance level of $p < 0.001$ and with a partial Eta-squared of 0.742, concluding that the cluster solution is statistically different from a random solution.

Effect	N Group 1	N Group 2	Wilks' Lambda	F	Partial Eta Squared
CLUS1ST	44	21	.258	13.84***	.742

*** significant at the $p < 0.001$ level

Table 13. Cluster Significance: MANOVA of the Vectors of Cluster Variable Means

A number of checks were performed to ensure that the cluster solution was reliable. First, since each variable had a range of 1 to 7, they contributed equally to cluster differentiation. Next, the difference in final cluster centre values of each variable across the two groups was tested for significance using the F statistic. A culling procedure for removing non-significant variables from the cluster model was followed as described in Chapter 3. It resulted in eliminating two items as cluster variables due to lack of discriminatory power. The first item was Q6 "Did you receive any exclusive rights to the new university technology." This variable was re-coded to provide the range "1" non-exclusive and "7" exclusive but failed significance (F=0.821, Sig=0.368). Likewise for the second item, Q13.2 "This new university technology is very difficult to duplicate by our competitors," mean value was not significantly different between the clusters (F=2.68, Sig = 0.107). The average value for this item across the whole sample was 3.85 suggesting that NEUT, on average, was perceived not to be particularly difficult to duplicate by firms' competitors. In the final model, the difference in means between the two groups for each remaining variable was statistically significant at the 0.05 level or less as shown in Table 14. Thus each variable contributed significantly to the cluster discrimination thereby providing support for the reliability of the cluster result.

	Cluster Centres		Cluster		Error		
Variable	Group 1	Group 2	Mean Square	df	Mean Square	df	F
12_1	5	2	113.161	1	2.467	63	45.878***
12_2	5	3	65.737	1	2.462	63	26.698***
12_3	6	2	164.163	1	2.667	63	61.564***
13_1	6	3	94.312	1	1.846	63	51.088***
13_3	6	3	91.169	1	1.950	63	46.760***
13_4	6	2	151.252	1	2.172	63	69.651***
13_5	6	3	98.803	1	2.130	63	46.389***
13_6	5	3	112.641	1	1.866	63	60.356***
13_8	5	3	36.028	1	3.143	63	11.462***
13_10	2	1	10.182	1	2.297	63	4.434*
13_12	5	2	96.464	1	3.086	63	31.262***

* significant at the $p < 0.05$ level
*** significant at the $p < 0.001$ level

Table 14. Cluster Discrimination: ANOVA of the Cluster Variables Means

A split replication process was also used to test the stability of the cluster solution. This involved randomly selecting 50 cases (approximately two-thirds of the total data set) and performing a cluster solution on them. Each resulting cluster membership assignment was compared to the original solution using the kappa coefficient as an objective measure of agreement. Table 15 shows the results for 5 random selections.

The value of kappa ranged from 0.911 to 1.000 with an average value of 0.982. All values of kappa were significant at $p < 0.001$. The distance between cluster centres ranged from 8.537 to 9.138 with an average value of 8.809 compared to 8.528 for the original solution. The case assignments for cluster 1 and cluster 2 ranged from 32:18 to 36:14. The ratio of case assignments for cluster 1 to cluster 2 ranged from 1.777 to 2.571 with an average value of 2.108 compared to 2.095 for the original solution. These results demonstrate convergence of the sub-sample clusters with the original cluster solution and provides further evidence of the stability and reliability of the cluster solution.

Trial	N	Cluster Assignment	Kappa Coefficient	Ratio of Assignments	Distance Between Cluster Centres
1	50	34 : 16	1.000***	2.125	8.806
2	50	36 : 14	1.000***	2.571	8.537
3	50	32 : 18	0.911***	1.777	8.593
4	50	34 : 16	1.000***	2.125	8.969
5	50	33 : 17	1.000***	1.941	9.138
Average			0.982***	2.108	8.809
Original	65	44 : 21		2.095	8.528

*** significant at the $p< 0.001$ level

Table 15. Cluster Stability: Cluster Comparision Using Split Replication

The cluster solution was then tested for criterion validity to demonstrate that the clusters differ on conceptually similar variables independent of the measures used for cluster formation. The proposition variables, TACIT, LIFECYC1, LIFECYC2, FUTMKT, PLATF and DERIV, were used as the external criterion since they were independent from the cluster variables (see Table 2 for variable descriptions). A MANOVA was performed to test the equality of the vectors of the means of the criterion variables across the two groups. The results are shown in Table 16. After discarding missing values from all variables, the number of valid cases was 58 and these were allocated as 40 for cluster 1 and 18 for cluster 2. The value of Wilks' Lambda was 0.642 with an F-value of 4.73 significant at the $p<0.001$ level and a partial Eta-squared of 0.358. This result provides evidence in support for criterion validity.

Effect	N Group 1	N Group 2	Wilks' Lambda	F	Partial Eta Squared
CLUS1ST	40	18	.642	4.73***	.358

*** significant at the $p< 0.001$ level

Table 16. Cluster Validity: MANOVA of Criterion Variables

As noted earlier, most of the subjects were cases of NEUT from Canadian universities and used by established Canadian firms. However, five cases were new technology from non-Canadian universities and used by Canadian firms, one was an example of Canadian university technology that used by a non-Canadian firm, and two involved early-stage spin-off companies based on NEUT. As a check for data dependency, cluster analysis was performed with these cases removed and the resulting assignments compared with the original data set using the kappa coefficient. Table 17 below shows complete agreement for the cluster solutions in each of the above exclusions indicating that they do not affect the stability of the cluster solution.

Cases Excluded (n)	N	Cluster Assignment	Kappa Coeff.	Distance Between Cluster Centres
None (0)	65	44 : 21	-	8.806
Non-Canadian NEUT (5)	60	40 : 20	1.000***	8.479
Non-Canadian firm (1)	64	44 : 20	1.000***	8.603
Early stage firm (2)	63	42 : 21	1.000***	8.441
All above (8)	57	38 : 19	1.000***	8.468

*** significant at the $p < 0.001$ level

Table 17. Test for Data Dependency: Exclusion of Special Cases

In conclusion, the foregoing results indicate that the cluster solution is significantly different from a random solution as indicated by the difference in vectors of the means of the cluster variables across two groups. The solution is reliable, in that all variables contribute equally in terms of their range and that all variables contribute significantly to cluster discrimination. Stability and reliability have also been re-affirmed by comparing the results of cluster solutions from five split-sample replications with the original solution. Finally, a degree of criterion validity has been established by the examining the difference in the vectors of the means of the proposition variables that are independent of the measures used for cluster formation. Based on these results, the cluster solution can be used with a high degree of confidence for testing the research model. This cluster solution has been obtained by using the 11 measure items that comprise the CCA scale as the cluster variables. The resulting case assignments into two groups has been used to test the propositions using a MANOVA and individual contrasts for the variables.

Correlation coefficients have also been calculated between the variables and the CCA scale for the combined data set in order to evaluate the magnitude of the effects. The CCA scale was determined to be internally consistent and reliable as indicated by the value of 0.9 for the coefficient alpha shown in Table 2. The scale was also validated by using it as a single cluster variable and comparing the resulting group assignments with the multi-variate cluster solution. Table 18 shows that the cluster solution using the single cluster variable CCA produced a group membership of 42:23 compared with the original cluster membership of 44:21. The kappa coefficient of agreement was 0.931 and was significant at the $p < 0.001$ level which demonstrates a high degree of agreement.

Multi-variate Solution	Single Variable Solution: Group 1	Group 2	Total	Kappa
Group 1	42	2	44	
Group 2		21	21	0.931***
Total	42	23	65	

*** significant at p < 0.001 level

Table 18. Validation of Variable CCA: Crosstabulation of Single CCA Variable Cluster with Original Multivariate Cluster

A final test was performed to determine the stability and reliability of the k-means cluster algorithm under different starting conditions. Using the CCA variable, three initial cluster seeds were selected and the final cluster centres were compared. Table 19 shows that for all three initial cluster centres the final cluster centres and group assignments were identical. This demonstrates the reliability of the k-means algorithm to produce a consistent result independent of differing initial conditions.

Trial	Initial Cluster Centres	Dist. Between Centres	Number of Iterations	Final Cluster Centres	Cluster Assignments
1	74 ; 13	61	14	57.19 ; 30.57	42 ; 23
2	65 ; 20	45	14	57.19 ; 30.57	42 ; 23
3	50 ; 35	15	12	57.19 ; 30.57	42 ; 23

Table 19. Robustness of K-means Algorithm: Different Initial Cluster Centres

4.5 Descriptive Statistics for the Variables Across Groups 1 and 2

The descriptive statistics for the variables across groups 1 and 2 are shown in Table 20. All variables have means close to the centre of the range and appear to have adequate variance. The skewness of each variables does not exceed two times the standard error of the statistic and therefore the variables are considered to be only mildy skewed. Likewise, the kurtosis of each variables does not exceed two times the standard error of the statistic and therefore the variables are considered to exhibit only mild kurtosis. Therefore, assumptions of normality are not unreasonable for these variables. A Levene's test for equality of variance was performed for each variable and found to be not significant. Therefore, assumptions of homogeneity of variances are not unreasonable for these variables.

Table 20. Descriptive Statistics for the Variables Across Groups 1 & 2
(See Table 2 for variable descriptions)

VARIABLE	GROUP 1							GROUP 2						
	N	Mean	Std. Dev.	Skewness	Std. Err.	Kurtosis	Std. Err.	N	Mean	Std. Dev.	Skewness	Std. Err.	Kurtosis	Std. Err.
TACIT	44	23.07	7.01	-0.06	0.36	-0.93	0.70	21	18.24	6.13	0.19	0.50	1.54	0.97
LIFECYC1	39	12.10	5.96	0.20	0.38	-1.26	0.74	17	10.94	5.72	0.09	0.55	-1.03	1.06
LIFECYC2	41	20.12	9.01	0.40	0.37	-0.77	0.72	18	25.44	11.3 3	0.20	0.54	-1.24	1.04
FUTMKT	43	9.14	3.47	-0.33	0.36	-0.67	0.71	21	7.58	2.99	0.03	0.50	0.12	0.97
PLATF	43	9.42	3.39	-0.35	0.36	-0.70	0.71	21	6.24	3.80	0.31	0.50	-1.34	0.97
DERIV	43	15.86	6.53	-0.60	0.36	-0.60	0.71	21	14.28	6.45	-0.32	0.50	-1.38	0.97

4.6 Control Variables

The descriptive statistics of the control variables are presented in Table 22. The control variables exhibit extreme skewness and kurtosis. Non-parametric statistics have been used to evaluate the controls since assumptions of normality are not valid.

One measure of the effect of these controls is obtained by examining their between-group differences. The Mann-Whitney U statistics, shown in Table 21 below, indicate that the controls do not differ significantly across groups 1 and 2. This suggests that these controls will not have a significant effect on the propositions.

VARIABLE		N	Mean Rank	Sum of Ranks	Mann-Whitney U	Z	Significance
	Group 1	39	28.28	1103.00			
FSIZE	Group 2	16	27.31	437.00	301.00	-.204	.838
	Total	55					
	Group 1	37	25.61	947.50			
RD	Group 2	13	25.19	327.50	236.50	-.089	.929
	Total	50					
	Group 1	44	31.74	1396.50			
DIST	Group 2	21	35.64	748.50	406.50	-.918	.359
	Total	65					
	Group 1	42	31.90	1340.00			
TTIME	Group 2	21	32.19	676.00	437.00	-.059	.953
	Total	63					

Table 21. Mann-Whitney Statistics for Control Variables Across Groups 1 & 2
(See Table 2 for variable descriptions)

Table 22. Descriptive Statistics for Controls Across Groups 1 & 2
(See Table 2 for variable descriptions)

CONTROL	N	Mean	Std. Dev.	GROUP 1 Skewness	Std. Err.	Kurtosis	Std. Err.	N	Mean	Std. Dev.	GROUP 2 Skewness	Std. Err.	Kurtosis	Std. Err.
FSIZE	39	293.8	429.0	1.51	0.38	0.66	0.74	16	288.6	460.0	1.95	0.56	2.75	1.09
RD	37	20.68	15.22	2.23	0.39	5.64	0.76	13	20.15	14.23	0.85	0.62	0.06	1.19
DIST	44	1.59	1.13	2.21	0.36	4.18	0.70	21	1.86	1.31	1.60	0.50	1.56	0.97
TTIME	42	1.98	3.38	2.52	0.36	6.29	0.72	21	1.954	7.23	1.72	0.50	2.69	0.97

4.7 Tests of Propositions

In this section the results of tests for each proposition is reported. As noted above, the cluster analysis procedure produced two heterogeneous groups with minimal within-group variance and maximum between-group variance using the 11 cluster variables. Group 1 represents those cases where there is a HIGH association between NEUT and the firm's core competencies. Group 2 represents those cases where there is a LOW association between NEUT and the firm's core competencies. For simplicity, these groups have been labeled as "associated with" and "not associated with" core competencies respectively. They form the bases for between-group analyses that are used to test the propositions. Proposition 1 is related to research question 1 and is the first to be reported followed by Propositions 2 to 5.

4.7.1 Results for Proposition 1

Propositions 1a and 1b can be restated in the form of null and alternate testable hypotheses as follows:

H1o: There is no difference between the frequency of occurrence of instances where NEUT is associated with the firm's core competencies and where NEUT is not associated with the firm's core competencies.

H1a: The frequency of occurrence is greater for instances where NEUT is NOT associated with the firm's core competencies than for instances where NEUT is associated with the firm's core competencies.

H1b: The frequency of occurrence is greater for instances where NEUT is associated with the firm's core competencies than for instances where NEUT is NOT associated with the firm's core competencies.

The results support Hypothesis 1b and Proposition 1b. The frequency distribution of the case assignments from the telephone survey and its goodness of fit test statistic χ^2 are shown in Table 23. Since the value of $\chi^2_{(2)}$ is 6.768 and it is significant at the $p<0.05$ level, the null hypothesis is rejected. It is concluded that the obtained frequencies differ from the expected frequencies more than would be predicted by chance. Furthermore, only 4 cases responded as unrelated to core competencies while 66 were for strengthening existing core competencies and 21 for building new core competencies. Thus the frequency of occurrence of instances where NEUT is associated with the firm's core competencies is far greater than the frequency of occurrence of instances where NEUT is not associated with the firm's core competencies. Therefore, the alternate hypothesis H1b is accepted and Proposition P1b is supported while alternate hypothesis H1a is rejected along with Proposition P1a.

	Observed N	Expected N	Residual	χ^2	$\chi^2_{(crit)}$	df
Unrelated to existing core competencies	4	30.33	-26.33			
Strengthen existing core competencies	66	30.33	35.67	6.768*	5.99	2
Build new core competencies	21	30.33	-9.33			
Total	91	91	0			

* significant at the $p< 0.05$ level

Table 23. Core Competence Association: Frequency Distribution and Goodness of Fit (Telephone Survey)

Turning next to the cluster analysis of the main survey data, the frequency distribution of the case assignments and the goodness of fit test statistic χ^2 are shown in Table 24.

	Observed N	Expected N	Residual	χ^2	$\chi^2_{(crit)}$	df
Group 1	44	32.5	11.5			
Group 2	21	32.5	-11.5	8.138***	7.88	1
Total	65	65	0			

*** significant at the p< 0.005 level

Table 24. Core Competence Association: Frequency Distribution and Goodness of Fit (Cluster Analysis of Main Survey)

Since the value of $\chi^2_{(1)}$ is 8.138 and it is significant at the $p < 0.005$ level, the null hypothesis is rejected. It is concluded that the obtained frequencies differ from the expected frequencies more than would be predicted by chance. Since the case assignments are 44 for group 1 and 21 for group 2, the frequency of occurrence of instances where NEUT is associated with the firm's core competencies is greater than frequency of occurrence of instances where NEUT is not associated with the firm's core competencies. Therefore, in agreement with the telephone survey data, the alternate hypothesis H1b is accepted and Proposition P1b is supported while alternate hypothesis H1a is rejected along with Proposition P1a.

The position of the cluster centres along the measurement scale also needs to be examined in order to determine whether the groupings do, in fact, reflect "high" and "low" degrees of association with core competencies. This can be readily done by looking at the univariate cluster solution that uses the multi-item CCA scale as the cluster variable. From Table 19, the cluster centres are located at 57.19 for group 1 ("high" association) and 30.57 for group 2 ("low" association). The total scale ranges from 11 to 77 with a mean at 44. Thus the two groups do have centres at the low and high end of the scale, thus supporting the notion of "high" and "low" association with core competencies.

It was noted earlier that increasing firm size and R&D expenditure may result in a greater likelihood for firms to have developed their core competencies. Table 25 below shows the Spearman's correlation coefficient between CCA and FSIZE and RD. The coefficients for FSIZE and RD are small and not significant. This agrees with the results of Table 21 indicating that there is no correlation between firm size and R&D expenditures on the one hand and whether NEUT is associated with core competencies on the other hand.

		FSIZE	RD
CCA	Spearman's rho	.091	.012
	Significance	.511	.934
	N	55	50

Table 25. Correlations between Variable CCA and Controls FSIZE and RD.
(See Table 2 for variable descriptions)

4.7.2 Results for Propositions 2 to 5

Propositions 2 to 5 can be restated in the form of null and testable hypotheses as follows:

H2o: There is no difference in the platform family orientation, as measured by PLATF, between products where NEUT is associated with the firm's core competencies and products where it is not.

H2: Products will tend to be more like platform family products, as measured by PLATF, when NEUT is associated with the firm's core competencies than when NEUT it is not associated with the firm's core competencies.

H3o: There is no difference in the degree of new future market orientation, as measured by FUTMKT, between products where NEUT is associated with the firm's core competencies and products where it is not.

H3: Products based on NEUT that is associated with the firm's core competencies will tend to have a higher degree of new future market orientation, as measured by FUTMKT, than products using NEUT that it is not associated with the firm's core competencies.

H4o: There is no difference in the degree of tacitness of the transferred technological knowledge, as measured by TACIT, between instances where NEUT is associated with the firm's core competencies and instances where NEUT is not associated with the firm's core competencies.

H4: The degree of tacitness of the transferred technological knowledge, as measured by TACIT, will be greater for instances where NEUT is associated with the firm's core competencies than for instances where NEUT is not associated with the firm's core competencies.

H5o: There is no difference in the stage of development of NEUT along its lifecycle, as measured by LIFECYC1 and LIFECYC2, between instances where it is associated with the firm's core competencies and instances where it is not associated with the firm's core competencies.

H5: The development of NEUT will be less further along its lifecycle curve, as measured by LIFECYC1 and LIFECYC2, for instances where it is associated with the firm's core competencies than for instances where it is not associated with the firm's core competencies.

Two MANOVAs were performed to test the significance of the model for the combination of dependent variables. The first MANOVA model, shown in Tables 26a and 26b, included all the dependent variables. Because of missing values in the LIFECYC variables, the total number of useable cases was reduced from 64 to 58 and allocated as 40 for group 1 and 18 for group 2. The value of Wilks' Lambda was 0.642 with an F-value of 4.73 significant at the $p<0.001$ level and with a partial Eta-squared of 0.358. The between-subject effects are shown in Table 26b.

Effect	N Group 1	N Group 2	Wilks' Lambda	F	Partial Eta Squared
CLUS1ST	40	18	.642	4.73***	.358

*** significant at the p< 0.001 level

Table 26a. MANOVA with All Dependent Variables

Dependent Variable	Mean Group 1	Std Dev. Group 1	Mean Group 2	Std Dev. Group 2	F	Significance
PLATF	9.45	3.48	5.89	3.53	12.86	.001
DERIV	16.10	6.46	13.22	6.27	2.50	.119
FUTMKT	9.02	3.50	7.67	3.07	2.01	.161
TACIT	23.45	6.96	18.00	6.51	7.90	.007
LIFECYC1	12.22	5.95	11.89	6.47	.038	.847
LIFECYC2	19.75	8.80	25.44	11.33	4.33	.042

Table 26b. Between-Subject Effects for MANOVA with All Dependent Variables
(See Table 2 for variable descriptions)

The second MANOVA model, shown in Tables 27a and 27b, was performed using a reduced set of variables. Two variables, DERIV and LIFECYC1, were discarded because they were used as complementary measures for Propositions 2 and 5 respectively and were not significant in the first MANOVA. The LIFECYC2 variable was also removed because of its missing values. This resulted in an increase in the number of useable cases to 64 allocated as 43 for group 1 and 21 for group 2. The value of Wilks' Lambda was 0.771 with an F-value of 5.95 significant at the $p<0.001$ level and a partial Eta-squared of 0.229.

Effect	N Group 1	N Group 2	Wilks' Lambda	F	Partial Eta Squared
CLUS1ST	43	21	.771	5.95***	.229

*** significant at the $p< 0.001$ level

Table 27a. MANOVA with Three Dependent Variables

Dependent Variable	F	Significance
PLATF	11.49	.001
FUTMKT	3.14	.081
TACIT	7.87	.007

Table 27b. Between-Subject Effects for MANOVA with Three Dependent Variables (See Table 20 for descriptive statistics)

Both models provide overall evidence in support for Propositions 2 to 5. In comparing the two models, the only major difference is the increase in significance for the between-subject effect of the dependent variable FUTMKT in the second model with the larger subject size.

The following sections examine the contrasts for the individual dependent variables more closely as they relate to their respective propositions. One-tailed tests were used where indicated since specific directionality had been proposed. The level of significance for individual tests was reduced in proportion to the total number of tests so as to reduce the likelihood of accumulating Type 1 error probabilities and limit the familywise error rate (i.e., alpha level) (Dunn 1961). Since four main variables were tested concurrently in the combined model, each individual significance level was set to one quarter the familywise error rate.

4.7.3 Results for Proposition 2

The research results show full support for Hypothesis 2 and Proposition 2. From Table 26b, the mean value of PLATF in group 1 is greater than that of group 2 as predicted. The one-tailed significance for the difference between means is 0.0005 which is significant compared with an alpha of 0.0025 for a one-tailed familywise error rate of

$p<0.01$. Thus the null hypothesis is rejected and the research hypothesis is supported. It is concluded that group 1 and 2 are distinct populations with differing mean values of PLATF. Furthermore, since the mean value of group 1 is greater than that of group 2, it is concluded that products are more like platform family products when NEUT is associated with the firm's core competencies than when NEUT it is not associated with the firm's core competencies. The variable DERIV is not significantly different between the two groups as noted previously.

Two regression models for predicting PLATF were constructed using a cluster dummy variable and CCA for predictors as shown in Table 28. Examination of the histograms of regression standardized residuals showed near normal distributions and the expected versus observed cumulative probability plots of the regression standardized residuals showed straight line diagonals indicating assumptions of normality are valid for the models. The results of the regression models support the research hypothesis and Proposition 2. The beta coefficients for the two models are 0.395 and 0.455 and are very significant at the $p<0.001$ level. Cluster membership explains up to 14% of the variance of PLATF and the scale CCA explains up to 19% of the variance. As noted earlier, controls FSIZE and RD show extreme skewness and kurtosis and so did not meet the normality assumptions required for the regression models. Spearman's rho for the correlations between FSIZE, RD and PLATF are -.161 (N=55) and .195 (N=50) respectively and are not significant.

	Model 1	Model 2
Adjusted R^2	.143***	.194***
Cluster Dummy	.395*** (3.39)	
CCA		.455*** (4.02)

Notes: The first number represents the standardised beta coefficient.
The number in brackets is the t-statistic. N = 64
*** significant at the p < 0.001 level

Table 28. Regression Models for Proposition 2, PLATF Score

4.7.4 Results for Proposition 3

The research results show some support for Hypothesis 3 and Proposition 3. From Table 26b, the mean value of FUTMKT in group 1 is greater than that of group 2 as predicted. The one-tailed significance for the difference between means is 0.08 for the 58 subject model in Table 26b and 0.04 for the 64 subject model in Table 27b. These are not significant compared with an alpha of 0.025 for a one-tailed familywise error rate of p<0.10. However, when taken in isolation from the other dependent variables, they are significant.

Two regression models for predicting FUTMKT were constructed using a cluster dummy variable and CCA for predictors as shown in Table 29. Examination of the histograms of regression standardized residuals showed near normal distributions and the expected versus observed cumulative probability plots of the regression standardized residuals showed straight line diagonals indicating assumptions of normality are valid for the models. The results of the regression models show support for the research hypothesis. The beta coefficients for the two models are .220 and .321 respectively and are significant at levels of $p<0.10$ and $p<0.01$. Cluster membership explains only 3% of the variance and scale CCA explains up to 9% of the variance of FUTMKT. As noted earlier, control FSIZE did not meet the normality assumptions required for the regression models. Spearman's rho for the correlation between FSIZE and FUTMKT is -.069 (N=55) and is not significant.

	Model 1	Model 2
Adjusted R^2	.033*	.088**
Cluster Dummy	.220* (1.77)	
CCA		.321** (2.66)

Notes: The first number represents the standardised beta coefficient.
The number in brackets is the t-statistic. N = 64
* significant at the $p < 0.10$ level
** significant at the $p < 0.01$ level

Table 29. Regression Models for Proposition 3, FUTMKT Score

Based on the above evidence, the null hypothesis is rejected and the research hypothesis is supported. It is concluded that group 1 and 2 are distinct populations with differing mean values of FUTMKT. Furthermore, since the mean value of FUTMKT in group 1 is greater than that in group 2, it is concluded that products based on NEUT that is associated with the firm's core competencies tend to have a higher degree of new future market orientation.

4.7.5 Results for Proposition 4

The results support Hypothesis 4 and Proposition 4. From Table 26b, the mean value of TACIT in group 1 is greater than that of group 2 as predicted. The one-tailed significance for the difference between means is 0.0035 which is significant compared with an alpha of 0.0125 for a one-tailed familywise error rate of $p<0.05$. Therefore, the null hypothesis is rejected and the research hypothesis is supported. It is concluded that groups 1 and 2 are distinct populations with differing mean values of TACIT. Furthermore, since the mean value of TACIT in group 1 is greater than that of group 2, it is concluded that the degree of tacitness of the transferred technological knowledge is greater for instances where NEUT is associated with the firm's core competencies than for instances where NEUT is not associated with the firm's core competencies.

The correlation coefficient of the bivariate relationship between TACIT and CCA is also positive and supports the research hypothesis. The value of Pearson's r, shown in Table 10, is 0.348 and is significant at the 0.01 level. This result is consistent with that of the equality of means test above and indicates that the more tacit the knowledge the more associated NEUT is with the firm's core competencies. Correlations between TACIT and controls, DIST and TTIME, are shown in Table 30. Spearman's rho for DIST is negative, as expected, but not significant. There is no significant correlation between travel time (TTIME) and TACIT.

		DIST	TTIME
TACIT	Spearman's rho	-.159	.026
	Significance	.205	.843
	N	65	63

Table 30. Correlations Between TACIT and Controls DIST and TTIME
(See Table 2 for variable descriptions)

4.7.6 Results for Proposition 5

The research results generally support Hypothesis 5 and Proposition 5. LIFECYC1 represents the extent to which the university has developed the NEUT up to the time of transfer to the firm. LIFECYC2 represents the amount of future development needed to be done by the firm before the product is ready to release to the market. From Table 26b, the difference in means for LIFECYC1 is not significant. However, for LIFECYC2, the one-tailed significance for the difference between means is 0.021 which is significant compared with an alpha of 0.025 for a one-tailed familywise error rate of $p<0.10$. Also, the mean value of LIFECYC2 in group 1 is less than that of group 2 as predicted. Therefore, the null hypothesis is rejected and the research hypothesis is supported. It is concluded that groups 1 and 2 are distinct populations with differing mean values of LIFECYC2. Furthermore, since the mean value of LIFECYC2 in group 1 is less than that in group 2, it is concluded that NEUT is not as far along its lifecycle curve, for instances where it is associated with the firm's core competencies compared with instances where it is not associated with the firm's core competencies.

The correlation coefficient the bivariate relationship between LIFECYC2 and CCA is also negative and supports the research hypothesis. The value of Pearson's r, shown in Table 10, is -.228 and is significant at the 0.10 level. This result is consistent with that of the equality of means test above and indicates that the earlier NEUT is in its lifecycle, the more associated NEUT is with the firm's core competencies. The correlation between LIFECYC1 and CCA is small and not significant.

Correlations between LIFECYC2 and controls FSIZE and RD are shown in Table 31. Spearman's rho for FSIZE not significant. However, Spearman's rho for RD is -.344 and significant at the p<0.05 level. This suggests that early lifecycle NEUT is more likely to be adopted by firms with larger R&D expenditure as would be expected.

		FSIZE	RD
LIFECYC2	Spearman's rho	.162	-.344*
	Significance	.251	.018
	N	52	47

* significant at the $p < 0.05$ level

Table 31. Correlations Between LIFECYC2 and Controls FSIZE and RD

5.0 DISCUSSION AND CONCLUSION

5.1 Conceptual Framework

The adoption of external sources of technology has been studied mainly within the context of inter-firm relationships such as strategic alliances, joint ventures and networks (Hagedoorn and Schakenraad 1994; Kotabe and Swan 1995; Steensma 1996; Dutta and Weiss 1997). These contemporary studies have often examined "make-vs-buy" alternatives which compare internal development with external sourcing and have been a fruitful area of strategy research (Quin and Hilmer 1994; Kurokawa 1997).

Universities are also sources of new technological knowledge. However, firm-university linkages have been studied mainly from a public policy perspective, with the aim of understanding the process of technology transfer and ensuring that research results are effectively transferred to industry (Betz 1994; Betz 1997). A recent framework for evaluating firm-university relationships proposed four categories of firm motivations for establishing such linkages. These included getting access to early access scientific frontiers, increasing the predictive power of science, delegating selected development activities and lack of internal resources (Bonaccorsi and Piccaluga 1994, p. 229).

This framework found some support in a recent in-depth study of knowledge flows from university to the industry conducted by Faulkner and Senker (1995). Their work examined the application of public sector research (PSR) within the biotechnology, engineering ceramics and parallel computing industries and found that PSR was most useful for "scanning research frontiers" and "underpinning knowledge" in ongoing R&D (Faulkner and Senker 1995, p. 222). The benefits of such applications of PSR knowledge, however, are often intangible and difficult to quantify. Indeed, the study fell short of providing any correlation between PSR linkages and the commercial success of companies.

This research aims to address the gap in this stream of knowledge. Most notably, it is the first empirical study to specifically examine PSR knowledge that has resulted in the creation or improvement of new products. The study therefore offers evidence for the tangible application of PSR knowledge and examines the efficacy of new university technologies to enable the creation of new products in industry. Secondly, by taking a firm level perspective, the research builds on and extends current themes in strategy literature such as the resource-based view of the firm, core competencies, strategic outsourcing and technological accumulation.

The research also aims to answer two fundamental questions. Of primary import is the need to understand the impact that NEUT has on the firm. For example, if the new technology is aligned with those areas which provide the firm with its competitive advantages, then it would be considered to be strategically important (Prahalad and Hamel 1990; Leonard-Barton 1992). The first question, therefore, asks if there is a preference for firms to adopt NEUT that is associated with the firm's core competencies over NEUT that is not. The approach here has been to conduct a comparative study of two "buy" alternatives in contrast to the "make-vs-buy" alternatives of contempory strategy research. Following from this is the need to understand what makes these situations different. The secondary question, therefore, asks if there are differences in the characteristics of the NEUT between instances where it is associated with the firm's core competencies and instances where it is not. The results of this empirical study suggest that the answer to both these questions is a resounding "yes" and this has implications for theory, management and public policy.

The adoption of NEUT can be evaluated using the resource-based view (RBV) of the firm. It maintains that superior returns are generated from internal resources and capabilities that are rare, inimitable, non-substitutable and valuable (Wernerfelt 1984; Aaker 1989; Barney 1991; Barney 1992, p. 44; Peteraf 1993). Although this theory has been extensively debated in the literature (Penrose 1959; Andrews 1971; Leonard-Barton 1992; Peteraf 1993), empirical support has been more slowly forthcoming. Longitudinal studies by Miller and Shamsie (1996) found that financial performance was aided by property-based resources in the form of exclusive long-term contracts with stars and theatres during stable predictable environments; and knowledge-based resources in the form of production and coordinative talent and budgets during changing and unpredictable environments. Another study found that strategic regulation in the Dutch audit industry stimulated demand for audit services and protected rent-producing resources (Maijoor and Van Witteloostuijn 1996). More recently, Yeoh and Roth (1999) found that firm's internal R&D efforts to produce self-originated drugs increasingly resulted in drugs having significant gains over existing therapies.

The RBV has also proposed higher level constructs that are sources of competitive advantage. These include distinctive competencies (Selznick 1957; Andrews 1971), core competencies (Prahalad and Hamel 1990) and core capabilities (Leonard-Barton 1992; Stalk, Evans and Shulman 1992; Hamilton, Eskin and Michaels 1998). However, empirical research using these constructs has been hindered by difficulties with operationalisation and generalisability (McGrath 1996). One methodological approach adopted by researchers has been to get at the content of competencies. This method is quite firm-specific and has been used in case study designs (Mascarenhas et al. 1998). Another approach has been to get at the management processes involved by measuring the inputs or outputs of the constructs. For example, Henderson and Cockburn (1994), defined the presence or absence of firm-specific disciplinary or disease related expertise in pharmaceutical firms by measuring the publications and stocks of patents obtained. They found that local knowledge and skill in particular disease areas, embedded in component competencies, resulted in increasing drug discovery productivity. Grandstrand et. al. (1997) also used firm-specific patenting data to measure and classify the technological competencies of firms in a wide variety of technical fields. In a similar manner, end product analysis has been used to create proxy measures for the strength of firms' core competencies. Hamilton et. al. (1998) used the number of defects per car in the automobile industry as a measure of core competencies. Markides and Williamson (1994) measured the percentage of product lines made to order and the average skill level of employees as proxies for the strength of process experience assets.

In this research, the impact of NEUT to the firm is evaluated by looking at how well the technology is aligned with the core competencies of the firm. This approach has parallels in other areas of strategy research. For example, concept of strategic relatedness was explored by measuring the degree of similarity between strategic assets of SBU's (Markides and Williamson 1994). The research here has developed a new construct, "core competence association" to evaluate the impact of NEUT to the firm and in doing so, builds upon and extends methodologies used to tap the management processes involved in building core competencies (McGrath 1996). One objective of the research design was to develop an operational definition that would rely less on industry-specific contexts, thereby improving generalisability and minimising the difficulties discussed above. This has been achieved by measuring the attributes through which core competencies are identified and evaluated. It is similar to a "black box" approach in that it measures the external conceptual attributes of core competencies without needing to get at the unique internal composition. The core competence association construct was operationalised using eleven different perceptual measures that tap RBV concepts such as customer value, uniqueness, enduring and dynamic characteristics, economies of scope and strategic capabilities. These measures formed the discriminating variables in a cluster analysis model that allocated the 65 subjects into two groups of minimum within-cluster variance and maximum between-cluster variance. Rigorous objective tests were then applied to ensure that the results were reliable, robust and valid. This procedure avoided over-reliance on researcher judgement, an issue cited as a weakness in cluster analysis designs of prior strategic management research (Ketchen and Shook 1996).

The theoretical arguments for and against the adoption of NEUT associated with core competencies are revisited here. Central to this theme is the need to decide what to make internally versus what to buy from external sources. This has been debated extensively in the outsourcing literature. Outsourcing is the process of obtaining high quality components or services from external sources more efficiently than what could be done using internal resources. This reduces costs and thereby increases competitiveness (Williamson 1989; Venkatesan 1992). Outsourcing, however, needs to be done strategically to avoid "hollowing out" the corporation through the erosion of core competencies (Bettis et al. 1992, p. 7; Miles and Snow 1992). Thus only non-critical components or capabilities should be outsourced while strategic components or capabilities should be sourced internally (Venkatesan 1992; Welch and Nayak 1992; Quin and Hilmer 1994). This theme finds agreement in recent findings in the service industry where "core" services are almost always performed by the firm itself while "supplementary" services might be sourced from external suppliers (Murray and Kotabe

1999, p. 793).

One may contend that outsourcing of technology is analogous to outsourcing of components, since "all technologies are systems" (Betz 1997, p. 10). When the needed technology is closely related to the firm's key technology, inhouse R&D is less costly and less time consuming resulting in more efficient utilisation of internal R&D resources. Conversely, when internal R&D resources can not be efficiently utilised, it is preferable to rely on external technology (Kurokawa 1997). The outsourcing model, therefore, favours the acquisition of external technology that is not closely related to core competencies, the sources of competitive advantage, but rather technology which is supplementary. This view has received mixed support from a recent study of small technology based companies which examined the correlation between the number of external technology acquisitions in the form of patents, R&D contracts, collaborative projects and joint ventures and the relatedness of the needed technology to the firm's core technology (Kurokawa 1997). The relationship was found to be negatively correlated, as anticipated, in a sample of 40 projects in Japan but with a one-tailed significance level of only $p<0.05$. The second sample of 27 projects in the USA did not provide statistical support.

The research results presented here, however, tell a different story. The resulting frequency distribution of 44:21 indicates an odds ratio greater than 2:1 in favour of adopting NEUT that is associated with core competencies. The result is significant at a two-tailed level of $p<0.005$, concluding that firms are twice as likely to adopt NEUT associated with core competencies than NEUT that is not.

Why, then, is the outsourcing view not able to explain this strategic behaviour? One possibility is that the acquired NEUT is not a finished technology and requires further developement. As suggested by Betz (1997), new university technologies often result from scientific advances in forms not directly useable by industry. Firms must apply additional resources to further develop the technology or improve it, often resulting in new innovations and patents (Mazzoleni and Nelson 1998, p. 278).

This notion finds support from two areas of this research. Firstly, the research indicates that the more NEUT is associated with core competencies, the earlier it tends to be in its technology lifecycle. The difference, as measured by the variable LIFECYC2, was found to be statistically significant at the $p<0.05$ level for a one-tailed test. This suggests that a transformation takes place through which the new technology is further developed until it and the new product are ready for the market. Secondly, the research found that when NEUT was adopted in regimes of high association with core competencies, the new knowledge was found to be more tacit than when it was adopted in regimes of low association with core competencies. The difference was statistically significant at the $p<0.01$ level for a one-tailed test. This higher degree of tacitness indicates that the technological knowledge is not readily codified and therefore cannot be readily and easily integrated into new innovations. Thus while the outsourcing concepts explains the acquisition of finished goods, components or services that can be neatly integrated into the whole product, it cannot readily explain the adoption of early stage technologies that require further development. This seems internally consistent, since the objective of outsourcing is to free the firm to redirect valuable internal skills and capabilities to high value-added areas (Murray and Kotabe 1999).

The adoption of early stage NEUT is thus better explained by the technological accumulation perspective. Here the approach is not only to acquire external technologies, but improve them wherever possible and integrate them with internal technologies to produce new products, processes and applications (Bowonder and Miyake 1990). As previously noted in Chapter 2, Sony licensed new transistor technology from Western Electric in 1953 and proceeded to improve its performance to a level adequate for the pocket transistor radio. This included a radical shift from the licensed p-n-p transistor structure based on positive charge carriers to a new n-p-n transistor structure based on faster negative charge carriers. In a similar manner, Critical Control Corporation acquired a new data-over-voice technique designed for rural applications and developed it into an "always-on" voice and data modem for metro applications[6]. The above view also finds support in the concept of internal asset accumulation (Markides and Williamson 1994). It argues that even when external assets can be accessed through acquisition, alliance or sharing, it is quite likely that they will not perfectly fit the requirement of the markets they will be used to serve. Such assets generally need some adaptation and integration with existing asset bundles through a process of internal asset accumulation.

In summary, then, there are two factors that appear to play a dominant role. Firstly, the resource-based view requires that firms focus their scarce resources on those competencies that yield competitive advantages. Secondly, new university technologies are, by definition, in the early stages of their lifecycle and thus require ongoing development in order to commercialise them. These factors combine to suggest a strategic behaviour that involves adopting only those early stage technologies in the domains of their core competencies so that valuable internal resources can be applied effectively to assimilate them.

[6] See Appendix B for the case study.

Another important objective of this research was to provide additional evidence in support of the RBV of the firm, i.e., to provide fresh empirical links between resources and superior performance. When making assesments of firm performance, traditional management research often focuses on financial measures such as sales growth and return on sales (Collis 1991; Miller and Shamsie 1996). As noted earlier, some recent work has tended to evaluate performance in broader terms such as the number of radical innovations (Yeoh and Roth 1999), the number of disclosed audit accounts (Maijoor and Van Witteloostuijn 1996) and patent output (Henderson and Cockburn 1994).

This research builds on that theme by measuring product and market characteristics as antecedents of new resource allocations for core competence building. New platform family products introduce new concepts or bundles of functionality to the market in ways that have not been seen before. As such they are more radical than derivative products that are more incremental in nature. These new platforms are also more disruptive to the established balance of competition in the marketplace (Utterback and Abernathy 1975; Tushman and Anderson 1986; Tatikonda 1999). Platform products are associated with greater profit margins and therefore represent a measure of superior performance for the firm. This research has established an empirical link between the degree of association of the new technology with the firm's core competencies and the platform-like nature of the product formed around the new technology. Indeed, the degree of core competence association explains up to 19% of the variance in platform-like characteristics, as measured by adjusted R-square. This finding, therefore, lends strong support for the resource-based view of the firm and adds to the existing stream of empirical research.

Another measure of superior performance of the firm is the ability to address new and emerging markets (Hamel and Prahalad 1989; Hamel and Prahalad 1994; Christensen 1997). Core competencies are gateways to creating new markets where competitors do not already exist (Prahalad and Hamel 1990). Thus, the RBV of the firm can be supported by establishing empirical links between resource allocations and the development of new markets. This research has established such an empirical link between the degree of association of the new technology with the firm's core competencies and the degree to which the new product is intended to serve new future markets. The results indicate that the degree of core competence association explains up to 9% of the variance in new future market orientation. This finding, then, lends additional support for the resource-based view of the firm.

5.2 Implications for Theory

The outsourcing literature has received a number of contributions over the last decade. Most noticably, warnings against the loss of economies of scope and resulting hollowing of the corporation (Bettis et al. 1992) have resulted in a renewed focus on identifying the strategic systems and components that are outputs of core competencies and ensuring that these are developed inhouse (Venkatesan 1992; Quin and Hilmer 1994; Quin 1999). Outsourcing has also been extended to address the acquisition of external technologies in favour of advantages such as lower development cost, faster product development and greater diversification (Atuahene-Gima 1993; Kurokawa 1997). The recurring theme in this literature is that technologies and products which are strategic to the firm must be developed inhouse, while those that are peripheral or supplementary should be acquired from external sources. In contrast, the results of this research show that new external university technologies are more likely to be acquired for the strategically important core competencies than for supplementary areas. This finding suggests that all the factors involved in the external technology adoption process have not yet been fully explored. In particular, outsoucing theory needs to address the issue of technological lifecycles in the context of immature technologies such as those emerging from universities. Early stage technologies are likely to require further development or refinement leading to new technological knowledge different from and more valuable than the original technology. Since each development path is ideosyncratic to the firm internalising the technology, the finished and commercially useful technology has the potential to be a resource that is unique to the individual firm. This suggests that a new node in the outsourcing model should include a decision to acquire external technologies that are closely associated with core competencies and in the early stages of development, thereby having the potential to become a unique source of competitive advantage. In a similar manner, the resource-based literature needs to extend the current debate to explicitly deal with valuable technological resources that are acquired from external sources. The core competence association construct developed here provides an initial step in extending this framework.

This research also has implications for public policy with regard to the transfer of technology from universities to industry. Public policy literature has addressed a number of areas in this regard including guidelines for focusing the direction of scientific research, (Betz 1994; Lee 1996; Betz 1997), mechanisms and practices for the effective transfer of technology from public institutions to industry (Souder, Nashar and Padmanabhan 1990; Grigg 1994; Shohet and Prevezer 1996), and frameworks for evaluating university-industry relationships (Bonaccorsi and Piccaluga 1994; Autio, Hameri and Nordberg 1996). A recently emerging theme has been the need to understand the nature of knowledge flows from university to industry (Faulkner and Senker 1995) and the benefits that ensue (Martin 1998). This research sheds additional light into this new area by measuring, for the first time, the efficacy of new university technology in the context of industrial product innovation. It has found that new university technologies transferred to industry have strategic value to firms in that they are closely associated with the firms' core competencies. Also, these technologies form the basis of platform family products, those that are expected to result in higher economic returns. These findings might provide a useful guide for individual researchers and/or university research offices by helping them form their strategies for seeking industrial partners. It has also demonstrated that characteristics of new technological knowledge, such as tacitness and immaturity, are important factors driving the adoption of NEUT within firms' core competencies where regimes of high absorptive capacity are at work.

5.3 Implications for Management

This research has a number of important implications for management. In the first instance, as a piece of research in the stream of the resource-based theory of the firm, it draws management attention to the importance of decisions relating to resource allocation. More specifically, some resources have a greater potential to generate superior returns than others. In this context, the concept of the firm's core competencies takes a central theme within management thought. The work presented here has probed deeper into this theme and produced a fresh definition of core competencies which brings together thoughts from a variety of sources. This work has also highlighted the importance of building core competencies through the strengthening of existing ones or building of new ones. The importance of management effort spent on identifying core competencies and establishing a core competence building agenda cannot be overstated.

Failure to do so, or not doing it properly can result in a false understanding of sources of competitive advantage with dire consequences[7].

In industry sectors such as information and communications technology, the rate of technological change is very rapid. Managers are hard pressed to develop all the needed technology to keep their product lines competitive. Maintaining and building the knowledge and skill bases that comprise the firm's core competencies is a complex and demanding task. One approach for doing this is to look for external sources of new technology such as those emerging from universities.

Common wisdom might suggest that universities have little to offer in the form of useful technological knowledge that can be brought into product innovation. On the contrary, this research has uncovered a host of examples of new product development formed around new university technology with varying degrees of association with their core competencies. Although this research has not specifically examined the successfulness of such behaviour[8], we might assume that companies have been smart enough to ensure that such activities were advantageous to their overall performance. Managers would do well, therefore, to broaden and strengthen firm-university linkages with the aim of increasing knowledge flows into the organisation, especially for the purpose of product innovation. Common wisdom also suggests that external technology should be adopted only for supplementary functions while the key technologies are developed strictly in-house. Once again, the research dispels this notion by finding that new university technologies have been adopted in areas associated with core

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[7] For example, inaccurate interpretation of core competencies resulted in RHP's competitive position being devastated by imports of high volume product lines (Collis 1991, p. 59).

[8] Please see the discussion on successfulness under Section 5.4 Limitations and Section 5.5 New Research Questions.

competencies twice as often as in areas not associated with core competencies. These have been used for developing new *platform* products that were intended to serve new emerging markets, thereby providing new sources of competitive advantage. Thus, managers would benefit from actively seeking out new university technologies that are closely tied to the knowledge bases of their core competencies.

Another interesting finding is that new university technologies associated with core competencies are more tacit in nature than those not associated with core competencies. This should not be surprising if firms seek out those technologies on the leading edge of their technological capabilities. The implications, however, are that firms must foster an environment that enables frequent face-to-face communication and encourages the mobility of personnel from university to industry and vice-versa to facilitate the transfer and codification of this new knowledge.

5.4 Limitations

This research has been conducted in the context of the information and communications technology industry sector that is characterised by rapid rates of technological change. The finding that new university technologies are more often used by firms in areas associated with their core competencies should be externally valid for other high-technology industry sectors. It is less clear whether this finding would be replicated in industries that are not challenged by rapid technological change such as chemical engineering and pharmaceutical sectors. The underlying theoretical rationale upon which this research is based, however, should endure changes in industry specific characteristics. Perhaps the only limitation will be the degree of the effect size for varying sectors. Nevertheless, attempts should be made to replicate the research in other setting so as to increase confidence in the generalisability of the results.

The research is limited to reporting only what has been done in regard to cases of new university technology adoption for product innovation. It is to a large extent a study of strategic behaviour vis-à-vis the adoption of new university technology associated with core competencies. A broad underlying rationale has been offered in support of such behaviour that goes some way to explaining causality and internal validity among the construct relationships. The research approach taken was to find as many different industry-university links as possible and to explore each one to uncover examples of technology adoption for product innovation. What has not been determined, however, is how these relationships were established nor how the technology was developed. If these were developed mainly, for example, through collaborative targeted research, then the resulting technologies might have a bias towards the firm's core competencies. Similarly, the research did not examine the successfulness of these projects. The issue of key success factors must also be left to further research. Therefore, more needs to be done, especially in the determination of causal and success factors relating to the adoption of new technologies associated with core competencies. This will go a long way to develop more fully a theory in support of this behaviour.

Another limitation concerns the instruments used to collect data. The use of perceptual data, although common in management research, reflects the early stages of the research. As discussed in Chapter 3, care has been taken in instrument design to avoid common sources of bias. The use of objective measures, however, should be considered for future research. The challenge for operationalisation, especially for the core competencies association construct, will be to design measures that tap the output of the management process without needing to get at the content of core competencies which are unique to each firm. The issue of perceptual recall may also pose a problem. The research timeframe spans a period of 10 years and perceptual recall, for the most distant projects, may be a source of error. Nevertheless, the effect size found in this research has been large enough to dampen such concerns and increase confidence that recall did not pose a problem in data collection.

5.5 New Research Questions

This research has shed light on the fundamental question of whether universities are useful sources of technology for new product innovation. It has done this by using a resource-based perspective for examining the extent of adoption of new university technologies in the domains of firms' core competencies. This work has opened the door to some interesting new research questions.

Success Outcomes

As noted above, this research has not evaluated the successfulness of the product developments using these new university technologies. Thus, further research should be done to evaluate success outcomes and determine the key success factors. For example, are new products based on new university technology that is associated with core competencies more successful than those that are not? Likewise, when new university technology that is highly tacit is adopted in areas not associated with core competencies, are the projects less likely to succeed?

Appropriability of New Technological Knowledge

One aspect of external technology acquisition which has received attention in the past is the concern over appropriability, i.e., the ability of a firm to appropriate rent from its investment in the new technology (Teece 1986). This issue is a particular concern for university technologies because of the public institution context. Yet this research found that exclusivity arrangements were not a significant differentiator between technologies associated with core competencies and those that were not. Also, for technologies associated with core competencies, there was little difference in the number of cases with exclusivity versus those without. This raises some interesting questions. For example, what are the factors affecting appropriability that firms perceive are important versus those that have a material effect on rent generation. Can firms appropriate rent from new external university technologies without barriers preventing competitor access to those same technologies? These questions will become increasingly important in the stream of research examining the adoption of new university technologies in regimes of rapid technological change.

Technology Development Paths

The past two decades has seen a substantial debate in the literature concerning university-industry linkages and the importance for university research to be done in collaboration with industry and targeted to industrial needs. Generally speaking, new university technology can be developed either independent from industry or in collaboration with industry. Obviously, those technologies developed through collaborative arrangements will likely find applications within the sponsoring firms. But what about new technologies that have emerged through independent research? Are these discovered and valued by industry? Furthermore, does this development path make a difference in the propensity to adopt technologies associated with core competencies? In a similar manner, have the past decades of collaborative research shaped the selection process of university researchers sufficiently well so that independent research is being pursued in areas of interest and importance to industry? Early work to address some of these questions is already ongoing. As background to this research, a theoretical framework was developed for classifying the differing technology development paths.

Plans are being considered to carry this work forward through new research that could answer some of these questions.

Management by Core Competence

Although the early roots of the resource-based view of the firm appeared as much as four decades ago (Selznick 1957; Penrose 1959), the theory did not receive formal academic attention until more recent times (Wernerfelt 1984). Furthermore, only during the last decade has empirical work been undertaken to lend support to this theory. Core competence is one major concept so fundamental to the firm's performance that has emerged from this theory. Yet its application within industry is still subject to question (Coyne et al. 1997). More empirical work, therefore, still needs to be done to clarify and validate such concepts so that management can apply these principles in corporate governance. This research has contributed to this flow of knowledge by developing and operationalising a new construct "core competence association." The construct can now be applied in innovative ways to answer new research questions. For example, how much of the firm's resources are allocated to developing core competencies? Similarly, are firms appropriately rewarded according to the magnitude of these resource allocations?

In the course of developing this research framework, the author also explored a new construct "management by core competence," for measuring the degree to which firms govern by a core competence approach. Initial development of this construct involved 37 measure items tapping into four dimensions. This work is still in progress with the aim of validating the construct through empirical research. Such a construct can be used in answering new research questions that probe the relationship between the degree of management of core competence and the performance of the firms across many different dependent variables.

5.6 Conclusion

In conclusion, this dissertation has made contributions in a number of areas.

Adoption of New University Technology for Product Innovation

University-industry linkages take on many different forms and are driven by many differing motivations. Public policy research has tended to focus on frameworks for effective technology transfers with few studies aimed at empirical examination of industrial use of university research output. This is the first empirical study devoted to examining the specific context of university research output used for industrial product innovation. It also is the first study to measure the relative importance of new university technology to industry by evaluating how well such technologies are aligned with the strategic core competencies of firms. Both through the framework developed here and the empirical findings, this study provides a useful contribution to the growing stream of knowledge that is concerned with the study of the value of new university technology to industrial product innovation.

Definition, Operationalisation and Instrumentation

The definition and operationalisation of the construct "core competence association" has been developed as a way of evaluating the alignment of specific new technologies with the firm's core competencies. Measures have been selected which are easy to obtain and generally applicable across firms. This circumvents the difficulties associated with measuring the unique contents of core competencies. An instrument has been carefully developed and tested for reliability. Validity of the measures and construct has been determined to the extent possible. This instrument can be used by researchers to address new questions and by practitioners concerned with evaluating the fit between new technological resources and their firms' core competencies.

An Empirical Link Between Core Competence and Performance

The research has established empirical links between the degree to which a new university technology is associated with core competencies and firm performance. Underlying assumptions are that platform products are superior sources of returns compared to derivative products and new emerging markets potentially bring greater returns than existing markets. In this framework, association of new university technologies with core competencies has been empirically linked to both the creation of platform products and the intention of serving new emerging markets with those products. These findings add to the current stream of empirical support for the resource-based view of the firm.

An Empirical Link Between Tacitness and Core Competence

The research has also established an empirical link between the tacitness of the new technological knowledge and the degree to which the technology is associated with core competencies. This link has shown that the greater the tacitness of knowledge, the more closely the knowledge is associated with core competencies where regimes of high absorptive capacity are assumed to be at work. These higher absorptive capacity regimes are required to overcome the barriers inherent in transferring and codifying highly tacit knowledge.

This dissertation has taken an initial step in examining the adoption of new university technology by firms for product innovation. It has found that these technologies are closely associated with firms core competencies and result in the creation of new platform products. They are a valuable external resource that makes a strategic contribution to the firm.

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APPENDIX A: Case Report on the Commercialisation of the Hypercube Network Switch Technology

Table of Contents

1.0 Introduction

This report is a brief case study of the major events and circumstances surrounding the commercialisation of the hypercube network switching technology that originated from the University of Saskatchewan.

2.0 The Hypercube Network Switch Beginnings

The "hypercube"[9] architecture is typically the domain of the supercomputer community. It had not been seriously considered by industry for application in network switching equipment although two companies were somewhat active in this area. Another two universities were known to be involved in some research using the hypercube for network switching although little work had been published in this area. A professor at the Department of Computer Science at the University of Saskatchewan, however, recognised the potential for applying the unique characteristics of the hypercube in network switching applications. In particular, the hypercube architecture was suited to switching messages of fixed length and for call control. The novel idea to develop an asynchronous transfer mode (ATM) network switch based on the hypercube was conceived and further refined through system modeling and simulation. It focussed on the intrinsic characteristic that the hypercube provided: a distributed switching system. The result was a proprietary cell-relay switching technology concept based on a distributed cell-relay algorithm running in a hypercube architecture. This architecture also provided important operational characteristics such as its scalability and high fault tolerance, which were potentially desirable to equipment manufacturers.

[9] Also called the n-dimensional binary hypercube

For example, all the important costs could be contained in the port cards. Consequently switch costs scale nearly linearly with port count providing high performance at a very low replication cost. This permits highly economical implementations of switches as small as 622Mbps to 160Gbps[10] in increments of 622Mbps. Thus it is attractive for switch vendors who require low entry cost. These features provided unique advantages not generally available at the time.

The origins of the hypercube ATM switch concept evolved out of the extensive scientific and technological knowledge of the principal university innovator. This is evident from the number of scientific publications in various journals, conference proceedings, technical reports and book chapters. These include 29 publications in the field of algorithms and architectures, 15 related to computer languages and 5 related to fault tolerance and testability.

3.0 First Steps to Commercialisation

Table 1 shows a timeline of significant milestones in the process of commercialising the new technology. With an initial grant from CANARIE[11], the inventors worked with a local Saskatoon company, Digital Systems Group (DSG), to turn the concept into a hardware prototype. The principal university inventor was closely involved in this work which resulted in a second CANARIE grant. However, after 18 months, DSG's primary business activities failed and the firm went into bankruptcy.

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[10] Mbps = mega bits per second. Gbps = giga bits per second

[11] CANARIE is a private, not-for-profit organization supported by Industry Canada, 120 members and over 500 project partners. Its mission is to accelerate Canada's Advanced Internet Development and use by facilitating the development of Canada's communications infrastructure and by stimulating next generation products, applications and services.

Date	Milestone	Notes
1993	Initial commercialisation steps	Digital System Group commences internal activity to bring the concept to a prototype
1995	Hypercore Technology incorporated	Funding from CANARIE to develop technology as a marketable product. 3 employees
Fall 1995	Hypercore Technology partnership with Develcon	Develcon receives a 40% stake in Hypercore Technology
Fall 1996	ATM forum spec TM4.0 released	Design changed to incorporate new specification. Significant work/delay to prototype completion
Spring/ Sum `97	Decided on FPGA instead of ASIC for prototype	System vendor sought
Sept 1997	Complete switch prototype	6 employees
Oct 97	Demonstrate to Canarie	Much excitement. But efforts on switch start to wane, as other application studies such as internet protocol switch commence while searching for customer
Fall 96/ Winter 1997	Negotiations with Nortel and Newbridge Networks	Seeking System vendor as partner.
End 1997	Negotiate with Nortel for contract to build demo systems	Nortel undecided
Feb 1998	Negotiations with Newbridge Networks to acquire Hypercore Inc.	No acquisition
Sep 1997	Initial discussions with PMC-Sierra	
Apr 1998	Acquired by PMC-Sierra. Manager from head office joins team	Hypercore Inc. becomes PMC-Sierra Saskatoon Design Centre. Integrate hypercube technology within PMC-Sierra
Winter 1998	Marketing person joins team, 5 months late	Product definition delayed 3-4 months of critical time
Oct/Nov 1998	Hypercube derivative product definition presented to customers	Unsuccessful in finding customer. Couldn't meet customer timeframe by 1-2 quarters. Overestimate market capacity demands
Feb 1999	Senior executives shift focus to defending market share	Team diverted to building new products to strengthen existing portfolio. Hypercube product shelved.
Win 2000	New product due for release	Developed by Hypercore team and incorporating some key hypercube knowledge

Table 1. Timeline of Significant Commercialisation Milestones

Then, with infrastructure support from TRLabs, and the funding from CANARIE, HyperCore Technology Inc. was created in 1995 to pursue the development of the technology and create a marketable product. With only three employees, it set about building a basic switch fabric prototype. This was later followed by a full working prototype that included the switch, the protocol stack and the interface ports.

In the fall of 1995, Hypercore entered into a partnership with Develcon Electronics Limited[12], a manufacturer of a wide range of digital telecommunications equipment, to produce a range of ATM switching products based on this HyperCore technology. This partnership brought in needed technical resources for printed circuit board development and product manufacturing capability. Develcon also had a distribution capability and provided marketing input through the period of Spring 1996 to Summer of 1997. In return, Develcon received a 40% stake in Hypercore Technology Inc.

In the Fall of 1996, the ATM forum brought out a new traffic management specification called TM 4.0[13]. The HyperCore management decided it was necessary to modify their switch design to meet this new standard. It involved significant work to both hardware and software with resulting delays to prototype completion.

The target was to build a full UNI 3.1[14] entry level ATM switch prototype. They needed to decide what type of digital hardware building blocks or silicon chips to use. One option was to use field programmable gate arrays (FPGA). These are integrated circuits that programmed to accommodate the desired logic design.

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[12] Develcon Electronics Ltd. was based in Saskatoon. At the time of writing the firm has relocated to Toronto, Ontario.
[13] Traffic Management 4.0
[14] User-to-Network Interface 3.1

Each FPGA however, can only accommodate a small amount of logic complexity and operates at relatively low speed. This requires that many FPGA's be used resulting in a larger form factor and speed performance. The other option was to use Application Specific Integrated Circuits (ASIC). When these integrated circuits are manufactured by the silicon foundry the logic design is hardwired onto the chip. These devices can incorporate a larger amount of logic complexity and can operate at higher speeds. This results in a more compact form factor operating at full speed.

HyperCore was targeting system vendors such as Nortel and Newbridge Networks. They perceived there was no point in building an ASIC form factor for system vendors and therefore decided to build the prototype using the FPGA form factor. A functional 2.4 Gbps ATM switch prototype comprising 16 OC-3 ports[15] was completed by September 1997 and demonstrated to CANARIE in October 1997. At this point, HyperCore had grown to six employees.

4.0 The Technology Acquisition Process

Negotiations with Nortel and Newbridge Networks proceeded from October 1997 to February 1998. In particular, HyperCore tried to secure a contract with Nortel at the end of 1997 to build a demonstrator system for Nortel's laboratories. Nortel management, however, remained indecisive. Discussions with Newbridge Networks concerning the acquisition of HyperCore Technology Inc. took place in February 1998. Although these discussion brought the two companies quite close together, apparent internal resistance within Newbridge Networks resulted in a decision not to purchase Hypercore Technology.

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[15] Optical Carrier – 3 ports

In September/October 1998, initial discussions commenced with PMC-Sierra, a supplier of off-the-shelf semiconductor chips for high speed internetworking solutions. Two key PMC-Sierra staff led these discussions. One of them was primarily interested in the hypercube technology while the other was mainly interested in acquiring the human capital of Hypercore Technology Inc.

Although PMC-Sierra did have a network switching product at the time, they were in the process of acquiring IgT, a business active in switching products. This indicated PMC-Sierra's intention to become active in the network switching market. Since the HyperCore technology was a potentially valuable network switching technology, it was considered important for PMC-Sierra to have control of the technology and lock out competitive access. To facilitate the acquisition process, Hypercore Technology Inc. became a company wholly owned by Develcon Electronics Ltd and PMC-Sierra bought the complete and exclusive rights to the HyperCore technology from Develcon. In addition, the staff of HyperCore Technology transferred to PMC-Sierra becoming the PMC-Sierra Saskatoon Design Centre, thus assisting the transfer of skills and technological knowledge from HyperCore Technology. The principal university innovator, who is a professor at the university, undertook a four-year assignment with PMC-Sierra to support the commercialisation of the technology. The acquisition process was completed in April 1998 at which point HyperCore Technology Inc. had existed for a little more than three years.

5.0 PMC-Sierra's Core Competence and Product Strategy

PMC-Sierra is a leading supplier of off-the-shelf semiconductor chips for high speed internetworking solutions. The firm is a major merchant telecom chip supplier with a significant architectural knowledge of network transport technologies such as SONET[16] and ATM. This has helped them to produce a catalogue of integrated products that was much broader than any of their competitors. It has also enabled them to be first to market with ATM and SONET products.

PMC-Sierra also has considerable technological expertise in the design of the high-speed serial interfaces that these switches require. The acquisition of the HyperCore Technology Inc. represented an opportunity for PMC-Sierra to increase its degree of system integration and strengthen its architectural design capability. The new technology was closely aligned with the firm's area of expertise in switch fabrics.

The product development process in PMC-Sierra has been described using various terms such as diffuse and amorphous, anarchistic and autocratic, competitive and collegial. Marketing and R&D are closely linked in the process of ideation and concept development. They use "System Vision Teams" comprising technical and marketing staff to develop new product ideas and evaluate their market potential. These teams meet once a month to review and discuss presentations by lead engineers on product ideas in their areas of specialty. The teams are guided by the Director of Product Development who articulates the product development strategy. New product ideas that are approved for further investigation proceed to the feasibility stage. During this stage, both technical and marketing resources are assigned. The feasibility team developed a detailed product definition, define the market, seek feedback from key customers and develop a strong marketing plan.

[16] Synchronous Optical Networking

Since PMC-Sierra is heavily committed to key customer partnerships, their aim is to develop new products that have strong expressions of interest or design wins from their key customers. Prospective new product concepts are reviewed at the quarterly product planning meetings and design approval status is given to the most promising concepts. These then enter the design and manufacturing stage with the first samples typically produced within 12 months and production units within another 12 months.

6.0 Bringing the Hypercore Technology to Market

A PMC-Sierra manager from head office was immediately assigned to integrate the HyperCore team with the organisation. As a result, the team was able to present their technology to staff and were quickly integrated within the organisation. However, a key marketing person needed to push the product definition was not available till five months later. The new product definition for an OC12 ATM switch was finally completed, approved by senior executives and presented to key customers by October/November 1998.

7.0 Leveraging the Technology into Products

This new product definition, however, did not get immediate acceptance from key customers. There were two possible explanations for this offered by the interviewees. Firstly, the product definition overestimated the immediate capacity demands needed by customers in the market place. Secondly, the delay in getting the marketing person resulted in losing three to four months of critical time. This translated into missing customer product lead-time requests by one or two quarters and resulted in losing customer design wins.

By February 1999, senior executives recognised the potential of competitive threats against their established product positions in primary physical interfaces and redirected efforts to defending this position. Although the hypercube-based product was completed up to the detailed design stage, it was not implemented any further. The resources were re-focussed onto the core product line to develop a new switch that strengthened their existing capabilities. This new product incorporated new ideas and techniques, such as certain call set-up and scalability approaches, that had evolved from the Hypercube technology. PMC-Sierra was therefore able to leverage aspects of the new technology into new products that are due for initial release in the first half of year 2000.

8.0 Implications for Future New Technology Development

HyperCore Technology Inc. built a prototype system whose capacity was much greater than what the system manufacturers were shipping to the market place. This suggests perhaps that HyperCore went too far in their market estimation of switch performance needs. In other words, they may have overestimated the performance requirements of future switching systems. Their experience points to the importance of matching performance requirements of new innovations with near-term future market need to ensure rapid adoption of the product innovation. However, the design team still felt that the hypercube architecture had a place for future very high bandwidth switch applications. At the time of writing, market requirements have evolved considerably and the hypercube architecture is now positioned as an important contender for meeting performance needs.

During the development of the prototype, Hypercore Technology decided to upgrade their design to be compliant with the ATM forum's TM 4.0 specification. This resulted in a significant increase in complexity and required design effort in hardware and software which translated into delayed prototype completion. However, the TM 4.0 specification today has only "spotty" support in the market place. The development delay may have contributed to missing the market window for the end product and suggests caution in accommodating requirements creep during new product innovation.

Hypercore were targeting system manufacturers (or networking equipment vendors) such as Nortel or Newbridge Networks as their primary customers. Yet the end result was that PMC-Sierra, a leading supplier of semiconductor chips ("building blocks") for equipment manufacturers, became their customer. In terms of the network equipment manufacturing value chain, this represents a shift from the system vendors back towards the component suppliers. The prototype form factor chosen by Hypercore (i.e., FPGA's) addressed the equipment manufacturer's position along the value chain. However, the semiconductor vendor required an ASIC form factor. As a result, significant design effort was needed to convert the FPGA based design to the ASIC form factor. As was stated by one of the interviewees, it was necessary to "take it into their realm." This additional effort may have also contributed to the inability of the new product based on the hypercube technology to meet key customer lead-times.

This suggests the importance of considering how the new technology could be targeted to differing positions along the value chain and what form factors are needed to meet potential customer requirements in those value chain positions. With these options considered, it may be advisable to develop the technology into the form factor that has the greatest potential of adding value to as many different types of customers along the chain as possible.

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APPENDIX B : Case Report on the Commercialisation of the "Always-On" DSL Technology

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1.0 Introduction

This report is a brief case study of the major events and circumstances surrounding the commercialisation of the "Always-On" digital subscriber line technology that originated from the University of Saskatchewan and Telecommunications Research Laboratories (TR*Labs*)[17].

2.0 The Always-On Beginnings

With the growth of the World Wide Web, the adoption of Internet connection capabilities in domestic households has become almost ubiquitous in the developed world. The most common form of Internet connection is the dial-up analogue modem that uses special modulation techniques to send digital data across an analogue telephone line. Current standards, such as V.90, allow data rates up to 56 Kbps[18] to be transmitted. When such a modem is used, however, the telephone line is dedicated to the internet connection thus prohibiting the use of normal voice calls. New digital technologies, such as digital subscriber line (DSL) and Asymmetric DSL (ADSL), allow simultaneous voice calls and higher bandwidth internet connections. However, these have a limited operating range because of the attenuation of the high data frequency signal along the wire. For DSL, the distance between the subscriber and the telephone company's central office (CO) is limited to 3.5 km and for ADSL the range is about 2.5 km.

In telephony, rural subscribers are defined as being more than 5.6 km (18,000 feet) away from the CO. These long lines require special conditioning or "loading coils" in order to improve the frequency response of the voice signal.

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[17] TR*Labs* is Canada's largest not-for-profit information and communications technology research consortium whose research program is based on industry/university collaboration. It aims to produce original, industry-relevant, pre-competitive research that looks three to seven years into the future.

[18] Kbps = kilobits per second.

However, such conditioning severely attenuates frequencies above those used for voice calls thereby making the line unusable for simultaneous data and voice transmission. Rural users, therefore, need to maintain two telephone lines if they wish to have simultaneous voice and internet capability.

The initial "always-on" concept addressed two issues. Firstly, it provided simultaneous transmission of voice and data on a standard single telephone line by using a simple "data over voice" technique. Using a combination of frequency band filters (splitters) and frequency translators, it shifted the operating bandwidth of the data modem from voice frequencies (approximately 200 to 3700Hz) to a higher band (5400 to 8900Hz). As a more simple alternative to the sophisticated DSL technologies, it provided simultaneous data and voice using standard lines. Secondly, when combined with a reduction in loading coil values, it hoped to enable rural lines in excess of 5.6 km to have simultaneous data and voice.

The idea was first conceived by a professor at the Department Electrical Engineering, University of Saskatchewan. This professor has an extensive 30 years of knowledge and experience in telecommunications and good connections within the industry. The initial design was developed by a student through a Master's program. The student received a scholarship from TR*labs*[19] and used their laboratory infrastructure. The objective, as a curiosity investigation, was to solve a technical problem rather than address specific market requirements.

[19] In this capacity, TR*Labs* acts as an incubator for developing promising new concepts in telecommunications.

At completion in December 1998, a 33.6 Kbps prototype modem demonstrated the feasibility of the concept over a limited range. The results of the research were reported in the thesis along with technical problems that still remained, items that the design did not address, and suggestions for how it could be improved. TR*labs* also sought to protect the intellectual property by filing a patent of the design.

3.0 First Steps to Commercialisation

The industrial members of TR*labs* were then informed of the availability of this new technology. One of its members, SaskTel,[20] expressed an interest in the design. Discussions then took place between TR*labs*, the R&D department of SaskTel, and a local Saskatoon company, Critical Control Corporation. As a result, Critical Control was contracted by SaskTel to do a three-month evaluation of the design. This investigation found that the initial suggestions for improving the design could not solve the outstanding technical problems and that a fundamental change in concept was needed. Critical Control proposed some new ideas to SaskTel and was contracted to develop a new prototype over a six-month period. This was achieved with a design that could reach 3.5 km and, as a result, ten prototypes were installed for a six-month field trial.

By this time SaskTel's marketing group recognised the need to extend the distance to 5.6 km, the maximum distance before the first loading coil. However, the focus on rural applications beyond 5.6 km was dropped. This would have required the labour intensive procedure of reducing the loading coils values on each user's line with the associated problem of degrading the voice quality.

[20] SaskTel is the main telecommunications provider in Saskatchewan.

Critical Control evaluated the design and found that it would not reach the required distance. They proposed a new concept using a dual frequency method. SaskTel's Strategic Business group then contracted Critical Control to develop the new design into a full beta product. The new product was called eDSL-33 and 10 units were put on a six-month internal field trial. This proved satisfactory and another 200 units were placed on a limited public trial which is currently in progress. The eDSL-33 product comprises two components. The first is the eDSL-33 client which is a data modem. It is connected to the user's PC via a standard serial cable and to the same telephone line as the voice telephone. The second component is the eDSL-33 server which is located in the CO. The server replaces the line cards that would otherwise be needed for the dedicated modem pool connections.

4.0 Critical Control Corporation's Core Competence

Critical Control was founded in Saskatoon in 1987 as privately owned custom electronics design and manufacturing organisation. It was initially focussed on developing customer specific instrumentation solutions such as smart sensors, image processing, remote sensing and positioning systems. It has developed a variety of microcontroller based systems and has gained considerable expertise in hardware, software and firmware design. In 1995, Critical Control started developing wireless telemetry and telecommunication systems. Their focus on telecommunication solutions was intensified through their involvement in the Always-On technology between 1999 and 2000.

At the end of 1999, Critical Control made the strategic decision to redefine their role as an organisation. Drawing on their increasing telecommunication systems knowledge and strong product development expertise, they shifted from being a custom

R&D provider to being a developer of their own telecommunications products. Their renewed focus is on the connection between the subscriber and the CO, often called the "last mile" network access market segment. In 2000, the firm changed its name to Critical Telecom and planned an initial public offering for the fall of that year.

Critical Control has developed considerable expertise in two main technical areas. The first area is wireless baseband which includes all aspects of wireless systems control except the radio frequency component. The knowledge and skill bases include communications theory (especially spread spectrum), modulation techniques and the know-how to implement entire radio systems in hardware and embedded firmware. The second area of technical depth is that of subscriber loop technology. This includes an in-depth understanding of transmission line theory and the detailed characteristics associated with the wireline connection between the subscriber and the CO.

5.0 Insights From The Always-On Technology Development

A number of interesting observations and insights can be made concerning the development of the Always-On technology. Although the technology and its associated product are owned by SaskTel, the technology was actually developed by Critical Control.

A first observation may be made about the evolution of the technology itself. As a curiosity investigation to solve an existing meaningful problem, the original university technology was reasonably successful. However, even though its feasibility was demonstrated through a conceptual prototype, the original technology required several fundamental changes before achieving commercial product status as the eDSL-33 modem. Thus, from Critical Control's perspective, the final technology and associated intellectual property[21] looked quite different from the original Always-On technology. At least two insights may be drawn from this observation. Firstly, the newly emerging university technology in itself was not directly commercialisable. Rather, as a conceptual prototype, it drew attention to a meaningful problem that could be solved. The new university technology, therefore, might be looked upon as a source of a new innovative idea for a new product opportunity. The second insight relates to the issue of appropriability. When a firm acquires an external technology, it may not be able to fully appropriate the benefits of its internal investment if other competitors have equal access to the same technology. Thus, it is often argued, university technologies may not provide adequate benefits to firms unless they are secured on an exclusive basis. However, in case of the Always-On technology, the further investigations and development resulted in clearer understanding of customer needs, revised product requirements and new technical solutions. Thus the final technology and its associated eDSL-33 product were considerably different from the original concept. Critical Control introduced a significant amount of firm-specific technological knowledge. It is unlikely that another firm having acquired the same technology would have followed the same path of technology development. For Critical Control, this evolution of technology has resulted in the ability to appropriate or capture the benefits of their investment. For example, Critical Control applied for a patent on their own proprietary technique and have plans to develop the next generation high- speed version of their eDSL product.

[21] Critical Control filed for its own patent on the new techniques used.

A second observation concerns the impact of the Always-On technology development on Critical Control's core competencies. Previously, the firm had been developing a wireless payphone link which was completed in August 1999. This project enabled the firm to develop an initial knowledge base in the telephone subscriber loop area. As a result of the experience gained from developing the Always-On technology, their knowledge base in subscriber local loop systems was considerably enhanced.

The Always-On technology program helped underpin the firm's decision to change from a contract designer to a telecommunications equipment developer. Thus the new technology had a role in both the building up and the shaping of the firm's core competencies.

6.0 Sources of Information[22]

Critical Control Corp. (2000a). Capabilities. Available: http://www.cc.ca/capabilities.htm

Critical Control Corp. (2000b). News. Available: http://www.cc.ca/news.htm

Critical Control Corp. (2000c). Products. Available: http://www.cc.ca/products.htm

Critical Control Corp. (2000d). Projects. Available: http://www.cc.ca/projects.htm

Swanson, L. D., "Rural Internet Access Using Modem Above Voice," unpublished Master's thesis, Dept of Electrical Engineering, University of Saskatchewan, Dec 1998.

TRLabs. (2000a). Saskatoon Network Access-Research Laboratory. Available: http://www.sask.trlabs. ca

TRLabs. (2000b). What we do. Available: http://www.trlabs.ca/whatwedo/index.html

van den Berghe, L. (2000). [Interviews with Critical Telecom's Vice President and Chief Technology Officer. Apr - Aug. 2000]. Unpublished raw data.

[22] As a result of Critical Control Corporation's name change to Critical Telecom and their new focus, the old website www.cc.ca ceased to be available on 1st September 2000. The companies new website is www.criticaltelecom.com.

APPENDIX C: Example Email Invitation To Participate In Research

Mr. XXX
R&D Director
XXX. Inc.

Survey on the Adoption of New University Technology for Product Innovation

Dear Mr XXX,

I am conducting a telephone survey to ask senior executives how university research is being used for new product innovation. My PhD research aims to provide new knowledge which will be helpful to managers who need to make decisions about using new university technology in their product innovation.

Your firm has been selected because it is actively involved in the Micronet network. I also note from the NSERC grant website that your firm has sponsored a collaborative research project called "Graphics acceleration hardware on a field-programmable system" with Dr. Jonathan Rose of the University of Toronto.

I would like to ask you some questions about these and other projects using university research. Would you be willing to participate in this brief telephone survey which should take about fifteen minutes? I will call you shortly to discuss this with you.

My supervisor is Professor Paul Guild and we are both from the Department of Management Sciences at the University of Waterloo. We will be pleased to provide an executive summary of the final research findings to all those who participate in the survey. Your answers will be kept strictly confidential and all information collected from participants will be aggregated before reporting. This project has received ethics clearance through the Office of Research Ethics at the University of Waterloo.

Thanks and regards

Larry van den Berghe
PhD. Candidate
University of Waterloo
lgvanden@uwaterloo.ca
Tel: (306) 384-0663
Fax: (561) 382-6475

APPENDIX D: Extract from Telephone Survey Script

Hello Mr./Ms./Dr. [Name of Manager],

My name is Larry van den Berghe and I am a Ph.D. Candidate from the University of Waterloo.

I am following up my email sent to you about your firm's involvement in [title of network] and how it has used the results of the [title of grant] with Professor [Name of Professor] at the [University Name]

This call should take about ten minutes.

1. Mr./Ms./Dr.[Name of Manager], would you be willing to participate in this brief telephone survey?

- ❍ No [Go to question 2]
- ❍ Yes [Go to question 3]

2. In order to understand the survey better, please would you let us know why you do not wish to participate……

Thank you Mr./Ms./Dr. [Name of Manager] for your time today. End.

3. Thank you for agreeing to participate in this telephone survey.

Could you describe briefly the background of this project and whether it was used in any product development

The new knowledge was used ....

- ❍ ... in a product [Go to question 4]
- ❍ ... in a process (such as design, modelling, etc.) [Go to question 4]
- ❍ ... as background technical knowledge [Go to question 7]

4. [If Product/Process]. Which of the following statements best describes how the new technical knowledge was used in your product/process.

The new knowledge was used ....

- ❍ ... to create a new product/process
- ❍ ... to improve the existing product/process

[If Product]. Which of the following statements best describes the new product as perceived at the beginning of its development.

5. Our new product....

❍ ... marks the beginning of a new platform family / product line for our firm.
❍ ... is an extension of our existing platform family / product line.

6. How long was it from receiving the technology to releasing the product to the market

.... years or months

7.

Are you familiar with the term ***"core competencies?"*** This can mean different things to different people. I would like to read you my definition of core competencies and ask you a question related to it.

I define ***"core competencies"*** as those combinations of complementary knowledge and skill bases that are difficult for competitors to imitate; they enable the firm to execute one or more critical processes that create substantial customer value in a wide variety of ways and at a world-class standard.

Using this definition, which of the following best describes the relationship between the new technical knowledge and your firm's core competencies?

The new technical knowledge...

❍ ... is *unrelated* to our firm's *existing* core competencies
❍ ... helps *strengthen* our firm's *existing* core competencies
❍ ... helps *build a new* core competence for our firm

I would finally like to ask a few general questions about your firm.

8. Approximately how many people are employed at the business unit or division when it acquired acquired the new university technology?

9. Approximately how many people were employed at your firm Canada-wide?

10. Approximately what % of revenue did your firm spend on R&D last year?

The next step in my research is to ask more detailed questions on specific projects like yours using a web-based survey. Participants can go directly to the web and complete the questionnaire which usually takes about 15 to 20 minutes.

Would you be prepared to participate in this survey?

Thank you Mr/Dr. xxx. I will send a formal invitation email to you today

APPENDIX E: Example Email Invitation To Participate In Web-Based Survey

Mr. AAA
Director, Research and Development
XYZ Inc.

Dear Mr. A,

Thank you for your time today and agreeing to participate in our web-based survey. We believe this study, which is supported by the Natural Sciences and Engineering Research Council, will provide useful insights about using new university technology in product innovation. Therefore, all participants will be provided with an executive summary of the research findings. Pre-tests have shown it requires 15 to 20 minutes to complete.

As per our discussion, please complete this survey in the context of the "surface pasting" technology developed at the University of Waterloo and used in your new product. Please answer the questions from your firm's perspective at the time the technology transfer was in progress.
Please proceed to the survey site by clicking this link http://survey.uwaterloo.ca.

You may omit any question you prefer not to answer, although we encourage as complete a response as possible. Your participation in this project is voluntary and anonymous. This project has received ethics clearance through the Office of Research Ethics. The information you provide will be held in the strictest confidence and will be securely stored and kept for a period of 5 years.

Thank you in advance for your interest in this project.

Yours sincerely,

Larry van den Berghe
Ph.D. Candidate
University of Waterloo
lgvanden@uwaterloo.ca
Tel: (306) 384-0663

APPENDIX F: Web-Based Survey Instrument

University of Waterloo

Survey of the Adoption of New University Technology in Product Innovation

Thank you for agreeing to participate in this survey of new products that have used new university technologies. The goal of this study is to increase our understanding of the way university research is helping firms develop or improve their products. We will be pleased to send you an executive summary of the findings when the study has been completed.

YOUR RESPONSE IS VERY IMPORTANT TO US. On the basis of pre-tests, we have found that this survey takes 15 to 20 minutes to complete. If we can assist you in anyway, or if you have any questions or comments, please contact:

Larry van den Berghe
Doctoral Candidate
Department of Management Sciences
University of Waterloo
Waterloo, Ontario
lgvanden@uwaterloo.ca
Tel. Saskatoon (306) 384-0663

Paul D. Guild
Director, Institute for Innovation Research
Department of Management Sciences
University of Waterloo
Waterloo, Ontario
guild@uwaterloo.ca
Tel. Waterloo (519) 888-4802

Statement of Confidentiality

The information you provide will be held in the strictest confidence. All results from this research will be aggregated before reporting. We will neither publish, release, nor disclose any information on, or identifiable with, individuals participating in this study. This project has been reviewed by, and received ethics clearance through, the Office of Research Ethics at the University of Waterloo. If you have any questions or concerns resulting from your participation, please contact this office at (519) 888-4567 Ext. 6005.

Instructions

While completing this survey, please keep in mind one specific **new product and the new university technology** that is used to create it. The new product can be:

· a completely new product or an improvement to an existing product,

· at any stage of development (e.g., product concept, prototype, production, or terminated).

The survey is intended to be answered by a manager who has been closely involved with this specific product development. Throughout the survey, "we/our" means you and your management colleagues in particular, and your business unit in general.

Start Your Responses Here

1. Please describe in a few words your new product that uses the new university technology.

2. Please describe in a few words the new university technology that was used in your new product.

About Your New University Technology

3. From which university did you receive the new technology?

4. How close is the university to your firm?

- c Same city
- c Same province
- c Neighbouring province
- c Distant province
- c Outside Canada

5. Approximately how many hours does it take to travel door-to-door from your firm to that university? (Example response: 3.5)

6. Did you receive any exclusive rights to the new university technology?

- c Yes
- c No

7. If you answered "Yes" above, please select the option that best describes the degree of exclusivity you received for each dimension below.

	Limited/Specific 1	Unlimited/Any 2
Duration of time	c	c
Type of product application	c	c
Market or industry sector	c	c

Below are a number of statements about the new technology. Please indicate how well each one describes what you received from the university by selecting the appropriate number in the right hand column. If not applicable to this type of technology, please select N/A.

8. When we received this new technology, the university provided us with ...	**Does not describe this new university technology at all**						**Describes this new university technology exactly**	**N/A**
		2	**3**	**4**	**5**	**6**	**7**	**8**
... a detailed theoretical description.	○	○	○	○	○	○	●	○
... a simulation model or software program that enabled us to evaluate it.	○	○	○	○	○	○	●	○
... a prototype that demonstrated the general principle or concept.	○	○	○	○	○	○	●	○
... a prototype that demonstrated the functions of the technology as it should perform in the final product.	○	○	○	○	○	○	●	○

9. In order to meet our new product requirements, we changed this new technology by ...	**Does not describe this new university technology at all**						**Describes this new university technology exactly**
	·	**2**	**3**	**4**	**5**	**6**	**7**
... adding more functions.	○	○	○	○	○	○	●
... improving the performance level.	○	○	○	○	○	○	●
... making major changes to the technical concept.	○	○	○	○	○	○	●
... making major changes to the physical implementation (such as circuits or software).	○	○	○	○	○	○	●
... significantly re-engineering it for production.	○	○	○	○	○	○	●
We made no major changes to the technology.	○	○	○	○	○	○	●

10. Below are a number of statements about the transfer of the new technical knowledge from the university to your firm. Please indicate how well each one describes the transfer by selecting the appropriate number in the right hand column.

	Does not describe the transfer of this technology at all						Describes the transfer of this technology exactly
	·	2	3	4	5	6	7
There was much more to know about this technology than what could easily be written down.							
To assist with the technology transfer, the university researchers spent an extended period of time at our firm.							
To assist with the technology transfer, university students who worked on the technology spent some time at our firm.							
To further develop this new technology, we hired some of the university researchers.							

11. Our technical staff ...	Does not describe the transfer of this technology at all						Describes the transfer of this technology exactly
	·	2	3	4	5	6	7
... are very knowledgeable in disciplines closely related to those of the university researchers.							
... received in-depth technical documentation from the university researchers describing this new technology (such as blueprints, drawings, reports and software code).							
... found it relatively easy to understand the technical details as shared by the university researchers.							
... needed frequent discussions with the university researchers to fully understand this new technology.							

12. Below are a number of statements about the new university technology and your organisation ***at the corporate level***. Please indicate how well each one describes your situation by selecting the appropriate number in the right hand column.

	Does not describe this new university technology at all						Describes this new university technology exactly
	·	2	3	4	5	6	7
Controlling this new university technology will be very important to our competitiveness.	c	c	c	c	c	c	c
We would have a distinct advantage if our competitors did not have access to this new university technology.	c	c	c	c	c	c	c
We will continue to invest in this new university technology for a significant period of time.	c	c	c	c	c	c	c

Note: In the statements below, we use the term "Customers" to mean the buyers of your firm's products; and

"***Key*** technologies" to mean those that are proprietary to some degree and which your firm seeks to control; they differentiate your firm from its competition by enabling it to provide greater value to your customers.

13. This new university technology ...	Does not describe this new university technology at all						Describes this new university technology exactly
		2	3	4	5	6	7
... will be useful for a significant period of time.	c	c	c	c	c	c	c
... is very difficult to duplicate by our competitors.	c	c	c	c	c	c	c
... will increase the value our customers perceive of our products.	c	c	c	c	c	c	c
... is likely to be deployed across a range of our products.	c	c	c	c	c	c	c
... has exceptional synergy with our existing strategic capabilities.	c	c	c	c	c	c	c
... will help build a new strategic capability in our firm.	c	c	c	c	c	c	c
... is very different from any of our existing technologies.	c	c	c	c	c	c	c
... will improve one of our existing ***key*** technologies.	c	c	c	c	c	c	c
... will improve one of our existing non-key technologies.	c	c	c	c	c	c	c
... is likely to replace one of our existing ***key*** technologies.	c	c	c	c	c	c	c
... is likely to replace one of our existing non-key technologies.	c	c	c	c	c	c	c
... is likely to become a ***key*** technology some time in the future.	c	c	c	c	c	c	c

About Your New Product

Below are a number of statements describing your business unit's expectations of your new product as perceived at the ***beginning*** of its development. Please indicate how well each one described your new product by selecting the appropriate number in the right hand column.

14. Our new product ...	**Does not describe our new product at all**						**Describes our new product exactly**
	1	2	3	4	5	6	7
... marks the beginning of a new platform family / product line for our firm.	c	c	c	c	c	c	c
... is an extension of our existing platform family / product line.	c	c	c	c	c	c	c
... adds new functionality to our existing product line.	c	c	c	c	c	c	c
... substantially increases the performance level of our existing product line.	c	c	c	c	c	c	c
... substantially increases the level of functional integration of our existing product line.	c	c	c	c	c	c	c
... substantially increases the level of functional integration compared to anything seen in the marketplace before.	c	c	c	c	c	c	c
... is unlike anything seen in the marketplace before.	c	c	c	c	c	c	c

15. We expected our new product to ...	**Does not describe our new product at all**						**Describes our new product exactly**
	1	2	3	4	5	6	7
... increase our existing market share.	c	c	c	c	c	c	c
... meet a need that already existed in the marketplace.	c	c	c	c	c	c	c
... serve a market need not addressed by our competitors at that time.	c	c	c	c	c	c	c
... address the needs of a newly emerging market.	c	c	c	c	c	c	c

16. We expected to launch our new product to the market within .... years of receiving this new technology from the university. (Example response: 3.5)

17. Below are a number of statements about the stages of your new product's development. Please indicate whether or not each one has been achieved. If not applicable to your product development, select N/A.

	No 1	Yes 2	N/A 3
We have produced a product concept.	c	c	c
We have produced a detailed product definition.	c	c	c
We have produced a prototype.	c	c	c
We have produced some pre-production units.	c	c	c
We have manufactured some production units.	c	c	c
We are manufacturing production units on a regular basis.	c	c	c
Our product has come to the end of its product life.	c	c	c
We terminated product development prior to market entry.	c	c	c
We withdrew our new product after market entry.	c	c	c

About Your Firm

18. Below are a number of statements about corporate level management in your organisation. Please indicate how well each of them describes your firm by selecting the appropriate number in the right hand column..

Recall that "*Key* technologies" are those which are proprietary to some degree and which your firm seeks to control; they differentiate your firm from its competition by enabling it to provide greater value to your customers.

	Does not describe our organisation at all						Describes our organisation exactly
	1	2	3	4	5	6	7
We allocate most of our R&D budget based on near-term market opportunities or threats.	c	c	c	c	c	c	c
We allocate most of our R&D budget based on long-term market opportunities.	c	c	c	c	c	c	c
We often commit resources to advance emerging technologies.	c	c	c	c	c	c	c
We often commit resources to develop applications for emerging markets.	c	c	c	c	c	c	c
Our technology planning and development involves people from many organisational functions.	c	c	c	c	c	c	c
Cross-functional collaboration is essential for our main business processes to succeed.	c	c	c	c	c	c	c
There is a lot of communication between marketing and other departments concerning market trends.	c	c	c	c	c	c	c

19. We put a lot of effort into ...	Does not describe our organisation at all						Describes our organisation exactly
	·	2	3	4	5	6	7
... identifying which business processes we do much better than our competitors'.	○	○	○	○	○	○	●
... identifying the *key* technologies used in each of our products.	○	○	○	○	○	○	●
... benchmarking our *key* technologies against our main competitors'.	○	○	○	○	○	○	●
... understanding exactly what our customers value about each of our products.	○	○	○	○	○	○	●
... discussing what our customers will need in three or more years time.	○	○	○	○	○	○	●
... forecasting what our markets will look like in three or more years time.	○	○	○	○	○	○	●
... forecasting how our technologies will change in three or more years time.	○	○	○	○	○	○	●
... exploring new ways of applying our *key* technologies.	○	○	○	○	○	○	●

20. Please provide us with your personal contact information so that we may send you a copy of the survey findings.

First Name ____________

Last Name ____________

Company Name ____________

E-mail Address ____________

Telephone ____________

Thank you for taking the time to complete this survey. Select Submit Survey now to send your responses to us.

Survey Completed

Thank you for your participation in our research.

Upon completion of the study, an executive summary will be produced and sent to you.

APPENDIX G: A Discussion of Science, Technology and Innovation

1.0 Science

Simply put, "'science' is the discovery and understanding of nature" (Betz 1998). A more detailed view of science distinguishes between analytical and empirical forms (Leoncini 1998, p. 79). Analytical sciences[23] do not allow the possibility for direct experience to accept or refuse the validity of certain statements as do empirical sciences. The latter may further be divided into pure sciences[24] and applied sciences[25] (Leoncini 1998, p. 79). Pure (or basic) science has a stronger cognitive dimension (Leoncini 1998, p. 79) and is about intellectual understanding (Mayr 1982, p. 254), i.e., the understanding of nature through the production of knowledge (Faulkner and Senker 1995, p. 31). Applied sciences have a stronger instrumental dimension and assume usefulness as the landmark whereas theoretical understanding plays less of a role. It is acknowledged, however, that this distinction is fairly arbitrary and without an absolute boundary line between the two (Leoncini 1998, p. 79).

Closely associated with the above are the terms basic and applied research which are defined as follows: "Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view. Applied research is also original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective" (OECD 1981:ch2, cited in Faulkner and Senker 1995, p. 7).

[23] Such as mathematics and logic.
[24] Such as physics and chemistry.
[25] Such as engineering and medicine.

Thus basic research is more concerned with a deeper understanding of the natural laws and phenomena taking place whereas applied research is concerned with usefulness.

2.0 Technology

Dosi proposed a broad definition of technology as "a set of pieces of knowledge, both 'theoretical' (but practically applicable although not necessarily already applied) and directly 'practical' (related to concrete problems and devices) know-how, methods, procedures, experiences of success and failures and physical devices and equipment" (Dosi 1982).

Technology has also been defined as those tools, devices, and knowledge that mediate between inputs and outputs (process technology) and/or that create new products or services (product technology) (Rosenberg 1972; Tushman and Anderson 1986).

A useful and recent three-fold disaggregation of technology has been given as knowledge, skills and artefact (Metcalfe and Boden 1992). 'Technology as knowledge, is the formal abstract representation of technology in a codified form. Technology as skills includes the human resources who have the specific capabilities to employ technological knowledge, as well as the tacit knowledge which is not codified. Technology as artefact concerns the physical objects which embody particular technologies' (Metcalfe and Boden 1992).

Coombs provides a further useful disaggregation of the artefact dimension into a functionality profile and a technological recipe (Coombs 1996). The functionality profile can be expressed in terms of 'the range of services it provides and the performance levels it is capable of.' A specific technological recipe consists of the particular choice and combination of technologies, design practices, configurations of subsystems that actually deliver the functionality. Thus the technological recipe is more likely to be the dimension of the artefacts which exhibit the 'signature' of the specific skills and knowledge deployed by a particular firm in its construction. Thus a four-fold conceptualisation of technology as knowledge, skills, recipes and functionality profiles is arrived at which may usefully be applied to issues of strategic management of technology (Coombs 1996).

3.0 Technological Change

Technological change may be expressed in terms of the type of change and the rate of change. Types of technological progress have been described in terms of 'technological paradigms' and 'technological trajectories' (Dosi 1982). These paradigms (or technological research programmes) result in 'clusters of technologies.' Progress within these existing paradigms is effected through the pattern of normal problem solving activity resulting in distinctive 'technological trajectories' (Dosi 1982). New technological paradigms result from breakthrough or radical innovations or discoveries. Certain attributes of technological paradigms may be useful for their identification. These are the (i) generic tasks to which it is applied (e.g. electrical switching), (ii) the material technology it selects (e.g. silicon), (iii) the physical and chemical properties it exploits (e.g., the transistor effect) and (iv) the technological and economic dimensions and trade-offs it focuses upon (e.g., circuit density) which are indicators of performance progress (Dosi 1982). These factors may be used to identify a technological paradigm and map its path or trajectory of progress. Likewise, these factors may prove to be useful tools in the search for new technology to include in innovation.

One way of describing the trajectory is in turns of the S-curve of innovation performance (Foster 1986). This curve or technological lifecycle may be divided approximately into the three stages of early development, rapid growth and maturity (Twiss and Goodridge 1989). New technologies emerging from the early stage and entering the application stage of rapid growth and adoption are valuable resources for enhancing product innovation performance or developing radical innovations.

The technological lifecycle may also be described by 'technological discontinuities' that trigger a period of high technological activity or 'ferment' culminating in a 'dominant design'. This, in turn, is followed by a period of technological progress driven by numerous incremental improvements (Tushman and Anderson 1986). The period of technological fermentation is accompanied by a substantial rate of product variation. Such discontinuities may be further classified as competence-enhancing or competence-destroying. Competence-enhancing technological discontinuities represent an order of magnitude improvement in price/performance, build on existing know-how and doesn't render obsolete skills. With competence-destroying discontinuities, on the other hand, new or substitute product classes emerge which break the existing order, significantly advance the technological frontier and result in a shift in the skills and knowledge base or competencies required to operate the new technology. They 'afford a rare opportunity for competitive advantage for firms willing to risk early adoption' (Tushman and Anderson 1986).

Types of technological change are important in that they determine the changes needed in the knowledge base of the firm. The rate of change, on the other hand, is important because it relates to whether the firm is able to keep up with this pace of change. Both types of change are determinants to the firm's drive to seek out additional resources and technological capability from external sources.

4.0 Science and Technology

Technological knowledge is distinguished from scientific knowledge in its purpose or orientation. Science is about *understanding* nature through the production of knowledge, whereas technology is about *controlling* nature through the production of artefacts (Faulkner and Senker 1995, p. 31, italics added). As Mayr notes, "the essential difference is one between intellectual understanding and practical utility" (1982, p. 254). Thus technology comprises a "practical and artefactual orientation" (Faulkner and Senker 1995, p. 34).

This skill and artefact dimension of technology is highlighted by De Solla Price, "basic and applied research are linked inseparably to technology by the crafts and techniques of the experimentalist and inventor" (DeSollaPrice 1984; cited in Faulkner and Senker 1995, p. 28)[26]. Applied science and technology are, however, more closely related since they both embrace the notion of applicability. A useful distinction can still be made between these two by implying a more "rational" nuance in applied science while implying a more "pragmatic" nuance in technology (Leoncini 1998, p. 79).

In conclusion, Gibbons and Johnston (1974) view science and technology as two parallel streams of activity with blurred boundaries but having an interactive relationship and sharing intimate activities in the same fields. They should be used as umbrella terms while maintaining only nuances of meaning.

5.0 Science in Technological Innovation

Stankiewicz (1986) argues that modern technology has reached a degree of intellectual sophistication that makes its institutional separation from science counterproductive (cited in Grigg 1994, p. 296). As Grigg also points out: "The growing intellectual complexity of technology tends to favour increasing university-industry interaction because the more 'scientified' the technology becomes the more sensitive it is

[26] see also Metcalfe (1992)

to what happens at the frontiers of science and the more need there is for knowledge input from a large number of scientific and technical disciplines which even the largest companies find difficult to maintain within their own R&D resource capabilities" (Grigg 1994, p. 288).

This has been an impetus for firms to seek outside their own organizations for sources of complementary scientific knowledge, since no one industrial firm or organization can be self-contained in the knowledge base that it needs to produce its products or services (Ziman 1991; cited in Grigg 1994, p. 289). Some technologies, such as biotechnology, are strongly science-related and extensive reliance is made on the university based scientific community (Arora and Gambardella 1990). Technologists, far from relying on archival literature[27], keep up with the "research front" literature in science (Faulkner and Senker 1995, p. 28).

Some evidence for this is given by the decreasing time lags between investment in academic research projects and the industrial utilisation of their findings (Kay 1988; Bonaccorsi and Piccaluga 1994). As De Solla Price notes, the time lag in interaction between science and technology may at times be very short indeed (DeSollaPrice 1984; cited in Faulkner and Senker 1995, p. 28).

This reliance of technology on science is further shown by the significant increase in the number of science articles that have been cited in patents over the last decade (cited in Narin and Norma 1985; Narin and Frame 1989; Bonaccorsi and Piccaluga 1994; Faulkner and Senker 1995). A recent empirical study used the ratio of the number of science papers (i.e., non-patent literature) cited in patents to the number of patents per

[27] Archival literature here refers to textbooks that have codified past knowledge.

technology sector as a measure of the strength of the science-technology link. The resulting strength of the science base for a given technology sector per year and per country was described using the four levels of strong, above average, below average and not at all (Grupp and Schmoch 1992)[28].

This study also noted that the expected public science-base support for technology sectors was contingent on local contexts, i.e., whether universities had the required expertise and resources to support them (Meyer-Krahmer 1997, p. 302).

6.0 Technological Push and Market Pull

Technology push and market pull forces are both determinants of innovation. Innovations are motivated either by conceiving a technological opportunity or by perceiving a market need (Betz 1994). In the technology-push model (dominant from 1950 to the mid-1960's) the marketplace was seen as a sink for innovation. A study of innovations in computers from 1944-1962 for this period found that manufacturers dominated innovation (Knight 1963; von Hippel 1986). This appeared to be the case because the industry was more technologically advanced than the computer users (Betz 1994).

However, during the latter part of the 1960's, more emphasis was placed on the role of the market pull on innovation (Rothwell 1994a) because users were becoming

[28] A new technology classification scheme was developed based on the International Patent Classification. Technologies were partitioned into twenty eight major sectors. Technology sectors most strongly based on science included genetic engineering/pharmaceuticals (including biotechnology) and laser technology with microelectronics (comprising telecommunications, electronic components, information storage, data processing, image transmission, and sensor technology) some distance behind. Above average science-based technology sectors included optics, surface technology (coating), organic and inorganic chemistry, and food technology (nutrition). Below average science-based technology sectors included polymer chemistry, resins, instrument building, printing technology, electrical engineering, electricity and nuclear engineering, machine tools and process technology. The remaining sectors not (or weakly) based on science included engines and turbines, transport and traffic, and handling.

more familiar with technology and competitive forces were on the increase. Kelvin Lancaster, in his approach to consumer theory, proposed that goods have characteristics and it is these which give rise to utility. Consumption is an activity in which goods are inputs and bundles of characteristics are outputs. These characteristics are what the consumer wants to satisfy his/her need (the term consumer used here means the recipient or user and does not infer any type of market segment). In Lancaster's model the producer is ultimately selling bundles of characteristics rather than goods (Lancaster 1966; Lancaster 1966). This meeting of needs or characteristics is an important aspect of innovation.

During the late 1970's to the late 1980's, von Hippel contributed further to the market pull model through his concept of lead-users. These users were defined as those organizations whose present strong needs will become general in a marketplace months or years in the future and who are positioned to benefit significantly by obtaining a solution to those needs (von Hippel 1986).

Market pull may be further understood in terms of need and demand. Although a market need may be perceived by product developers, the actual market demand may not be present resulting in a gap that needs to be bridged (Price 1996). Thus for firms developing radical innovations, customer acceptance is an important determinant of innovation success.

Empirical studies in the 1970's found technology push and market pull concepts to be oversimplifications with the reality being somewhere in the middle. An interactive or coupling model was proposed where "the process of innovation represents the confluence of technological capabilities and market needs within the framework of the innovating firm" (Rothwell and Zegveld 1985). Thus the two main dynamics involved are the consumer need/market demand and the firm's technological capability to meet them. For technical innovation to be commercially successful, markets must be created or matched to technological possibility (Betz 1994).

7.0 Newness in Innovation

The degree of newness introduced by innovation may be viewed in several ways. One three-level classification of innovation is incremental, radical and systems (Marquis 1968). Another four-level classification uses incremental, radical, changes of "technology system" and changes in "techno-economic paradigm" ("technological revolutions") (Freeman and Perez 1988). While the first two levels of distinction apply to the product and/or process level of analysis, the latter two levels describe more the affects at the industry and economic levels of analysis. Furthermore, the distinctions of systems and technology system prove to be problematic when levels of analysis are interchanged between the product/process and industry/economy. Betz, arguing that all technologies are systems, abandoned the distinction of "systems innovation" as not useful and by inference likewise the distinction of "technology system." A more useful distinction according to him is that of a "next generation technology" (Betz 1997, p. 11). Since this research has a product focus, this latter distinction will be used.

Incremental innovation, then, is a change in an existing technology system that does not alter functionality but "incrementally" improves performance, features, safety, quality or lowers cost (Betz 1997, p. 11). It occurs more or less continually in industry, "not so much the result of deliberate research than as the outcome of inventions and improvements suggested by engineers and others directly engaged in the production process, or as a result of initiatives and proposals by users" (Freeman 1987). Although their combined effect is important, no single incremental innovation has dramatic effects.

This incremental innovation represents continuous progress along the technological trajectory of its related technological paradigm (Dosi 1982).

At the other end of the extreme, radical innovations are discontinuous events and in recent times are usually the result of a deliberate research and development activity in enterprises and/or in university and government laboratories. They are important as the potential springboard for the growth of new markets (Freeman 1987) and may represent new emerging technological paradigms (Dosi 1982).

In the middle of the extremes, next generation technological innovation is a change in an existing technology system that does not alter functionality but *dramatically* improves performance, features, safety, quality or lowers cost (Betz 1997).

APPENDIX H: A Discussion of Firm-University Relationships

Two ways of viewing firm-university relationships are presented here. On the one hand, universities may be considered a source of R&D assistance to innovative activities taking place in industry, while on the other hand, universities may be considered a source of inventions and technical entrepreneurship (Grigg 1994). Universities traditionally advance basic scientific knowledge through long-term research thus providing a basis for new technologies that are likely to be radical in nature (Pavitt 1990; Rosenberg 1990; Rosenberg 1992; Betz 1994; Bonaccorsi and Piccaluga 1994).

Firm-university relationships are driven by various reasons. "Motivations to start cooperative R&D activity with academic laboratories include: risk reduction, early access to scientific or technological knowledge, access to unique research skills, and cost reduction through delegation of selected activities" (Rosenberg 1986; Link and Tassey 1989; cited in Bonaccorsi and Piccaluga 1994). Universities are often viewed as important sources of basic science and getting access to scientific frontiers is thus an important motivation for firms to enter into industry-university relationships (Bonaccorsi and Piccaluga 1994). Considerable attention in literature has been given to understanding this quest for basic science (Arora and Gambardella 1990; Betz 1994; Bonaccorsi and Piccaluga 1994; Grigg 1994). Industry needs new science when technological progress in an existing technology cannot be made without a deeper understanding of the science underlying the technology or when new basic technologies need to be created from new science (Betz 1997). For example, a study of large firms in the biotechnology industry showed that relationships with universities tended to focus on more basic science objectives and were motivated by the need to acquire some familiarity with the basic knowledge in the field. These relationships often provided the firms with a first option on the license of any new discovery made (Arora and Gambardella 1990).

A comprehensive model of firm-university relationships has recently been proposed which links firm motivations, the knowledge transfer process, and inter-organisational structures and procedures with relationship performance (Bonaccorsi and Piccaluga 1994). It provides four categories of firm motivations: getting access to scientific frontiers, increasing the predictive power of science, delegation of selected development activities, and lack of resources (Bonaccorsi and Piccaluga 1994). This agrees with other recent studies that identify accessing specialist technical support, extending in-house research and providing a window on emerging technologies (Tidd and Trewhella 1997). While this model is a useful description of the firm-university relationship, it does not examine the product innovation and resulting performance from the firm's perspective. It thus lacks important elements such as the nature of innovation, impact on markets and industry and impact on firm performance.

Firm-university relationships can take on various forms. The most common one involves the participation of academics in technology development activity initiated and managed by industrial firms (Grigg 1994). Another common form is that of the collaborative research centre (CRC). These are logical extensions of department based industrially sponsored research projects involving one or more companies (Grigg). They are particularly suited to long-term development in the areas of basic or generic technologies. Companies are often happy to support CRCs in the hope that they will "acquire a 'window' on the research front, access to the flow of scientific talent and the opportunity to acquire a sophisticated network of consultants, and the right to such inventions as may arise" (Grigg , p. 294). It has been found at Massachusetts Institute of Technology that CRCs do best when they "focus on a combination of basic and applied research" and the areas in which they are involved cut across industry lines (Grigg , p. 294). A study of 437 industry-university research centres in the USA found that the primary impetus behind their formation came from the entrepreneurial activity of universities and in particular the faculty members (Cohen and Goe 1994; Lee 1996).

In a recent survey of 1000 faculty members at research-intensive US universities, a majority support was found for universities to participate in local and regional economic development, facilitate commercialisation of academic research, and encourage faculty consulting for private firms. It found that universities where industrial contract research is encouraged often have associated large engineering colleges (Lee 1996). Industry sponsored research within disciplinary departments often appears to be proceeded by consultancy links (Grigg 1994).

Successful firm-university relationships often involve targeted research and exist over relatively long time periods (Betz 1997). One of the basic issues at stake is that universities are traditionally seen to advance science in forms not directly usable by industry nor in a timely manner since science has a long-term perspective, whereas technology and industry have shorter term perspectives (Betz 1997). As a result, some success factors have been proposed (Stankiewicz 1986; Betz 1994; Grigg 1994): These include using long-term projects with basic research instead of short-term development; preceding research collaboration with consultancy links; creating university policies defining property rights, time allocation of academics, and involvement of students and non-university personnel ensuring the focus of basic research is planned with industrial participation; engaging industrial participation immediately after technological feasibility of research has been demonstrated; inserting basic research results into an existing technology system or developing it into a substituting technology system.