IMPACTS OF A FIRM'S TECHNOLOGICAL DIVERSIFICATION ON PRODUCT DIVERSIFICATION AND PERFORMANCE

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A THESIS SUBMITTED
FOR THE DEGREE OF MASTER OF SCIENCE IN BUSINESS
DEPARTMENT OF STRATEGY AND POLICY
NATIONAL UNIVERSITY OF SINGAPORE
2010

ACKNOWLEDGEMENTS

I would like to express my great appreciation to my supervisor, Prof. Sai Yayavaram, who has devoted considerable time guiding me through this thesis project. His critical comments have pushed me to keep thinking and improving this work.

In addition, I want to thank Prof. Trinh Kim Chi and Prof. Peter Hwang for being my mentors in my first two years in the NUS Business School. I also want to thank Prof. Sai Yayavaram, Prof. Chung Chi-Nien, Prof. Jane Lu, and Prof. Kim Young-Choon whose seminal courses have provided me the background for doing research in strategic management.

I also wish to express my appreciation for the help of my friends in the NUS Business School, particularly Kong Qingxia, Vinit Kumar Mishra, Sun Li, Song Liang, Gu Qian and Tanmay Satpathy.

Finally, I dedicate this work to my parents and younger brother who have been my constant and most encouraging source of support throughout my studies.

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ABSTRACT

In this study, I investigate the impact of technological diversification (i.e., the phenomenon that firms expand their technological bases into a diverse range of technical fields) on the firm's product diversification. Based on the RBV (resource-based view) framework about dynamic economies of scope, I argue that the nature of the relationship between technological diversification and product diversification is essentially bidirectional. Specifically, technological diversification positively influences product diversification but at a decreasing rate and vice versa. To test my arguments, I used patents granted by the United States Patent and Trademark Office to represent technologies of a sample of firms extracted from the COMPUSTAT database from 1984 to 2000. Applying a dynamic panel data framework developed by Holtz-Eakin et al. (1988) and Arellano and Bond (1991) to test the dynamic and bidirectional relationship between technological diversification and product diversification, I have found that technological diversification exhibits an inverted U-shaped relationship on product diversification and vice versa. However, the impact of technology on business diversification has a time lag of two years while the impact of product diversification on technological diversification shows a one year lag. I proposed but did not find support for any moderating effect of technological interdependency (i.e., the inherent interrelation between multiple technological areas in a firm's knowledge base) on the relationship between the firm's technological and product diversification.

I further proposed and found evidence of an inverted U-shaped relationship between technological diversification and firm financial performance. Technological diversification is beneficial to a firm by improving its absorptive capacity to integrate external technologies for development of new strategic innovations and commercialize them successfully. However, with high levels of technological diversification come greater complexity in management, which taxes the ability of the firm to diversify its product portfolio and harms its performance. Moreover, I also found that the performance gains attributable to a given level of technological diversification can vary in their magnitude in accordance with the level of the firm's product diversification.

1. INTRODUCTION

1.1. Motivation and the research questions

Today, a growing number of firms have become reliant on technology to explore and exploit business opportunities (Granstrand, 1998). The evolution of the corporate technological domain highlights technological diversification, i.e., the phenomenon that firms expand their technological bases into a diverse range of technical fields and become multi-technological (e.g., Pavitt et al. 1989; Patel and Pavitt, 1994; Granstrand et al., 1997). Technological diversification is prevalent in modern corporations but it has not received enough attention in strategic management literature.

Managing a diversified technological base could raise as many challenges and implications for a firm as managing a diversified product portfolio (Torrisi and Granstrand, 2004). For example, several studies have shown evidence of linkages between technological diversification and a firm's strategic variables such as internal organization structure, product scope, innovation, and performance (e.g., Argyres, 1996; Gambardella and Torrisi, 1998; Garcia-Vega, 2006). However, with only a few studies, the literature on technological diversification is still immature and remains explorative in nature.

This study provides theoretical arguments and evidence that answer an immediate but under-explored enquiry concerning corporate technological diversification: "How does technological diversification influence product scope (i.e., product diversification) in corporations?" Several descriptive studies have attempted to investigate the relationship between technological diversification and product diversification (Cantwell and Fai, 1999; Fai and Cantwell, 1999; Fai and von Tunzelmann, 2001; Cantwell, 2004; Suzuki and Kodama, 2004; Miller, 2004; Gambardella and Torrisi, 1998). In particular, technological diversification was found to be related to both increasing and decreasing levels of firm product diversification (Granstrand et al., 1997). The nature of this relationship is even more complex if we consider different sources of technological diversification. One major source is from "technological fusion" strategy as firms deliberately pursue combinations of multiple technologies to create new products. The interdependency of different knowledge components in the firm's diversified technological base determines potential "technology fusions" and opportunities for it to commercialize new innovative products. Therefore, it is interesting to see how this factor influences the main relationship between the firm's technological and product scope.

In this study, I would also like to further investigate the implications of technological diversification on a firm's financial performance. How does technological diversification influence firm performance? And how does the combined impact of technological and product diversification affect firm performance? Management of technological diversification could be so complex that over-diversification may not be efficient (Torrisi and Granstrand, 2004). Moreover, the influence of technological diversification on firm performance might not be simple when it is combined with product diversification.

1.2. Research summary and contributions

To address these questions, I based my research on the RBV framework about dynamic economies of scope to develop my theoretical arguments. The RBV literature implied a dynamic relationship between a firm's technological resources and product scope (e.g., Wernerfelt, 1984; Dierickx and Cool, 1989; Helfat and Eisenhardt; 2004). In particular, I argued that the firm accumulates new technological assets over time through problem solving and learning as it organizes its production activities (Dierickx and Cool, 1989). These newly added technologies then offer it new entry opportunities at product level because (i) they can be applied in other product markets and (ii) each technology in the firm's increasingly diversified knowledge base has a lot of potential to cross-fertilize (i.e., to be combined with) others, which yields new functionalities or product inventions.

By leveraging its diversified technological base across multiple product markets, the firm then obtains two kinds of technology-based cross-business synergies: sub-additivity of production costs (i.e., costs saved from the shared use of technologies simultaneously in several product lines) and super-additivity of value (i.e., economies enabled by cross-fertilization of ideas among multiple technological fields in the firm's diversified knowledge base). However, I argue that technological diversification positively influences product diversification but at a decreasing rate. To obtain technology-based synergies, the firm incurs costs of integrating new competences into its knowledge base and coordinating R&D efforts that combine multiple technical fields. It will obtain less synergistic benefits and cease to expand product scope following increases in diversification of its knowledge base as the costs it incurs are larger than the benefits it receives.

I also expect a positive but decreasing impact on the reverse causal influence from product to technological diversification. In particular, there is a potential feedback from product diversification to technological diversification. Technological diversification leads a firm to diversify its product base and product diversification, in its turn, may facilitate further technological diversification. The nature of the relationship between technological and product diversification is essentially bidirectional. However, as the level of product diversification increases in a firm, its positive influence on technological diversification will gradually decrease. As one technology can be applied in many ways in multiple products, the existing stock of technological competences can be combined in novel ways for production improvement and new innovations (Fai and Cantwell, 1999). Hence, the firm gains less marginal benefits from additional technological resources to serve an increasingly diversified product portfolio while the marginal costs of integrating new technological competences into its knowledge base and coordinating multidisciplinary R&D efforts keep growing.

Moreover, I further contend that technological interdependency positively moderates the relationship between technological and product diversification. A high level of interdependency leads to further combinations or re-combinations of technologies in multidisciplinary technical areas. These in-exhaustive syntheses, hence, enable more potential “technological fusions” for future deployment and increase the chances that a firm may launch new innovative products in the market.

To test my arguments, I used patents granted by the United States Patent and Trademark Office to represent technologies of a sample of firms extracted from the COMPUSTAT data base. I obtained an unbalanced longitudinal dataset comprising technology, product scope, and financial information for each Firm-Year from 1984 to 2000. I then applied a dynamic panel data framework developed by Holtz-Eakin et al. (1988) and Arellano and Bond (1991) to test the dynamic and bidirectional relationship between technological and product diversification. I found that technological diversification exhibits an inverted U-shaped relationship with product diversification and vice versa. However, the impact of technology on business diversification has a time lag of two years while the impact of product diversification on technological diversification shows a one year lag. I did not find support for any moderating effect of technological interdependency on the relationship between firm technological diversification and product scope.

On the relationship between technological diversification and firm financial performance, I proposed and found evidence for an inverted U-shaped relationship. Technological diversification is beneficial to a firm through the improvement in its absorptive capacity to integrate external technologies for the development of new strategic innovations and their successful commercialization. However, with high levels of technological diversification come greater complexity in management, which taxes the ability of the firm to diversify its product portfolio and harms its performance. Moreover, I also found that the performance gains attributable to a given level of technological diversification can vary in their magnitude in accordance with the level of the firm's product diversification. I argue that firms obtain technology-based synergies by leveraging their diversified technological base across multiple product markets. Costs are saved as technologies are shared with minor adaptation costs in several products and ideas are cross-fertilized among multidisciplinary R&D efforts underlying their product portfolios. The technology-based cross-business synergies gained from a given level of technological diversification is greater when their scope of use is greater.

This study, hence, has two particular contributions:

(i) Inspired by the RBV theory, I provide clear theoretical arguments to reveal the dynamic bidirectional relation between a firm's technological competences and product diversification. The use of patent-based measures for technological diversification and interdependency offers a more meaningful picture of the relationship between corporate knowledge and product scope than that other crude measures like R&D intensity.

(ii) To practical managers, our results therefore suggest the importance of managing technological diversification and provide practical guidance for it. While low to medium levels of technological diversification is beneficial, high levels of technological diversification are more complex to manage, a fact which taxes the ability of the firm to diversify its product scope and harms its financial performance. Moreover, it seems that corporate strategies which are rooted in a diversified technological scope are sustainable and profitable regardless of the level of product diversification.

2. LITERATURE REVIEW

This chapter is divided into three sections. The first one reviews the efficiency-based theories of product diversification and empirical studies of this phenomenon. I particularly emphasize those that link the firm's technological resources with its product scope. The second section then summarizes the recently developed literature of technological diversification. It highlights technological diversification as a prevalent phenomenon in modern firms, which yields many under-explored implications for strategic management issues (e.g., organizational structure, scope, and performance) (Granstrand and Sjolander, 1990; Argyres, 1996; Granstrand et al., 1997; Gambardella and Torrisi, 1998; Granstrand, 1998; Brusoni et al., 2001). This chapter ends with the introduction of my research questions. I suggest that applying the RBV theoretical framework reviewed in the first section, to investigate these research questions will yield potential insights.

2.1. Theories and empirical evidence on product diversification

2.1.1. Efficiency-based theories of product diversification

Neoclassical economics

Neoclassical economics treats the firm as a product function. A firm producing *x* will also engage in producing *y* only if its production technology possesses sub-additive characteristics such that $c(x,y)<c(x,0)+c(0,y)$, in which $c()$ represents production cost functions. In other words, it is stated that a firm obtains economies of scope if joint production of multiple products in the same firm is more profitable or less costly than the production of each product alone in separate firms (Panzar and Willig, 1981). Diversified firms acquire a sub-additive production cost structure or economies of scope by exploiting shared activities or common resources across multiple product lines.

Transaction cost economics (TCE)

TCE literature on product diversification emphasizes the transaction conditions of production activities. The firm producing x of which the production technology yields excessive resources for the production of y might not internalize y into its product portfolio to realize economies of scope. It can contract out these excessive resources instead. The literature clearly states several characteristics of excessive resources such as indivisibility, complementary, and quasi-public good property that make it difficult for the firm to contract out these resources through the market (Panzar and Willig, 1981; Teece, 1982; Milgrom and Roberts, 1990, 1995).

The approaches suggested by the neoclassical economics and TCE frameworks are static as a rational firm will choose an optimal scope of product portfolio based on its existing resources and the cost of using market mechanisms to exploit excessive services from those resources.

Resource-based view (RBV)

The topic of product diversification was investigated by Penrose (1959) whose work is later developed into the RBV framework to analyze business strategy in 1980s. In "Theory of the Growth of the Firm", Penrose (1959) stated that internal inducements for a firm's expansion arise from the availability of unique bundles of unused productive resources within the firm that bring it advantages over rivals to improve production of old products or to launch new products. In other words, the firm expands through reemploying these excessive resources, either to further develop its extant product markets, or to diversify into new lines of business, where the resources give it the advantages to compete successfully. However, it prefers the excessive resources being invested in its existing markets. Only when, either exhaustion in market demands restrains the growth of the firm's primary markets, or the amount of the excessive resources generated is more than what is needed to extend the firm's existing production, will the firm diversify. Penrose (1959) further clarified that these excessive productive resources are continually created in the firm from the indivisibility and more specialized use of resources. Moreover, a firm's expansion is dynamic as newly productive resources are always generated at each stage of its expansion.

Hence, Penrose (1959) also claimed, there is no optimal expansion point for a firm because of the continuality of these unused productive resources.

However, Penrose (1959) also predicted the split of the new expansion activities from the firm's boundary. This happens as the economies of expansion are not enduring and disappear once the expansion is completed. This is due to the resources employed in the firm's new activities becoming specialized in their new uses, without any significant connection with its existing activities. Hence, the original justification for the firm's expansion fades. The new activities are split from the firm's boundary and then grow by themselves.

Inheriting Penrose's (1959) legacy, RBV literature clearly advances the efficiency-based theories of diversification on two points. First, it makes clear that only firms with strategic resources that are valuable, rare, and inimitable will enjoy economies of scope while leveraging these resources into multiple related product lines (e.g., Markides and Williamson, 1994). These resources are mostly intangible resources (e.g., management, marketing, technological resources), whose internal exploitation in other production lines gives sustainable rents (e.g., Chatterjee and Wernerfelt, 1991).

Second and more importantly, RBV literature offers a dynamic and evolutionary view of economies of scope. Authors such as Dierickx and Cool (1989) and Teece et al. (1997) particularly emphasize the creation and accumulation of a firm's strategic resources over time. Firms have accumulated strategic assets through problem solving and learning in organizing its production activities (e.g., Dierickx and Cool, 1989; Cantwell and Fai, 1999; Breschi et al., 2003). These assets later enable economies of scope when the firm expands into new businesses to fully exploit these assets' excessive services. Hence, the accumulated strategic resources become dynamic sources of a firm's growth through diversification.

Wernerfelt (1984) has used a resource-product matrix to illustrate the idea of dynamic resources management. In his article, he prescribed that the firm should balance exploitation of existing resources and development of new ones. Those resources then are leveraged into multiple product bases through sequential entries. Wernerfelt (1984) is the first who gave attention to both the diversification of the firm's resources and of its products. He proposed that the firm should emphasize both the short term and long term views in the management of its resource portfolio. The short term view focuses on contemporaneous sharing of resources across businesses. For the long term, candidates for product or resource diversification should be evaluated in their functional capacity to enable further expansion for the firm in a "stepping stone" strategy. Therefore, we can derive that the interaction between the firm's resource and product diversification over time gives impetus to the firm's growth (Granstrand, 2004).

Moreover, RBV literature also specifies the reconfiguration of the firm's strategic resources, which brings about the reconfiguration of its business scope. In their seminal article, Helfat and Eisenhardt (2004) define the term inter-temporal or dynamic economies of scope. These dynamic economies are obtained as the firm enters new markets while exiting others to re-arrange resources between its related product businesses over time. Galunic and Eisenhardt (2001) have exemplified how a Fortune 100 multi-business firm creates dynamic capability by applying modular corporate forms. In that corporation, business divisions with distinctive organizational resources and product-market responsibilities are regularly separated and recombined in various ways. Chang (1996) has also suggested that the firm dynamically restructures its product scope through sequential entry and exit activities as a search and selection strategy to find new applications from its knowledge base. Take note that this stream of literature implicitly prescribes a potential bidirectional adaptation between the firm's strategic resources and its product scope.

2.1.2. Empirical studies on product diversification

Product diversification and firm performance

Scholars from different disciplines (e.g., financial economics, strategic management) have exhaustively investigated and proposed varying hypotheses about the relationship between product diversification and performance.

This research stream started with Rumelt's (1974) seminal work. Rumelt (1974) had categorized diversification strategies into seven groups: single business, dominant-constrained, dominant-vertical, related-constrained, related-linked, unrelated, and conglomerate. He then found that related diversifiers whose businesses share some commonalities in production technology, customer base, and marketing assets perform better than single business firms and unrelated diversifiers. This empirical result was further reinforced in a meta-analysis of fifty five strategic management studies over three decades by Palich et al. (2000).

While researchers in strategic management have generally reached a consensus finding that diversification exhibits an inverted U-shaped relationship with performance, financial economists have found that there is a "diversification discount" such that diversified firms perform less well than single-business ones (e.g., Lang and Stulz, 1994). Moreover, several other researchers have attempted to see if stock market reactions to announcements of related acquisitions are more favorable than to those of unrelated acquisitions (Singh and Montgomery, 1987; Lubatkin, 1987). These studies provide mixed support for the hypothesis that related diversified firms perform better as some of them found no difference between stock market responses to announcements of related and unrelated acquisitions.

The linkage between firm technological resources and product diversification

In this part, I review empirical studies that examine the influence of a firm's strategic resources, particularly technological resources, on its product diversification. Business history studies (e.g., Chandler, 1990) have described corporate firm growth through diversification in the U.S., U.K., and Germany throughout the twentieth century. These firms obtain dynamic economies of scale and scope from the exploitation of accumulated firm-specific resources across businesses. Both Penrose (1959) and Chandler (1990) have particularly emphasized the role of technological resources as important sources for dynamic economies of scope. For example, Chandler (1990) noted that the need to fully exploit underutilized resources like nitrocellulose technology was the initial incentive for Dupont to diversify in the 1920s. Dupont's entry into additional product markets such as synthetic materials, gasoline additives and refrigerators were due to the response of its industrial research laboratories to market opportunities. Hence, diversification by industrial firms was supported by organized research. These firms started building their own R&D facilities to improve their products and processes and, subsequently, to develop new ones. The description of firm growth in Chandler (1990) has provided support for the RBV argument that technological resources are sustainable sources of competitive advantage that can be transferred and leveraged across a firm's businesses.

Hence, extensive empirical studies have long used R&D intensity (R&D expenditure over annual sales) as a proxy for a firm's technological resources to examine the impact on product diversification. This stream of research mostly reaches a consensus that (i) R&D intensity positively influences product diversification and (ii) firms are more likely to expand into industries with similar level of R&D intensity (e.g., Chatterjee and Wernerfelt, 1991; Lemelin, 1982; Montgomery and Hariharan, 1991). These results corroborate the RBV proposition about product diversification that strategic intangible resources like technological resources are at the centre of consideration when a firm plans to diversify. However, a few exceptional studies report a negative correlation between R&D intensity and product diversification. Miller (2004) found that, between 1980 and 1992, firms in his sample extracted from Compustat had less R&D intensity than other peers in the same industry before they diversified.

Another stream of studies has investigated the inverse process of how product diversification induces to firm innovation. A product diversification strategy implicitly drives a firm's R&D investment policy to support diversification (e.g., Rodriguez-Duarte et al., 2007). Product diversification was found to be positively related to R&D expenditure in a study by David and Thomas (1993). In contrast, Hoskisson and Johnson (1992) found this relation to be negative. These authors argue that diversification strategies could discourage the firm from making further risky long-term investments in R&D.

Simultaneity of technological resources and firm business diversification can be inferred from the concurrence of the two streams of empirical studies mentioned above. The RBV framework, as reviewed above, has also implied a dynamic bidirectional relationship between a firm's product scope and technological resources. I have found only two studies so far attempting to investigate the endogenous relationship between technological resources and diversification. First, Rodriguez-Duarte et al. (2007) have investigated the simultaneity between PAT_{ik} (the applicability of firm *i*'s patents in an industry *k*) and DIV_{ik} (firm *i*'s decision to enter *k*) in a cross-sectional sample of Spanish firms. Using R&D intensity as the instrumental variable (IV) for PAT_{ik} in a probit model predicting DIV_{ik}, these authors did not find the proposed endogenous relationship. Their results showed that technology influences diversification but not the reverse. One minor suspect for such a result is their choice of R&D intensity as the IV since it is highly likely to be endogenous to the diversification decision. In another attempt, Alonso-Borrego and Forcadell (2010) apply a bivariate vector auto-regression (VAR) of R&D intensity and product diversification with augmented covariates to account for their dynamic and bidirectional relation in a panel sample of Spanish firms between 1991 and 2000. They showed that while R&D intensity positively influences diversification, the inverse effect of business diversification on R&D intensity shows an inverted U-shaped form.

Empirical studies reviewed so far in this part encounter two limitations. Firstly, they almost always employ a static and unidirectional approach regarding the relationship between the firm's technological resources and product diversification. This may be one of the reasons why there is no consensus in the empirical results from these studies. Secondly, even in the study by Alonso-Borrego and Forcadell (2010) that uses a dynamic bidirectional framework, R&D intensity is only a crude measure of technological resources.

2.2. Technological diversification and empirical evidence of its implications on other strategic management dimensions

2.2.1. Technological diversification in a firm's knowledge base

Empirical studies investigating the evolution of the corporate technological base highlight the phenomenon of technological diversification. In particular, firms exhibit a high level of technological diversification as their technological bases are increasingly distributed among various technological fields (e.g., Patel and Pavitt, 1994; Granstrand et al., 1997). The diversification of the technological bases of modern firms is not a new phenomenon but increasing attention has been paid to it since its discovery in the late 1980s and early 1990s. Technological diversification was observed in Japanese corporations (Kodama, 1992) and among the largest firms in UK (Pavitt et al., 1989). The phenomenon is also confirmed in a study the 400 largest corporations worldwide (Patel and Pavitt, 1994).

Moreover, firms generally know more than what they make since their technological competence is much greater than what is required for their in-house product scope (Patel and Pavitt, 1994; Granstrand et al., 1997; Brusoni et al., 2001). For example, Granstrand et al. (1997) show that about 34% of patents applied by the electrical/electronic firms in their sample were outside the core electrical and electronic fields; in fact 20% of them were about machinery. Likewise, vehicles and engines account for only 19% of Ford's patents. This automobile company had diversified its technological competence into other technological fields including organic chemical, chemical process, semiconductors, computer and materials.

The diversification trajectories of a firm's knowledge base show evidence of path-dependency (e.g., Patel and Pavitt, 1994; Cantwell and Fai, 1999). The distinctive characteristics of the firm's technological capabilities in its early years influence the breadth, composition, and evolutionary trajectories of its subsequent accumulated technological competence (Cantwell, 2004). Patel and Pavitt (1994) found a strong correlation, at 1% percent level of significance, between the technology profiles of the world's 400 largest firms in two periods, 1969-74 and 1985-1990.

Evidence also shows that firms diversify their knowledge base into "related" technological fields which rely on common sets of scientific principles or share common knowledge backgrounds (Breschi et al., 2003). Sources of technological relatedness are from the learning process (e.g. knowledge spillover or local learning) and underlying knowledge links (i.e. the inter-relation between knowledge fields) (Breschi et al., 2003).

There are three main reasons that explain why a firm diversifies its technological base. Firstly, it keeps a high level of technological diversification for sustainable innovative performance, which relies on economies of scope in R&D efforts (Henderson and Cockburn, 1994). The firm's research productivity is significantly enhanced from knowledge spillover and cross-fertilization of ideas among multiple technological fields in its knowledge base (Garcia-Vega, 2006). The diversified technological base also enables the firm to explore and experiment with new technological combinations for future deployment (Granstrand et al., 1997). The literature of technology fusion (Kodama, 1992) has described how Japanese firms deliberately focused on discovering and blending multiple technologies in their knowledge base for new strategic innovations. For example, Fanuc fused mechanical and electronic technologies to develop a numerical controller. This product also marked the birth of mechatronic technologies.

Secondly, firms keep a diversified technological base to coordinate technical changes in the supply chain of their products (e.g., Granstrand et al. 1997; Brusoni et al., 2001). Modern products are increasingly complex with imbalanced changes in sub-product component technologies. There are strong technological interdependencies between what firms make themselves and what they buy from their suppliers. Consequentially, a decision to outsource a production component is different from the decision to outsource the component's underlying technologies. A broad knowledge base enables a firm to handle and integrate novelties in related component technologies and interdependencies among different components into its principal products (Brusoni et al., 2001).

Thirdly, technological diversification also comes from the spillover of general purpose technologies across industries and firms (Torrisi and Granstrand, 2004). These are technologies that can be combined with many other technologies and have a multitude of potential applications in different industries (Bresnahan and Trajtenberg, 1995). The generic nature of these technologies enables the firm to try many different applications and combinations that might serve as "platforms" for the firm to enter a variety of technological fields (Kim and Kogut, 1996).

2.2.2. Empirical evidences on implications of technological diversification on other organizational strategic dimensions

The phenomenon of technological diversification has been investigated in the last decade. Management of a diversified technological base could raise as many challenges and implications for other firm strategic dimensions (e.g., structure and scope) as management of a diversified product portfolio does (Torrisi and Granstrand, 2004). These issues are promising research topics as they are still under-explored. So far, there are only studies attempting to inspect the influence of a firm's technology diversification on (i) firm performance, (ii) internal organizational structure, and (iii) product scope.

2.2.2.1. Technological diversification and firm performance

Gambardella and Torrisi (1998) found that technological diversification is positively related to firm performance but the best performing firms are those which focus on their product scope but widened their technological domains. This study is still explorative in nature as the authors provide no theoretical arguments underlying their empirical model.

2.2.2.2. Technological diversification and internal organizational structure

Argyres (1996) found that multi-division firms reduce the number of divisions when they pursue a technological diversification strategy. Specifically, the use of R&D findings in multiple technical fields emphasizes interdivisional coordination of knowledge transfer. Syntheses of multidisciplinary technical areas bring *systems technologies* which create technological interdependencies among product units of large firms, particularly in high-tech sectors (Doz, Angelmar, and Prahalad, 1987). Assigning the development and commercialization of these technologies to independent ventures like "skunkworks" detached from the rest of the corporation may give suboptimal results when these technologies have potential applications for multiple businesses (Doz, Angelmar, and Prahalad, 1987). Argyres (1996), hence, argued that a low level of divisionalization facilitates greater coordination among divisions on the applications of systems technologies as it increases internal knowledge/resources transactions inside each division and reduces the number of semi-autonomous bargaining parties.

2.2.2.3. Technological diversification and product diversification

The linkage between firm technological and product diversification is assumed to be positive. Products and their underlying technologies implicitly have even been treated interchangeably and technological diversification considered as a by-product derived from firm product diversification (Fai and von Tunzelmann, 2001). However, as I will review here, the nature of this relationship is unexplored as some empirical evidence suggests a more complex relationship.

So far, studies attempting to investigate the relationship between technological and product diversification are descriptive without consensus in the results (Gambardella and Torrisi, 1998; Cantwell and Fai, 1999; Fai and Cantwell, 1999; Fai and von Tunzelmann, 2001; Cantwell, 2004; Suzuki and Kodama, 2004; Miller, 2004). In particular, Fai and Cantwell (1999) and Fai and von Tunzelmann (2001) have observed diversification in the knowledge base of the world's 32 largest corporations throughout the 20th century. They claim that technological diversification came with increasing product diversification and growing firm size in the world's largest corporations up to 1980s; nonetheless, there is no such a clear linkage since 1980s. Note that these authors did not explicitly investigate the product scope of the firms in their sample. They came up with this claim indirectly by comparing the evolution of technological bases of the firms in their sample with the evolution in the product scope of large firms described in the literature of product diversification (e.g., Chandler, 1990). In another study, Miller (2004) observed that diversified firms have greater technology breadth than the ones which stay focused. He speculates that laggards in the technology-based competition within an industry will diversify their technological base to enter new product markets to avoid direct competition with the technology leaders. In contrast, Gambardella and Torrisi (1998) found that firms in the electronics and telecommunications industries, whether highly specialized or diversified in their product scope, all tend to spread their technological bases.

The above empirical evidence suggests that no signs of a clear positive relationship between technological and product diversification have emerged.

Technological diversification is related to both increases and decreases in product diversification (Granstrand et al., 1997). The nature of this relation is even more complex if we consider the three different forces reviewed in 2.1.1 that cause technological diversification (i.e., “technology fusion” strategy, coordination of technical changes in supply chain, and the spillover of general purpose technologies). For example, if the force is from “technological fusion” strategy as firms deliberately pursue combinations of diverse existing technologies to create new products, technological diversification is strongly related to increases in firm product scope. However, if the force is from increases in the complexity of the firm’s current product(s) with more embedded technologies over time, technological diversification may not lead to product diversification (Fai and Cantwell, 1999). Firms diversify their technological base just to absorb new technologies being included in their current product(s) (Granstrand et al., 1997).

2. 3. Summary

In short, technological diversification is observed in today’s firms as modern artifacts become increasingly complex, technologically speaking (Granstrand et al., 1997; Brusoni et al., 2001). This complex phenomenon may hold many potential implications for other strategic management variables, which are worth investigating. Within the scope of this thesis, I specifically examine two immediate research directions:

(i) How does technological diversification influence a firm's scope (i.e., product diversification)? RBV literature on the bidirectional dynamic relationship between firm technological resources and product diversification reviewed above provides a clear theoretical framework to address this question. Moreover, meaningful insights on the relationship between technological resources and product diversification could be revealed if technological diversification, instead of R&D intensity, were to represent a firm's technological resources. Moreover, the interdependency among different knowledge components in the firm's knowledge base determines potential "technology fusions" and opportunities to commercialize new innovative products. It would be interesting to see how this factor influences the main the relationship between the firm's knowledge and its product scope.

(ii) How does technological diversification influence a firm's financial performance? And how does the combined impact of technological and product diversification affect firm financial performance? Management of technological diversification is as complex as that of product diversification so that over-diversification might not be efficient (Torrisi and Granstrand, 2004). Moreover, the influence of technological diversification on firm performance may not be simple when it is combined with firm product diversification.

3. HYPOTHESIS DEVELOPMENT

3.1. Relationship between firm technological diversification and product diversification

A typical process of how firm technological diversification influences product diversification is described as follows. Often, the effort to learn and solve specific technical problems in a firm's production activities will expand its internal knowledge base into adjacent technologies (e.g., Cantwell and Fai, 1999; Breschi et al., 2003). Sometimes, a firm simply picks up new, potential – but so far unrelated – technologies for exploration (Granstrand et al., 1997; Granstrand, 2004; Suzuki and Kodama, 2004). These newly added technologies not only improve the firm's production efficiency, but also offer new entry opportunities at the product level. This happens in two ways. Firstly, each technology has an associated range of products where it can be applied and, similarly, each product has an associated range of technology components. Hence, the firm will accumulate a technological base with a wider applicability to different product areas through technological diversification. Secondly, each technology has the potential to cross-fertilize others. It means that each technology can potentially be combined with other technologies to yield improvements in production processes and, more importantly, new functionalities or product inventions (e.g., Kodama, 1992; Granstrand, 1998). Given the difficulties of contracting out excessive services from the potential cross-fertilization among multiple technologies in its diversified technological base, a firm has incentives to pursue technology-related product diversification.

Figure 1 illustrates the interaction process described above between a firm's increasingly diversified technological base and its product diversification. The development history of Canon portrayed here is abstract and incomplete, and highlights only the main points in the evolution of the company's technological and product bases. From its incorporation until 1960, Canon was primarily a camera manufacturer. In the early 1960s, it started to diversify its technological base by expanding its core competences in optical equipment technologies into related electro-photography technologies and photo-lithography technologies. The newly added competences in electro-photography technologies then enabled Canon to expand into the production of copiers and printers while those in photo-lithography technologies allowed it to start production of semiconductor manufacturing equipment in the 1970s. Canon had also built new production facilities for data recorders/readers in the late 1950s and early 1960s. Although this new business was not successful, the generic nature of the newly acquired digital processing technologies enabled it to explore and experiment with many potential technological combinations for later deployment. Canon has enjoyed many synergies from cross-fertilization among the multidisciplinary R&D efforts underlying its products. For example, a high number of its patents were simultaneously assigned to both the fields of optical equipment technologies and electro-photography technologies or semiconductor manufacturing technologies.

They enable Canon to continually improve its products and launch different generations of cameras, copiers/printers, and semiconductor manufacturing equipment. More clearly, we can see the fusion of digital processing technologies with either electro-photography technologies to produce digital printers and copiers in the late 1980s or optical equipment technologies to develop digital cameras in the late 1990s.

Firms such as Canon thus obtain two kinds of technology-based cross-business synergies by leveraging their diversified technological domains across multiple product markets. The first is sub-additivity of production costs or economies of scope. They are costs saved from the shared use of technologies simultaneously in several product lines (Teece, 1982). The second type of technology-based synergies is super-additivity of value (Davis and Thomas, 1993). Granstrand (1998) has referred to these two synergies as economies of scale and scope derived from technological diversification.

We examined briefly the technology-product matrix of Canon in the 1990s to illustrate the concepts of sub-additivity of production costs and super-additivity of value. In table 1, we can see that some technology, like T_1 (optical equipment), is applied across the firm's businesses without much adaptation cost. Sub-additivity of production costs is defined as cost savings in product cost to Canon when multiple production processes exploit the same technology such as T_1. The production cost of Canon's three products sharing T_1 is less than the cost of using

T_1 to produce each product in separate firms: $C[P_1(T_1), P_2(T_1), P_3(T_1)] < C[P_1(T_1)] + C[P_2(T_1)] + C[P_3(T_1)]$.

On the other hand, super-additive synergies of value arise when values gained by using two (or multiple) inter-related technologies together are greater than the value of exploiting each of them separately across product lines: $value(T_1, T_2, T_3, T_4) > value(T_1) + value(T_2) + value(T_3) + value(T_4)$. The fruitful cross-fertilization of ideas among multiple technological fields underlying the firm's businesses enables these synergies. An example is the fusion of digital processing technologies with "camera" technology to develop digital cameras . Milgrom and Roberts (1990, 1995) have developed a similar concept of knowledge complementary. Multi-product firms enjoy super-additive synergies of value when they employ a complementary set of related knowledge resources across their business portfolio (Tanriverdi and Venkatraman, 2005).

However, I expect that as the level of technological diversification increases, its positive influence on product diversification will gradually decrease. To obtain technology-based synergies, the firm incurs the cost of integrating new competences into its knowledge base and coordinating R&D efforts that combine multiple technical fields. The firm encounters management complexity from huge information-processing demands and internal governance costs when it increases technological diversification. It also faces a cognitive limit in realizing technology-based synergies as technological diversification increases. Then, to further expand product scope, the firm will obtain less synergistic benefits in parallel with increasing coordination and other internal governance costs. The firm will cease to expand product scope from further diversification of its knowledge base when this cost is greater than the benefit it receives.

The underlying assumption here is that multi-business firms organize their product portfolios to benefit from the coordination of multidisciplinary R&D activities in the underlying technological base (Argyres, 1996). Empirical evidence also shows that the firm dynamically redefines its product scope for better exploitation of its underlying knowledge resources (e.g., Galunic and Eisenhardt, 2001; Karim and Mitchell, 2004). The increasing diversification of a firm's technological contexts will enable continual changes to its technological economies of scope. Hence, Chang (1996) has described how firms obtain dynamic economies of scope from sequential business entries and exits to re-arrange resources among their related product businesses over time. I expect to see more splits than additions of business activities at the firm's boundary as the diversification of its technological contexts grows: it is more difficult to link multiple businesses to exploit this increasingly diversified technological base.

Moreover, as I reviewed, the nature of the relationship between technological and product diversification is essentially bidirectional. Increasing product diversification will lead to increases in the level of the firm's technological diversification. On the one hand, the firm might need to enlarge its technological scope to support the implementation of new products. On the other hand, by expanding its product scope, the firm obtains a greater range of adoptions for its technological resources. The firm then has the incentive to further diversify its technological base to continually improve its products. However, as the level of product diversification increases, its positive influence on technological diversification will gradually decrease. As one technology can be applied in many ways in multiple products, the existing stock of technological competences can be combined in novel ways for product improvement and new innovations (Fai and Cantwell, 1999). Hence, the firm gains less marginal benefits from additional technological resources to serve an increasingly diversified product portfolio. At the same time, the marginal cost of integrating new technological competences into its knowledge base and of coordinating multidisciplinary R&D efforts keeps growing. I argue that,

Hypothesis 1: *Technological diversification positively influences product diversification but at a decreasing rate and vice versa.*

The potential cross-fertilization among multiple technological fields described above is determined by technological interdependency, or the inherent inter-relationship between these technological fields. Yayavaram (2009) further suggests that the technological interdependency or the natural inter-relation among technical knowledge components can never be fully explored. We have learnt that technological inventions come from syntheses or re-combinations of different knowledge components (Fleming and Sorenson, 2001). Each element of technical knowledge then has enormous potential to be combined with other knowledge components. Hence, the interdependency between a set of knowledge elements enables many unexpected novelties and innovations when they are employed together.

For a given technological base, technological interdependency between knowledge elements determines the number of potential combinations among them. A high level of interdependency leads to additional combinations or re-combinations of technologies in multidisciplinary technical areas. These innumerable syntheses enable more potential "technological fusions" for future deployment and increase the firm's chances of launching new, innovative products into the market. For example, carbon fiber technologies could be either fused with cable and electronics technologies to produce fiber optics or with mechanical technologies to produce air frames (Kodama, 1992). Hence, I argue that:

Hypothesis 2: *Technological interdependency moderates the relationship between technological and product diversification in such a way that a high level of potential technological interdependency raises the positive influence of technological diversification on product diversification.*

3.2. Technological diversification and firm financial performance

Technological diversification is an important component of intangible assets that determine firm performance heterogeneity (Wernerfelt, 1984; Barney, 1991; Dierickx and Cool, 1989). This is why economists have long used R&D intensity or patent stock as an independent variable to explain firm market value (e.g., Hall, 1998). Hall (1998) has found that the market values of listed U.S. firms are strongly determined by their technological assets.

Technological diversification enables firms to explore and experiment with new technological combinations to develop revolutionary and inimitable products. Kodama (1992) has exemplified the success of many Japanese firms in discovering and blending multiple technologies in their knowledge base for new strategic innovations. For example, Fanuc has fused mechanical and electronic technologies to develop a numerical controller. Similarly, Sharp has successfully commercialized its development of the first liquid crystal display (LCD) screen by combining electronic, crystal, and optics technologies. In 1992, the company controlled 38% of the world market for LCDs which was valued at more than (U.S.) $2 billion (Kodama, 1992).

Technological diversification also enhances firm performance through its improvement of the firm's absorptive capacity (Granstrand et al., 1997; Brusoni et al., 2001). Absorptive capacity is the firm's ability to realize the value of external knowledge, fully understanding, and exploiting it for commercial ends (Cohen and Levinthal, 1990). Absorptive capacity is a function of the firm's prior related knowledge and the diversity of its knowledge background. Brusoni et al. (2001) have shown that a diversified technological base has enabled three leading air-craft engine makers to coordinate and integrate evolutions of related technologies underlying distinctive sub-components into their principal products, despite the fact that they increasingly outsource these components to specialized suppliers.

I further propose that the relationship between technological diversification and firm performance will be positive only for low to medium levels of technological diversification and will become negative at high levels of technological diversification. Beside economic benefits, technological diversification also comes with costs. In particular, they are the costs that a firm incurs to expand its technical competencies in new technological areas and to coordinate R&D efforts across multiple technical fields. As technological diversification rises, firms encounter more management complexity from huge information-processing demands and internal governance costs. Therefore, the cost curve of technological diversification keeps rising steeper. Meanwhile, the firm faces a cognitive limit in realizing economic benefits from increasing technological diversification. As the cost curve of technological diversification climbs ever more steeply the higher it goes, it will reach a point where the costs will outweigh the benefits of technological diversification.

Hypothesis 3: *Technological diversification exhibits an inverted-U relationship with firm performance: technological diversification is positively related to performance across the low to moderate range of technological diversification and is negatively related to performance across the moderate to high range of technological diversification.*

3.3. Combined effects of technological and product diversification on firm financial performance

I have argued above that a firm obtains technology-based synergies from leveraging its diversified technological base across multiple product markets. Technological diversification produces further technology-based business opportunities from syntheses of knowledge in multidisciplinary technical areas (Garcia-Vega, 2006). Given the difficulties of contracting out quasi-public knowledge like technologies, firms have an incentive to pursue new entries at product level. They then obtain technology-based cross-business synergies from costs saved as technologies are shared with minor adaptation costs in several products and from the cross-fertilization of ideas among multidisciplinary R&D efforts underlying their product portfolios.

The technology-based cross-business synergies I mentioned above can vary in their magnitude with the level of firm product diversification. Specifically, the net benefit gained from a given level of technological diversification is greater when its scope of use is greater. Consequently, firms with a certain level of technological diversification should be able to generate more returns from increasing their product scope through technology-based cross-business synergies. Hence, I expect:

Hypothesis 4*: Product diversification moderates the relationship between technological diversification and firm performance in such a way that a high level of product diversification increases the performance gains attributable to technological diversification.*

4. METHOD

4.1. Data

This study required data on the technology, financial information, and product scope of many firms. I used patents to represent a firm's technologies as patents can be considered as individual elements of a firm's technological resources (Silverman, 1999). Researchers have long used patent statistics to measure different dimensions of technological competences at firm level (e.g., Jaffe, 1989; Silverman, 1999; Garcia-Vega, 2006). The distribution of a firm's patents across patent classes in the US Patent Classification System adequately represents the diversification of a firm's technical knowledge and also can reveal the interdependency among knowledge components in its knowledge base. Patent data was obtained from the National Bureau of Economic Research's (NBER) Patent Data Project (2006 version) and the NUS-MBS patent database. I then relied on the COMPUSTAT data base for firm financial information and product scope.

I started with datasets from the NBER's Patent Data Project (2006 version) to develop firm technology measures. The NBER patent datasets store information of every utility patent granted by the United States Patent and Trademark Office (USPTO) from 1976 to 2006. I leveraged work by Hall et al. (2001) and Bessen (2009) in matching patents to their corporate owners. In these datasets, patents are assigned to firms or their subsidiaries (if any) with unique assignee-organization identifiers. The datasets also account for changes in patent ownership as the original assignee-organization is acquired/merged/or spun-off. As the NBER patent datasets only record a patent's primary technological class, I added supplementary information regarding all listed technological classes of a patent from the NUS-MBS patent database (data available from 1976 to 05/2005). Following the conventions in patent literature, I treated the timing of a patent by its application date. As it takes about 3 years for 95% of the patents applied in the same year to be fully granted by USPTO (Hall et al., 2001), I encountered the issue of right truncation with my patent population. Patents applied in recent years (e.g., 2001, 2002, or 2003) have not been fully granted nor recorded. Therefore, to avoid the issue, I only used patents on the cohorts from 1976 to 2000.

Information about a firm's product scope or financial variables was extracted from the Annual Fundamentals and Business Segments components of the COMPUSTAT North America database. The COMPUSTAT database is a familiar source of information on firm scope in strategic management literature. It identifies each firm by a unique GVKEY number. In 1997, COMPUSTAT reformed its Business Segments as the Statement of Financial Accounting Standards No. 131 (June 1997) enforced changes on how companies would report information related to their operating segments. However, COMPUSTAT "backfilled" the Business Segments until 1984. Hence, COMPUSTAT's Business

Segments provides companies' business segments information only from 1984 onwards.

The GVKEYs attached with the unique organization-assignees provided in each NBER's patent offer the key to identifying the firms which own patents. They were employed to dynamically match information in each patent with its owner's other characteristics (i.e., finance and product scope) in COMPUSTAT datasets[1]. As a result, I obtained an unbalanced longitudinal dataset comprising technology, product scope, and financial information for each Firm-Year from 1984-2000. The number of 4-digit SIC industries that each firm involves ranged from 1 to 10 as known for firms in COMPUSTAT. In addition, the number of technological classes (3-digit level) that each firm is patenting ranged from 1 to 284 classes (mean=14.87) in a technological space of about 400 technological classes. These ranges in innovative activity indicate our sample captured firms with varying levels of technological diversification.

It should be noticed that my final dataset is necessarily unbalanced in nature due to the dynamics of the firms' product scope. It reflects changes in firm scope such as mergers, splits, or restructures. Hence, a firm could enter or exit from my dataset in the observed period from 1984 to 2000. Consequentially, the sample sizes in different model specifications in my empirical analysis were unequal. Equalization of the sample sizes in different model specifications to get a

[1] The detail documentation on procedures to match NBER datasets to COMPUSTAT datasets is available at NBER Patent Data Project's website: https://sites.google.com/site/patentdataproject/Home/downloads

single united sample size would lead to a drop of many observations and we could lose important information on firm dynamics or encounter survivor bias.

4.2. Variables

Product diversification. To measure product diversification, I used the Jacqemin-Berry's entropy measure as in Davis and Duhaime (1992). A firm *i*'s product diversification in year *t* was calculated as:

$$Prodiv_t = \sum_n P_{nt} \times \ln(1/P_{nt})$$

where P_{nt} is the share of the n^{th} segment in total sales of the firm in year *t*. Industry segments were measured at the 4-digit SIC level.

Technological diversification. I calculated an entropy measure of technological diversification from shares of different technical areas in a firm's technological base. I defined a technological space as comprising all patent classes in the US Patent Classification System at the 3-digit level (about 400 technical areas). The technological base of a firm *i* in a year *t* includes all of its utility patents accumulated from year *t-2* to year *t*. Technological diversification was then calculated as follows:

$$Techdiv_t = \sum_j M_{jt} \ln(1/M_{jt})$$

In which M_{jt} is the share of the technical area j^{th} in the patent stock of the firm in year *t*. To better capture a firm's technological diversification, patents that were assigned more than one technological area were treated as different applications. A similar measure based on Herfindahl-typed index was employed in several other studies (Gambardella and Torrisi, 1998; Garcia-Vega, 2006; Quintana-Garcia and Benavides-Velasco, 2008).

Firm financial performance. I used Tobin's Q to firm financial performance. I followed a formula suggested by Kaplan and Zingales (1997) to calculate Tobin's Q as the ratio of market value of assets divided by the book value of total assets.

Technological interdependency in a firm's knowledge base. Technological interdependency represents the number of potential combinations/re-combinations of technologies in different technological areas of a firm's knowledge base. Here, I used a measure developed by Yayavaram and Chen (2008). Specifically, I calculated the interdependency of the technological context that a firm *i* is involved in as the weighted average of the potential for recombinations (E_{kt}) of each of the technological classes *k* in the firm's technological base:

$$Interdependency_t = \sum g_{kt} \times E_{kt}$$

In which:

The weight for each technological class (g_{kt}) is the fraction of patents held by the focal firm *i* in each technological class *k*.

Potential for recombination of a technology class k (E_{kt}) was calculated as the number of other classes with which a class k had been combined in the previous five years divided by the number of patents that were assigned to that class during the same period (Fleming and Sorenson, 2001).

$$E_{kt} = \frac{\text{number of tech classes previously combined with } k}{\text{number of patents in } k}$$

The logic behind this measure is that the level of technological interdependency in a firm's knowledge base is high when a firm is engaging in an innovative context where each technological element has many potential combinations with other technologies. While E_{kt} measures the potential for recombination of each technological class k at time t with other technology classes, the weight g_{kt} takes into account the different technology contexts in which a focal firm i is engaged across time.

Control variables. The control variables that were included in the analysis are listed below.

Firm size: natural logarithm of the firm's number of employees.

R&D intensity: the ratio of annual R&D expenses to sales.

Advertising intensity: the ratio of annual advertising expenses to sales.

Capital intensity: the ratio of annual capital expenditure to sales

Leverage: the ratio of total debt to total equity

Current ratio: the ratio of current assets to current liabilities

Return on assets: the ratio of net income to total assets.

North America: a dummy for North American firms

Year dummies and Industry dummies: year dummies and industry dummies were included to control for time varying effects and industry wide effects.

4.3. Econometric issues and empirical models

4.3.1. Empirical models for hypotheses 1 and 2

There were two econometric concerns about the dynamism and simultaneity in the relationship between technological and product diversification. Technological diversification could be endogenous in models predicting product diversification as there may be a bidirectional relationship between these two variables. In particular, there is potential feedback from product diversification to technological diversification. Technological diversification leads a firm to diversify its product base and product diversification, in its turn, may facilitate further technological diversification. Moreover, this bidirectional relation may not be contemporaneous. It may take some time for technology to influence product diversification and vice versa. To account for these issues, I employed a bivariate-augmented vector auto-regression (VAR) model first developed by Holtz-Eakin et al. (1988) for product and technological diversification. This model has been applied in Alonso-Borrego and Forcadell (2010) to investigate the bidirectional relationship between product diversification and R&D intensity in Spanish firms.

Formally, we treated these two issues using a dynamic panel data model framework:

$$y_{it} = \alpha_0 + \sum_{l=1}^{m} \alpha_l y_{it-l} + \sum_{l=1}^{m} \beta_l x_{it-l} + \mathbf{w'}_t \omega + f_i + u_{it} \quad (1)$$

where the dependent variable y (*product diversification*) depends on its own m lags and m lags of the endogenous variable x (*technological diversification*). $\mathbf{w}_t$ is a vector of control covariates and u_{it} is a the idiosyncratic disturbance. First differencing model (1) to remove unobserved heterogeneity f_i we got:

$$\Delta y_{it} = \sum_{l=1}^{m} \alpha_l \Delta y_{it-l} + \sum_{l=1}^{m} \beta_l \Delta x_{it-l} + \Delta \mathbf{w'}_t \omega + \Delta u_{it} \quad (2)$$

Holtz-Eakin et al. (1988) and Arellano and Bond (1991) suggested a generalized method of moments-typed (GMM-typed) approach to estimate the parameters in model (2). They used lagged levels of x and y as instrumental variables. For a period t, the vector of instrument variables to identify the parameters in (2) is: $\boldsymbol{Z}_{it}=[1, y_{it-2}, \ldots, y_{i1}, x_{it-2}, \ldots, x_{i1}]$. We got GMM estimators of the parameters in (2) from following moment equations: $E(Z'_{it} * \Delta u_{it})=0$. The role of y and x is identical; by switching their roles in (1) and (2) we obtained an estimation of the model where x is the dependent variable and y is the main exploratory variable.

The dynamic structure in (1) enables us to examine (i) the causality hypothesis between x and y (i.e., whether there is unidirectional relationship from x to y and vice versa or both) and (ii) the distributed lag structure of this relationship (the correct lag length m). Another attractiveness of this GMM-typed method is that we did not need a model for x to be specified to estimate parameters in (2).

There are two specification tests for this type of model: (i) the Arellano-Bond's (1991) test for the assumption of no second-order autocorrelation in error terms and (2) the Hansen-Sargan's test for the exogeneity of the model's instrument variables. Failure to reject the null hypotheses of no second-order autocorrelation and the exogeneity of the instrument variables provides confidence in the model's results. In GMM estimation, the number of moment equations is larger than the number of parameters to be estimated and the Hansen-Sargan's test is robust only when there is no heteroskedasticity. Hence, I also employed a GMM two-step procedure which makes use of the estimated covariance matrix of the moment conditions in the normal GMM estimation. Two-step GMM estimators are more efficient as their estimation employ more information and the Hansen-Sargan's test are free of heteroskedasticity.

I used the command *xtabond* in STATA 10 to estimate the above models. Lagged values of technological diversification and its squares were considered as endogenous variables to predict product diversification and vice versa. I estimated these models for the firms in my sample in the time span from 1989 to 1990 so that I could test the distributed lag structure of the endogenous variable for at least $m=3$. Moreover, I included in the model estimations only firms for which I had full information on product and technological diversification for at least four consecutive years. For increasing the relevance of instrument variables (i.e., lagged levels of endogenous variables and dependent variables) in these dynamic panel data models, my measure of technological diversification relied on firm technological base comprised of patents accumulated in one year, instead of 3 years, as is normal. The reason is that measuring technological diversification based on patents accumulated in the past three years would make the effects of lagged independent variables mixed, create persistent time series, and increase multicollinearity among covariates.

The control variables in $\boldsymbol{w}_t$ included: *Firm size*$_{i,t-1}$, *R&D intensity*$_{i,t-1}$, *Advertising intensity*$_{i,t-1}$, *Capital intensity*$_{i,t-1}$, *Leverage*$_{i,t-1}$, *Current ratio*$_{i,t-1}$, *Performance*$_{i,t-1}$, *North America*, *Year dummies*. Reasons to include those control variables were suggested in the literature. In particular, *R&D intensity, ADS intensity, CAP intensity* represent intangible and physical assets that a firm could exploit into multiple businesses to gain economies of scope. Chatterjee and Wernerfelt (1991) reported that *R&D intensity*, *ADS intensity* and *CAP intensity* are positively related to a firm's level of related product diversification. The variables *leverage* and *current ratio* represent a firm's financial resources. These variables were found to be positively related to a firm's level of unrelated diversification (Chatterjee and Wernerfelt, 1991). I used a dummy for firms from the North America region to account for the influence of national institutional environments.

4.3.1. Empirical models for hypotheses 3 and 4

The equation to test hypothesis 4 and 5 is given as:

Tobin's $Q_{i,t}$ = *f*(*Technological diversification*$_{i,t-1}$*, Firm size*$_{i,t-1}$*, R&D intensity*$_{i,t-1}$*, Advertising intensity*$_{i,t-1}$*, Leverage*$_{i,t-1}$*, Performance*$_{i,t-1}$*, Product diversification*$_{i,t-1}$*, North America, Industry dummies, Year dummies*)

I lagged all covariates one year to facilitate the causal inference. Besides the main independent variables, i.e., technological and product diversification, all the included control variables are classical control variables to explain firm financial performance. I used *return on assets* to represent firm performance in *t-1*.

5. RESULTS

Table 2 represents the sampled firms in the model explaining product diversification. I report basic descriptive statistics and correlation matrices of all variables in the models predicting product diversification in table 3.

Models 1, 2, and 3 of table 4 present results from the two-step GMM estimations predicting product diversification while models 1 and 2 of table 5 show results predicting technological diversification. In both of these two tables, I start with the basic model including in the right hand side one lag level of the dependent variable and the endogenous variable. I then increase additional lag levels of the endogenous variable in the subsequent models. Table 4 only shows estimated coefficients on technological diversification at lag levels *t-1* and *t-2*. I also run the model specification adding the lag level at time *t-3* of technological diversification to predict product diversification. However, these results are omitted as the estimated coefficients are only significant at the first two lags. Hence, the results provide no evidence that the product diversification equation contains more than two lag levels of technological diversification. Similarly, results of model 2 in table 5 suggest that the technological diversification equation contains only one lag level of product diversification.

I am now concentrating on my preferred estimates in model 2 of table 4 and model 1 of table 5. Model 2 of table 4 indicates that technological diversification has an inverted U-shaped relationship with product diversification. However, the effect of technological diversification on product diversification has been lagged two years as the coefficients on technological diversification are only significant at lag level *t-2*. Similarly, model 1 of table 5 shows that product diversification, in its turn, also exhibits an inverted U-shaped relationship with technological diversification at lag level *t-1*. All the models pass both the specification tests of no second autocorrelation and exogeneity of the instrumental variables. In hypothesis 1, I predicted that technological diversification positively influences product diversification but at a decreasing rate and vice versa. This hypothesis was unsupported as the results show an inverted U-shaped relationship between technological and product diversification and vice versa. Moreover, using coefficients in model 2 of table 4, we can calculate the inflection point for technological diversification at approximately 1.15 which is inside the value range of technological diversification from 0 to 4.9. In model 1 of table 5, the inflection point for product diversification is at 0.88 while firm product diversification varies from 0 to 2.3.

In figure 2, I further portray the relationship between technological diversification and product diversification of selected firms in the automobile, chemical, and electronics industries through the last two decades of the 20^{th} century. Clear evidence of a negative relationship between technological diversification and product diversification at high levels of technological diversification can be observed in all three industries. For automobile manufacturers, as technological diversification increases, its impact on product diversification is positive but gradually decreases in the case of Daimler while this impact is clearly negative in the cases of Ford, General Motor and Honda at high levels of technological diversification (figure 2a). In figure 2b, selected companies in chemical industry possess high levels of diversification in both technological and product scope. We also see here a general negative relationship between firm technological and product scope, especially in Dow. Similarly, there is a downsize trend in the product scope of companies in the electronics industry at high levels of technological diversification in the cases of Hitachi and Toshiba (figure 2c).

When I added the interaction term between technological diversification and interdependency in model 3 of table 4 to predict product diversification, the estimated coefficient on the interaction term is positive but it is insignificant. Hence, hypothesis 2 about the positive moderation of technological interdependency on the main relationship between technological and product diversification was also unsupported.

I report basic descriptive statistics and correlation matrices of all variables in the models predicting firm performance in table 6. I further present percentages and mean performance of firms with different combination levels of technological and product diversification in table 7. I shaded the upper half of the table divided by the main diagonal. We can see that there are many more firms operating in the shaded areas of the table and they perform better than their peers in the unshaded areas.

In table 8, I report results of the general linear squares (GLS) random effects models explaining firm performance. In hypothesis 3, I predicted an inverted U-shaped relationship between technological diversification and firm performance. This hypothesis was supported as the coefficient on technological diversification was positive and significant, while the coefficient on its squared term was negative and also significant in model 3. Moreover, as the coefficient on the interaction term between technological diversification product diversification was positive, hypothesis 4 was also supported.

I plot the interaction effects of technological and product diversification on figure 3. We clearly see that, for a given level of technological diversification, a higher level of product diversification increases the performance gains attributable to technological diversification as the curve for high diversification has steeper slopes than the curve for low diversification. I also found strong evidence of a "diversification discount" here as product diversification is negatively related to firm performance.

6. DISCUSSION AND CONCLUSION

In this study, I have investigated the dynamic bidirectional relationship between a firm's technological and product diversification. I found that technological diversification exhibits an inverted U-shaped relationship with product diversification and vice versa. These results suggest that technological diversification is complementary to product diversification across the low to moderate range of technological diversification. However, there may be a trade-off between the two knowledge and product diversification strategies as expanding technological scope will enable the firm to reduce its product scope at high levels of technological diversification.

Why do high levels of technological diversification have a negative impact on product diversification? Tanriverdi and Venkatraman (2005) found that firms need to obtain cross-business synergies simultaneously from multiple domains such as technological base, production processes and distribution systems for a sustainable product diversification strategy. However, it is hard to get synergies in all these domains because the internal governance costs associated with these synergies increase exponentially as the firm product scope grows. More importantly, we learnt that economies of technological diversification not only come from leveraging a firm's diversified technological base into multiple product markets but also from creating increasingly complex and inimitable products. Gambardella and Torrisi (1998) have suggested that a firm may focus on developing a narrow range of complex core products, which combine many technologies to extract rents from a high level of technological diversification. Hence, given the inability to obtain complementary cross-business synergies in production processes and distribution systems, I expect that the firm will downsize its product scope by outsourcing non-core production activities as its technological diversification keeps increasing. It then switches to extract greater rents from a narrow range of complex core products created from a highly diversified technological base (Gambardella and Torrisi, 1998).

On the reverse causal direction from product to technological diversification, I also expect such a negative relationship between a firm's product and technological scope at high levels of product diversification. As one technology can be applied in many ways in multiple products, an existing or even lesser stock of diversified technological knowledge can completely serve a growing product scope.

It should be noted that technology-product matching investigated here is at the aggregate level in the relationship between technological and product diversification. My arguments then have ignored the variety in product scope that each specific technological component in the firm's knowledge base can be applied to. The underlying assumption here is that any variation in technology-product matching can be canceled out at the aggregation level[2]. However, we have learnt that some technologies have much more applicability than others. The

[2] I thank one of my thesis examiners for pointing this out.

literature of general purpose technologies has commended the existence of technologies of a generic nature, which have a lot of potential applications in the products of different industries/(e.g., Bresnahan and Trajtenberg, 1995). Therfore, investigating the role of general purpose technologies in the relationship between a firm's technological base and its product scope could be a potential research direction.

For hypothesis 2, the coefficient on the interaction term between technological diversification and interdependency is positive, but not significant. For a given knowledge scope, a high level of technological interdependency may lead to more strategic innovations from combinations of technologies and offer opportunities for the firm to commercialize new products. However, as suggested by Gambardella and Torrisi (1998), firms still need suitable downstream assets like marketing abilities and distribution systems to launch a new product line successfully. Sometimes, just because of a lack of the product-specific marketing and distribution assets, a firm may fail to commercialize a new product, even though this product has many potential technology-based cross-business synergies with its existing product portfolio. For example, as shown in Gambardella and Torrisi (1998), the differences in types of clients among personal computers (PCs) and telecommunication equipment markets is the main reason why IBM, given its abundant technological resources, failed to enter the related telecommunications equipment market. Telecommunications equipment producers still sell their products to very few known buyers while PCs producers sell to millions of anonymous and non-specialized customers. The bottom line here is that a diversified technological base containing knowledge elements with high interdependency may be necessary but not sufficient to enable firm product diversification.

My study then introduces the usage of dynamic panel data models to test hypotheses based on the RBV theory. The RBV approach suggests that we postulate theories of the firm from its resources (Wernerfelt, 1984). Moreover, the relationship between the firm's specific resources and other strategic variables are essentially dynamic and bidirectional. The usage of the augmented bivariate VAR for panel data here could be a good method to reveal the changes and dynamic interactions among resources and other strategic dimensions (e.g., structure, scope) that enable firm growth.

To practical managers, this study emphasizes the importance of managing technological diversification and provides practical guidance on this matter. The empirical results show that technological diversification exhibits an inverted U-shaped relationship with firm performance. It means that low to medium levels of technological diversification is beneficial to a firm by improving its absorptive capacity to integrate external technologies for development of new strategic innovations and commercialize them successfully. However, high levels of technological diversification come with greater complexity in management, which taxes the ability of the firm to diversify its product portfolio and hinders firm performance. Moreover, table 7 reveals that firms in the shaded areas not only include most firms in the sample but also perform better than their peers in the unshaded areas. This suggests that operating in the unshaded areas is a temporary and unstable state for firms as they only get long-term stability from operating in the shaded areas. Moreover, it seems that strategies which are rooted in technological diversification are sustainable and profitable, regardless of the level of product diversification.

In summary, technological diversification is observed in contemporary firms as modern artifacts become more technologically complex (Granstrand et al., 1997; Brusoni et al., 2001). This complex phenomenon yields many potential implications on other strategic management variables which are worthy of investigation. For example, Argyres (1996) claimed that development of products from multiple technological areas generally requires cooperation among firm divisions to coordinate knowledge transfer. Firms then have to reduce the degree of divisionalization to pursue technological diversification strategies. In this study, I have investigated the bidirectional relationship between technological and product diversification and the implications of this relationship on firm performance. My analyses suggest that management of a high level of technological diversification could be as complex as that of product diversification. It may tax the firm's ability to diversify its product base and hinder firm performance. To continue with this line of inquiry, future research could bring organization structure into the relationship between technological and product diversification. Investigating how the firm adjusts its organisation structure (e.g., the level of divisionalization) following dynamic interactions between knowledge and product scope might yield interesting insights. Moreover, research directions that investigate the management of technological diversification in multinational corporations or the impact of technological diversification on firm behavior and R&D alliances are also promising (Cantwell et al., 2004).

TABLE 1. The Technology-Product Matrix of Canon

Technology	Product area			
	Cameras (P_1)	Mask aligners/Steppers (P_2)	Printers/Copiers (P_3)	Electronic Calculators (P_4)
T_1	x	x	x	
T_2	x	x	x	
T_3	x	x	x	
T_4	x		x	x

Legend:
T1: optical equipment technologies
T2: photo-lithography technologies
T3: electro-photography technologies
T4: digital processing technologies

TABLE 2. Distribution of Firms by Industries (Product diversification model)

SIC (2-digit)	Industry	No. of firms	Percent (%)
1	Agriculture production crops	4	0.25
10	Metal mining	3	0.18
13	Oil and Gas Extraction	16	0.98
14	Mining and Quarrying of nonmetallic minerals	3	0.18
16	Heavy Construction other than building contraction contractors	3	0.18
20	Food and kindred products	32	1.97
21	Tobacco products	2	0.12
22	Textile Mill Products	13	0.8
23	Apparel and other finished products made from fabrics and similar materials	3	0.18
24	Lumber and wood products, except furniture	7	0.43
25	Furniture and fixtures	17	1.04
26	Paper and allied products	38	2.34
27	Printing, publishing, and allied industries	9	0.55
28	Chemical and allied products	277	17.03
29	Petroleum refining and related industries	17	1.04
30	Rubber and miscellaneous plastics products	34	2.09
31	Leather and leather products	4	0.25
32	Stone, clay, glass, and concrete products	13	0.8
33	Primary metal industries	29	1.78
34	Fabricated metal products, except machinery and transportation equipment	40	2.46
35	Industrial and commercial machinery and computer equipment	238	14.63
36	Electronic and other electrical equipment and components, except computer equipment	253	15.55
37	Transportation equipment	70	4.3
38	Measuring, analyzing, and controlling instruments; photographic, medical and optical goods; watches and clocks	268	16.47
39	Miscellaneous manufacturing industries	20	1.23

TABLE 2. Distribution of Firms by Industries (Product diversification model) (Continued)

SIC (2-digit)	Industry	No. of firms	Percent (%)
40	Railroad transportation	1	0.06
42	Motor freight transportation and warehousing	1	0.06
45	Transportation by Air	3	0.18
47	Transportation services	2	0.12
48	Communications	20	1.23
49	Electric, gas, and sanitary services	16	0.98
50	Wholesale trade-durable goods	12	0.74
51	Wholesale trade-nondurable goods	7	0.43
53	General merchandise stores	2	0.12
56	Apparel and accessory stores	1	0.06
57	Home furniture, furnishings, and equipment stores	1	0.06
58	Eating and drinking places	1	0.06
59	Miscellaneous retail	5	0.31
61	Non-depository credit institutions	1	0.06
67	Holding and other investment offices	7	0.43
70	Hotels, rooming houses, camps, and other lodging places	1	0.06
72	Personal services	2	0.12
73	Business services	92	5.65
75	Automobile repair, services, and parking	2	0.12
76	Miscellaneous repair services	4	0.25
78	Motion pictures	2	0.12
79	Amusement and recreation services	3	0.18
80	Health services	7	0.43
82	Educational services	1	0.06
87	Engineering, accounting, research, management, and related services	14	0.86
99	Nonclassifiable establishments	6	0.37
Total		1627	100

TABLE 3. Descriptive Statistics and Correlations
(Product Diversification Model with Interaction Term)

		Mean	S.D.	1	2	3	4	5	6	7	8	9	10	11
1	Product diversification (t)	0.33	0.46											
2	Firm size (t-1)	1.8	1.42	0.5										
3	R&D intensity (t-1)	1.24	22.55	-0.03	-0.06									
4	Ads intensity (t-1)	0.01	0.05	-0.01	0.04	-0.01								
5	Capital intensity (t-1)	0.37	13.2	-0.02	-0.03	0.65	0							
6	Leverage (t-1)	0.97	15.33	0.02	0.03	0	0	0						
7	Current Ratio (t-1)	2.96	3.22	-0.22	-0.37	0.1	-0.02	0.12	-0.01					
8	Tobin's q (t-1)	2.26	1.97	-0.24	-0.26	0.07	0.05	0.02	-0.02	0.19				
9	Tech diversification(1) (t-1)	1.95	0.93	0.36	0.67	-0.04	0.01	-0.02	0.01	-0.21	-0.13			
10	Tech diversification^2 (t-1)	4.68	4.23	0.38	0.69	-0.03	0.01	-0.02	0.02	-0.21	-0.14	0.97		
11	Tech interdependency (t-2)	0.05	0.03	0.21	0.19	-0.06	0	-0.03	0.02	-0.2	-0.31	0.03	0.02	
12	Tech diver*Tech inter (t-2)	0.1	0.07	0.4	0.58	-0.05	0.01	-0.03	0.02	-0.26	-0.29	0.73	0.7	0.64

N=1405

TABLE 4. Results from Regression Predicting Product Diversification (1989-2000)

Dependent Variable	**Product diversification (GMM-2step)**		
VARIABLES	**Model 1**	**Model 2**	**Model 3**
Firm size (t-1)	0.02	0.01	0.01
	(0.02)	(0.03)	(0.03)
R&D intensity (t-1)	-2.45E-05	-1.90E-05	5.37E-05
	(2.06E-05)	(2.27E-05)	(3.31E-05)
Advertising intensity (t-1)	0.04	0.04*	0.08***
	(0.03)	(0.02)	(0.02)
Capital intensity (t-1)	1.58E-04	1.61E-04	2.25E-05
	(1.41E-04)	(1.40E-04)	(5.89E-05)
Leverage ratio (t-1)	4.39E-05	7.11E-05	1.22E-04
	(1.03E-04)	(1.37E-04)	(1.53E-04)
Current ratio (t-1)	-1.16E-04	-8.81E-05	3.68E-04
	(3.06E-04)	(3.05E-04)	(3.09E-04)
Tobin's q (t-1)	-9.23E-04	-7.05E-04	-2.47E-05
	(9.23E-04)	(9.87E-04)	(1.16E-03)
North America	-0.10	-0.18	-0.123
	(0.12)	(0.12)	(0.113)
Product diversification (t-1)	0.70***	0.68***	0.63***
	(0.06)	(0.06)	(0.05)
Tech diversification (t-1)	0.02	0.03	0.03
	(0.03)	(0.03)	(0.03)
Tech diversification^2 (t-1)	-4.90E-03	-2.51E-04	1.64E-03
	(0.01)	(0.01)	(0.01)
Tech diversification (t-2)		0.05**	0.13**
		(0.03)	(0.05)
Tech diversification^2 (t-2)		-0.02*	-0.04**
		(0.01)	(0.01)
Tech interdependency (t-2)			-0.02
			(0.46)
Tech diver*Tech inter (t-2)			0.15
			(0.32)
Number of firms	1627	1627	1405
Sargan test's Chi-squared	329.44	301.7	461.40
p-value	0.28	0.29	0.56
Autocorrelation order 2 test's Z	-0.72	-0.58	-0.77
p-value	0.47	0.56	0.44
Wald test of joint significance	328.32***	313.59***	299.21***

Windmejier's (2005) robust standard errors are in parentheses.
Year dummies are omitted. *** p<0.01, ** p<0.05, * p<0.1

TABLE 5. Results from Regression Predicting Technological Diversification (1989-2000)

Dependent Variable	**Tech diversification (GMM-2step)**	
VARIABLES	**Model 1**	**Model 2**
Firm size (log of employees) (t-1)	0.24***	0.21***
	(0.06)	(0.06)
R&D intensity (t-1)	2.47E-04	1.47E-04
	(1.82E-04)	(1.87E-04)
Advertising intensity (t-1)	-0.01	-0.02
	(0.03)	(0.03)
Capital intensity (t-1)	-2.32E-04	-9.52E-05
	(2.25E-04)	(2.26E-04)
Leverage ratio (t-1)	2.59E-04	6.37E-04**
	(3.27E-04)	(2.67E-04)
Current ratio (t-1)	-2.15E-03	-3.39E-03
	(2.50E-03)	(2.58E-03)
Tobin's q (t-1)	0.01	0.01*
	(0.01)	(5.92E-03)
North America	-0.28	-0.3
	(0.33)	(0.32)
Tech diversification (t-1)	0.04	0.04
	(0.03)	(0.03)
Product diversification (t-1)	0.56**	0.33
	(0.26)	(0.27)
Product diversification squared (t-1)	-0.32**	-0.25**
	(0.15)	(0.12)
Product diversification (t-2)		0.05
		(0.28)
Product diversification squared (t-2)		-0.04
		(0.14)
Number of firms	1704	1568
Sargan test's Chi-squared	332.78	315.05
p-value	0.23	0.14
Autocorrelation order 2 test's Z	0.87	0.35
p-value	0.38	0.94
Wald test of joint significance	63.45***	70.57***

Windmejier's (2005) robust standard errors are in parentheses.
Year dummies are omitted. *** p<0.01, ** p<0.05, * p<0.1

TABLE 6. Descriptive Statistics and Correlations
(Firm Performance Model)

		Mean	S.D.	1	2	3	4	5	6	7	8	9
1	Tobin's q (t)	2.22	2.09									
2	Product diversification (t-1)	0.28	0.44	-0.21								
3	Firm size (t-1)	1.32	1.34	-0.24	0.53							
4	R&D intensity (t-1)	1.29	22.01	0.08	-0.04	-0.05						
5	Ads intensity (t-1)	0.02	0.32	0.01	-0.01	-0.01	0.04					
6	Leverage (t-1)	2.06	111.39	-0.01	0.01	0	0	0				
7	ROA (t-1)	-0.04	0.28	-0.34	0.15	0.28	-0.13	-0.04	0			
8	Tech diversification (t-1)	1.65	1.06	-0.1	0.37	0.61	-0.02	-0.01	-0.01	0.14		
9	Tech diversification^2 (t-1)	3.86	4.26	-0.13	0.41	0.68	-0.03	-0.01	0	0.15	0.94	
10	Tech * Prod Diver (t-1)	0.63	1.25	-0.17	0.86	0.6	-0.03	-0.01	0	0.13	0.59	0.66

N=3966

TABLE 7. Firm Performance of Combinations of Different Levels of Technological and Product Diversification[a] (1985-2000)

		Technological diversification			Total
		Low	Medium	High	
Single business firms	% of whole sample	20.98	23.97	19.20	64.16
	Mean Tobin's q	2.52	2.75	2.36	2.56
Low to medium product diversifiers	% of whole sample	5.05	6.08	10.06	21.19
	Mean Tobin's q	1.70	1.82	1.72	1.74
High product diversifiers	% of whole sample	1.92	2.84	9.90	14.66
	Mean Tobin's q	1.35	1.43	1.46	1.44
Total	% of whole sample	27.95	32.89	39.16	100
	Mean Tobin's q	2.29	2.46	1.97	2.22

N=3966 firms

[a] I used 33th and 66th percentiles of technological diversification as cut-off points to distiguish low, medium, and high levels of technological diversification. I then followed Hitt at al. (1997) to categorize three groups of product diversification. Low to medium product diversifiers are firms with product diversification scores lower than 0.813 while high product diversifiers are firms with product diversification scores above 0.813.

TABLE 8: Results of GLS Random Effect Models to Explain Firm Tobin's Q[b] (1985-2000)

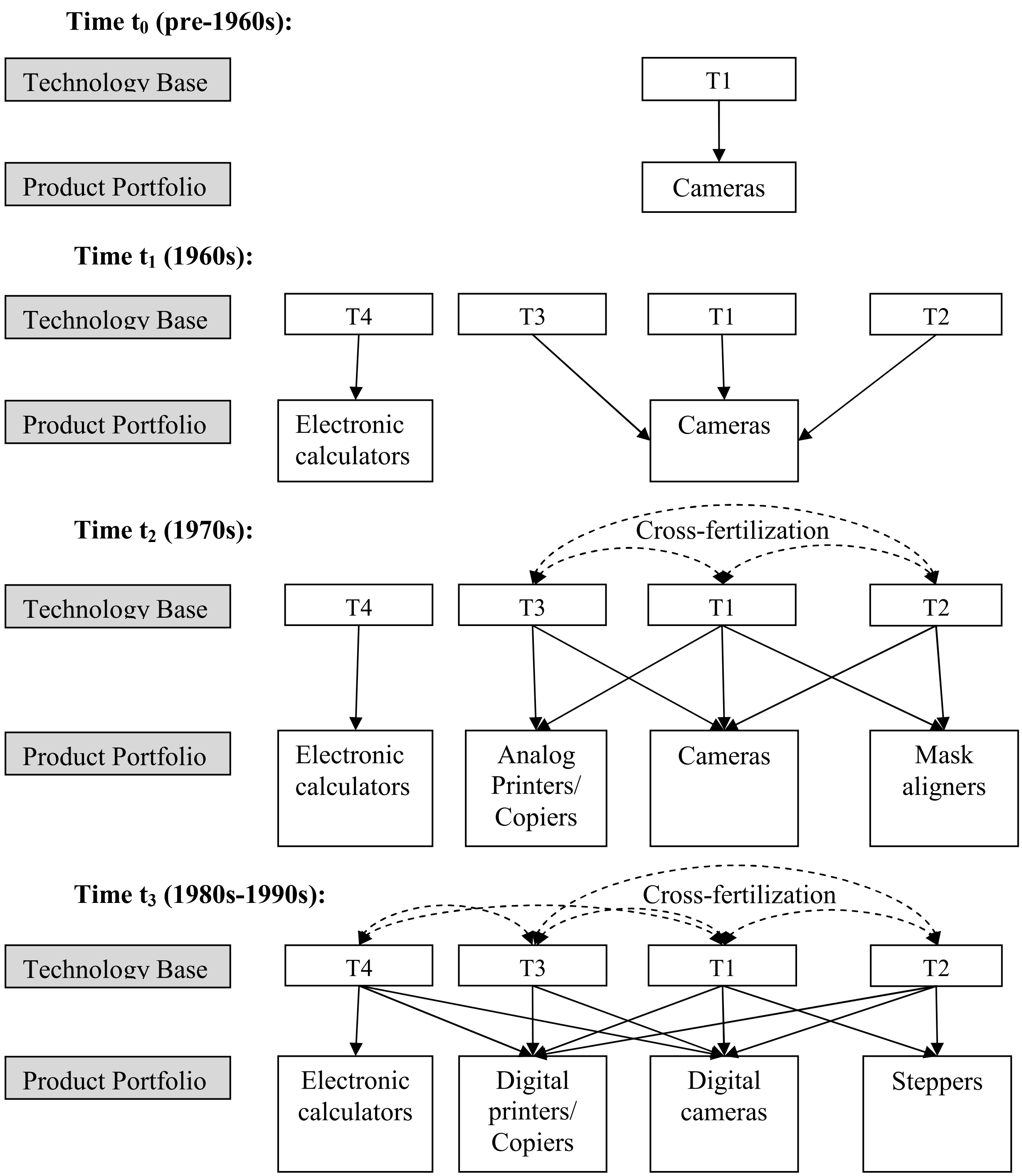
			Tobin's Q	
	Model 1	**Model 2**	**Model 3**	**Model 4**
VARIABLES				
Constant	2.62***	2.63***	2.56***	2.59***
	(0.45)	(0.45)	(0.45)	(0.45)
Product diversification (t-1)	-0.21***	-0.21***	-0.21***	-0.37***
	(0.04)	(0.04)	(0.04)	(0.07)
Firm size (t-1)	-0.24***	-0.23***	-0.21***	-0.21***
	(0.02)	(0.03)	(0.03)	(0.03)
R&D intensity (t-1)	6.82E-04	6.84E-04	6.83E-04	6.82E-04
	(7.11E-04)	(7.11E-04)	(7.12E-04)	(7.12E-04)
Ads intensity (t-1)	-0.11**	-0.11**	-0.11**	-0.11**
	(0.05)	(0.05)	(0.05)	(0.05)
Leverage ratio (t-1)	-4.69E-05**	-4.75E-05***	-4.71E-05**	-4.53E-05**
	(1.82E-05)	(1.83E-05)	(1.83E-05)	(1.84E-05)
ROA (t-1)	-1.00***	-1.00***	-1.01***	-1.00***
	(0.11)	(0.11)	(0.11)	(0.11)
North America	-0.24*	-0.24*	-0.24*	-0.23*
	(0.13)	(0.13)	(0.13)	(0.13)
Tech diversification (t-1)		-0.01	0.07*	0.08**
		(0.02)	(0.04)	(0.04)
Tech diversification ^2 (t-1)			-0.03***	-0.04***
			(0.01)	(0.01)
Tech Div*Product Div (t-1)				0.08***
				(0.02)
Number of firms	3966	3966	3966	3966
R-squared	0.21	0.21	0.21	0.21
Wald χ^2	4299.00***	4326.47***	4365.44***	4337.37***
Wald test $\chi^2(1)$		0.46	7.81***	10.10***

Robust standard errors are in parentheses

Coefficients for year and industry dummies are omitted. *** p<0.01, ** p<0.05, * p<0.1

[b] The Hausman's tests do not reject the null hypothesis that the unobserved firm effect is uncorrelated with all exploratory variables. It means that there are no statistical differences between random effects and fixed effects estimates. I followed Wooldridge's (2006) suggestion by using random effects estimates as we can add time-constant controls such as industry dummies into our models.

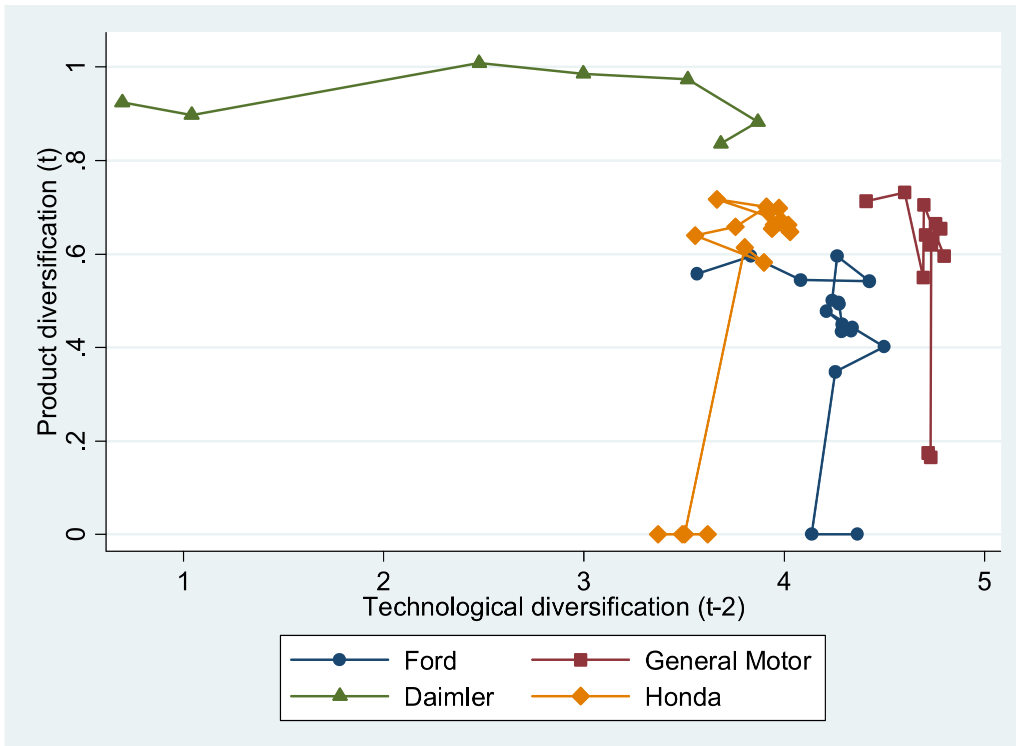
Figure 1: Historical Development of Canon in terms of Changes in Technological and Product Bases over Time



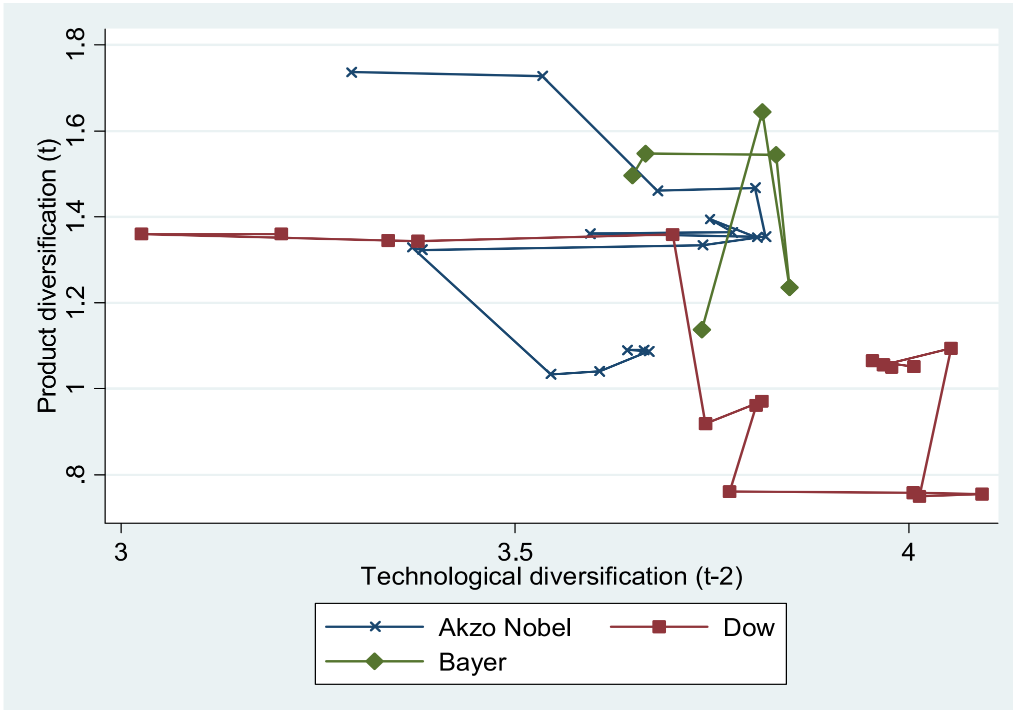
Legend:
T1: optical equipment technologies
T2: photo-lithography technologies
T3: electro-photography technologies
T4: digital processing technologies

Figure 2. Relationship between Technological and Product Diversification of Selected Firms in Three Different Industries through the Last Two Decades of the 20th Century

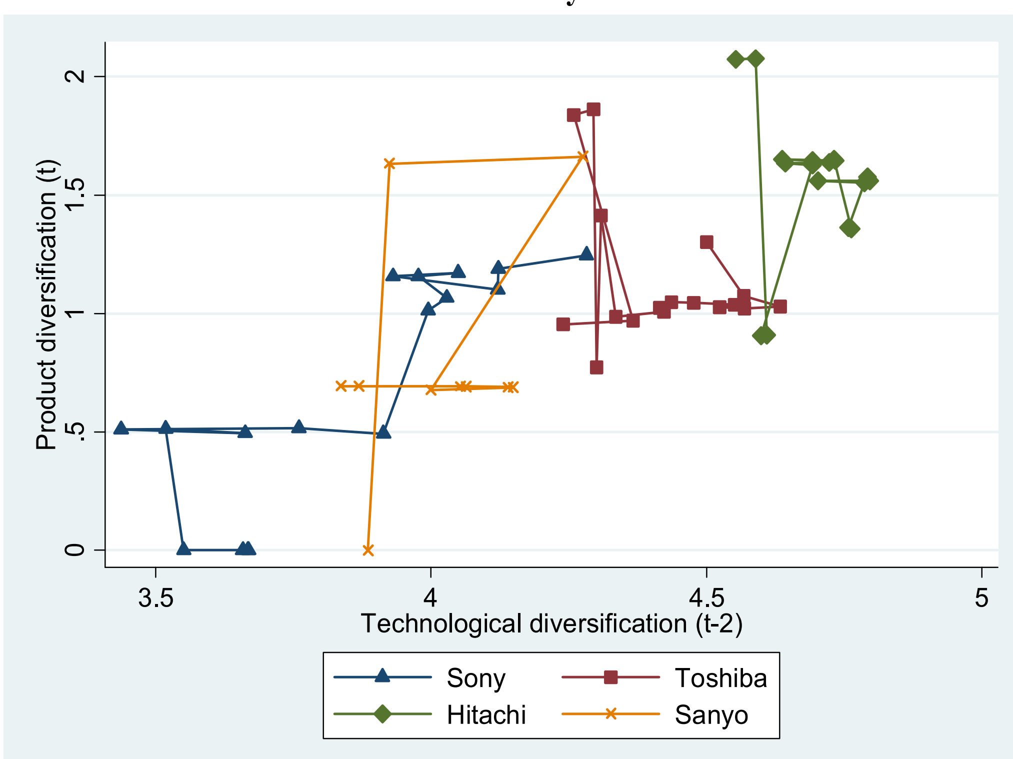
a. Automobile Industry



b. Chemical Industry



c. Electronics Industry



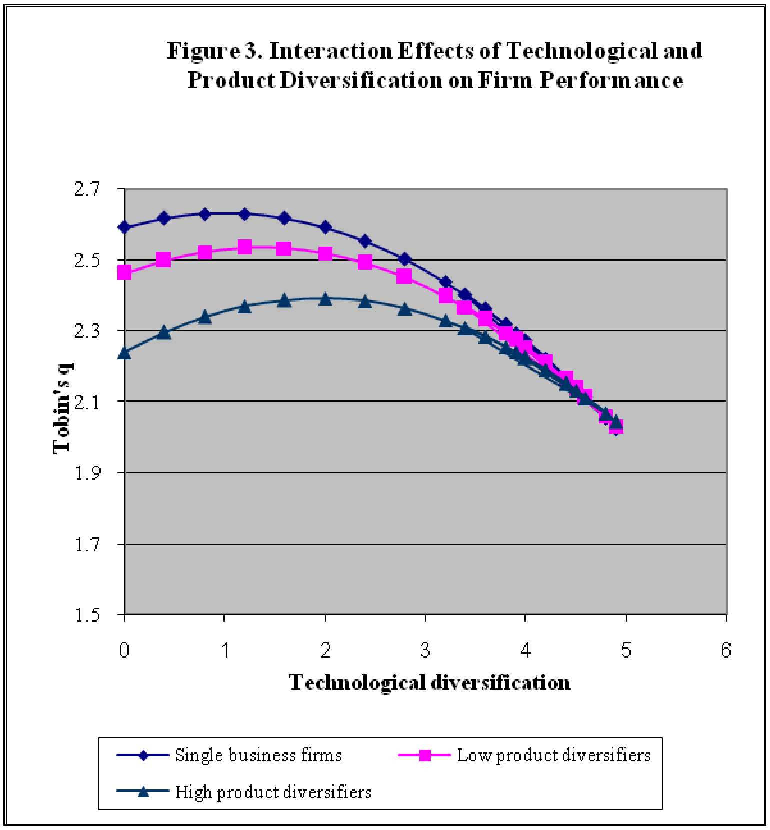


Figure 3. Interaction Effects of Technological and Product Diversification on Firm Performance
2.7
2.5
2.3
2.1
1.9
1.7
1.5
Tobin's q
0
1
2
3
4
5
6
Technological diversification
Single business firms
Low product diversifiers
High product diversifiers

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