The Moderating Effects of Knowledge Characteristics of Firms on the Financial Value of Innovative Technology Products

Abstract

The development of innovative technology products is both costly and risky, and their economic value is highly uncertain. Based on a sample of 312 innovative technology products introduced between 1987 and 2006 in the U.S. and a long-horizon event study with control firms, we study the impact of innovative technology products on the long-term financial performance of a firm. In particular, we examine how the knowledge characteristics of the firm, which embrace its knowledge absorptive capacity, knowledge impact, and knowledge diversity, moderate such an impact. We find that on average an innovative technology product increases the firm's return on assets (ROA) (relative to control firms) by 2.18% in the second year after product introduction. However, the value of an innovative technology product varies with the knowledge characteristics of the firm that invented it. We find that the financial impact of technology products is stronger when firms have higher knowledge absorptive capacity, and more impactful and less diversified knowledge (as measured by patents). We classify firms into three categories based on their knowledge characteristics. We find that firms with a high knowledge fit increase their ROA by 4.55% after product introduction, while those with a low knowledge fit receive no benefit from the innovative technology products at all.

Keywords: innovative technology products; knowledge-based view; knowledge characteristics; patent citation; return on assets

1. Introduction

The successful launch of innovative technology products by manufacturers reflects a firm's ability in incorporating unique, advanced knowledge in developing new products. Generating and leveraging advanced knowledge in new product development and the subsequent creation of innovative technology products are considered to be critical competitive capabilities in the high-tech sector. In fact, the importance of knowledge sources, technological competence, and innovative capability is well recognized in business disciplines such as operations and technology management (Ettlie, 1998; Shane and Ulrich, 2004), strategic management (Roberts, 1999; Zahra and Nielsen, 2002), and financial economics (Chan et al., 2001; Eberhart et al., 2004). The launch of an innovative technology product is the result of a firm's research efforts, representing the unique, state-of-the-art technological knowledge that the firm has created. The development of an innovative technology product requires extensive knowledge sources and capabilities within the firm. However, an interesting question needs addressing: To what extent and under what circumstances can these firms benefit financially from their innovative technology products?

The development of innovative technology products represents the fruitful result of a firm's marketing and technology research efforts. It is thus reasonable to assume that firms introducing innovative technology products have substantial differentiation advantage over their competitors. However, previous research suggests that technologically innovative firms do not necessarily outperform their rivals. Technological innovation requires substantial research and development (R&D) investments, and introducing innovative new products is highly risky (Cooper, 2000; Zahra and Nielsen, 2002). Innovators face the risk that other firms may imitate their actions, typically earning profits that are much greater than their initial investments (Chaney et al., 1991;

Teece, 1986). As the financial benefits from innovative technology products are debated in the literature, researchers have explored a number of contingency factors that affect their impact on financial returns (Hendricks and Singhal, 1997; Langerak et al., 2004; Song and Parry, 1999; Sorescu et al., 2003). Previous studies have examined the contingency effects based on various marketing perspectives, focusing on such moderating factors as marketing proficiency, firm's market dominance, and customer knowledge (Joshi and Sharma, 2004). Recent research has taken a different perspective by focusing on the firm's own resources, behaviors, and capabilities. In particular, the knowledge possessed by the firm is considered an important contingent variable for the competitive outcome of its innovative technology products (Birkinshaw et al., 2002).

In this study we examine the impact of innovative technology products on a firm's value creation. Specifically, we focus on the knowledge characteristics of the firm, which embrace the firm's knowledge absorptive capacity, knowledge impact, and knowledge diversity, as contingent variables for the economic value of innovative technology products. Knowledge in this study refers to the result of any form of learning in technology, which reflects the amount of knowledge that the firm has accumulated over time and is embedded in the organization (DeCarolis and Deeds, 1999; Wu and Shanley, 2009). We argue that the firm's knowledge characteristics in new product development determine the products' attributes and thus their competitive outcomes. The development of innovative technology is likely to be associated with a greater appropriation of innovation rent (Langerak et al., 2004; Smith et al., 2005; Wang and Chen, 2010).

We conduct this study based on a sample of 312 technology products introduced in the U.S. between 1987 and 2006 that had won a major innovation award. Using return on assets (ROA) as the financial indicator, we carry out a long-horizon event study with control firms to detect long-term abnormal financial gains. We use R&D expenses and patent data from the National Bureau of Economic Research (NBER) to measure the firms' knowledge characteristics. We find that on average an innovative technology product increases a firm's ROA (relative to control firms) by 2.18% in the second year after product introduction, which is roughly US$303 million. We estimate that the four-year total abnormal financial return is US$767 million. However, the value of an innovative technology product varies with the knowledge characteristics of the firm that invented it. We find that the financial impact of technology products is stronger when firms have higher knowledge absorptive capacity, and more impactful and less diversified knowledge (measured by patents). We further classify firms into three categories based on their knowledge characteristics. We find that firms with a high knowledge fit increase their ROA by 4.55% after product introduction, while those with a low knowledge fit receive no benefit from their innovative technology products at all.

2. Literature Review and Hypotheses

2.1. Innovative Technology Products, Value Creation, and Moderating Factors

It is generally believed that innovative, highly differentiated products provide firms with sustainable competitive advantage (Calantone et al., 2010). Innovative technology products, which are putatively the most advanced in terms of technology and technical functionality, are likely to greatly increase customer benefits (Atuahene-Gima, 2003; Kleinschmidt and Cooper, 1991; Sorescu et al., 2003). After their introduction into the markets, such innovative products are likely to offer novel ways for solving problems and meeting customer demands.

The development of the knowledge-based view (KBV) over the past two decades provides a theoretical lens through which we understand the competitive advantage derivable from innovative technology products. The fundamental assumption is that firms possessing uncommon and idiosyncratic stocks of organizational knowledge stand a good chance of generating high value (Ranft and Lord, 2002). In particular, a firm’s capability to develop new knowledge-based assets can create core competence and sustain competitive advantage (Kogut and Zander, 1992; Pemberton and Stonehouse, 2000). The development of innovative technology products embodies the creation, transfer, and application of the firm’s knowledge. This knowledge leading to innovative technologies is relatively inaccessible and difficult for rivals to imitate. Such firms have several technological advantage over their potential rivals in relevant fields. As the first mover in the technological race, these innovative firms can develop strong brand names and customer preferences (Min et al., 2006). Accordingly, despite the potential drawback of having to make large investments to develop highly innovative products, we hypothesize that firms with innovative technology products have substantial competitive advantage over rival firms as follows:

H1: The introduction of innovative technology products leads to higher firm financial performance.

The knowledge characteristics of a firm might influence the firm’s development process of innovative technologies and subsequently its performance outcome in the market. Advanced knowledge of technology may enhance the novelty and inimitability of innovative products. The literature suggests that a firm’s knowledge resources can act as a fence that deters the entrance of competition in the same product market. When a firm has high appropriability capability, rivals may have little incentive to invest heavily in similar products, or cannot easily develop a similar product or a substitute to compete with the original innovator. Consequently, some knowledge characteristics can maximize the value of market opportunities and inhibit competitive imitation after product introduction (Grant, 1991; Lieberman and Montgomery, 1988).

KBV also provides the theoretical background for us to hypothesize the moderating roles of a firm's knowledge characteristics. In general, KBV asserts that knowledge is a primary source of favorable organizational outcomes (Sullivan and Marvel, 2011). Various scholars have empirically demonstrated that knowledge development capacity and intellectual capital can serve as a strategic resource, leading to a competitive edge (Craighead et al., 2009; Patel et al., 2012). However, relatively little is known about the sustainability of knowledge-based advantages (McEvily and Chakravarthy, 2002) and the factors that lead firms to appropriate more value from their innovations (Wang and Chen, 2010). In particular, complex, profound, and firm-specific intellectual capital is considered an effective isolating mechanism preventing imitation by rival firms (Nag and Gioia, 2012; Wang and Chen, 2010). Building on this line of research (e.g., McEvily and Chakravarthy, 2002; Nag and Gioia, 2012; Wang and Chen, 2010), we investigate some knowledge characteristics of firms that help sustain the knowledge-based advantage, leading to higher rents from technological innovations. Specifically, we examine the knowledge characteristics that prevent distinctive technology advantages from diffusing to competitors, heightening the imitation barriers of innovative technology products, and generating rents better than competitors producing apparently similar innovative products.

2.1.1. Knowledge Absorptive Capacity

Knowledge absorptive capacity refers to the capacity of a firm to value, acquire, assimilate, transform, and exploit knowledge from external sources for commercial ends (Cohen and Levinthal, 1990; Todorova and Durisin, 2007; Tsai, 2009; Zahra and George, 2002). The knowledge absorptive capacity of a firm is greatly dependent on its current level of technological knowledge (Cohen and Levinthal, 1990; Kim, 2001, 1997), which is derived in turn from previous and current efforts in internal R&D (e.g., Stock et al., 2001; Veugelers, 1997). The efforts of a firm on R&D, and subsequently its knowledge absorptive capability, are related to the firm's ability in technology learning (Benner and Tushman, 2003; Cohen and Levinthal, 1990; Stock et al., 2001), particularly in assimilating knowledge from various external information sources (e.g., latest advances in science and technology) to create sophisticated and unique expertise in a certain area (Bierly and Chakrabarti, 1996; Millar et al., 1997).

Firms with high knowledge absorptive capacity should be able to generate higher rents from their innovative technology products than firms with low knowledge absorptive capacity. Firms with strong absorptive capacity in technology learning are more likely to possess more complex knowledge and incorporate it into their innovative technology products (Lane et al., 2006; Macher and Boerner, 2012; Wiklund and Shepherd, 2003). According to McEvily and Chakravarthy (2002), knowledge complexity prevents competitors' performance replication by obscuring the sources of superior performance, raising the costs of transfer, and increasing the likelihood of imperfect imitation. In addition, firms with high absorptive capacity (normally with strong R&D) are more likely to develop idiosyncratic knowledge that is firm-specific (Minguela-Rata et al., 2012), frustrating competitors' effort to replicate. On the other hand, innovative products developed by firms with low absorptive capacity are likely to be based on more general, relatively less advanced, and more mobile set of knowledge (Lane et al., 2006). Firms with such innovations are less likely to achieve unique advantages and persistent rents, as products of similar functionality can be imitated by competitors, leading to price competition. Firms with strong absorptive capacity also benefit more from continuous external knowledge flows (Escribano et al., 2009), enabling them to further improve their products, staying ahead of the competition, and preserving the rents. Accordingly, we develop a contingency perspective on the relationship between innovative technology products and firm's financial performance as follows:

> *H2: The knowledge absorptive capacity of a firm positively moderates the relationship between innovative technology products and firm's financial performance.*

2.1.2. Knowledge Impact

Knowledge impact refers to the extent to which other firms value the knowledge produced by the firm creating it. It has been used to map the development of fields of scientific inquiry (Small and Griffith, 1974) and to estimate the quality of the scientific capabilities of firms in specific fields (Healey et al., 1986). Knowledge impact may determine a firm's knowledge-based standing in the industry compared with its competitors. Forward patent citations, i.e., citations made by later patents of a patent previously issued, are indicative traces of the importance of commercial innovations (Hall et al., 2001). We measure the knowledge impact of firms based on forward patent citation analysis.

Firms with high knowledge impact are likely to generate higher rents from their innovative technology products than firms with low knowledge impact. Firms with highly cited patents are likely to be pioneers of certain technologies that enable them to develop brand loyalty in certain technology products (Aaker, 2007; Weerawardena et al., 2006). Impactful knowledge reflects a firm's stature, reputation, and credibility, leading to price premium. Firms with impactful knowledge might also appropriate higher rents from their innovative products due to pioneering technology advantages (Bogner and Bansal, 2007). They are more likely to develop a dominant design in which a preferred technological "hierarchy" that becomes evident through de-selection (Suarez, 2004), or raising entry barriers to competitors (Hess and Rothaermel, 2011). On the other hand, firms whose patents are rarely cited (i.e., firms with less impactful knowledge) tend to have stand-alone, disconnected technologies, rather than possessing a dominant set of technology advantages (Anderson and Tushman, 1990; Verspagen, 2007). They enjoy weaker customer confidence and loyalty for seemingly innovative technology products and thus are subject to more severe price competition. Accordingly, we hypothesize that:

H3: Knowledge impact of a firm positively moderates the relationship between innovative technology products and the firm's financial performance.

2.1.3. Knowledge Diversity

A firm's knowledge diversity reflects the scope of technological and application areas in which the firm has expertise (Wu and Shanley, 2009). Although some researchers argue that creating a wide range of knowledge is very important for a company in developing more competitive products, such an argument is not consistent with the traditional view of strategic management that stresses a few focused areas of core competence. From the KBV perspective, it is critical for organizations to be specialized in a few technological areas, developing core competences and gaining durable advantage from their innovative technology products (Macher and Boerner, 2012; Wu and Shanley, 2009).

In general, firms with focused knowledge in a certain technological area are likely to generate higher rents from their innovative technology products than firms with a diversified knowledge base. When a firm focuses on developing a few technology domains, they are more likely to develop technological expertise that is firm-specific and idiosyncratic (Nag and Gioia, 2012). Such focused knowledge domains are explicit to certain applications and technology settings, enabling the firm to develop unique new products (Wu and Shanley, 2009). Focused and specialized knowledge prolongs a firm's advantage by increasing the immobility of its distinctive resources and protecting its rent generating capability when a product is launched (Macher and Boerner, 2012; McEvily and Chakravarthy, 2002). On the other hand, firms with more general and diversified knowledge are likely to have knowledge that is less firm-specific and more mobile, thus limiting their rent generating capability as similar applications can be imitated by competitors or substituted by related products (DeCarolis and Deeds, 1999; Nag and Gioia, 2012). Also, firms with focused learning in certain areas are more likely to develop tacit knowledge that is difficult to be codified, further protecting the knowledge-based advantages with respect to certain product range. Accordingly, we develop the last hypothesis as follows:

H4: The knowledge diversity of a firm negatively moderates the relationship between innovative technology products and the firm's financial performance.

3. Methods

3.1. Sample Selection

To identify innovative technology products, we focused on products that have received external awards for their innovativeness. External awards for innovative technology products clearly signal the novelty of the products in terms of technology, ensuring that they are genuinely "innovative". In particular, such awards are normally given after extensive reviews by technology specialists (Hargadon and Sutton, 1997). We identified more than 20 major technology innovation awards such as the *EDN Innovation Awards*, the recipients of which are winners of innovation competitions organized by the *EDN Magazine* (Electrical Design News) to recognize the most creative electrical and electronics products, and the *R&D 100 Awards*, which are innovation prizes awarded by the *R&D Magazine* for all technological areas widely recognized by the industry, academics, and government. We compiled a list of 1,014 award-winning technology products introduced between 1987 and 2006.

However, we needed to make sure that each sample firm has sufficient data for us to perform various analyses. First, the sample firm must be publicly listed and have sufficient financial information in COMPUSTAT for analysis. Second, it needs to have a clearly identifiable date of product introduction. Since technology innovation awards may be given before or after the products are introduced, and our purpose is to analyze the financial impact of awarded products after they are launched (rather than after the awards are given), a specific introduction date of the awarded product is important for this study. We searched various academic and business databases to confirm the dates of introduction of 475 award-winning technology products from stock-listed firms. Among them, 316 had sufficient data available in COMPUSTAT for analysis.

3.2. Dependent Variable and Moderating Factors

To examine the impact of innovative technology products on financial performance, we focused on return on assets (ROA), which is an accounting-based measure of value creation. ROA, measured as operating income before depreciation, interest, and taxes divided by total assets, is the most widely used indicator of financial performance (Guthrie and Datta, 2008), particularly in the manufacturing industry. We gathered performance data for four successive years upon and after the introduction of an innovative technology product (i.e., t to t+3, where t is the year of introduction). This is because a successful innovative product does not only have an impact in the year of introduction, but also a few years after it is introduced. Previous research shows that the technology life cycle in fast-changing industries is about three to four years (Deng et al., 1999; Terwiesch et al., 1998) and about 90% of our sample firms were from these industries. Accordingly, we expected that the introduction of an innovative technology product should have an impact on the introducing firm for about three to four years after product introduction. Repeated measures enabled us to obtain more reliable performance results.

The moderating factors considered in this study include three knowledge characteristics of a firm, namely knowledge absorptive capacity, knowledge impact, and knowledge diversity. Consistent with previous research (Cohen and Levinthal, 1990; Escribano et al., 2009; Stock et al., 2001), we used R&D intensity to measure the knowledge absorptive capacity of each sample firm. As discussed above, the knowledge absorptive capacity of a firm is greatly dependent on its current level of knowledge of a certain technology (Cohen and Levinthal, 1990; Kim, 2001, 1997), which is in turn derived from previous and current efforts in internal R&D (e.g., Stock et al., 2001; Veugelers, 1997). R&D activities represent a firm's efforts to value, acquire, assimilate, transform, and exploit external knowledge for product development, indicating the knowledge absorptive capacity of the firm. We calculated each sample firm's R&D intensity by taking the average of its R&D expenditures in the two years prior to the introduction of an innovative product and dividing it by the average sales in those two years. The average and median of the R&D intensity of our sample firms are 9.173% and 7.721%, respectively.

We examined the firms' patent data to measure their knowledge impact and knowledge diversity. Since a patent by definition includes a description of a technical problem and a solution to that problem, patent data provide a detailed and consistent chronology of how a firm accumulates its knowledge stock (Wu and Shanley, 2009). We calculated knowledge impact as follows. We first counted the number of patents that a sample firm had obtained over the preceding five years, prior to the introduction of an innovative product. We then counted the number of forward citations by other firms in the following two years after each patent was registered successfully, and then divided the number of citations by the total number of patents. The two-year period of forward citations after the patent was successfully registered was considered to be appropriate because the citation of a patent usually peaks during the early years and then declines steadily (Trajtenberg, 1990). For example, Macro (2007) finds that the citation frequency in the population is hump-shaped in age and falls after two to three years. Our choice of two years is consistent with previous research measuring knowledge impact (e.g., DeCarolis, 2003). The average and median of the patent impact (in two years) of our sample firms are 1.52 and 1.06 times, respectively.

We measured knowledge diversity by the Herfindahl-Hirschman concentration index (HI), which records the number of patent classes in the past five years prior to the introduction of an innovative product (Prabhu et al., 2005). Following the patent classification methods developed by Bessen (2009), there are 37 different major categories of patents. The HI measures whether the patents obtained by a firm are concentrated in a few categories or they are widely distributed over different categories. The concentration in patent categories is widely used in the literature to measure the knowledge diversity of a firm (Ahuja and Katila, 2001). The average and median of the HI of our sample firms are 0.679 and 0.777, respectively.

3.3. Control Variables

We included some firm-level and industry-level controls in our model. The firm-level controls were firm size, performance prior to the introduction of an innovative technology product (i.e., in year *t*-1), and the control firms' performance changes. The industry-level controls were industry-specific (rather than firm-specific) R&D intensity and industry concentration. We measured firm size by taking the natural logarithm of the firm's total assets. We measured industry concentration by the HI in terms of sales (in the year before product introduction, i.e., year *t*-1). We took the sum of squared market shares of each firm in an industry. The higher the HI value is, the more concentrated is the industry. Finally, we measured industry R&D intensity as the median R&D intensity of the industry.

As mentioned above, we studied the impact of each sample innovative technology product over a four-year period after its introduction. To avoid any overlapping periods of analysis for a sample firm, we excluded a second innovation award to the same firm within the four-year period. On the other hand, a second award won by the same firm beyond the four-year period (e.g., awards given to the same firm in 1995 and 2005, respectively) was included in our analysis. Our sample of 316 awarded products was taken from 243 different firms. We developed a dummy variable called "multiple introductions" as a control factor to indicate whether or not a firm has more than one awarded product (beyond the four-year period) included in our analysis.

In order to examine the impact of innovative technology products on firm performance, we adopted the event study approach by selecting appropriate sample-control matched pairs. We matched sample and control pairs based on specific matching criteria to minimize the confounding effects caused by some special factors in a particular industry or by the overall state of the economy at a specific time period. Barber and Lyon (1996) suggest that matching pre-event performance is the most critical factor for event studies. They also suggest that matching industry type and 90%-110% pre-event performance create the most appropriate matching groups between the sample and control firms. Following Hendricks and Singhal (2008), we matched each sample firm to a portfolio of control firms based on two-digit SIC code, 50%-200% of firm size (in terms of total assets), and performance range of 90%-110% in the year before product introduction (i.e., in year *t*-1). Our sample size reduced to 312 as we could not find comparable control firms with similar pre-event ROA for some sample firms. On average, a sample firm matched with 27.16 control firms.

3.4. Statistical Models

3.4.1. Estimation of Abnormal Performance

As mentioned above, we adopted the long-horizon event study method to examine the abnormal financial performance after the introduction of innovative technology products to markets. We set year *t*-1 as the base year and measured the changes over the next four years (i.e., *t*, *t*+1, *t*+2, *t*+3). Using year *t*-1 as the base year is considered to be appropriate as it is free from the impact of the innovative technology products (as the products have not yet been introduced). We determined the impact of the products by estimating the *abnormal performance*. We took abnormal performance as the sample post-event performance (i.e., actual performance between *t* and *t*+3) minus expected performance. We estimated expected performance as the sample pre-event performance plus the corresponding median change of its control group during that period (Barber and Lyon, 1996).

We applied the parametric t-test to analyze the mean abnormal performance and the non-parametric Wilcoxon signed-rank (WSR) test to analyze the median abnormal performance. The use of the WSR test to supplement the t-test ensures that our results are not seriously biased by outliers. Before we examined the post-event abnormal performance of sample firms (i.e., *t* to *t*+4), we tested if there was any pre-event bias. We did not find any pre-event abnormal performance changes in ROA from *t*-2 to *t*-1 ($p > 0.1$).

3.4.2. Estimating Moderating Effects using Hierarchical Linear Models

To evaluate the moderating role of knowledge characteristics on the relationship between innovative technology products and financial performance, we applied Hierarchical Linear Modeling (HLM) in our study. HLM is widely used to study multilevel data (Bloom and Milkovich, 1998; Raudenbush and Bryk, 2002). It overcomes the statistical weaknesses of traditional methods for analyzing nested data. In this study we used repeated measures within firms, which in turn are nested within industries, creating a hierarchical data structure with three levels of random variables. Following Ang et al. (2002), we adopted an incremental approach.

For each analysis, we first specified a null model with no predictor variables in order to test whether there are significant variations in performance. Next, we specified the base model that incorporated all the control variables. After that, we included the firm-level moderating variables one by one into the base model. Our HLM analysis for moderating effects was based on a sample of 244 award-winning products (instead of all the 312 cases) in 196 firms as we did not have patent information for 68 cases (in 55 firms).

4. Results

As mentioned above, we have a sample size of 312 for the analysis of abnormal ROA. The average (median) total assets are US$13,922 (US$2,284) million and the total sales are US$13,146 (US$1,742) million. Table 1 shows the descriptive statistics of the sample and control firms in the base year (i.e., *t*-1). The mean and median of ROA for the sample firms are 7.671% and 11.860%, respectively, and those for the control firms are 7.576% and 11.990%, respectively. The performance of the sample and control firms in terms of ROA is very similar before the introduction of innovative technology products.

[… Table 1 …]

4.1. Impact on Financial Performance

Table 2 reports the results of two firm performance indicators using the t-test and the WSR test. All abnormal returns are measured against the base year *t*-1. Both tests show that abnormal changes in ROA are consistently positive and highly significant from *t* to *t*+3. In the year of introduction of an innovative technology product, the mean abnormal increase in ROA is 0.77%, which is highly significant at $p < 0.05$. The mean abnormal ROA increase further rises to 1.59% in the year after introduction of the product (i.e., *t*+1, $p < 0.01$) and reaches 2.18% in the second year (i.e., *t*+2, $p < 0.01$), which is roughly US$303 million considering that the average total assets of our sample are about US$13.9 billion. However, the mean abnormal ROA drops to 0.98% in the third year (i.e., t+3), although statistically it is still significant ($p < 0.1$). The four-year total abnormal financial returns (i.e., from t to t+4) are estimated to be US$767 million. Applying the WSR test to analyze the median provides similarly significant results, although the magnitudes are slightly different. Therefore, Hypothesis 1 is fully supported.

[… Table 2 …]

4.2. HLM Test Results of Moderating Factors

We conducted HLM estimations with ROA as a dependent variable. Our intention was to investigate the moderating effect of firms' technological knowledge characteristics on the impact of innovative technology products on firm's financial performance. Table 3 presents the HLM estimation results. In the table, the null model shows that there is a significant variance in ROA across the firms ($p < 0.001$). When incorporating the control variables into the ROA model, both AIC and -2 Log-likelihood indicate that Model 2 has a much better model fitness. The results of Model 2 suggest that, as control variables, firm size ($p < 0.01$), pre-event ROA ($p < 0.001$), control firms' ROA changes ($p < 0.01$), and multiple awards (beyond the four-year period as mentioned above) by a firm ($p < 0.1$) are significant predictors of post-event ROA.

For Models 3A to 3C in the HLM estimations, we included knowledge absorptive capacity, knowledge impact, and knowledge diversity one by one into the models. In Model 3D, we included all the three moderating factors. The results show that as with the inclusion of the moderating factors, the values of both AIC and -2 Log-likelihood decrease significantly (Chi-square > 3.84 with 1 df, $p < 0.05$), indicating that a significantly better fit of the model is obtained with the inclusion of any one of the three moderating factors.

[… Table 3 …]

Specifically, H2 predicts that knowledge absorptive capacity positively moderates the relationship between the introduction of innovative technology products and the firm's financial performance. This hypothesis is supported (see Table 3). In Table 3, the individual model (Model 3A) and the full model (Model 3D) show that knowledge absorptive capacity is a significant predictor of ROA upon the introduction of an innovative technology product. The un-standardized coefficients of knowledge absorptive capacity are 0.171 (SE = 0.057) in Model 3A and 0.154 (SE = 0.057) in Model 3D.

The results show that the coefficients of knowledge impact are 0.996 (SE = 0.317) in Model 3B and 0.725 (SE = 0.324) in Model 3D; both are highly significant ($p < 0.05$), indicating that knowledge impact positively moderates the relationship between innovative technology products and post-event ROA. Thus, H3 is supported. The results further show that knowledge diversity negatively moderates the relationship between innovative technology products and ROA, and the coefficients of the individual model (Model 3C) and the full model (Model 3D) are -6.642 (SE = 2.197) and -5.508 (SE = 2.200), respectively. Thus, H4 is also supported.

5. Discussion

Our results indicate that when a firm introduces an innovative technology product, its long-term financial performance is enhanced. Compared with control firms from the same industry, sample firms with innovative products obtain significantly higher financial performance in the first year and a few years after product introduction. The development of the products enables a firm to obtain higher ROA. The average increase in abnormal ROA reaches the peak of 2.18% in the second year (i.e., t+2) after product introduction, but drops slightly in the third year (i.e., t+3).

More importantly, we find that the capability of appropriating financial performance is contingent upon some important knowledge characteristics of the firm in question. Our findings suggest that knowledge absorptive capacity increases the firm's financial performance to a greater extent as the products are introduced. This positive moderating effect might indicate that a firm with high knowledge absorptive capacity can create complex and idiosyncratic knowledge, which preserves the firm's rent-generating capacity after the products are launched.

The economic value of impactful knowledge to the firm that creates it is debated in the literature. McGahan and Silverman (2006) suggest that impactful knowledge gives rise to technology opportunities to competitors, so the actual benefits of those who invent it might be rather limited. Endogenous growth theory assumes that knowledge, once created, spills over almost automatically to other firms, leading to a knowledge paradox (Audretsch and Keilbach, 2008). In contrast, our results show that knowledge impact increases firms' rents from their innovative technology products. We argue that firms with knowledge impact (i.e., highly cited patents) are more likely to be the pioneer of a certain technology, enabling them to develop brand loyalty and technology dominance (e.g., culminating in a dominant design) (Hess and Rothaermel, 2011; Suarez, 2004).

Using the Herfindahl-Hirsehman concentration index of patents as a measure of knowledge diversity, Wu and Shanley (2009) find that wider knowledge diversity (i.e., low concentration) in terms of technological classes is associated with the quantity of innovations as measured by new, successfully registered patent numbers. Although it is possible that knowledge diversity is associated with the quantity of innovations, it does not necessarily lead to stronger value creation of a technological innovation. We find that the financial performance of an innovative product from firms with diversified knowledge is actually weaker. Our finding extends the understanding of the knowledge-based advantage by showing focused learning in a certain technological domain leads to a higher rent-generating capability with regard to innovative technology products.

5.1. Theoretical Implications

Researchers in technology management are increasingly interested in knowledge-based competition and in knowing how firms preserve their product or process advantages. Previous studies on KBV have shown that, as an intangible resource, a firms' knowledge confers significant competitive advantages (Craighead et al., 2009). However, very little is known about how such product or process advantages are sustained or preserved. Innovating firms may not always be able to fully appropriate rent from their technology products due to the rapid diffusion of innovative knowledge across firms (Wang and Chen, 2010). Studies have further suggested that the intrinsic characteristics of resources and capabilities, such as complexity, tacitness, and specificity, preserve knowledge-based advantages (Macher and Boerner, 2012; McEvily and Chakravarthy, 2002) and absorptive capacity helps sustain the firm's advantage in a dynamic environment (Patel et al., 2012; Wang and Chen, 2010). Building on this line of research, we extend understanding of KBV by explicitly identifying the knowledge characteristics of firms that influence the rent-appropriating capability of firms from their innovative products.

We postulate and demonstrate that some knowledge attributes can help preserve innovative products' technological advantages. Firms certainly need innovative ideas to develop new products. However, the questions of whether or not, and under what circumstances, such innovation-based advantages are sustained are equally important to address (McEvily and Chakravarthy, 2002; Nag and Gioia, 2012). We contribute to theory by demonstrating that what matters is not only whether or not firms have innovative products, but more importantly the types of firms' knowledge characteristics based on which these products are developed. Previous research asserts that the competitive advantage of a firm is achieved through accumulated, idiosyncratic, and imperfectly mobile knowledge (e.g., Verona, 1999). We further demonstrate that the rent-generating capability of innovative technology products increases if these products are developed based on sustainable knowledge, i.e., knowledge that is based on strong R&D, and is impactful and focused (rather than being highly diversified). Our treatment of firms' knowledge characteristics as moderating factors allows us to better demonstrate the idea that knowledge helps sustain innovation-based advantage, rather than innovations having a direct impact on performance per se. In this sense, we test the knowledge-based advantage of products in a more explicit way, leading to more direct insights.

5.2. Managerial Implications

Our analysis has obvious implications for firms competing on the basis of innovative technology products. We show that some innovations have greater rent-generating capabilities than others, and this could depend on the knowledge characteristics of the firms, not simply on the innovations themselves. For example, if an innovation is developed based on less complex (instead of advanced R&D), less impactful, and more general knowledge, it probably can be imitated or substituted quickly (Nag and Gioia, 2012; Verona, 1999). The management of technology firms needs to re-consider the rent-generating capacity of such innovative products as the advantages of these products can easily be eroded by imitators.

We believe that our results are relevant not only to managers who are directly involved in new product development, but to all practitioners or firms that are engaged in knowledge-based competition. For example, operations managers might be involved in the development of process innovations that lead to significant competitive advantage (Anand et al., 2010; Craighead et al., 2009; Patel et al., 2012). However, if such process innovations are not based on complex, unique, and idiosyncratic set of skills, they might be imitated easily by competitors. In the context of knowledge-based competition, it is not just about the effectiveness of an innovation in solving problems, but also how such knowledge-based advantage of the innovation is sustained. Managers need to consider this dimension when they embark on product or process innovations.

5.3. Categorizing Three Types of Knowledge Fitness

We find that firms that invest heavily in R&D (i.e., high knowledge absorptive capacity), have their patents highly cited (impactful knowledge), and those concentrating on certain technological domains are likely to gain more benefits from their innovative technology products. To further demonstrate this, we classified the sample firms into three categories according to their knowledge characteristics. We first categorized each of the three variables of knowledge characteristics into ten percentile groups and assigned a score to each variable. A score of 1 and 10 represented the least and most favorable characteristic, respectively (i.e., reverse of the coding for knowledge diversity). We then calculated the total fitness score of the three variables. The total score ranged from 4 to 30. We divided all the sample firms (n = 244) into three groups: High (n = 82), Medium (n = 77), and Low (n = 85) Fit Groups, based on their total fitness scores. Note that there are slight variations in the numbers of sample firms in each group as the total fitness scores of some firms are tied. For simplicity, we consider only t+2 (the second year after product introduction) because this is the year when the abnormal financial returns of the sample firms reach the peak. The results are shown in Table 4.

We find that the mean abnormal ROA (relatively to the control groups) of the firms in the Low Fit Group is 0.156% (median = -0.141%). Both the mean and the median are not significantly different from zero ($p > 0.1$), which implies that these firms receive no benefit from their innovative technology products. On the other hand, the firms in the Medium and High Fit Groups achieve a highly significant abnormal ROA of 2.35% ($p < 0.05$) and 4.55% ($p < 0.01$), respectively. These results confirm a significant moderating effect of firms' knowledge characteristics on the profitability of innovative technology products.

[…Table 4…]

5.4. Limitations in Measurements

There are some limitations related to our measurements of knowledge characteristics. Following previous research, we measure absorptive capacity by using R&D intensity. However, as discussed in the literature (Zahra and George, 2002), absorptive capacity is a complex construct. Our use of R&D intensity might only capture the financial resources on technology learning, which does not fully reflect the richness of the construct (Minbaeva et al., 2003). In the literature, there are some other proxies for absorptive capacity, such as number of doctorates and ratio of researchers to total employees (Escribano et al., 2009). Future research may consider these proxies as supplements and develop a more comprehensive measure of absorptive capacity. Another direction is to use a survey instrument to measure the learning behaviors of firms as indicators of absorptive capacity. For example, Jansen et al. (2005) developed a survey instrument to measure potential absorptive capacity (e.g., collecting industry information) and realized absorptive capacity (e.g., recording and storing newly acquired knowledge).

We use patent data to measure knowledge impact and knowledge diversity. Patenting is a legal form that protects a firm's intellectual property rights. However, as pointed out by Trajtenberg (2011), patenting is a firm's "strategic decision" to protect its technological assets, and not all firms protect their technological innovations by patents (Wu and Shanley, 2009). Furthermore, not all innovative ideas are patentable. For example, purely scientific advances devoid of immediate applicability cannot be patented (Park and Lee, 2006; Trajtenberg, 2011). In addition to patent data, there are alterative measures of knowledge impact and diversity. For example, knowledge impact is also measured in the pharmaceutical industry by the number of "star scientists" or the significance of research publications by the firm (Hess and Rothaermel, 2011). Similarly, researchers may also measure knowledge diversity by using the number of business segments or diversifications of new technology products. Future research can consider these proxies as supplements, capturing the richness of these constructs. Finally, our R&D or patent data only capture the knowledge characteristics of firms, rather than the knowledge characteristics of individual products. Further research can be conducted at an individual product level if the knowledge characteristics of some product innovation schemes are available.

6. Conclusions

Success in launching innovative technology products is crucial for firms in enhancing financial performance. However, the extant literature is limited in providing an understanding of the financial value of innovative technology products and the moderating effects of firms' knowledge characteristics on such value. Based on a large sample of innovative technology products in the U.S., we find that an innovative technology product increases the ROA of a firm (relative to control firms) on average by 2.18% in the second year after product introduction, which translates roughly to US$303 million. However, the value of an innovative product varies with the knowledge characteristics of the firm that invented it. We find that the impact of technology products on financial performance is stronger when firms have higher knowledge absorptive capacity, and more impactful and less diversified knowledge. Firms with a good fit to these knowledge characteristics obtain an even higher abnormal profit from their innovations, while those with a poor knowledge fit receive no benefit from their innovative technology products.

We make two suggestions for future research. First, we believe that it is interesting to study the financial value of some process innovations (e.g., Six Sigma) and explain how firms' knowledge characteristics could moderate the financial value of such process innovations. Another possible direction for future research is to examine the moderating effect of other firms' knowledge characteristics. For example, some firms carry out basic research on science (e.g., publishing academic papers), while others do not. Firms with basic research might be in a better position to generate higher rent from their innovative technology products due to the profoundness of their knowledge. Future research can be conducted to examine the related propositions.

Appendix

Table 1 Descriptive Statistics of Pre-event Data for Sample and Control Firms (Year *t*-1)

	N	Mean	Median	Min.	Max.	St. dev.
Sample Firms						
Total Assets [a]	312	13.92	2.28	0.32	198.94	257.78
Return on Assets (ROA) [b]	312	7.671	11.860	-257.500	42.140	25.004
Control firms						
Total Assets [a]	312	13.32	2.25	0.34	188.20	256.63
Return on Assets (ROA) [b]	312	7.576	11.990	-263.600	41.840	25.107

Note: [a] in billion US dollars; [b] in percentage

Table 2 Abnormal Performance Results of Sample Firms

Firm Performance	Test Method	Median/Mean (*p*-value)			
		t-1 to *t*	*t*-1 to *t*+1	*t*-1 to *t*+2	*t*-1 to *t*+3
ROA [a] (*n*=312)	*t*-test for mean	0.770 (0.029)	1.589 (0.005)	2.180 (0.000)	0.979 (0.068)
	Wilcoxon signed-rank test for median	0.460 (0.013)	1.092 (0.038)	1.516 (0.001)	0.640 (0.037)

Note: [a] in percentage for the median and mean

Table 3 HLM Estimation for ROA

	Model 1	Model 2	Model 3A (KAC)	Model 3B (KI)	Model 3C (KD)	Model 3D (All)
Intercept	12.221***	2.776+	-0.915	0.629	5.342**	0.031
	(1.177)	(1.546)	(1.971)	(1.683)	(1.758)	(2.246)
Firm Size		0.456**	0.644***	0.548**	0.727***	0.915***
		(0.174)	(0.184)	(0.174)	(0.195)	(0.201)
Previous Performance		0.520***	0.563***	0.511***	0.504***	0.537***
		(0.028)	(0.031)	(0.028)	(0.028)	(0.031)
Change of Control Firms' Performance		0.111**	0.114**	0.110**	0.115**	0.116**
		(0.036)	(0.036)	(0.036)	(0.036)	(0.036)
Multiple Introductions		1.526+	1.339+	1.272	1.909*	1.493+
		(0.807)	(0.803)	(0.798)	(0.814)	(0.807)
Industry Concentration		-5.063	0.138	-1.332	-4.134	3.193
		(15.095)	(15.124)	(15.074)	(15.020)	(15.054)
Industry R&D Intensity		-1.946	-2.177	0.059	-2.099	-0.808
		(5.697)	(5.660)	(5.674)	(5.670)	(5.637)
Knowledge Absorptive Capacity (KAC)			0.171**			0.154**
			(0.057)			(0.057)
Knowledge Impact (KI)				0.996**		0.725*
				(0.317)		(0.324)
Knowledge Diversity (KD)					-6.642**	-5.508*
					(2.197)	(2.200)
Model Fit:						
AIC	5217.15	4959.93	4952.87	4952.12	4952.74	4942.69
-2 Log-likelihood (Deviance)	5209.15	4939.93	4930.87	4930.12	4930.74	4916.69
ANOVA significance (*p*-value)		0.000	0.003	0.002	0.002	0.000

Note: ***: *p*-value < 0.001; **: *p*-value < 0.01; *: *p*-value < 0.05; +: *p*-value < 0.1

Table 4 Means and Medians of Abnormal ROA in Low, Middle, and High Fit Groups at *t*+2

	High Fit Group	Medium Fit Group	Low Fit Group
Number of Sample Firms	82	77	85
Mean[1]	4.550%**	2.352%*	0.156%
Median[2]	3.941%**	1.661%*	-0.141%

Note: Tests for differences against zero (i.e., no abnormal ROA)

[1] Independent sample t-test for means; [2] Wilcoxon signed-rank test for medians;

**: *p*-value < 0.01; *: *p*-value < 0.05

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