FOCUSING THE HIGH-TECHNOLOGY FIRM—HOW OUTSOURCING AFFECTS TECHNOLOGICAL KNOWLEDGE EXPLORATION

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ABSTRACT

This study argues and shows that the extent to which high-technology firms focus efforts by outsourcing production, assembly, and logistics activities enhances the extent of technological knowledge exploration. This occurs through three modalities: 1) intensifying the effect of internal R&D efforts on exploration; 2) intensifying the effect of learning from competing partners, through R&D alliances, on exploration; and 3) intensifying the effect of learning from customers on exploration. Empirical analysis of a panel dataset of Israeli high-technology firms supports the view that the combination of these three modalities is associated with greater exploration of new technological knowledge.

Keywords: Outsourcing, exploration, focus, learning from alliances, learning from customers.

INTRODUCTION

The exploration of technological knowledge new to the firm involves "search, variation, risk taking, experimentation" (March, 1991: 71) and is, therefore, challenging for firms. However, new technological knowledge is critical to the performance of high-technology firms since it is a central means for creating and sustaining competitive advantage in the face of product and industry life cycles (Abernathy & Utterback, 1978; Henderson, 1993; Klepper, 1997; Leiblein & Madsen, 2009; Schumpeter, 1942).

The extant literature has mainly engaged in studying how different R&D strategies influence the extent to which high-technology firms explore new technological knowledge (e.g. Katila & Ahuja, 2002; Laursen & Salter, 2006; Lavie & Rosenkopf, 2006; Zhou & Li, 2012). The current study suggests that, in addition to specific R&D strategies, the outsourcing patterns of *other* value chain activities are also associated with the exploration of new technological knowledge. The study combines insights from transaction cost economics (TCE), the knowledge-based view of the firm (KBV), and the strategic alliances literatures to support this notion.

More specifically, the study advocates the separation of the value chain into three main activities: R&D, operations (including production, assembly, and logistics) and customer-facing activities (including marketing, sales, and customer support). It then emphasizes how focusing the high-technology firm by outsourcing its operations influences the extent of its technological knowledge exploration. First, greater focus enhances the effect of the firm's internal R&D efforts on technological knowledge exploration. Second, it enhances the firm's capability to explore technological knowledge by learning from its R&D alliance partners. Third, it enhances the exploration of technological knowledge that occurs when a firm conducts its marketing, sales, and customer support activities in-house, as means to facilitate closer customer interaction.

Importantly, these arguments emphasize that the capability to explore new technological knowledge is closely associated with increasing the firm's focus through outsourcing some of its operations. Such focus increases the firm’s capability of combining internal R&D knowledge, technological knowledge gained from R&D alliance partners, and technological knowledge gained from customers to foster the exploration of technological knowledge.

I analyze a sample of 147 Israeli high-technology firms over a period of seven years and find that the interaction between the extent to which a firm outsources production, assembly, and logistics activities and its R&D investments is positively associated with technological knowledge exploration. I further find that the outsourcing of production, assembly, and logistics activities is positively associated with the number of R&D partners, and with the proportion of integrated marketing, sales, and customer support activities. The results are robust to control for endogeneity and omitted variable biases.

Overall, these results support the view that focusing the high-technology firm on R&D and customer-facing activities is strongly associated with the exploration of new technological knowledge, thus suggesting a novel explanation for many high-technology firms’ choice to integrate R&D and customer-facing activities, while outsourcing their operations (Contractor, Kumar, Kundu & Pederson, 2010; Mudambi, 2008). The results emphasize that the capability to explore new technological knowledge is closely associated with increasing the high-technology firm's focus on different learning channels (Parmigiani & Mitchell, 2009). Combining R&D investments, R&D collaborations and customer interaction allows high-technology firms to explore new forms of technological knowledge that collectively build on internal R&D knowledge, new technological knowledge gained from R&D alliance partners and customer-based technological knowledge. More broadly, these results support the view that, given the interconnections between value-chain activities, firm-boundary decisions in specific value-chain activities affect firm-specific capabilities in *other* value-chain activities (Penrose, 1959; Porter & Siggelkow, 2008).

CONCEPTUAL FRAMEWORK

R&D activities can be classified into two broad categories: those that rely on the "exploration" of technological knowledge new to the firm, and those that enhance the "exploitation" of existing technological knowledge (March, 1991; Levinthal & March, 1993). Exploration is generally associated with the “pursuit of knowledge… that might come to be known” and leads to the development of new technological knowledge (Levinthal & March, 1993: 105), while exploitation is associated with the “use and development of things already known” and leads to the refinement of existing technological knowledge (Levinthal & March, 1993: 105).

Naturally, high-technology firms must balance their scarce resources between the competing objectives of exploration and exploitation (March, 1991; Freel, 2003; Levinthal & March, 1993; He & Wong, 2004). However, the exploration of new technological knowledge is often a means through which high-technology firms aim to gain a competitive advantage, because such exploration facilitates the introduction of new technological paradigms that, in turn, may become dominant technological designs (Abernathy & Utterback, 1978; D’aveni, 1994; Henderson, 1993; Mudambi & Zahra, 2007; Schumpeter, 1942).

The extant literature has dealt intensively with questions pertaining to the ways high-technology firms conduct R&D activities as means of exploring new technological knowledge. Among the key factors shown to be associated with the exploration of new technological knowledge are increasing existing stocks of technological knowledge through greater R&D investments (Dunlap-Hinkler, Kotabe & Mudambi, 2010; Cohen & Levinthal, 1990; Zhou & Li, 2012); greater depth and breadth of technological search (Katila & Ahuja, 2002; Laursen, Leone & Torrisi, 2010); a larger variety of technology search channels (Laursen & Salter, 2006); R&D alliance activity (Lavie & Rosenkopf, 2006), and behavioral biases and slack technological resources (Chen & Miller, 2007; Chen, 2008; Knudsen & Levinthal, 2007).

However, very limited attention has been given to the question of whether the ways high-technology firms conduct other activities, such as production, assembly, logistics, marketing, sales and customer support, may also be associated with their exploration of new technological knowledge. To address this gap, the current study focuses on the association between the outsourcing of activities along the firm's value chain (Porter, 1985) and the firm's propensity to explore new technological knowledge.

A firm’s value chain is composed of a series of complementary activities designed to add cumulatively to the firm’s value-creation efforts (Porter, 1985; Porter & Siggelkow, 2008). At one extreme, the firm may choose in-house control, wherein highly integrated firms undertake most of their value-chain activities within their boundaries. At another extreme, the firm can become highly specialized, governing relatively few value-chain activities through ownership and for the most part relying on market transactions (Mudambi, 2008). The firm can also adopt intermediate boundary forms, such as joint ventures or alliances, where it cooperates with other firms to complete a specific activity.

Transaction cost economics (TCE) theory provides general guidelines that enable prediction of when the firm will manage a value-chain activity in-house, and of when it will implement an activity via the external market (Armour & Teece, 1980; Williamson, 1985; Teece, 1986). Essentially, transaction costs theory predicts that when the costs of integration exceed the costs of transactions with third parties, the firm will outsource a value-chain activity. Significantly, this view suggests that firms that keep more value-chain activities in-house will have greater control over these activities and a lower probability of losing valuable proprietary knowledge. In contrast, firms that outsource their value-chain activities face the risk of proprietary knowledge spillover threatening their competitive advantage. Therefore, firms are more likely to outsource value-chain activities involving simple, codified knowledge, but will prefer to integrate activities involving complex and more tacit knowledge, which is difficult to transact.

Offering a similar reasoning, the knowledge-based view (KBV) of the firm suggests that one of the primary purposes of the firm is to create new knowledge, and to recombine it in ways that create value (Kogut & Zander, 1992; Grant, 1996). Knowledge-based theorists posit that firms must be organized in ways that promote the capture and transfer of tacit and complex knowledge to the right places within the firm, where such knowledge can best be exploited to create value. The KBV, therefore, implies that value-chain activities involving tacit and complex knowledge will allow firms to create more value when these activities are conducted within firm boundaries. Combining the TCE and KBV perspectives, Jacobides and Winter (2005) observe that if capabilities were homogeneously distributed across firms, there would be no transactions between firms. Thus, the decision to undertake an activity in-house, or via arms-length transactions with external parties is a function of a focal firm's capabilities relative to the external market. This reasoning suggests that firms are likely to integrate value-chain activities in which they possess superior capabilities and outsource activities where they possess inferior capabilities (Jain & Thietart, 2014).

Recent research has shown that firms may also choose intermediate boundary forms, where they engage in collaborations with external partners to reap the benefits generated from the interplay between the knowledge gained from internal and external sources (Cassiman & Veugelers, 2006; Frohlich & Westbrook, 2001; Leiblein & Madsen, 2009; Parmigiani, 2007; Parmigiani & Mitchell, 2009, 2010). Cassiman and Veugelers (2006) show that internal and external R&D activities are complementary, and the extent of firms' engagement in basic science enhances this complementarity. This is because firms that engage in basic science develop strong capabilities to identify useful components of their partners' knowledge, enabling them to bring that knowledge into the firm and combine it with existing internal knowledge. Given the risks of inadvertently providing proprietary knowledge to partners that are potential competitors, firms will collaborate with external partners only to the extent they believe they can benefit from the knowledge exchange. Alliances are therefore described as "learning races," wherein firms engaged in an alliance strive to learn faster than their partners (Khanna, Gulati & Nohria, 1998).

Building on these key insights of TCE, KBV, and alliance literatures, I argue that firm boundary choices are also likely to be associated with high-technology firms' ability to learn and, more specifically, to explore new technological knowledge. Importantly, since each value-chain activity has its own set of interfaces with the firm's internal and external environments (Porter, 1985; Porter & Siggelkow, 2008; Teece, 1986), I expect the outsourcing patterns of value-chain activities, other than R&D, to be associated with the ability of high technology firms to explore new technological knowledge.

I essentially argue that focusing the high-technology firm on specific activities that enhance technological learning, by outsourcing production, assembly, and logistics activities (hereinafter *operations*), is positively associated with the ability to explore new technological knowledge from three main channels: First, greater focus enhances the effect of the high-technology firm's internal R&D efforts on technological knowledge exploration. It allows the top management team to make more long-term, aggressive knowledge exploration efforts while reducing possible resistance from production, assembly, and logistics managers and workers who may fear being displaced if the firm adopts substantially new technological knowledge. Second, greater focus enhances the high-technology firm's ability to explore technological knowledge by learning from its R&D alliance partners (Ahuja, 2000; Lavie & Rosenkopf, 2006; Leiblein & Madsen, 2009; Phelps, 2010), where greater resources and attention can be directed to technological learning through R&D collaborations. Third, high-technology firms often "learn from customers" through direct interactions involving customer-facing activities such as marketing, sales, and customer support and end customers (von Hippel, 1976; 1977; Franke and Shah, 2003; Chatterji, 2009). Greater focus enhances the technological knowledge exploration that occurs when a firm conducts such customer-facing activities in-house, as means to facilitate closer customer interaction, where greater resources and managerial attention can be directed toward technological learning from customers.

The semiconductor industry provides an archetypical example that illustrates the arguments above. In this industry, brand owners outsource production to semiconductor fabrication plants (these types of designers are often called "FAB-less") (Lee, 2002), but remain in charge of marketing, sales, and customer support. Such firms often invest heavily in R&D, but also engage extensively in multiple types of R&D consortia and collaborations within and outside their industry. In this industry, brand owners are those that often come up with novel technological innovations, while the manufacturing firms are implementing "best-in-class" processes to minimize costs, but do not create new technological knowledge.

In the following paragraphs, I offer a set of hypotheses explaining how the outsourcing of the high-technology firm's operations influences its ability to explore new technological knowledge.

Focus and Internal R&D Efforts

Managerial capacity is a non-scale free resource (Levinthal & Wu, 2010; Penrose, 1959); time spent tending to issues in specific value-chain activities creates an opportunity cost in other value-chain activities. When high-technology firms outsource operations such as production, assembly, and logistics (Hashai & Almor, 2008; Mudambi, 2008) they are able to direct more managerial resources to R&D activities where their key strengths usually lie (Prahalad & Hamel, 1990; Quinn, 1999). This view is consistent with the view that managers' attention is limited and hence firms must be selective about the issues they attend to (Ocasio, 1997). It is further consistent with the view that focusing managers' attention on specific activities the firm excels in while outsourcing activities in areas where it does not possess particularly strong capabilities should lead to more favorable outcomes (Jacobides & Winter, 2005).

The firm's R&D activities involve both technological knowledge exploration and exploitation. The extant literature shows, however, that higher investments in R&D activities are positively associated with technological exploration (Dunlap-Hinkler, Kotabe & Mudambi, 2010; Cohen & Levinthal, 1990; Zhou & Li, 2012). Importantly, by directing more managerial resources toward their R&D activities, high-technology firms can enhance the positive association between R&D investments and the exploration of new technological knowledge through the facilitation of two main phenomena. First, greater involvement of top managers in R&D processes paves the way for more aggressive, long-term, focused technological efforts that, when combined, enhance the likelihood of increased exploratory R&D efforts (Ettlie, Bridges, and O'Keefe, 1984). Greater involvement of top management in R&D processes may lead to greater managerial time spent on directing the firm's technological trajectories, and to the involvement of "innovation champion(s)" in technological efforts, which together have been shown to encourage technological knowledge exploration (Chakrabarti, 1974; Ettlie, et al., 1984). Second, since the creation of new forms of technological knowledge increases uncertainty, this may raise resistance within the firm (Hage, 1980). This resistance may often come from managers and workers in production, assembly, and logistics operations, because new forms of technological knowledge may displace managers and workers with more conventional skills. Outsourcing higher shares of these activities will reduce infighting (because a smaller share of operations managers and workers will remain part of the firm), facilitating the ability to explore new technological knowledge (Germain, 1996).

To allow effective outsourcing of operations, high-technology firms often need to modularize their operations (Baldwin & Clark, 2003; Hoetker, 2006; Sanchez & Mahoney, 1996), where they codify the technological knowledge necessary for conducting their operations and manage those transactions via contracts. In this way, high-technology firms can wall off proprietary technological knowledge spillovers to third parties by keeping the relatively more complex tasks related to operations in-house, and sharing only standardized practices and technological knowledge with their arms-length suppliers. This view is supported by recent research showing that high-technology firms often outsource production activities involving simple problems, while conducting production activities involving more complex problems, or embedding proprietary technological knowledge, in-house (Macher & Boerner, 2012). In this way, the high-technology firm can keep high transaction costs interfaces between complex operations and R&D activities in-house, while maintaining only lower transaction costs interfaces between simple outsourced operations and R&D activities (Baldwin, 2008).

I therefore predict that when a high-technology firm invests more in R&D activities it will exhibit greater technological knowledge exploration, and that when it outsources higher shares of its operations, it will further enhance the effect of R&D investments on the exploration of new technological knowledge. Outsourcing higher shares of operations frees managerial resources from the tasks required to handle these value-chain activities and allows the firm to devote more managerial time and attention to more aggressive, long-term technological efforts while avoiding intra-firm resistance to the pursuit of exploratory R&D activities. Thus, I hypothesize the following:

Hypothesis 1a: There is a positive relationship between the R&D investments of a high-technology firm and its technological knowledge exploration.

Hypothesis 1b: The more a high-technology firm outsources operations, the stronger the positive relationship between R&D investments and technological knowledge exploration.

Focus and Learning from R&D Partners

High-technology firms also explore new technological knowledge by interacting with R&D partners (Kale & Singh, 2007; Rothaermel & Deeds, 2004). Specifically, when engaging in R&D collaborations, the firm cedes some control over its intellectual property while increasing the chances of creating new technological knowledge. Therefore, to the extent that a high-technology firm believes it can benefit from technological knowledge exchange, it will collaborate with R&D partners that are also potential competitors (Khanna, et al, 1998).

Exposure to external complementary technological knowledge of R&D partners is likely to lead to more diversity in the firm's knowledge base, and, as a result, to new technological knowledge creation (Ahuja, 2000; Lavie & Rosenkopf, 2006; Phelps, 2010; Sampson, 2007). When collaborating with R&D partners, high-technology firms can combine their existing technological knowledge with external technological knowledge to create new technological knowledge (Ahuja & Lampert, 2001; Cassiman & Veugelers, 2006; Leiblein & Madsen, 2009; Parmigiani, 2007; Parmigiani & Mitchell, 2010; Zhou & Li, 2012). A high-technology firm with enhanced technological expertise is likely to be better at managing its R&D collaborations (Parmigiani & Mitchell, 2009, 2010) as well as to possess sufficient absorptive capacity (Cohen & Levinthal, 1990) to allow this firm to learn effectively from its partners and, therefore, increase its ability to explore new technological knowledge.

However, learning from partners is likely to consume a significant amount of essential non-scale free resources to be successful, where firms must absorb external knowledge effectively and integrate this knowledge with their own. In this case, the outsourcing of operations once again plays an important role. I expect that the outsourcing of operations is not only likely to free critical scarce managerial resources for internal explorative R&D efforts, but to also allow a greater allocation of managerial resources and attention to building on partners' technological knowledge as means to explore new technological knowledge more effectively.

Outsourcing operations allows greater involvement of top managers in R&D collaborations, which is expected to increase the aggressiveness of the firm's efforts to win the learning race, and capture new forms of technological knowledge from partners. Outsourcing operations is further expected to reduce intra-firm resistance to the pursuit of novel technological knowledge due to the threats such knowledge may impose on the relevance of existing production, assembly, and logistics practices (Garmain, 1996).

I therefore expect that when a high-technology firm engages more extensively in R&D alliances it will exhibit greater technological knowledge exploration. I further expect that the outsourcing of operations will enhance the capability of a high-technology firm to capture external technological knowledge and combine it with its own technological knowledge, to create new technological knowledge. The next hypotheses are the following:

Hypothesis 2a: There is a positive relationship between the R&D alliance activity of a high-technology firm and technological knowledge exploration.

Hypothesis 2b: The more a high-technology firm outsources operations, the stronger the positive relationship between R&D alliance activity and technological knowledge exploration.

Focus and Learning from Customers

Customers can also provide knowledge that enhances the firm’s exploratory efforts to create new technological knowledge. Across multiple industries, end-user customers have been shown to play a dominant role in new technological knowledge creation (von Hippel, 1976; 1977; Franke & Shah, 2003; Chatterji, 2009). In the scientific instrument industry, customers established the prototype for new products; manufacturers merely refined and standardized them (von Hippel, 1976). In the sporting goods industry, novel product innovations were generated by end customers who received support from others within their interest community (Franke & Shah, 2003).

The knowledge-based view of the firm emphasizes the role of intra-firm direct interaction between individuals as a critical means for allowing efficient knowledge transfer and learning, especially when knowledge is tacit and complex (Kogut & Zander, 1993; Grant, 1996; Martin & Salomon, 2003). However, similar mechanisms are also at work when the firm interacts with its customers. By interacting directly with its customers, the firm gains a firsthand understanding of customer needs, and can absorb new ideas from its customers, sparking novel technological knowledge. In that way, the firm can transform customer-facing knowledge into new technological knowledge and integrate more effectively with its customers (Frohlich & Westbrook, 2001).

Extensive interactions with end-user customers are not only required to allow high-technology firms to more effectively transfer complex new technological knowledge to their customers (Almor, Hashai, & Hirsch, 2006; Adler & Hashai, 2007); the interactions also serve as a central means for receiving technological knowledge from customers. Such knowledge may result from more effective communication that allows the firm to update its understanding of customer needs and preferences; or it can be the outcome of observing customers' amateur innovations, and then internalizing and professionalizing these innovations (Frohlich & Westbrook, 2001; von Hippel, 1988; Riggs & von Hippel, 1996; Porter, 1998; Laursen & Salter, 2006).

Firm-level ability to create new technological knowledge by “learning from customers” is likely to be closely associated with the extent to which the firm integrates within their boundaries, marketing, sales, and customer support activities (hereinafter *customer-facing* *activities*). Once the firm has captured new technological knowledge from its customers, it can transfer that knowledge to the right places within the firm, where the knowledge can best be exploited to create value (Kogut & Zander, 1992; Grant, 1996). The integration of customer-facing activities exposes the firm to direct interaction with its customers. By maintaining customer-facing activities within firm boundaries, the firm facilitates the interfaces and transaction efficiency between these activities and its R&D activities (Baldwin, 2008) and becomes better at exploring new technological knowledge.

Importantly, outsourcing operations is expected to increase top managers' attention and efforts to take long-term commitments to absorb and implement new technological knowledge that has originated from customers. This enhanced attention and efforts are likely to result in more involvement of "innovation champion(s)" in finding, understanding, and applying customer-based innovations as well as in meeting specific customer needs with novel technologies (Chakrabarti, 1974; Ettlie, et al., 1984). At the same time, outsourcing operations may allow the firm to confront less intra-firm resistance for the adoption of new technological knowledge, from those who may be threatened that existing production, assembly, and logistics practices will become irrelevant and, in turn, displaced (Garmain, 1996). In turn, a firm that outsources its operations increases its managerial capacity to integrate more extensively with its customers, as means to speed up exploration and new product development initiatives (Frohlich & Westbrook, 2001).

I therefore expect that when a high-technology firm integrates more its customer-facing activities within its boundaries it will exhibit greater technological knowledge exploration, and that the outsourcing of operations will enhance the capability of a high-technology firm to explore new technological knowledge. This leads to the following hypotheses:

Hypothesis 3a: There is a positive relationship between the extent of in-house integration of customer-facing activities of a high-technology firm and technological knowledge exploration.

Hypothesis 3b: The more a high-technology firm outsources operations, the stronger the positive relationship between the extent of in-house integration of customer facing activities and technological knowledge exploration.

Figure 1 summarizes the above arguments and presents the association between outsourced operations, R&D investments, R&D collaboration, and the integration of customer-facing activities, and the exploration of new technological knowledge, as spelled out in the hypotheses.

[Insert Figure 1 about here]

DATA AND METHODS

The Sample

The hypotheses are tested on a sample of Israel-based, single-business high-technology firms. The dynamic and intensive technological investments of firms in the high-technology sector are likely to enhance the meaningfulness, reliability, and variance of the relationships I wish to test. Further, the identification of novel technological knowledge is a key determinant of competitive advantage for high-technology firms (e.g. Schumpeter, 1942; Abernathy & Utterback, 1978; Henderson, 1993). Israel is a suitable setting for the study of high-technology firms, since it ranks first in the world in per capita R&D investments, in venture capital investments and in per capita high-technology start-up formation (Bosma & Levie, 2009). Israel is renowned for its high-technology sector success (Senor & Singer, 2009).

Relevant data for the study was collected from multiple secondary and primary sources. Secondary data sources include the full list of Israel-based, high-technology firms constructed by Dolev and Abramovitz Ltd (D&A) for the year 2006. D&A is a private company that collects information on the Israeli high-technology sector. The data from the D&A dataset were extensively supplemented with data from the Israel Venture Capital (IVC) dataset, annual financial reports, prospectuses and other written reports supplied by firms. The D&A and the IVC datasets are both recognized as comprehensive sources on Israeli high-tech industries. Indeed, formal publications of the Israeli Central Bureau of Statistics concerning high-tech industries in Israel are based on the IVC dataset.

I also collected additional data from the LexisNexis Academic database and from the archives of leading Israeli financial newspapers, such as TheMarker and Globes, on technological partnerships in which the sampled firms participated, including licensing in, R&D joint ventures, and joint R&D projects (that are not equity based). In addition, I matched the firms to the most comprehensive available data source, namely the NBER U.S. Patent Citations Data File (Hall, Jaffe, & Trajtenberg, 2001). This file contains detailed information on over three million U.S. patents from 1963 to 1999, and all citations made to these patents from 1975 to 1999. Additionally, I pulled all patent grants from the U.S. Patent and Trademark Office database (U.S. Department of Commerce, 2009) to ensure accuracy as well as to complement patent data to 2006 (the last year of the panel data). I use this data to determine the number of patents granted to the sampled firms, the number and sources of patents cited in these patents (backward citations), and the number of citations those patents have received.

Additional data that was unavailable from secondary sources was collected through a personal survey based on structured questionnaires with the senior management of each surveyed firm. The 2006 D&A dataset includes 408 such firms that have reached the stage where they are selling their products or services, a necessary condition for testing the hypotheses relating to the outsourcing of operations that I study. I randomly selected 200 of the firms in the original dataset and asked their senior management to complete a personal survey.

Senior representatives of 165 firms agreed to participate in the survey involving interviews conducted by the author and three research assistants by means of a structured questionnaire. The research team interviewed two to three senior firm representatives whose replies were triangulated to ensure consistency.[1] Fifty-five percent of the interviewees were at the CEO level, twenty percent were at the chairman level and twenty-five percent were at the senior management level (mostly CTOs, CFOs, and VPs of business development). The average tenure of interviewees at their firms was five years and a month, only seven months less than the average age of the firms in the sample. Interviewees, therefore, had enough tenure at their firms to reflect effectively on the firm's history and to access supporting formal documentation.

In addition, the research team presented a calendar of major events in each firm's history (as obtained from secondary sources) to the interviewees to minimize the likelihood of information omission bias. Typical events included specific rounds of investments in the firm, introduction of the first prototype and subsequent product versions, appointment of key executives in the firm, entry to new foreign markets, alliance announcements and terminations, and so forth.

The questionnaires covered a wide range of data at an annual level, including outsourcing of R&D, operations (production, assembly, and logistics activities), customer-facing activities (marketing, sales, and customer-support), the distribution of R&D efforts into projects involving the exploration of new technological knowledge and projects involving enhancement of existing technological knowledge, sales, number of employees, and market size. These data items often originated in written annual financial reports and prospectuses and could be cross-checked for consistency. The personal survey, therefore, allowed the collection of primary data, on an annual level, on the sampled firms.

Out of the 165 firms, I screened out 18 firms whose interviewees supplied incomplete information. This resulted in a sample of 147 firms. Basic T-test comparisons between the 165 participating firms and the 35 non-participating firms, as well as between the 147 sample firms and the remaining 53 firms (out of the original 200 firms that were approached), showed no evidence of any non-response bias in terms of the averages of sales, number of employees, the age of the firm, firm valuation or industrial classification (at the six-digit North American Industrial Classification System (NAICS) level). Overall, this procedure resulted in an unbalanced panel data of 756 firm-year observations for the 147 analyzed firms within the period 2000-2006.[2] The sampled firms operated in the following high-technology industries: Printing machinery and equipment, semiconductor machinery, optical instruments and lenses, computer terminals, telephone apparatuses, radio and television broadcasting equipment, wireless communications equipment, semiconductor and related devices, electronic components, electromedical and electrotherapeutic apparatuses, surgical and medical instruments, software, custom computer programming, and computer systems design.

Measures

Dependent variable. I have implemented the procedure employed by Katila and Ahuja (2002) to proxy technological knowledge exploration to proxy the dependent variable of this study. More specifically, I use the number of patent citations found in a focal year's citations (including self-citations) that could not be found in the previous five years' list of patents and citations by the firm, as the proxy for the exploration of new technological knowledge (denoted as *new patent citations*). When this measure is high, the firm cites many patents it has not used in the last five years. This suggests that the firm is more actively involved in exploring new technological knowledge, so that it does not extend its previously accumulated knowledge base. This measure displays high levels of skewness and is, therefore, log-transformed. I have further lagged the dependent variable measures in one year to address causality concerns between the realization of a particular outsourcing, integration or collaboration strategy for a focal value-chain activity and the exploration of new technological knowledge. [3]

Independent variables. The first independent variable is the extent of outsourced operations in each year (denoted as *proportion of outsourced operations*). The measure is computed as the average proportion of outsourced production, assembly, and logistics activities (in monetary cost terms), in each year, out of overall production, assembly, and logistics costs, respectively (see Appendix 2 for more details).

Next, I measure each firm's R&D investments using the ratio of annual R&D expenditures to sales. I denote this measure *R&D intensity*. The number of R&D collaborations, such as technology licensing in, joint R&D projects, or R&D joint ventures in which each of the sampled firms participated in each year, is used as a proxy for the firms' engagement in technological partnerships with other firms that may also be potential competitors (denoted as *R&D collaboration*).

Finally, I measure the integration of marketing, sales, and customer support activities within firm boundaries, as the complement of the proportion of outsourced marketing, sales, and customer support activities. The measure (denoted as *proportion of integrated customer facing activities*) is computed as one minus the average proportion of marketing, sales and customer support income from outsourced activities in each year, out of overall marketing, sales and customer support income, respectively (see Appendix 2 for more details). It is noteworthy that, unlike R&D, outsourcing of operations and customer-facing activities do not refer to collaborations in which the focal firm is engaged, but rather to the execution of these activities completely outside the firm's boundaries.

Control variables. I control for an extensive number of variables that may affect the exploration of new technological knowledge. First, I control for overall technological efforts (i.e., the efforts to both expand existing technological knowledge and explore new technological knowledge). The extant literature has identified that existing stocks of technological knowledge influence the extent of a firm's ability to explore new technological knowledge (Dunlap-Hinkler, et al, 2010; Zhou & Li, 2012). I include the number of citations to the firm's patents in each year (denoted as *overall patent citations*) as a measure for the firm's overall (rather than "new") technological knowledge creation ability (Ahuja & Katila, 2001; Grilliches, 1990; Trajtenberg, 1990; Hall, et al., 2005). This measure displays high levels of skewness and is, therefore, log-transformed.

In addition, firm size has been shown to affect firms' ability to explore new technological knowledge (Leiblein & Madsen, 2009). Thus, I include firm size as a control variable. Firm size is operationalized as the natural logarithm of the number of employees (denoted as *Ln Employees*) to reduce skewness.

Another factor that may affect emphasis on exploration of new technological knowledge is the availability of financial resources, which reflects the firm's capability for investment in novel technological efforts. Generally speaking, greater access to discretionary financial and other resources facilitates investments in the exploration of new technological knowledge (Bourgeois, 1981; Chen & Miller, 2007). Therefore, I control for the level of invested funds (*investments*) in millions of U.S. dollars (US$) for each year. This measure captures the total investments (in $US millions) that were made in each firm by private investors, venture capital funds, corporate venture capital, partial acquisitions or through public offerings. Since the *investments* measure is heavily skewed, I use a logarithmic transformation of this measure.

International diversification is also expected to correlate positively with the exploration of new technological knowledge, since diversification promotes learning from diverse environments (Almeida, 1996; Autio, Sapienza, & Almeida, 2000; Doz, Santos, & Williamson, 2001; Ghoshal, 1987; Zahra, Ireland & Hitt, 2000). *International diversification* is operationalized as an entropy measure of a firm's sales across six global regions in a given year (Kim, Hwang, & Burgers, 1993; Hitt, Hoskisson, & Kim, 1997). This classification has the advantage of capturing diversity between regions in terms of geographic, institutional and cultural distance (Delios & Henisz, 2003; Ronen & Shenkar, 1985). A detailed description of all the measures and their sources appears in Appendix 1.

Statistical Method

To test my predictions regarding the relationships between operations outsourcing, R&D intensity, R&D collaboration, the integration of customer-facing activities and the exploration of new technological knowledge, I use Two Stage Least Squares (2SLS) firm fixed-effects regression models. The use of this specific research design stems from the assumption that managerial decisions regarding outsourcing or collaboration in specific value-chain activities and managerial decisions regarding exploration of new technological knowledge are determined endogenously. That is, firm-level unobserved characteristics may influence both the exploration of new technological knowledge and outsourcing and collaboration patterns. In addition, there may be reverse causality where the emphasis on exploring new technological knowledge may affect firm boundary and collaboration decisions. Therefore, in the two-step process, I first estimate the extent to which a firm outsources operations (production, assembly, and logistics), invests in R&D, collaborates in R&D and integrates customer-facing activities (marketing, sales, and customer support), and then use the estimated variables to test the hypothesized relationships.

2SLS regressions (Wooldridge, 2010) enable testing the relationships between endogenous variables in a two-stage process. In the first stage, each of the endogenous variables is estimated based on all other independent variables in the system plus an additional instrumental variable. This estimated variable is then used to predict the other endogenous variable. The 2SLS technique accounts for the correlation in the disturbance term across equations to produce more efficient estimates. A crucial condition for such estimation is the inclusion of instrumental variables (IVs) that are correlated with the second-stage dependent variable (technological knowledge exploration) only through their correlation with the first-stage dependent variables (in this case *proportion of outsourced operations*, *R&D intensity, R&D collaboration* and *proportion of integrated customer facing activities*).

I have used four IVs for *proportion of outsourced operations*, *R&D intensity, R&D collaboration* and *proportion of integrated customer-facing activities*. The IV for the *proportion of outsourced operations* is the *number of suppliers*, capturing the annual number of suppliers of the firm. This measure is expected to be positively correlated with the *proportion of outsourced operations.* There is no apparent reason to assume any systematic association between this IV and *technological knowledge exploration*, other than through its correlation with *proportion of outsourced operations*. This is because the number of suppliers is not likely to directly affect the firm's technological exploration, and, if at all, it is expected to increase the demands on managerial capacity and attention and not reduce them (as I claim is the case when operations are outsourced).

The IV used for *R&D intensity* is the *number of R&D employees.* This measure is expected to be positively correlated with the *R&D intensity,* but it is not likely to have a systematic association with *technological knowledge exploration*, other than through its effect on *R&D intensity*. This is because the *number of R&D employees* does not include additional important components of R&D investments such as capital expenditures, and because, unlike *R&D intensity*, it does not reflect the cost implications of hiring relatively more highly skilled engineers and scientists who are likely to affect technological knowledge exploration (Hess & Rothaermel, 2011).

The IV used for *R&D collaboration* is the existence of a designated function for alliances within the firm. *Alliance function* is a dummy variable indicating whether a firm had a designated function to manage its alliances in a given year or not. The existence of such a function is expected to affect firms' propensity to engage in R&D collaborations, but it is not likely to have a systematic association with the *technological knowledge exploration*, other than through its effect on *R&D collaboration*.

Finally, the IV used for *proportion of integrated customer-facing activities* is a variable that indicates whether a firm sells *customized* or standard products or services in a given year. The sale of customized products is measured by a dummy variable that uses the value "1" if the firm primarily provides a product that needs to be tailored to specific customer needs, and "0" if it provides a standard product to all customers with minimal modifications. When selling customized products, firms are expected to be less likely to outsource their marketing, sales, and customer support activities, because such products and services often require high degrees of firm-specific knowledge and, consequently, direct interaction with customers (Almor et al., 2006). On the other hand, given that customization is related to the features of *existing* products and technologies, I do not expect any special association between selling customized products and the exploration of new technological knowledge other than through the effect of *proportion of integrated customer-facing activities* on new technological knowledge exploration.

The measures *number of suppliers, number of R&D employees, alliance function* and *customized* show significant correlation with *proportion of outsourced operations*, *R&D intensity, R&D collaboration* and the *proportion of integrated customer- facing activities*, respectively, but not with the measure of *technological knowledge exploration* (see Table 1) and, therefore, are good candidates for serving as effective IVs.

In the first stage of the 2SLS models, I derive separate estimates for *proportion of outsourced operations*, *R&D intensity, R&D collaboration* and the *proportion of integrated customer-facing activities* as a function of all the IVs and the exogenous control variables. In the second stage, these estimations are used to estimate the relationships between these measures and the firm's extent of *technological knowledge exploration* (Wooldridge, 2010). In addition, applying the 2SLS procedure with firm-fixed effects allows testing of intra-firm variance in the exploration of new technological knowledge. Firm-fixed effects further enable controlling for the impact of unobserved time invariant firm-specific effects on the exploration of new technological knowledge.

EMPIRICAL ANALYSIS

Descriptive Statistics

Table 1 presents the summary statistics of the sample data. The descriptive statistics of the sample data are consistent with intuition as well as prior research. First, it is evident that the firms in the sample are fairly small and young, and have high R&D intensity and international presence measures. On average, the firms in the sample are about 5.8 years old, have 125 employees, and have an average sales turnover of about $US 28 million (not reported in Table 1). The average R&D intensity of the firms in the sample is 0.25. In addition, as expected, the firms' overall technological efforts are strongly and positively correlated with efforts directed toward the exploration of new technological knowledge, as indicated by the correlations between *overall patent citations*, *R&D intensity,* and *new patent citations*.

It is further evident that firm age is positively correlated with *overall patent citations*, but the correlation between firm age and *new patent citations* is negative. This suggests that mature firms are more likely to direct their R&D efforts toward the refinement of existing technological knowledge and engage more in technological exploitation relative to younger firms.

[Insert Table 1 about Here]

Primary Tests

Table 2 presents the first-stage 2SLS firm fixed effects estimations for the *proportion of outsourced operations, R&D intensity, R&D collaboration* and the *proportion of integrated* *customer facing activities*. All IVs are significant and with the expected signs and the F-values of excluded instruments is above the critical value of ten (Staiger & Stock, 1997) and correspond to a five percent level test that the maximal 2SLS bias of the IV estimators is no more than five percent (Stock & Yogo, 2005).[4] These tests corroborate the strength of the chosen IVs and the robustness of the first-stage regressions.

[Insert Table 2 about Here]

Table 3 presents the second-stage 2SLS firm fixed-effect regressions. The table includes seven models as follows: Model 1 includes only the control measures; model 2 adds the first-stage estimation of *proportion of outsourced operations* and *R&D intensity*; model 3 adds the first stage estimation of *R&D collaboration*, and model 4 adds the first-stage estimation of the *proportion of integrated customer-facing activities.* Model 5 adds the interaction effect of *proportion of outsourced operations* and *R&D intensity*; model 6 adds the interaction effect of *proportion of outsourced operations* and *R&D collaboration,* and model 7 adds the interaction effect of *outsourced operations* and *proportion of integrated customer-facing activities*.

Models 2 through 4 show a significant positive relationship between *R&D intensity* and *new patent citations* (the measure for exploration of new technological knowledge), thus supporting the expectation of hypothesis 1a that higher R&D investments are associated with higher technological knowledge exploration. Models 3 and 4 show a significant positive relationship between *R&D collaboration* and *new patent citations,* thus lending support to the expectation that learning from partners corroborates new knowledge creation and showing support of hypothesis 2a. Model 4 shows a significant positive relationship between the *proportion of integrated customer-facing activities* and *new patent citations*, suggesting that when a high-technology firm integrates its customer-facing value-chain activities, its propensity to explore new technological knowledge increases, as suggested in hypothesis 3a.

Given this support to the baseline hypotheses I next turn to test the interaction hypotheses. Model 5 indicates that the interaction between *proportion of outsourced operations* and *R&D intensity* has a significant positive effect on the dependent variable. This result supports hypothesis 1b, where it shows that, other things being equal, when a high-technology firm outsources more of its operations the association between R&D investments and technological knowledge exploration intensifies. Model 6 reveals that the interaction between *proportion of outsourced operations* and *R&D collaboration* has a significant positive effect on *new patent citations*. This result supports hypothesis 2b, indicating that when a high-technology firm outsources more of its operations it becomes better able to use its technological collaborations for technological knowledge exploration. Finally, model 7 shows that the interaction between *proportion of outsourced operations* and *proportion of integrated customer-facing activities* has a significant positive effect on *new patent citations*. This result supports hypothesis 3b, indicating that when a high-technology firm outsources more of its operations it becomes better able to use its integrated marketing, sales, and customer-support activities to explore new technological knowledge.

As for the control measures, the measure *overall patent citations* is positively correlated with *technological knowledge exploration*. This indicates that greater overall technological efforts are likely to result with relatively more novel technological knowledge. Likewise, *international diversification* is positively correlated with the dependent variable. Finally, the measure *investments* is also shown to have a significant and positive relationship with *technological knowledge exploration*.

[Insert Table 3 about here]

Overall, all the second-stage regressions are significant at the $p<0.1\%$ significance level and Wald tests show that the increase in explained variance in model 5 relative to model 2, in model 6 relative to model 3 and in model 7 relative to model 4 are all significant ($p>F=0.01$), thus further corroborating the support of the role of focusing the high-technology firm, through the outscoring of its operations, in affecting technological knowledge exploration. Finally, to further test the validity of the IVs I conducted a Hansen/Sargan (Sargan, 1988) test for over-identification and verified that the instrumental variables used are indeed valid and that the models are not over-identified. In addition, the Kleibergen and Paap (2006) test of under-identification is rejected ($p<0.05$) and the null hypothesis of no serial autocorrelation of the residuals is retained.

Robustness Tests

I conducted several robustness tests to validate the findings. First, since ten of the sample firms have no patents at all, I have used the extent as well as the share of investments in new R&D projects (in $US millions), that is R&D projects that engage in the exploration of new technological knowledge (rather than the exploitation of existing technological knowledge), as an additional proxy for technological knowledge exploration. The results for the two measures remain fully consistent with the results reported for the primary measure of technological knowledge exploration.

Second, to confirm that the effects I find indeed reflect within-firm effects and not between-firm ones, I ran Allison's hybrid regression (Allison, 2009). The advantage of using these regressions is that unlike fixed effect models they also report random effect models (Certo & Semadeni, 2006). The hybrid regressions have resulted with coefficients very similar to those of the 2SLS fixed effects models, and with similar levels of precision (variance). On the other hand, Wald tests of the within/between coefficients reveal that in the vast majority of the cases the null hypothesis that the two types of coefficients are equal is rejected. Taken together, the results of the hybrid regression models suggest that the relationships found in this study reflect within-firm variance in technological knowledge exploration, rather than between firm-variance. It follows that, among other things, the extent of a firm's engagement in outsources may increase or decrease the firm's exploration of new technological knowledge.

I have also measured technological knowledge exploration by including the past six (rather than five) years of patents, and have also excluded self-citations from this measure to account for any differences between external and internal citations. Results have remained consistent with the original results also under these specifications.

I have further used the separate measures I have for the proportion of outsourced production, the proportion of outsourced assembly and the proportion of outsourced logistics instead of the average *proportion of outsourced operations* measure. Results do not change under these specifications. Results also remain robust when replacing the *proportion of integrated customer-facing activities* measures, with separate measures for the proportion of integrated marketing, the proportion of integrated sales and the proportion of integrated customer support. These robustness tests refute the suspicion of possible biases stemming from differences in the magnitudes of cost (revenue) between specific value chain activities.

In addition, I tested for the possibility that the respective impact of *proportion of outsourced operations*, *R&D intensity, R&D collaboration* and *proportion of integrated customer-facing activities* may have a curvilinear effect on the exploration of new technological knowledge. In other words, too much outsourcing of operations may limit the exploration of new technological knowledge through focus, too excessive R&D investments may lead to lesser technological exploration, too many technological collaborations may become excessive at some point and limit the extent of new technological knowledge exploration (Laursen & Salter, 2006), and too much integration of customer-facing activities may tax the firm's resources with no substantial technological exploration benefits. To that end, I added to the models in Table 3 estimates of the squared values of *proportion of outsourced operations*, *R&D intensity, R&D collaboration* and *proportion of integrated* *customer-facing activities*, by using the squares of the IVs. In all cases the quadratic measures came out insignificant, indicating that, at least within the ranges of these measures in the current sample, there are no diminishing effects for the association between the independent variables and the exploration of new technological knowledge.

I further tested the relationship between the number of collaborations the firm engages in either in its operations or customer-facing activities and the exploration of new technological knowledge. This test is important, because the hypotheses assume away collaboration agreements in operations and customer-facing activities and focus on analyzing whether these activities are conducted in-house or outsourced. In both cases, the coefficients of the number of operations-related collaborations and customer-facing-related collaborations came out insignificant, thus corroborating the idea that, where the emphasis given to technological knowledge exploration is concerned, different mechanisms come to the forefront for R&D activities and for operations and customer-facing activities.

Another robustness test included the addition of a dummy variable indicating whether serving business customers (B2B) or end consumers (B2C) affect the results. This distinction may be important for two reasons: first, serving individual consumers is more demanding than serving business customers as firms typically need to interact with a larger number of more dispersed customers. Therefore, firm boundary decisions concerning customer-facing activities may be affected by the customers served. Second, the learning mechanisms between a firm and business customers versus individual consumers are likely to be quite different. The addition of this dummy variable did not change the results; however, it is noteworthy that the majority of firms in the sample (76%) serve predominantly business customers rather than end individual consumers. I also controlled for the market size that each firm serves, since outsourcing decisions may be affected by the size of the market served. Market size did not have a significant effect on either the first- or second-stage regressions. In addition, when using the number of each firm's patents as an alternative measure for the overall technological output of the firm, the results were also not affected.

Another important consideration in testing the model is the fact that my predictions might suffer from selection bias if the same factors that influence technological knowledge exploration also cause firms to fail or drop out of the sample. Overall, I had 19 drop-out cases from the sample, including 13 firms that went out of business and six that were acquired by other firms. To account for the possibility of survivor bias among the sampled firms, I followed the technique described by Barnett (1994) and Henderson (1999), which entails the following calculation: $m= [d(\Phi^{-1}[F(t)]]/[1- F(t)]$, where d is the standard normal density function, Φ^{-1} is the functional inverse of the standard normal distribution, and $F(t)$ is the cumulative hazard function, derived from failure-rate models. These failure-rate models use the discrete-time event history analysis technique to predict failure based on the following variables: firm age, firm age squared, firm sales, and industry. In this case, once m is calculated, it is included as a control in second-stage regression analyses, employing the Heckman (1979) correction. The results, while correcting for survivor bias, did not change, indicating that the original models are robust.

DISCUSSION AND CONCLUSION

In recent years, more firms are "fine slicing" their value chain, outsourcing some value-chain activities while collaborating with others to increase their efficiency (Contractor, et al., 2010; Mudambi, 2008). The current study contributes to the emerging literature on value chain disaggregation by analyzing the impact of operations outsourcing on the emphasis that high-technology firms give to the exploration of new technological knowledge. In the current paper, I argue that a key driver of the fine slicing high-technology firms conduct is related to capability development, and more specifically, to technological knowledge exploration.

Main Theoretical Contribution

From a transaction cost-centered perspective, previous literature was mostly concerned with the specific costs of conducting a given value-chain activity within or outside firm boundaries (Barthelemy, 2003). For instance, Rawley and Simcoe (2010) demonstrate how outsourcing helps to manage diseconomies of scope at a particular point in the value chain. This approach implicitly treats value-chain activities as isolated. In practice, both the management and economics literatures (Ennen & Richter, 2010; Milgrom & Roberts, 1990; Parmigiani & Mitchell, 2009) have highlighted the importance of "complementarity" in organizational activities. In the context of the current study, this view suggests that value-chain activities are interlinked (Porter, 1985; Penrose, 1959; Porter & Siggelkow, 2008; Teece, 1986), and this activity linkage needs to be taken into account.

The current study contributes to the literature concerning intra-firm activity linkage by explicitly relating to the implications of the outsourcing of operations, such as production, assembly, and logistics activities, on the capability of high-technology firms to explore new technological knowledge. In essence, this paper supports the view that operations outsourcing affects the R&D capabilities and R&D performance of the high-technology firm. More specifically, this study shows that operations outsourcing is positively moderating the capability of a high-technology firm to explore new technological knowledge through internal R&D efforts, R&D collaborations and the integration of their customer-facing activities. In that respect, this study introduces an additional motivation for the revealed preference of many high-technology firms to outsource their operations while keeping R&D and customer facing activities in-house (Hashai & Almor, 2008; Mudambi, 2008).

I argue that the exploration of new technological knowledge is closely associated with the ability of a high-technology firm to focus (by outsourcing its operations) as a means to effectively leverage several sources of knowledge within the firm. I provide three pieces of evidence that are consistent with this view. First, focus intensifies the association between internal R&D efforts and the exploration of new technological knowledge. I propose that this effect results from freeing managerial resources from the tasks required to handle production, assembly, and logistics activities. The ability to devote more managerial time and attention to R&D activities, arguably, enhances the viability of more aggressive, long-term technological efforts while at the same time preventing intra-firm resistance to the adoption of novel technological knowledge (Chakrabarti, 1974; Ettlie, et al., 1984; Hage, 1980; Germain, 1996).

Second, the outsourcing of operations is shown to intensify the positive association between R&D collaboration and technological knowledge exploration. My main contention here is that freeing managerial resources from production, assembly, and logistics and focusing managerial efforts on technological collaboration makes a high-technology firm more capable of integrating its own technological knowledge with that of its R&D collaborators (Cassiman & Veugelers, 2006; Leiblein & Madsen, 2009; Parmigiani, 2007; Parmigiani & Mitchell, 2009, 2010). Freeing these resources, arguably, allows the high-technology firm to make more aggressive, long-term efforts to win learning races and avoid intra-firm resistance to the adoption of novel technological knowledge, and thereby increases the propensity to explore this knowledge.

Third, I argue that greater "learning from customers," by in-house integration of customer-facing activities, enables a high-technology firm to improve its interface with customers and become better capable of sparking new technologies and capturing novel technological knowledge from its customers. With respect to the integration of customer-facing activities, an important contribution of this study is that the mechanisms promoting knowledge exchange and recombination within the firm (Kogut & Zander, 1992) are also likely to emerge when direct interaction is facilitated between the high-technology firm and its customers. Once again, the outsourcing of operations arguably allows the high-technology firm to make greater efforts to learn from customers and to integrate more extensively with its customers (Frohlich & Westbrook, 2001) while avoiding intra-firm resistance to the adoption of novel technological knowledge, and thereby allows greater exploration of new technological knowledge.

The above arguments are consistent with supply-chain literature advocating the benefits of aligning the firm's operations with those of suppliers and customers with performance in general and new product initiatives in particular (Frohlich & Westbrook, 2001). In addition, these arguments complement the view of Parmigiani and Mitchell (2009) who argue that concurrent production and outsourcing expose firms to different knowledge sources. Such exposure, in turn, allows firms to better understand the technological relationships between complementary components and thereby augment their knowledge base. Consistently with these views, I show that the capability to explore new technological knowledge is closely associated with increasing the high-technology firm's focus on different learning channels. Combining R&D investments, R&D collaborations and customer interaction allows high-technology firms to explore new forms of technological knowledge that collectively build on internal R&D knowledge, new technological knowledge gained from R&D alliance partners and customer-based technological knowledge.

Implications for Practitioners

The combination of the theoretical predictions and results indicate that the outsourcing of operations is not only associated with operations "performance," but is also associated with the "performance" of R&D activities. These insights may prove instrumental to managers seeking to enhance their high-technology firms' focus on new technological knowledge exploration. Given the importance of the possession of new technological knowledge in creating and sustaining competitive advantage for high-technology firms (D'Aveni, 1994) the findings indicate that operations outsourcing may facilitate this goal.

Indeed it is important for a high-technology firm to engage in production to better understand the underlying nature of technology (Parmigiani & Mitchell, 2009) yet, the ability to focus the high-technology firm (by outsourcing some of its operations) frees managerial resources and reduces intra-firm resistance to the adoption of novel technological knowledge. This, in turn, allows the high-technology firm to leverage the combination of different learning channels, including internal R&D, R&D collaboration and customer interaction, to enhance its technological knowledge exploration. It is therefore important for managers to realize that outsourcing decisions should not only be driven by cost-efficiency considerations within a particular value-chain activity, but also have a wider effect that allows for capability development and performance enhancement in other value-chain activities.

Limitations and Future Research Avenues

The analysis has a number of limitations, some of which may lead to opportunities for future research. First, all firms in the dataset originate in a single country. Therefore, country-specific characteristics such as geographic and cultural attributes may affect the results. While I have controlled for the geographic diversification of the firms in the sample, the results may still be influenced by the origin of the firms in the sample.

In addition, the sectorial distribution of Israeli high-technology industries is biased toward areas such as capital equipment, medical devices, telecommunications and software. These sectors do not necessarily represent the same conditions found in low-technology sectors or in other high-technology sectors, where additional factors may influence both firm boundary decisions and technological knowledge exploration outcomes. For example, as noted above, the fact that most firms in the sample serve business customers rather than end consumers may affect the results. It may be easier (or harder) for firms to explore new technological knowledge from business customers than from end-user consumers.

Moreover, the fact that the sample consists of fairly young and relatively small high-technology firms implies that firm boundaries and the emphasis given to new technological knowledge exploration by these firms might differ from boundaries and emphasis in larger and more established firms. More mature firms, for instance, may be more capable than young firms of building on past experiences in interacting with customers or with R&D collaborators to explore new technological knowledge. Furthermore, while this study focuses on single business firms, in multi-business, multi divisional (M-form) structured firms, the divisional divide may lead to different outcomes in terms of the association between firm boundary choices and technological knowledge exploration. Thus, future analyses of larger, more diversified and more mature firms originating in multiple countries and industries are needed to enhance the external validity of this study's results.

Finally, this study has focused on a specific strategic endeavor – the exploration of new technological knowledge. Building on the core argument that focusing the firm by outsourcing specific value-chain activities is associated with the firm’s capabilities in other value-chain activities, promising research avenues may lie in investigating the association between additional strategic endeavors that may be associated with outsourcing patterns along the value chain. For instance, little can be said regarding the association between focusing the firm and technological knowledge exploitation, or the association between focusing and non-technological explorative efforts (e.g. novel production methods or business models). Future investigation of these associations as well as expanding the scope of firms analyzed to include also low-technology firms may enrich our understanding regarding the association between focusing firms and strategic endeavors.

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FOOTNOTES

1. In cases where answers to specific questions were different (less than 10% of the cases), the research team has returned to the interviewees and asked them to supply an agreed upon reply to the question.
2. The panel data is unbalanced because some of the firms in the sample were established after the year 2000, whereas other firms ceased to operate (either died or were acquired by other firms) before the year 2006.
3. The Akaike Information Criterion (AIC) indicates that a one-year level yields the optimal lag structure in terms of model quality, i.e. it minimizes information loss.
4. When using four instrumental variables the Stock and Yogo (2005) critical values are only available for up to two endogenous repressors. I have therefore repeated the tests for all possible pairs of endogenous repressors.

TABLE 1

DESCRIPTIVE STATISTICS AND PEARSON CORRELATIONS (N=756)

Variable	Mean (Std. Deviation)	Range	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
1. New patent citations	1.67 (5.69)	0-19	1												
2. R&D collaboration	2.65 (2.13)	0-10	0.16*	1											
3. Proportion of outsourced operations	0.38 (0.24)	0-100	0.10*	0.03	1										
4. Proportion of integrated customer facing activities	0.56 (0.31)	0-100	0.19**	0.05	0.05	1									
5. R&D intensity	0.25 (0.17)	0.11-1.20	0.24**	0.09*	0.04	0.10*	1								
6. Overall patent citations	3.21 (10.79)	3-36	0.25**	0.09*	0.02	0.07	0.23**	1							
7. Investments ($US Millions)	8.47 (16.30)	0-62	0.13*	0.08*	0.02	0.02	0.15**	0.02	1						
8. Employees	125 (201)	8-730	0.14*	0.05	-0.01	-0.01	0.22**	0.09*	0.12*	1					
9. International diversification	0.85 (0.30)	0-1.75	0.10*	0.09*	0.04	0.11*	0.12*	0.14*	0.09*	0.11*	1				
10. Firm Age	5.71 (5.04)	1-20	-0.10*	0.06	0.04	0.11*	0.16**	0.13*	0.10*	0.13*	0.07	1			
11. Number of suppliers	5.39 (8.66)	0-25	0.03	0.02	0.15**	0.06	0.03	0.05	0.08	0.12*	0.13*	0.17**	1		
12. Number of R&D employees	38.49 (55.06)	0-212	0.07	-0.08	0.04	0.03	0.16**	0.12*	0.09*	0.15**	0.04	0.14*	0.05	1	
13. Alliance function	0.16	0-1	0.05	0.14*	0.10*	0.05	0.09*	0.10*	0.01	0.12*	0.09*	0.04	0.07	0.06	1
13. Customized	0.18	0-1	0.05	-0.07	-0.09*	0.18**	0.01	-0.02	0.03	0.04	0.03	0.01	-0.08	0.02	0.01

*Notes: *** p < .001 ** p < .01 * p < .05*

TABLE 2

FIRST STAGE 2SLS FIRM FIXED-EFFECTS REGRESSION MODELS (N=756)

Dependent Variable:	(1) Proportion of outsourced operations	(2) R&D intensity	(3) R&D collaboration	(4) Proportion of integrated customer facing activities
Number of suppliers	.17*	.08	.05	.03
	(.07)	(.06)	(.04)	(.04)
Number of R&D employees	.06	.21**	-.10*	.012
	(.05)	(.07)	(.05)	(.09)
Alliance function	.13**	.03	.13**	-.07
	(.05)	(.02)	(.04)	(.11)
Customized	-.06**	.04	.03	.17**
	(.02)	(.07)	(.02)	(.06)
Overall patent citations	.13	.18**	.22*	.05
	(.17)	(.06)	(.19)	(.06)
Investments	-.16**	.25**	.03	.11**
	(.06)	(.08)	(.15)	(.04)
Ln_Employees	-.20*	.18*	.23	.17***
	(.09)	(.08)	(.18)	(.05)
International diversification	.21*	.04	.33**	.16**
	(.10)	(.03)	(.12)	(.06)
F-statistic	15.78***	16.12	15.53***	15.93***
Adjusted R^2	.15	.17	.15	.16

Unstandardized coefficients with robust standard errors in brackets (two tailed tests). Intercept is not shown.
*** p < .001, ** p < .01, * p < .05

TABLE 3

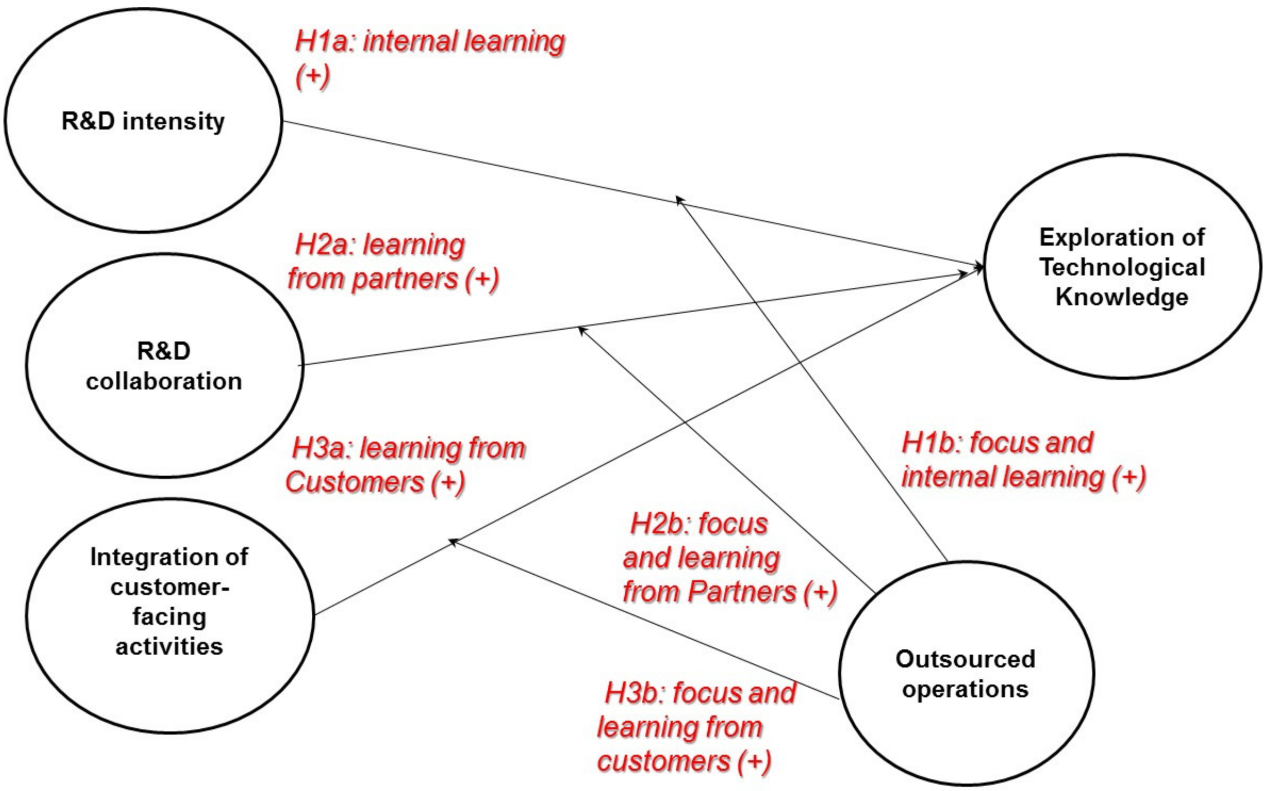
SECOND STAGE 2SLS FIRM FIXED-EFFECTS REGRESSION MODELS FOR NEW PATENT CITATIONS (N=756)

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**
R&D Intensity	0.22*	0.20*	0.22*	0.23*	0.24*	0.23*	0.21*
	(0.10)	(0.10)	(0.11)	(0.11)	(0.12)	(0.11)	(0.09)
Overall patent citations	0.22*	0.25*	0.26*	0.27*	0.26*	0.23*	0.25*
	(0.10)	(0.12)	(0.12)	(0.13)	(0.13)	(0.10)	(0.11)
Investments	0.35*	0.32*	0.34*	0.34*	0.34*	0.37*	0.41*
	(0.15)	(0.14)	(0.15)	(0.15)	(0.14)	(0.16)	(0.18)
Ln_Employees	0.16	0.23	0.21	0.21	0.23	0.19	0.16
	(0.12)	(0.19)	(0.16)	(0.17)	(0.18)	(0.13)	(0.10)
International diversification	0.74**	0.75**	0.77**	0.80**	0.78**	0.81**	0.74**
	(0.29)	(0.32)	(0.29)	(0.30)	(0.29)	(0.25)	(0.24)
Proportion of outsourced operations		0.33* (0.15)	0.34* (0.17)	0.36* (0.16)	0.37* (0.17)	0.36* (0.15)	0.37* (0.17)
R&D Intensity		0.23*	0.25*	0.25*	0.23*	0.24*	0.22*
		(0.12)	(0.12)	(0.12)	(0.11)	(0.11)	(0.10)
R&D collaboration			0.30*	0.31*	0.30*	0.32*	0.30*
			(0.14)	(0.14)	(0.15)	(0.15)	(0.14)
Proportion of integrated customer facing activities				0.32* (0.15)	0.33* (0.14)	0.35* (0.15)	0.34* (0.14)
Proportion of outsourced operations X R&D intensity					0.16* (0.07)	0.15* (0.07)	0.16* (0.07)
Proportion of outsourced operations X R&D collaboration						0.28* (0.13)	0.25* (0.12)
Proportion of outsourced operations X Proportion of integrated customer facing activities							0.10* (0.04)
Centered R^2	0.19	0.20	0.21	0.22	0.24	0.25	0.27
F-statistic- second stage regression	14.42***	17.57***	18.76***	21.61***	22.29***	23.72***	25.81***

Unstandardized coefficients with robust standard errors in brackets (two tailed tests). Intercept is not shown.
*** $p < .001$, ** $p < .01$, * $p < .05$

FIGURE 1

THE EFFECT OF OUTSOURCING OPERATIONS ON THE EXPLORATION OF TECHNOLOGICAL KNOWLEDGE



APPENDIX 1

DESCRIPTION OF VARIABLES AND MEASURES

Variable name	Variable description	Measure	Notes
Dependent variable			
New patent citations	Ln of the number of citations found in a focal year's citations that could not be found in the previous five years' list of patents and citations by the firm	Number	NBER U.S. Patent Citations Data File complemented by USPTO website. The measure is lagged in one year.
Independent variables			
Proportion of outsourced operations	The average proportion of production, assembly and logistics activities conducted outside the firm boundaries (in monetary cost terms) in each year	Number	Based on survey answers, cross checked with data from financial reports, LexisNexis Academic and Israeli financial newspapers archives. See Appendix 2 for more details.
R&D intensity	The ratio of R&D expenditures to sales in each year	Number	Based on firms' financial reports
R&D collaboration	The number of technological partnerships the firm is engaged in each year, including: licensing in, joint R&D projects and R&D joint ventures	Number	Based on survey answers, cross checked with alliance announcement and termination data from LexisNexis Academic and Israeli financial newspapers archives (Globes and The Marker).
Proportion of integrated customer facing activities	The average proportion of marketing, sales, and customer support activities conducted within the firm boundaries (in monetary revenue terms) in each year	Number	Based on survey answers, cross checked with data from financial reports, LexisNexis Academic and Israeli financial newspapers archives. See Appendix 2 for more details.
Control variables			
Overall patent citations	Ln of the number of citations to the firm's patents up to the end of each year	Number	NBER U.S. Patent Citations Data File complemented by USPTO website
Investments	The total amount of investments (Millions of $US) in the firm up to the end of each year	Number	Based on Dolev and Abramovitz and IVC datasets
Ln_Employees	Ln of firm employees at the each year	Number	Based on firms' financial reports, Dolev and Abramovitz and IVC datasets
International diversification	Entropy measure of annual sales dispersion across different regions. The entropy measure is defined as: $\Sigma[P_j*\ln(1/P_j)]$ where in each year t P_j is the proportion of sales attributed to region j (out of total sales) and $\ln(1/P_j)$ is the weight given to each region.	Number	Based on firms' financial reports, Dolev and Abramovitz and IVC datasets
Firm age	Firm age in 2006	Number	Based on firms' financial reports, Dolev and Abramovitz and IVC datasets

Instrumental variables			
Number of suppliers	The number of suppliers in a given year	Number	Based on survey answers crosschecked with financial reports and other written material
Number of R&D employees	The number of employees engaged in R&D in a given year	Number	Based on survey answers crosschecked with financial reports and other written material
Alliance function	A dummy variable indicating whether a firm has a dedicated alliance portfolio management function or not in a given year.	Dummy	Based on survey answers.
Customized	A dummy variable taking the value "1" if the firm primarily manufactures products that need to be customized to specific customer needs and "0" if standard products are primarily produced in a given year	Dummy	Based on survey answers crosschecked with financial reports and other written material

APPENDIX 2

CALCULATION OF PROPORTIONS MEASURES

The interviewees were requested to supply information concerning the proportion of outsourcing measures.

For the calculation of the *proportion of outsourced operations* measure, a typical question resembled the following example:

Please evaluate the **proportion of production outsourcing (in cost terms)** for each year:

	Proportion (0-100%)
2000	
2001	
2002	
2003	
2004	
2005	
2006	

Identical questions have also appeared for assembly and logistics. The measure itself was calculated as the average of the annual values supplied for production, assembly and logistics.

For the calculation of the *proportion of integrated customer-facing activities* measure, a typical question resembled the following example:

Please evaluate the **proportion of sales outsourcing (in revenue terms)** for each year:

	Proportion (0-100%)
2000	
2001	
2002	
2003	
2004	
2005	
2006	

Identical questions have also appeared for marketing and customer support. After averaging the annual values supplied for sales, marketing and customer support, the measure itself was calculated as one minus the average obtained.