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Technological activities and their impact on the financial performance of the firm: Exploitation and exploration within and between firms

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Technological activities and their impact on the financial performance of the firm: Exploitation and exploration within and between firms

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EXTENDED ABSTRACT

This paper analyzes the consequences for financial performance of technology strategies categorized along two dimensions: (1) explorative versus exploitative and (2) solitary versus collaborative. The financial performance implications of firms' positioning along these two dimensions has important managerial implications, but has received only limited attention in prior studies. Drawing on organizational learning theory and technology alliances literature, a set of hypotheses on the performance implications of firms' technology strategies are derived. These hypotheses are tested empirically on a panel dataset (1996-2003) of 168 R&D-intensive firms based in Japan, the US and Europe and situated in five different industries (chemicals, pharmaceuticals, ICT, electronics, non-electrical machinery). Patent data are used to construct indicators of explorative versus exploitative technological activities (activities in new or existing technology domains) and collaborative versus solitary technological activities (joint versus single patent ownership). The financial performance of firms is measured via a market value indicator: Tobin's Q index.

The analyses confirm the existence of an inverted U-shape relationship between the share of explorative technological activities and financial performance. In addition, it is observed that most sample firms do not reach the optimal level of explorative technological activities. These findings point to the relevance of creating a balance between exploitation and exploration in the context of technological activities. Moreover, they suggest that, for the majority of R&D intensive firms, reaching such a balance between exploration and exploitation implies investing additional efforts and resources in exploring new knowledge domains. The analyses also show that firms, engaging more intensively in collaboration, perform relatively stronger in explorative activities. At the same time, a negative relationship between the share of collaborative technological activities and a firm's market value is observed. Contrary to our expectations, it is collaboration in explorative technological activities, rather than collaboration in exploitative technological activities, that leads to a reduction in firm value. These findings question the relevance of open business models for technological activities. In particular, they suggest that the potential advantages of collaboration for (explorative) technological activities (i.e. access to complementary knowledge from other partners, sharing of technological costs and risks) might not compensate for the potential disadvantages, such as the incurred increase in coordination costs and the need to share innovation rewards across innovation partners.

INTRODUCTION

March (1991) made an explicit distinction between exploration and exploitation. Exploitation refers to the leveraging of existing capabilities by means of activities such as standardization, upscaling and refinement. Exploration refers to the creation of new capabilities by means of activities such as fundamental research, experimentation, and search. This exploration/exploitation dichotomy has been used in a wide range of research domains. The central tenet of this literature is that firms benefit from a balanced mix of exploration and exploitation activities, and that firms, that are able to combine both activities effectively, improve their survival chances and performance (O'Reilly and Tushman, 2004; Raisch et al., 2009). Although several studies have examined the impact of ambidexterity on innovation outcomes, remarkably few studies[i] have examined the ultimate effect on firms' financial performance.

At the same time, firms balance internal technological activities and externally oriented technological activities through external sourcing and collaboration with external partners (Chesbrough, 2003; Cassiman and Veugelers, 2006). Hence, firms can position themselves differently in terms of (i) the degree of exploration and (ii) the extent of external partner involvement (Rothaermel & Alexandre, 2009; Rosenkopf and Nerkar, 2001). The financial performance consequences of such positioning decisions is an important managerial issue, but has not been the subject of prior analysis.[ii]

In this article, the impact of collaborative versus solitary technological activities and exploitative versus explorative technological activities on the market value of firms is examined. Specifically, the focus is on technological activities as reflected in patent applications. Technological activities lie at the core of wealth creation in high-technology industries and have been shown to contribute substantially to the financial performance of firms (e.g. Ernst, 2001; Narin et al., 1987, Scherer, 1965; Hall et al, 2005). Explorative technological activities are defined as the development of ideas situated in technological domains where the firm has not patented in the past five years. In contrast, exploitative technological activities are acts of creation in technological domains where the firm has patented technology in the previous five years. Collaborative technological activities are reflected by the presence of patents assigned simultaneously to the focal firm and an external partner organization.

Organisational learning theory and the literature on technology alliances is used as theoretical background to derive the main hypotheses of the article. Specifically, the focus is on the potential differentiated impact of the intensity of collaboration in explorative and exploitative technological activities. The broad literature on strategic technology alliances indicates that collaborative R&D can facilitate access to technologies developed by partners and that sharing of resources and capabilities may open up new technological trajectories (e.g. Doz & Hamel, 1997; Hagedoorn, 1993; Teece, 1986). Hence, R&D collaboration can be seen as particularly useful for technology exploration and entry into new technologies. Collaborations drawing strongly on the existing technology bases and the core capabilities of firms may, on the other hand, carry the risk of dissipation of essential knowledge and hence appear subject to more critical governance issues.

Hypotheses are tested on a panel dataset (1996-2003) of 168 US, European and Japanese R&D-intensive firms active in the chemical, pharmaceutical, non-electrical machinery, electronics, and IT industries. In line with recent research by Uotila et al. (2009), the analyses confirm the existence of an inverted U-shape relationship between the share of explorative technological activities and firms' market value. At the same time, a negative relationship between the share of collaborative technological activities and the market value of firms is observed. This result suggests that value appropriation complexities introduced when engaging in collaborative technological activities may exceed their value-enhancing potential. Finally, whereas firms that are more intensively engaged in collaboration display higher levels of exploration technological activities, the share of collaboration in explorative technological activities has the strongest negative impact on the market value of firms.

This article is structured in four sections. First, a distinction is made between different kinds of technological activities relying on the existing organizational learning and technology alliances literature; and hypotheses are formulated regarding the financial performance implications of these activities. Subsequently, the methodology of the article is discussed, followed by an overview of the main results. Finally, the theoretical and managerial implications of the article are discussed, limitations are mentioned and suggestions for future research are made.

THEORETICAL BACKGROUND

A Typology of Invention Activities

This article focuses on technological activities and their impact on the financial performance of firms. Organizational learning scholars (March, 1991; Levinthal & March, 1993) have made an explicit distinction between exploration and exploitation. Exploitation refers to the leveraging of existing capabilities by means of activities such as standardization, scaling and refinement. Exploration refers to the creation of new capabilities by engaging in fundamental research, experimentation, and search. This exploration/exploitation dichotomy has been used in a variety of research domains including strategic management (e.g. He and Wong, 2004; Uotila et al., 2009); innovation management (e.g. Benner & Tushman, 2002; Jansen, Van den Bosch & Volberda, 2006), alliances (e.g. Faems, Van Looy & Debackere, 2005; Koza & Lewin, 1998; Rothaermel & Deeds, 2004), technology sourcing (e.g. Schildt, Maula & Keil, 2005; Rothaermel & Alexandre, 2009) and organizational design (e,g, Andriopoulos & Lewis, 2009; O'Reilly & Tushman, 2004; Lubatkin, et al., 2006). In this article, a distinction is made between explorative and exploitative technological activities. Explorative activities are defined as the development of ideas that are situated in technological domains where the firm has not patented technology during the past five years. In contrast, exploitative technological activities are defined as acts of creation in technological domains where the firm has patented technology in the previous five years.

Numerous scholars (e.g. Chesbrough, 2003; Rosenkopf and Nerkar, 2001) have emphasized that technological activities do not have to be situated exclusively within the boundaries of the firm. Instead, firms can choose to engage in collaboration with different kinds of partner to develop new ideas. Von Hippel, Thomke and Sonnack (1999), for instance, emphasize the relevance of collaborating with lead users to generate new ideas. Other scholars (Belderbos, Carree and Lokshin, 2004, Faems, Van Looy & Debackere, 2005; Santoro, 2000; Sherwood & Covin, 2008) point to universities as valuable partners to engage in joint idea creation activities. In addition, Browning, Beyer and Shetler (1995) describe how consortia of competitors have contributed to the emergence of breakthrough inventions in the semi-conductor industry. In this article, an explicit distinction is therefore made between solitary technological activities and collaborative technological activities.

In sum, technological activities are classified along two different dimensions: 1) explorative versus exploitative technological activities, and 2) solitary versus collaborative technological activities. Combining these two dimensions results in a typology of four different kinds of technological activities: 1) solitary exploitative technological activities; 2) solitary explorative technological activities; 3) collaborative exploitative technological activities; and 4) collaborative explorative technological activities (see Figure 1).

Insert Figure 1 about here

Hypotheses on the Financial Performance Implications of Different Invention Activities

In the following paragraphs, hypotheses on the financial performance effects of the two identified dimensions of technological activities are developed. First, the effects of the exploration/exploitation dichotomy and the solitary/collaborative dichotomy on the financial performance of the firm are discussed. Subsequently, the two dimensions are combined to develop hypotheses on the financial performance effects of collaborative exploitative technological activities (versus solitary exploitative technological activities) and collaborative explorative technological activities (versus solitary explorative technological activities).

Impact of Explorative and Exploitative Technological Activities on Financial Performance

Several scholars (e.g. He & Wong, 2004; March & Levinthal, 1993; McGrath, 2001; Tushman & O'Reilly, 1996; Jansen et al, 2006) argue that a central concern of corporate strategy relates to decisions on how to divide attention and resources between explorative and exploitative activities within firms. Focusing on exploitative activities is likely to improve the effectiveness and efficiency of existing core capabilities, which can lead to positive short-term effects. March and Levinthal (1993) suggest however that an exploitation focus can trigger a success trap in which exploitation drives out exploration. In this way, existing core capabilities can turn into core rigidities, which compromise the ability of the firm to adequately respond to forthcoming industrial and/or technological changes and thereby threatens the long-term survival of the firm (Leonard-Barton, 1992; Christensen & Overdorf, 2000). At the same time, it is recognized that focusing solely on exploration can be detrimental to the firm's financial performance. In order to realize growth and profit, focus and commitment are required (Ghemawat, 1992). Relying solely on exploration might even result in a reinforcing cycle in which 'failure leads to search and change, which leads to failure, which leads to more search and so on' (Levinthal & March, 1993: 105-106). It is therefore argued that companies able to establish a balance between exploration and exploitation are likely to outperform firms that focus solely on either exploration or exploitation.

He and Wong (2004) were the first to test this 'ambidexterity hypothesis' (Tushman & O'Reilly, 1996). They found a positive interaction effect between explorative and exploitative strategies on a firm's sales growth, while the relative imbalance between explorative and exploitative innovation strategies was negatively related to growth. A recent study by Uotila et al. (2009) provides further evidence of the need to balance exploration and exploitation. Conducting computer-assisted coding of firms' publicly available documents, they found an inverted U-shaped relationship between the relative share of the firm's exploration orientation and market valuation.

Based on these arguments, one may expect that firms seek a balance between exploration and exploitation in their technological activities. This leads to the following hypothesis:

> ***Hypothesis 1:*** *An inverted U-shape relationship exists between the relative share of explorative technological activities in a firm's technology portfolio and its financial performance.*

Impact of Solitary and Collaborative Technological Activities on Financial Performance

Technology collaboration enables firms to scan their environment for new windows of opportunity and promising new technologies; it is often used as an instrument to acquire technological knowledge and to develop new skills that reside within the partnering companies (Hamel, 1991; Hagedoorn and Schakenraad, 1994; Powell, Kaput and Smith-Doerr, 1996). Conditions of technological risk are the norm when it comes to developing new ideas (Hill & Rothaermel, 2003). In addition, the costs of technological activities are steadily increasing in many technology fields (Teece, 2002). Engaging in inter-firm collaboration has been suggested as a viable approach in seeking to address these issues. Bringing together different partners increases the amount of available human and physical resources to develop new ideas, which is likely to decrease technological risk (Dittrich & Duysters, 2007; Hagedoorn, 1993). Collaborative arrangements also facilitate the spreading of R&D costs among various partners (Harrigan, 1988; Veugelers, 1998).

Collaboration may not only reduce the risk and costs of technological activities, it may also increase the probability of their successful realization. Technological activities increasingly require the incorporation of a wide range of knowledge components into complex systems and integrated solutions (Teece, 2002). However, as the range of knowledge to be integrated widens, mastering and combining these different kinds of knowledge is increasingly difficult for single firms to handle (Doz & Hamel, 1997). Numerous scholars have stressed the advantages of inter-firm collaboration in this respect. First, collaborative arrangements might imply access to complementary assets required to turn technological activities into success (Hagedoorn, 1993; Teece, 1986). Second, working together with other organizations might encourage the transfer of codified and tacit knowledge, resulting in the creation and development of ideas that would be difficult to realize in isolation (Doz & Hamel, 1997; Faems, Janssens & Van Looy, 2007; Mowery, Oxley and Silverman, 1996). A range of previous studies has confirmed that technology collaboration – in particular, a portfolio of strategic technology alliances – can have a positive impact on the innovative performance of companies (e.g. Baum and Oliver, 1991; Mitchell and Singh, 1996; Powell, Koput and Smith-Doerr , 1996; Rothaermel and Deeds, 2004)[iii].

In sum, the above arguments suggest that, in comparison with solitary technological activities, collaborative technological activities might imply lower technical risks and costs whilst at the same time introducing a higher probability of success. This leads to the following hypothesis:

> ***Hypothesis 2a:*** *A greater share of collaborative technological activities in a firm's technology portfolio increases its financial performance.*

Although collaborative arrangements might reduce technical risks and costs, engaging in collaboration with external partners might, on the other hand, introduce relational risks and an increase in required coordination costs. Engaging in collaboration suggests the potential risk that the other partner may engage in opportunistic behaviour such as 'cheating, shirking, distorting information, misleading partners, providing substandard products/services, and appropriating partners' critical resources' (Das & Teng, 1998: 492). Mitigating such risks may require time-consuming contract negotiations and/or the implementation of costly monitoring mechanisms (Dyer, 1997; Williamson, 1985). In addition, the presence of cultural and organizational differences among collaborating partners would suggest that achieving coordinated action in such settings is not a straightforward task. As a result, it may be necessary to make relational investments that facilitate coordination among collaborating partners (Faems et al., 2008; Gulati & Singh, 1998; Madhok & Tallman, 1998).

In contrast to solitary technological activities, collaborative activities implies that firms also need to share the rewards with their collaborating partners. In other words, collaboration might increase the probability of generating ideas successfully but may substantially restrict the ability of the focal firm to appropriate the value of such activities (Lavie, Lechner & Singh, 2007; Ring & Van de Ven, 1994). Based on these potential disadvantages of collaborative technological activities, the following competing hypothesis is formulated:

> ***Hypothesis 2b:*** *A greater share of collaborative technological activities in a firm's technology portfolio decreases its financial performance.*

<u>Exploration and exploitation; jointly or separately?</u>

Previous research provides strong indications that the preference for, and the impact of, solitary or collaborative approaches might be different in exploitative and explorative settings. Several scholars (Das & Teng, 2000; Hagedoorn & Dusters, 2002) argue the more that technological activities are essential for the existing core business of a firm, the more a firm wishes to exert full control over such activities. According to transaction cost theory (e.g. Pisano, 1990; Williamson, 1991), such full control can best be achieved by internalizing technological activities. Additionally, the economic consequences of opportunistic behaviour in collaborative arrangements are likely to be higher in exploitative than in explorative settings. If the partner firm uses valuable knowledge obtained from the existing knowledge domains of the focal firm, the economic damage is likely to be higher than when there are unintended knowledge spillovers in knowledge domains that do not constitute the core technology of current business activities.

Looking at collaborative technological activities from a resource-based perspective, the value-generating properties of collaboration are expected to be higher for explorative technological activities than for exploitative technological activities. Exploitative technological activities refer to the generation of new ideas within the existing knowledge domains of the firm. It can be expected that, internally, the firm will have the necessary knowledge, skills and expertise to successfully accomplish such a task. Ahuja (2000) argues that firms have little inducement to engage in collaboration in fields where they already possess particular strengths. In contrast, explorative technological activities, or the development of ideas in new knowledge domains, are likely to require knowledge, skills and expertise that are not present within the firm. It is the combination of a diversity of resources that holds out the promise of building up new valuable and scare technological resources, which in turn build competitive advantage in the future (Hamel, 1991; Hagedoorn and Schakenraad, 1994; Powell *et al.*, 1996). Based on the above arguments, the following two hypotheses are formulated

Hypothesis 3a: *A greater share of collaboration in a firm's exploitative technological activities decreases its financial performance.*

Hypothesis 3b: *A greater share of collaboration in a firm's explorative technological activities increases its financial performance.*

DATA

Sample and Data

The impact of different kinds of technological activities on the financial performance of firms is investigated using a panel dataset (1996-2003) on the technological activities of 168 sample firms. The sample firms are R&D-intensive European, US and Japanese firms in five industries: (i) non-electrical machinery, (ii) pharmaceuticals & biotechnology; (iii) chemicals; (iv) IT hardware (computers and communication equipment); and (v) electronics & electrical machinery. The firms are drawn from the 2004 EU industrial R&D investment scoreboard, which provides listings of the 500 most R&D-intensive European, and 500 most R&D-intensive US and Japanese firms across all industries. The resulting sample of 168 firms contains roughly the same number of firms in each industry for each region of origin.

Patent data are used to construct indicators of firms' technological activities. There are numerous advantages to the use of patent indicators (Pavitt, 1985; Basberg, 1987; Griliches, 1990; Hall et al, 2005): patent documents contain highly detailed information on content and ownership of patented technology; they cover a broad range of technologies; patent data are 'objective' in the sense that they have been processed and validated by patent examiners; and patent data are publicly available. Like any indicator, patents are also subject to a number of drawbacks: not all technological activities are patented; patent propensities vary across firms and industries[iv]; and patented technological activities differ in their technical and economical value (Levin et al, 1987; Mansfield, 1986; Gambardella et al, 2008). Despite these shortcomings, no other indicator provides the same level of detail of the technological activities of firms as do patents (Griliches, 1990).

Firm patent data is collected at the consolidated level: i.e. all patents of the parent firm and its consolidated (majority-owned[v]) subsidiaries are collected. For this purpose, lists of subsidiaries included in corporate annual reports, 10-K reports filed with the SEC in the US and, for Japanese firms, information on foreign subsidiaries published by Toyo Keizai in the yearly 'Directories of Japanese Overseas Investments', are used. The consolidation is conducted on an annual basis (1996-2003) to take into account changes in the group structure of the firms over time. Using consolidated patent data is important in order to obtain a complete picture of the technological activities of firms since a significant proportion of firms' patents are not filed under the parent firm name. For the sample, on average 17.6% of firm patents are filed under the name of firm subsidiaries or name variants of the parent firms.

In this article, patent data from the European Patent Office (EPO) is used. European patent data was preferred to the more commonly used data from the United States Patent and Trademark Office (USPTO) because EPO patents are, typically, considered to provide a better indication of valuable technological activities: the cost of patenting is two to five times greater at EPO than at USPTO; the workload of patent examiners is four times smaller at EPO than at USPTO; and EPO has a 20-30% lower patent-granting rate than USPTO (Van Pottelsberghe de la Potterie and François, 2006; Quillen and Webster, 2001; Jaffe and Lerner, 2004). The explanatory variables are constructed from patent application data. Whereas patent grants are better indicators of firms' successful technological activities, patent application data provide a broader indicator of the variety of technological activities of the firm. The use of patent applications tends to result in a more complete picture of firms' technological activities, especially in the case of explorative activities. Moreover, patent-granting decisions in the European Patent Office, our source of patent data, take 5-6 years on average [vi], making patent grants a poor (incomplete) indicator of firms' recent technological activities.

Dependent Variable

The dependent variable is the annual (1996-2003) financial performance of a firm, measured by Tobin's Q. Tobin's Q is the ratio of the market value of a firm and the replacement (book) value of the firm's assets. A firm's market value is defined as the sum of market capitalization (share price multiplied by the number of common shares outstanding at the end of the year), preferred stock, minority interests, and total debt minus cash. In contrast to current profit indicators (e.g. sales, net profits, ROA), Tobin's Q is a forward-looking indicator that contains an assessment[vii] of firms' future financial results from current technological activities. This forward-looking aspect is important since returns from technological activities often only become manifest several years after the activities have taken place (Czarnitzki, Hall and Oriani, 2006). Information on the market and book value of firms is collected from financial databases (Worldscope and Compustat) and firms' annual reports.

Typology of Invention Activities

Patent indicators are used to develop a typology of firms' technological activities. All firm patents are classified into one of four categories using two dimensions: (1) *explorative* versus *exploitative* technological activities, and (2) *solitary* versus *collaborative* technological activities (Figure 1).

Technology class information is used to make a distinction between *explorative* and *exploitative* patents. The European Patent Office classifies all patents into at least one technology field, using the International Patent Classification System (IPC)[viii]. The IPC system classifies the technology landscape into 628 IPC-4 digit classes (used in the study) and several ten-thousands of subclasses nested within these classes. A patent is considered as an *explorative* one when it is situated in a technology domain that is new or unfamiliar to the firm (i.e. a technology in which the firm lacks prior experience). A technology domain is defined as new to a firm in year t, if the firm (i.e. firm subsidiaries in year t) did not patent in the technology domain in the past five years (t-5 to t-1). The choice of a five-year window to assess familiarity with technology domains is based on the observation that technical knowledge evolves rapidly in most technology fields, losing most of its technical and economical relevance within five years (Ahuja and Lampert, 2001; Hall et al, 2005; Leten et al, 2007). Since a technology domain remains relatively new and unexplored immediately after a firm embarks on technological activities, a technology domain keeps its explorative status for a period of three consecutive years.

Information on the ownership structure of patents is used to differentiate between *solitary-owned* and *collaborative* patents. A patent is considered as a *collaborative* one when it is jointly owned with an economic actor that is not part of the consolidated focal firm (another firm, university, public research institute etc.). Patents that are jointly owned by firms and individual persons have been excluded since one does not know whether these individuals are employed by the focal firm or not. Patent applicant names referring to individual persons are identified by patent allocation algorithms (source: Van Looy et al, 2006).

In total, 170,510 patents (belonging to the 168 sample firms for the period 1996-2003) have been classified along two dimensions. The majority of patents are classified as solitary exploitation (90.1%), followed by solitary exploration (6.5%), collaborative exploitation (2.9%) and collaborative exploration (0.5%) (Figure 2)[ix]. In Figures 3 and 4, a longitudinal perspective is followed by calculating the technology typology matrices for two subsequent four-year periods (1996-99; 2000-03). Figures 3 and 4 show a decline in the overall share of exploration patents over time (from 7.9% to 6.5%), whereas the share of collaboration patents has remained relatively stable over time (around 3.3-3.5%).

Insert Figure 2, 3 and 4 about here

Technology typology matrices are calculated annually (1996-2003) for all sample firms. In order to test Hypothesis 1, a variable that reflects the share of collaboration in a firm's technology portfolio is created. To test Hypothesis 2a and 2b, a variable reflecting the share of collaboration in technological activities is constructed. To test Hypotheses 3a and 3b, two additional variables are calculated reflecting (1) the share of collaboration in exploitative technological activities and (2) the share of collaboration in explorative technological activities.

Control Variables

Several variables that might influence the financial performance of firms are introduced as control variables in the analyses. First, two indicators for the *size* of firms' current *technological activities* are included: R&D intensity (R&D expenditures/total assets) and patent propensity (patents/R&D expenses). Firms that spend more money on technological activities (R&D intensity) and are more successful in these activities (patent propensity) are expected to realize a higher market valuation. This assertion has been confirmed by prior studies relating the stock market value of firms to measures of the size of their technological activities (Griliches, 1981; Pakes, 1985; Blundell et al, 1999; Hall et al, 2005; Czarnitzki, Hussinger and Leten, 2009). Second, a set of dummy variables are included to control for industry differences (five sectors). Firms belonging to different sectors face different competitive pressures and opportunities, which may translate into performance differences. Third, *region* (US, Japan, and 11 European countries) and *year* (1996-2003) dummies are included to control for differences in macro-economic trends across time and countries that may impact on the stock market valuation of firms. Finally, a one-year lagged value of Tobin's Q is included as an additional variable in line with the work of Griliches (1981). This will control for anyresidual unobserved heterogeneity across firms leading to systematic differences in market valuations. It has the advantage that one can rely on contemporaneous measures of the technological activity variables to examine their impact on market valuation, as previous technological activities are already reflected in the lagged value of q.

Descriptive Statistics

Table 1 shows sample statistics for the main variables used in the analyses (1138 observations). In line with prior studies (Hall et al, 2005 & 2006), Tobin's Q and measures of the size of firms' technological activities (R&D/assets; patents/R&D) are highly skewed. There is also considerable variance in the exploration and collaboration variables, with standard errors of the same order or exceeding mean values. This suggests that there is sufficient room for 'action' in the model variables. The (average) share of collaboration in explorative technological activities is larger (7.83%) than the (average) share of collaboration in exploitative technological activities (4.75%). This observation seem to confirm previous studies (e.g. Folta, 1998; Hagedoorn &

Duysters, 2002), arguing that collaborative approaches are more relevant in explorative settings than in exploitative settings.

Insert Tables 1 and 2 about here

Table 2 contains the Pearson correlation coefficients between the variables of interest. As expected, Tobin's Q correlates strongly with its lagged value, and the correlation between share of exploration and its squared term is considerable. Again as expected, a strong correlation between share of collaboration, on the one hand, and share of collaboration in exploitation/exploration, is found on the other hand. Separate models are therefore used to test the impact of these variables. The correlations between the other independent variables are not excessively high.

RESULTS

The results of the models explaining the impact of different kinds of technological activities on the financial performance of firms are reported in Table 3. Regressions have been estimated by ordinary least squares techniques, with robust standard errors clustered at the parent firm level. A lagged dependent variable is included in all regression models to control for the impact of unobserved firm-level heterogeneity.

Model 1 includes the control variables and a lagged dependent variable. The lagged dependent variable, R&D intensity and patent propensity variables have the expected positive signs and are significant, using conservative 2-tailed tests. In Model 2, the linear and quadratic terms of 'exploration share' are added. Exploration share has a positive and significant linear term, and a negative and significant quadratic term. These results confirm Hypothesis 1: there is an inverted U-shape relationship between the share of explorative technological activities and a firm's financial performance. Firms with moderate exploration shares outperform both firms with low and high exploration shares. In other words, the best performing firms maintain a healthy balance of explorative and exploitative technological activities. The peak of the inverted U-curve occurs at a value of 39% for 'exploration share', with 87% of the sample observations having smaller (and 13% larger) values than the peak value. This implies that most sample firms can further increase their financial performance by increasing the share of explorative activities in their technology portfolios.

Insert Table 3 about here

The ‘collaboration share’ variable is added in Model 3. This variable has a negative and significant coefficient, while the coefficients of the other variables remain largely unchanged. This disconfirms Hypothesis 2a and confirms Hypothesis 2b: a greater share of collaborative technological activities in a firm’s technology portfolio decreases its financial performance. These findings suggest that the relational costs and value appropriation disadvantages of collaborative technological activities may outweigh the technological savings and value realization advantages of such activities.

In Model 4, the impact of the collaboration share in exploitative and explorative technological activities on firms’ financial performance are compared. No significant effect of the share of collaboration in exploitative technological activities on the financial performance of firms is found. In other words, the data suggest that, in terms of financial performance, there is no differential impact of conducting exploitative technological activities in isolation or in collaboration with other partners. At the same time, a significant effect of the collaboration share in explorative technological activities on financial performance is found. However, in contrast to expectations, this effect proves to be negative: a greater share of collaboration in a firm’s total explorative technological activities significantly lowers the financial performance. These results indicate that, in comparison with solitary explorative technological activities, the added value of collaborative explorative technological activities to the future economic profits of the firm is negatively assessed by financial markets. In other words, the potential advantages of collaboration for explorative technological activities (i.e. access to complementary knowledge from other partners, sharing of technological costs and risks) appear not to compensate for the potential disadvantages (i.e. need to share the future benefits of the technological activities with external partners and/or additional relational costs of engaging in explorative collaboration).

Insert Table 4 about here

The unexpected negative relationship between firm value and the intensity of collaboration in explorative technological activities led us to explore the relationship between exploration and collaboration in further detail. In particular, the correlations, reported in Table 2, indicate that a greater intensity of collaboration in exploration is positively correlated with a greater share of exploration in technological activities, which can be seen to point to positive effects from explorative collaboration. This relationship is examined more formally, based on the working hypothesis that engaging in collaboration may help firms to increase their explorative technological activities. For that purpose, an additional analyses is conducted in which the impact of the share of collaboration in exploration in year t-1 on the total share of exploration in a firm's technology portfolio in year t is examined, controlling for the initial exploration intensity (t-1), sector, country, and year effects. The results are presented in Table 4 and show a significantly positive effect of collaborative exploration on the share of explorative activity. As most of the sample firms (i.e. 87%) have not achieved their optimal exploration level, an increase in exploration indirectly also implies an increase in the financial performance of these firms. In sum, whereas a negative direct effect of the collaboration share in explorative technological activities on firms' financial performance is found, there are also indications of a positive indirect effect of this variable (via an increasing share of exploration activities) on the firm's financial performance.

DISCUSSION, IMPLICATIONS AND FUTURE RESEARCH AVENUES

In this section, the main findings of the article and their implications are discussed. In addition, some limitations of the article are mentioned and avenues for future research are identified.

Toward a Balanced Innovation Strategy

Numerous scholars (e.g. March, 1991; Levinthal and March, 1993; Benner & Tushman, 2002; Jansen, Van den Bosch & Volberda, 2006) have emphasized the importance of a balance between explorative and exploitative activities for the long-term performance and survival of the firm. The findings of this article contribute to this literature in different ways. First, this research is expanded into the setting of technological activities, and an explicit distinction between explorative and exploitative technological activities is made by drawing on detailed technology class information on firms’ patents. Second, although previous research has emphasized the advantages of a balanced strategy, large-scale, quantitative empirical research that examined the performance implications of such a strategy has remained scarce. The recent study by Uotila et al. (2009) is an exception in this respect. They provided first evidence of an inverted U-shaped relationship between the share of exploration in a firm’s corporate actions and a firm’s market value. This article provides additional evidence for such a relationship in the context of technological activities. An inverted U-shape relationship between the share of explorative technological activities and the market value of the firm is found. Hereby, it has been observed that most firms in the sample did not yet reach the optimal level of explorative technological activities. In sum, these findings points to the relevance of creating a balance between exploitation and exploration in the context of technological activities. In addition, the findings suggest that, for the majority of R&D intensive firms, reaching a healthy balance between exploration and exploitation implies investing additional efforts and resources in exploring new knowledge domains.

Toward Open Innovation Practices?

Based on close observation of a relatively small number of companies, Chesbrough (2003) advanced an innovation paradigm shift from closed to more open innovation models. Open innovation is characterized by the use of purposive inflows and outflows of knowledge to both accelerate internal innovation and expand the markets for external use of innovation. Numerous companies (i.e. IBM, Intel, P&G) have begun to adopt the concept of open innovation. In addition, academic research on open innovation is proliferating (Chesbrough et al., 2006). While a broad range of studies has examined the impact of technology alliances on various performance measures, studies making an explicit distinction between explorative and exploitative types of activities have been limited. The study by Laursen and Salter (2005) is an exception in this respect. Examining sources of technological knowledge used by firms in the innovation process, Laursen and Salter (2005) find that searching widely and deeply is curvilinearly related to firms’ innovation performance. In this article, further insights into the extent to which firms adopt collaborative strategies of an explorative or exploitative kind, and how such strategies relate to firm value, are generated.

In a recent study, Poot et al. (2009) provide evidence that innovating firms in the late 1990s and early years of the new millennium have increasingly relied on external sources of information for innovation, while they have increasingly engaged in formal collaboration with external partners to support their innovation activities. Data on 168 top R&D spending firms in five technology-intensive industries used in this study, however, do not provide indications for such an increasing trend with respect to collaborative technological activities. In particular, no increase in co-patenting rates was observed when the periods 1996-1999 and 2000-2003 were compared. In other words, the data of this article did not provide evidence for the emergence of a paradigm shift with respect to *technological activities* and, more specifically, resulting patent applications, during the observed period.

This study also shows that the share of collaborative technological activities relates negatively to the market value of the firm. Moreover, contrary to our expectations, it is the share of collaboration in explorative technological activities rather than the share of collaboration in exploitative technological activities that leads to a reduction in firm value. Although these results are surprising, they do echo some of the findings on the drawbacks of intensive use of technology collaboration. It has been argued that embeddedness in existing technology partnerships can create a dependence that increases the risk of firms falling into a familiarity trap, reducing true experimentation (Ahuja & Lampert, 2001). Intensive use of collaboration may lead management attention and integration costs to grow exponentially, and a firm's effectiveness at managing its alliances will decline with the number of alliances it maintains (Deeds and Hill, 1996). Other scholars (Belderbos et al., 2006, Faems et al., 2009, Knudsen, 2007) provide further evidence that the diversity of a firm's technology alliance portfolio (i.e. the extent to which a firm simultaneously collaborates with different kinds of partners to support its innovation strategies) can have negative effects on firms' performance.

These findings suggest that the potential advantages of collaboration for (explorative) technological activities (i.e. access to complementary knowledge from other partners, sharing of technological costs and risks) might not compensate for the potential disadvantages, such as the incurred increase in coordination costs. At the same time, the collaboration indicator used in this study – co-patents – does not permit us to arrive at final conclusions on the level of the financial impact of open *innovation* practices, as co-patents only reflect a fraction of the firm's collaborative relationships. Indeed, collaborative R&D efforts will not always result in a patent application and, even if patent applications emerge from joint R&D efforts, co-owned applications are not a necessity. What co-patents do however signal is a willingness to remain a stakeholder during the further development of the invented technology towards commercial exploitation. Consequently, co-patents seem also to be a relevant indicator for signalling the occurrence of open business models (Chesbrough, 2006). From this perspective, our findings suggest that when the fruits of collaborative technological activities have to be shared with partner firms – resulting in a likely reduction in potential future revenues flowing to the focal firm compared with the situation of full ownership – the market value of the firm may be negatively affected. One possible explanation for the strong negative impact of collaboration in exploration – rather than exploitation – activities might reside in the fact that explorative technological activities are assessed (by financial markets) to be more valuable than exploitative activities. Therefore, the discount of sharing revenues in case of co-patenting is larger for explorative than exploitative technological activities. Additional support for this argument may be provided by the fact that a high peak value for the curvilinear curve of the exploration share variable is found in Table 3, which most sample firms did not yet reach.

Finally, it should be noted that, in a subsequent analysis, a positive relationship between collaboration in explorative activities and the total share of exploration in technological activities is found, which in turn has a positive effect on the financial performance of firms. These findings confirm the relevance of collaborative efforts in improving the firm's *technological* performance. At the same time, taken jointly, these findings signal the presence of a complex balancing act with respect to collaboration since technological and economical benefits do not seem to coincide – and even result in counterbalancing effects.

Limitations and Further Research

One limitation of this study relates to the use of co-patenting information to derive measures of collaborative technological activities, since not all collaborations will be captured by co-patenting indicators. First, not all collaborative R&D efforts will result in an application for a patent. Second, even if R&D collaboration yields a patent application, specific IP arrangements between the partners involved might result in patent applications from only one partner. This means that the collaboration variables used in the analysis should be viewed as a conservative estimation of the amount of collaboration taking place, with actual levels of collaborative technological activities being higher. Engaging in future research that incorporates additional indicators of collaboration seems highly relevant to further assess and corroborate the robustness of the findings of this article.

At the same time, it is clear that the occurrence of co-patents in itself signals a clear intention of both partners to remain involved in subsequent development and exploitation efforts. To the extent that such open business models imply joint efforts entrenched in appropriate IP arrangements, as reflected in cross-licensing and co-patenting, these findings signal important managerial points of attention. If open innovation models do not translate into additional firm value, one can and should question their relevance and sustainability. Future research examining the conditions that affect the actual occurrence of such value-creating dynamics, or that at least allow us to avoid the observed direct negative effect, seems highly appropriate. Further in-depth analysis of the relative importance of the observed direct (negative) effect of inventive collaboration, and the positive indirect performance effects through increasing the exploration orientation of firms, constitutes an important avenue for future research. One could state that avoiding the direct negative impact of collaboration on firm value holds the key to installing and developing open innovation practices of a sustainable nature. Hopefully the research findings reported in this article will inspire engagement in future investigation of these issues.

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TABLES

Table 1: Descriptive Statistics for Dependent and Explanatory Variables

Variable	Mean	Min	Max	St.Dev
Q	1.7358	0.1617	20.299	1.8925
R&D/Assets	0.0608	0.0044	0.5172	0.0453
Patents/R&D	0.2851	0.0004	1.9132	0.2775
Exploration Share	0.1946	0.0053	0.9000	0.1801
Collaboration Share	0.0531	0	0.6666	0.0787
Collaboration Share in Exploitation	0.0475	0	1	0.0954
Collaboration Share in Exploration	0.0783	0	1	0.1595

Note: Statistics for the ‘patents/R&D’ variable are multiplied by a factor of 1000

Table 2: Pearson Correlation Coefficients for Model Variables

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) Q	1								
(2) Lagged Q	0.86	1							
(3) R&D/assets	0.45	0.44	1						
(4) Patents/R&D	-0.10	-0.10	-0.29	1					
(5) Exploration Share	-0.06	-0.07	-0.16	-0.1	1				
(6) Exploration Share^2	-0.04	-0.05	-0.08	-0.12	0.94	1			
(7) Collaboration Share	-0.12	-0.09	-0.06	-0.13	0.22	0.24	1		
(8) Collaboration Share in Exploitation	-0.09	-0.08	-0.06	-0.09	0.16	0.20	0.77	1	
(9) Collaboration Share in Exploration	-0.12	-0.09	-0.05	-0.06	0.08	0.08	0.60	0.21	1

Note: The variables Q and ‘lagged Q’ are logarithmic transformed

Table 3: Financial Performance as Function of Firms' Technological Activities

	Model 1	Model 2	Model 3	Model 4
Lagged Q	0.7823**	0.7803**	0.7783**	0.7779**
	(0.0251)	(0.0245)	(0.0244)	(0.0245)
R&D/Assets	1.1312*	1.2112**	1.1832**	1.2000**
	(0.4403)	(0.4591)	(0.4462)	(0.4529)
Patents/R&D	103.6914**	111.8669**	104.3651**	107.5966**
	(36.1688)	(36.0735)	(35.0018)	(34.9454)
Exploration Share		0.4305*	0.4238*	0.4124*
		(0.1721)	(0.1732)	(0.1738)
Exploration Share^2		-0.5435*	-0.4757*	-0.4902*
		(0.2313)	(0.2364)	(0.2412)
Collaboration Share			-0.3717**	
			(0.1338)	
Collaboration Share in Exploitation				-0.1001
				(0.1037)
Collaboration Share in Exploration				-0.1293*
				(0.0563)
Sector Dummies	YES	YES	YES	YES
Country Dummies	YES	YES	YES	YES
Year Dummies	YES	YES	YES	YES
Constant	0.1718**	0.1292*	0.1544**	0.1477*
	(0.0538)	(0.0565)	(0.0569)	(0.0573)
Number of Observations	1138	1138	1138	1138
Number of Firms	168	168	168	168
R-Squared	0.808	0.809	0.810	0.810

Notes: Only observations with exploitation patents and exploration patents>0 (1138 obs) are included; Dependent variable = log Tobin's Q; Clustered standard errors at firm level; *,** indicate significance at the 5 and 1 percent level.

Table 4: Exploration Share as function of Collaboration Share in Exploration Activities

	Model 5
Lagged Exploration Share	0.5592**
	(0.0322)
Collaboration Share in Exploration (lagged)	0.0890*
	(0.0409)
Sector Dummies	YES
Country Dummies	YES
Year Dummies	YES
Constant	0.0444**
	(0.0139)
Number of Observations	1138
Number of Firms	168
R-Squared	0.5370

Notes: Only observations with exploitation patents and exploration patents>0 (1138 obs) are included; dependent variable = Exploration Share; Clustered standard errors at firm level; *,** indicate significance at the 5 and 1 percent level.

FIGURES

Figure 1: Different Kinds of Technological Activities in the Technology Portfolio

	Exploration	Exploitation
Collaborative	Collaborative explorative invention activities	Collaborative exploitative invention activities
Solitary	Solitary explorative invention activities	Solitary exploitative invention activities

Figure 2: Technology Typology Matrix (Patents in Period 1996-2003)

	Exploration	Exploitation
Collaborative	865 patents (0.5%)	4'891 patents (2.9%)
Solitary	11'170 patents (6.5%)	153'584 patents (90.1%)

Figure 3: Technology Typology Matrix (Patents in Period 1996-1999)

	Exploration	Exploitation
Collaborative	407 patents (0,6%)	2' 103 patents (2,9%)
Solitary	5'263 patents (7,3%)	63'951 patents (89,2%)

Figure 4: Technology Typology Matrix (Patents in Period 2000-2003)

	Exploration	Exploitation
Collaborative	458 patents (0,5%)	2'788 patents (2,8%)
Solitary	5'907 patents (6,0%)	89'633 patents (90,7%)

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ENDNOTES

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[i] The recent work of Uotila et al (2009) being a notable exception.

[ii] The exception is Rothaermel and Alexandre (2009). The focus of this article is however primarily on the need for balance in internal and external technology sourcing.

[iii] A notable exception is the work of Stuart (2000) who found no significant relationship between the number of alliances on the innovation rate of semiconductor firms.

[iv] As reported by Levin et al (1987) and Arundel and Kabla (1998), patent propensities are high in our five sample industries, making patents a meaningful indicator of firms' technological activities in these industries.

[v] A subsidiary is considered majority-owned if the parent firm holds at least a 50% share in the subsidiary.

[vi] For granted patents applied in 1996, the average granting decision took 5.25 years, with 25% of grants having a granting lag of seven years and longer (source: own calculations)

[vii] This assessment is made by stock markets. Hence, Tobin's Q is only an appropriate performance measure for firms listed on well-functioning stock markets.

[viii] IPC Classification version 7 is used in this article.

[ix] The numbers in Figures 2-4 are calculated for the set of firm/year observations used in the regression analyses.