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The Up- and Downsides of R&D Collaborations in Core and Non-Core Technologies

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Abstract

In this study we investigate firms? collaboration propensity and outcome in its different technological fields (core/ related non-core/ distant non-core). We distinguish between firms? core and non-core technological fields, and within those non-core technological fields, we further distinguish between related non-core technological fields, and distant non-core technological fields. We find that R&D collaboration is not necessary a good thing, the benefit of R&D collaboration depends to a large extent on the type of technological fields involved in collaborations. We find that firms in general have a higher propensity to collaborate in their core technological fields, but it is collaborations that are conducted in firms? non-core technological fields that benefits them the most. However, such collaboration partnerships are hard to establish if the firm has little, or no background knowledge in place. In order to benefit from collaborations in firms? non-core technological fields, it may not be good to rashly start partnerships in the very peripheral technological fields of the firm, instead, the firm may need to first possess some pockets of background knowledge as related non-core technologies.

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Abstract

In this study we investigate firms' collaboration propensity and outcome in their different technological fields (core/ related non-core/ distant non-core). We distinguish between firms' core and non-core technological fields, and within those non-core technological fields, we further distinguish between related non-core technological fields, and distant non-core technological fields. We find that R&D collaboration is not necessary a good thing, the benefit of R&D collaboration depends to a large extent on the type of technological fields involved in collaborations. We find that firms in general have a higher propensity to collaborate in their core technological fields, but it is collaborations that are conducted in firms' non-core technological fields that benefits them the most. However, such collaboration partnerships are hard to establish if the firm has little, or no background knowledge in place. In order to benefit from collaborations in firms' non-core technological fields, it may not be good to rashly start partnerships in the very peripheral technological fields of the firm, instead, firms may need to first possess some pockets of background knowledge as related non-core technologies.

Keywords

Open innovation, R&D collaboration, technological fields, core/ non-core technologies, collaboration propensity, collaboration outcome

1. Introduction

Survival and growth have been two major themes in firms' development. While firms compete in the marketplace on their *core* competencies (Prahalad and Hamel, 1990) which help them to sustain profit engines (Christensen, 1997), at the same time firms also possess and develop technological fields which they are less strong at, either as background knowledge supporting their core technology activities (Patel and Pavitt, 1997), or as new technology opportunities which may help them respond to frequent changes in a dynamic environment (Teece et al., 1997).

Because of the aggravating risks, costs, and complexity of innovation, increasingly more firms collaborate with external parties in their innovation activities to access and leverage outside resources and expertise (Powell et al., 1996; Hagedoorn, 2002). Recent practices show that many firms open up their boundaries and engage into R&D collaboration activities in their core (Caloghirou et al., 2004) or non-core (Chesbrough and Schwartz, 2007) technological fields. As firms develop idiosyncratic technology development trajectories over time (Nelson and Winter, 1982), certain technological fields may have accumulated more resources, established better technologies, developed higher levels of absorptive capacity, and are strategically more important for the firm than the others. Because collaboration activities essentially reflect the strengths and weaknesses of the technologies of the firm (Keupp and Gassmann, 2009), there are discrepancies in terms of resource allocation, decision making, activities and outcomes among these different types of technological fields. Hence, the propensity and consequences of firms' collaboration behavior in these technological fields are also likely to vary accordingly. Against this backdrop, in the context of R&D collaboration, some conceptual contributions suggest that firms should distinguish and develop different strategies when collaborating in their core or non-core technological fields (Chesbrough and Schwartz, 2007). However, so far, there is no empirical study investigating firms' collaboration strategies and consequences based on different types of technological fields involved in collaboration. This paper aims to address these issues by examining the propensity and outcome of firms' collaboration activities in their core and non-core technological fields.

To understand these issues, we rely on an extensive dataset of projects from a large multinational firm between the year 2003 and 2010. We identified the technological fields of its research projects and classified them as core or non-core technological fields based on the strength of specialization of firms in the field (Patel and Pavitt, 1997). In our data, technological fields of each project are carefully assessed and denoted by the 4-digit IPC code of the technological fields the project covers. Following Patel and Pavitt (1997), we calculate the *Patent Share* and *Revealed Technology Advantage*[1] of each technological field the firm covers and identified 25 core technological fields of the firm in the 9-year time (at IPC 4-digit level). Projects that are with both high patent share and high revealed technology advantage are classified as core technologies, while the rest are non-technologies (for more details please refer to methodology section). Within these non-core technologies, we further distinguish between related non-core technological fields and distant non-core technological fields of the firm, based on technology relatedness of the non-core technologies to the firm's core technological fields (Leten et al., 2007). Those technological fields that are highly related to firm's core technologies are considered as related non-core technologies, while the ones that are with a low relatedness to firm's core technologies are considered as distant non-core technologies.

We study both the firm's collaboration propensity and collaboration outcome (measured as financial returns each research project generated in the marketplace) in involving core and non-core technological fields. The empirical results suggest that although there is a higher propensity to collaborate in firm's core technological fields, it is collaboration in firm's non-core technological fields that brings the firm the most benefits. However, collaboration in firm's non-core technological fields is not easy, as there appears to be a "technology threshold" of firm's technology capability to start up R&D partnerships. When comparing collaboration propensities between related non-core technological or unrelated non-core technological fields, we find that the propensity to establish partnerships in related non-core technological fields is higher than in distant non-core technological fields. Collaboration activities conducted in firms related non-core technological fields show the largest benefits to the firm. In sum, our findings show first empirical evidence that firms should make clear decision in choosing which technological field to engage into external partnerships before they start R&D collaboration activities.

This paper is organized as follows: we first provide a brief literature review on R&D collaborations in firms' core and non-core technological fields. Next, we develop hypotheses on: 1) the propensity to collaborate in firms' core, related non-core and distant non-core

[1] For a more detailed description of the calculation procedure, please refer to the methodology session of the paper.

technological fields; 2) the outcome of collaborations in these different technological fields. The fourth section details the empirical findings. Conclusions and discussion are presented at the end of the paper.

2. Theoretical Background

Prahalad and Hamel brought the notion of core competencies into the innovation literature. In their 1990 paper, they describe the diversified corporation as a large tree: "The trunk and major limbs are core products" and "the root system that provides nourishment, sustenance, and stability is the core competence" (p 5). In a later paper by Hamel (1994), the author tries to provide a working definition for core competencies. He clarifies core competencies as a bundle of knowledge and skills. "Competencies are skills and technologies, providing superior customer value, deployable in multiple markets and rare among competitors". There are different types of core competencies a firm may possess, such as technological competencies which relate to technology development and R&D, or commercial competencies which relate to market development and production (Hamel, 1994; Ahuja, 2000). This paper focuses on the former— firms' core competencies in technologies.

The past decades witnessed a strong trend in firms' development to refocus on their *core* technological fields (Patel and Vega, 1999; von Zedtwitz and Gassmann, 2002). This trend can be explained by two major reasons: First, there are resource and capability limitations of firms in scattering their resources in multiple fields, particularly in those which are technologically less related. Many firms have suffered from the negative effects of over-diversification in the late 1980s (Hoskisson and Hitt, 1994). As over-diversification scatters precious firm resources into different fields, it dilutes managers' attention and time, engenders intra-firm competition for internal resource allocation (Bruton et al., 1994), and thus impairs firms' core competencies. Therefore firms have been divesting units that are unrelated to their core competencies to strategically refocus or "down scope" and concentrate on their core products and technological fields (Hoskisson and Hitt, 1994). Second, there is also a strategic need for firms to establish visibility and competitive advantage via concentrating resources in developing a few expertise fields. The driver of the development of core technological fields is the need to establish and maintain competitive advantages in different businesses. It is found that a specific set of idiosyncratic technological core capabilities is needed to generate performance differentials with competitors. Technological specialization, for instance through a focused patent position, appears more important than technological performance as such (Duysters and Hagedoorn, 2000). The great need to address a specific market niche and profit therein brings increasing specialization among firms (Carroll, 1985). As no firm is able to simultaneously pursue leaderships in multiple (unrelated) technological fields (Hagedoorn, 1995), being specialized in a particular or limited number of technological fields helps the firm to optimize the use of its resources, to establish its position in a certain market, to better appropriate and protect its technology value, and to build up competitive advantage based on its specification and expertise. Core competences are therefore also defined as "technological capabilities and specialization" by a number of scholars (e.g. Duysters and Hagedoorn, 2000).

As such, core technologies enable firms to achieve innovations which may lead to a competitive advantage. It is argued that, other things being equal, firms' existing technology strengths enable them to deliver more successful products (Tushman and Romanelli, 1985; Zirger and Maidique, 1990). However, being solely concentrated on the existing core technological fields may be dangers to the firm: as it may "miss the next big wave" (Bower and Christensen, 1995) and be vulnerable in face of competence-destroying technological discontinuities (Gavetti, Henderson and Giorgi, 2004; Tushman and Anderson, 1986). Therefore, at the same time, firms are suggested to diversify their technology portfolio and develop competences in new, non-core technological fields. Those *non-core* technologies enable the firm to explore new areas which may predict a potential technology direction (Granstrand, Patel and Pavitt, 1997), to sustain the long-term thrive (Teece et al., 1997), to build up a wider range of capacities and better monitor technology developments (Brusoni and Prencipe, 2001), to be responsive and adaptive to a highly dynamic environment (Eisenhardt and Martin, 2000), and still, to provide "background knowledge" which support the development of their existing core technologies (Pavitt and Patel, 1997). Hence, non-core technologies also play an important role in firms' innovation strategies (e.g.: Galunic and Rodan, 1998; Brusoni and Prencipe, 2001).

It should be noticed that here the distinction between core and non-core technologies is static. In reality, firms' technology capabilities are not static, but evolve over time (Teece, 1997; Lei, Hitt and Bettis, 1996). Consider, for instance, the Finnish firm Nokia who changed its technology base from wood-pulp mills to electricity production and mobile telephone, and the highly specialized Dutch chemical firm DSM was originally a coal mining company – as still reflected in its name "Dutch State Mining (DSM)". Therefore, firms' technology competences are dynamic (Lei, Hitt and Bettis, 1996), technological fields that were previously non-core to the firm may gradually evolve into its core technological fields, and vice versa. As technology development is an idiosyncratic and cumulative process during which firms gradually add *related* competencies to their existing knowledge stock (Helfat, 1994), therefore, although both are "non-core" technological fields of the firm, some technological fields may be closely *related* to the firm's existing core technological fields, while some others may be at distance (or even *unrelated)* to its existing core technological fields. Consequently, a technological field is considered as "related" when it shares a similar underlying knowledge base with at least one of the core technologies of the firm (Leten et al., 2007). (for a graphical explanation, please refer to *Figure 1: Technological Fields of the Firm*).

[Insert Figure 1 About Here]

The existing literature sheds some light on the necessity of involving external partners in firms' core and/or non-core technological fields. Unique and idiosyncratic resources and knowledge possessed by the firm constitute firms' core competencies (Penrose, 1959) and such competencies evolve over time (Teece et al., 1997). Therefore firms have to dynamically upgrade their existing core capabilities and also probe into those fields that are "non-core" to them. In this process, knowledge acquisition and transfer from external sources may help to strengthen firms' existing knowledge base (Grant, 1996), providing opportunities to explore new technological fields (Duysters and de Man, 2003), and build up firms' competitive advantages (Grant and Baden-Fuller, 2003). Two frequently highlighted benefits of R&D collaboration are the potential to leverage partner's complementary resources (Teece, 1998; Das and Teng, 2001), and to facilitate organizational learning from partnerships (Kale and Singh, 2007; Grant and Baden-Fuller, 2003). To benefit from R&D collaborations, a certain level of absorptive capacity of the firm is needed (Tsai, 2009; Escribano et al., 2009) as it will be very hard for the firm to absorb the knowledge in need and learn from its collaborating partners if without a basic level of understanding of that knowledge (Cohen and Levinthal, 1990). Prior research has established that the more experience and knowledge stock a firm has in a certain technological field, the stronger absorptive capacity it develops in that field (Cohen and Levinthal, 1990; Zahra and George, 2002), which may, in turn, facilitate learning in a R&D partnership. Taken together, the above-mentioned factors may affect the decision making and development outcome of core/non-core technological fields of the firm.

Despite the benefits, there are, however, a number of potential obstacles in R&D collaborations as well. A main concern is competition with partners in cooperative research relationships. A firm may enter alliances primarily to learn its partner's knowhow (Hamel, 1991) and hence the partner that is slow in the learning race may find itself at a great disadvantage in gaining benefits from the collaboration (Ireland et al., 2002). Also, there may exist considerable risks of knowledge dissipation and leakage in a research partnership as there may be unwanted knowledge spillovers from the technologically stronger partner to its less advanced partners (Ahuja, 2000; Belderbos et al., 2004), which may, be particularly pronounced in firms' core technological fields. Therefore, R&D partnerships are not unambiguously welcome, and their effects are likely to differ according to different technological fields that are involved into collaborations.

Given their benefits and drawbacks, firms may strategically choose to engage into research partnerships and be selectively open in different technological fields in order to better leverage the benefits of R&D collaborations. However, it is unclear in which technological fields the firm tends to collaborate with external partners, and what the outcome will follow the different choices. The existing studies on the relation between collaboration and firms' different technological fields are rather scant. Among the limited number of studies, most of them are centered on the tendency of firms' collaboration decisions. As collaboration involves considerable investments in the process of partner-searching, information-gathering, and relationship-nurturing (Fisher and White, 2000), some studies suggest that whether collaboration is conducted in the core technological fields of the firm reveals "whether the investment is well connected with a cohesive technology strategy and does not represent a random action" (Caloghirou et al., 2004, pp 74-75), thus the authors advocate conducting collaboration activities in technological fields that are core to the firm. A higher level of absorptive capacity may be another factor that favors firms' decision in collaborating in their technology core fields, as they are able to learn better and faster in the collaboration partnership. For instance, Vega-Jurado et al. (2008) show that the stronger the firm's technological competences, the higher the level of cooperation with external partners. Therefore, in-house R&D activities not only act as the powerhouse to generate new knowledge for the firm, but also promote its usage of external knowledge from outside sources. Some other studies, however, suggest that to sustain co-development relationships and to avoid knowledge leakage, firms should mainly collaborate in their non-critical technological fields, while leaving the core fields (to a great extent) to internal development

(Chesbrough and Schwartz, 2007). As the distinction between firms' core and non-core technological fields is dynamic, the attractiveness of firms' related or distant non-core technological fields may also vary. Via their linkages with the core technological fields of the firm, related non-core technologies may act as bridges or structural holes for partners to access focal firms' technology strong fields through indirect ties (Vanhaverbeke et al., 2008), which may affect their collaboration propensity and outcome over the distant non-core technologies of the firm.

Considering all the foregoing discussion, we can illustrate the main points by the following graph (Figure 2). We classify firms' technologies in three groups (core technological fields, related non-core technological fields, and distant non-core technological fields). We will compare firms' propensities to collaborate and the performance effects of collaboration in those three groups of technologies. The boundary of firms becomes increasingly porous in the context of open innovation, as represented by the dashed oval in the following graph. The dark-colored circles represent core technological fields of the firm, and the light-colored circles are the non-core technologies. The size of the circles denotes the knowledge coverage in a particular technological fields, and the distance between circles represents the technological distance between them. Hence, the circles that are close to the firms' (at least one of the) core technological fields denote the firm's related non-core technologies, while the circle that is remote to the firm's core technological fields represents the firm's distant non-core technologies.

[Insert Figure 2 About Here]

3. Hypotheses

In this section, we will first discuss firms' collaboration propensities in their core/ non-core technological fields, and then in a second step, we will discuss firms' collaboration outcomes.

3.1 Collaboration Propensity in Core and Non-Core Technologies

We suppose the firm will have little incentive to be open to external parties in their core technological fields. Although collaboration is a realistic strategy, there may be less incentives to collaborate when the firm is highly professional in a particular field (Daft, 1978). Moreover, from a pure economic point of view, the considerable time and efforts the firm may spend in searching for the right partners and establish relationships with them

(Fisher and White, 2000) to jointly exploit its own core competencies is not desirable as well. First, the benefits of collaboration in a core technological field of the firm may be limited. As the building-up of core competencies is a long term endeavor, it may be difficult to improve firms' core technologies through the relatively short term of collaboration process. It is both the complex character of modern technology and the difficulties associated with the transfer of technological knowledge (Mowery, 1988) that seem to favor internal development instead of external competence appropriation through R&D partnerships (Duysters and Hagedoorn, 2000). Further, firms that have developed core capabilities in a particular technological field likely have also established trajectories that negatively affect its receptivity to externally generated knowledge (Song et al., 2003). Because of the "Not-Invented-Here" syndrome (Katz and Allen, 1982), when a firm has developed strong capabilities in a particular technological field, it also developed certain routines which improve operations in that field, but makes it less receptive to changes and external knowledge. For instance, analyzing the knowledge base of the hiring firm and its newly hired engineers, Song and colleagues (2003) find that core areas, in which innovative activity proceeds along well-trodden paths, are less receptive to external influence[2] offer fewer opportunities to incorporate external knowledge than less-established or peripheral technological areas. Thus, learning in firms' core technological fields may be limited.

Second, there is also fear of unwanted knowledge leakage to its external partners, which may discourage the firm from collaborating in its core technological fields. In its core technological fields, the firm attaches significant value to reducing governance-based risks (Vanhaverbeke et al., 2012) and the prevention of leakage of strategically sensitive knowledge to collaboration partners. Therefore, in the case of core technologies, firms tend to put greater emphases on possibilities of reducing the risks in a partnership, compared to profiting from its benefits (Cassiman and Veugelers, 2002). For instance, it is found that the leading American carmakers, GM, Ford, and Chrysler act independently of each other as far as their core activities are involved (Hagedoorn, 1995). A number of risks are also involved in the process of R&D collaborations. For instance, there is potential learning race among partners in a R&D collaboration (Hamel, 1991), opportunistic behavior of partner such as technology free-riding (Tripsas et al., 1995), as well as technology appropriation and intellectual property (IP) allocation issues on the resulting innovations of the R&D collaboration (Dekker, 2004). While collaborating in the firm's non-core technological fields

[2] In their case, it is the new hirer's influence to the hiring firm.

may partly solve these problems, the collaboration outcome can be influenced as it was not built on the best available expertise. Hence, taking into account both the problems of marginal learning effects and knowledge-leakage risks of conducting collaborative activities in the core technologies, we hypothesize that:

H 1 : Compared to their non-core technological fields, firms have little propensity to collaborate in their core technological fields.

3.2 Collaboration Propensity in Related and Distant Non-Core Technologies

Knowledge that is core to a firm is developed through a long-established and well-implanted development trajectory (Nelson and Winter, 1982) which although provides the firm with competitive advantage over some period of time, may also create problems of "core rigidities" (Leonard-Barton, 1992) or "information myopia" (Rumelt, 1974; Levinthal and March, 1993) that erode its core advantages. As such, the core technological fields of the firm need to be rejuvenated over time, and knowledge transfer via collaboration is oftentimes mentioned as one possibly effective approach to address such needs (Chesbrough, 2003). However, knowledge that is core to a firm should be carefully protected and only limited shared. Knowledge transfer with external partners can "hollow out" the core competencies of the firm advantages (Reich and Mankin, 1986; Hamel, Doz, and Prahalad, 1989; Doz and Hamel, 1998). Hence, firms may be reluctant to open their core fields to external partners (Zhang and Baden-Fuller, 2008; Vanhaverbeke et al., 2008). While the fear of knowledge leakage exists when collaboration is conducted in firms' core technological fields, such concern may be less severe if firms collaborate in their non-core technological fields. Non-core technological fields are more positioned to "learn", where the firm has little or no prior knowledge to lose or leak away. As suggested by Chesbrough and Schwartz (2007), firms should collaborate in those "contextual fields" which are not in their core competencies. While from the perspective of the focal firm, it is favorable to establish partnerships in its non-core technological fields, it may face many challenges in doing so.

First, we suppose that in the non-core technological fields, the firm may suffer from unwillingness of potential partners in establishing collaborative relationships. Unlike the core technological fields, it can be particularly hard for the firm to convince external parties to collaborate with it in the non-core technological fields. As collaboration is essentially a mutual choice by both sides of collaborating partners, relation formation inherently requires that not only the firm in itself is desirous to establish a partnership, it should also be considered as attractive to its potential partners (Kogut, Shan, and Walker, 1992; Shan, Walker, and Kogut, 1994; Ahuja, 2000). In the non-core technological fields of a firm, if the technology is rather peripheral in which the firm has little knowledge to refer to, and its partner face great risks of knowledge leakage, it may be undesirable for external parties to establish collaborations with it.

Second, apart from concerns of knowledge leakage, the weaker partner may also serve as a limiting factor in collaboration activities, which in turn, bring uncertainties in the collaboration process[3]. Therefore, a weaker partner may reduce the desire of a stronger partner in establishing collaboration relationships because of a fear of uncertain (or unsuccessful) collaboration result. Hence, we suppose, compared to core technological fields, in the non-core technological fields of the firm, the observed possibility of collaboration is low.

However, not all non-core technologies should be treated the same, as there are differences between related and distant non-core technologies. The problems in collaborating in non-core technological fields may be alleviated if collaboration is conducted in fields which are backed-up by some pockets of background knowledge in the firm's core technological fields. Such background knowledge may help the firm better understand the content in collaboration, and can act as "indirect links" which enable the firm to be more attractive to its potential partners compared to if the collaboration field has no, or little knowledge to offer to its partner. The potential partner in the collaboration process may not directly aim to access the technology in the particular collaborating field of the focal firm, but instead, it may be interested in the related resources and expertise that surrounding it. For instance, some companies such as Cisco and IBM provide platforms (in which they themselves are not necessarily experts) for collaboration, the external partners are attracted to those platforms, contributing their expertise, and jointly developing products with them. They are attracted not because of the technological strength of Cisco or IBM in that certain fields, but the pockets of related background knowledge they may tap into during the collaboration process. Therefore, although the firm may not be strong in the focal technological field involved in the collaboration, if it has relevant background knowledge in its vicinity, the chance of collaboration may still be high. On the other hand, from the focal firm's point of view, there is also a need to engage into collaboration relationships in its related non-core technological

[3] "Liebig's Law of the Minimum" states that growth is controlled not by the total amount of resources available, but by the scarcest resource (limiting factor).

fields. Organizational learning theory suggests that incumbent companies attempt to learn new knowledge from their alliance partners and internalize the knowledge to build up their own internal competencies (Mowery, Oxley, and Silverman, 1998; Inkpen and Tsang, 2007). They may start with local search in fields that it is more familiar with (Katila and Ahuja, 2002). Consequently, learning through alliances can complement endogenous learning to create new competences (Kogut, 1991; Auster, 1992), which can be particularly helpful for developing firms' related non-core technological fields. Because of the stock of background knowledge the focal firm has developed around a certain related non-core technological fields, it may also be easier for the focal firm to absorb knowledge (Cohen and Levinthal, 1990) and transfer it via the collaboration relationship. Hence, we hypothesize:

H 2: *Compared to other technological fields, firms have a higher tendency for R&D collaborations in related non-core technological fields.*

3.3 Collaboration Outcome in Core and Non-Core Technologies

Given the collaboration propensity in different technological fields of the firm, we are also interested in the outcome of these collaborations. We suppose that the actual effects of collaborating in firms technology non-core fields will be higher compared to collaborations in the firm's core technological fields.

First, firms may learn more and better in their non-core technological fields compared to in their core technological fields. As the firm has already developed deep pockets of competencies and well-defined routines in their core technological fields, the effect of learning from external parties may be rather limited in those fields. On the contrary, as the firm lack in-house competencies in its non-core technological fields, it may benefit more from learning from external parties. The firm may facilitate learning from interactions with their (technologically more advanced) partners, even just simply being immersed in a learning environment.

Second, to create value from collaborations, opening up and freely sharing knowledge is needed. Compared to their core technological fields, firms are more willing to open up in their non-core technological fields, which, in turn, may improve their collaboration effects. Collaborations conducted in firms' core technological fields may be hampered by the particular attention paid to knowledge protection. It is stressed that, in order to effectively realize the synergies between partners in collaboration, intensive interaction between partners is necessary (Doz, 1996; Faems, Janssens & Van Looy, 2007). Existing studies on inter-firm R&D collaboration, however, observed that the willingness of partnering firms to engage in intensive interaction is often low because of ex-ante knowledge appropriation concerns. Madhok and Tallman (1998: 332), for instance, argue that 'such interaction acts as a double-edged sword since, in order to attain the underlying purpose of transferring, absorbing, and, generally, more effectively combining complementary capabilities at the heart of the collaboration, the firm also exposes critical resources and capabilities to transmission through the alliance to the partner firm.'. This may, in turn, negatively affect the collaborative interactions in firms' core technological fields. In a similar vein, Heiman and Nickerson (2004: 401) mention that intensive and fine-grained interaction 'increases the likelihood that economically valuable knowledge […] is expropriated.' In other words, these scholars suggest that firms' ability to come to joint value creation in collaborative projects might be restricted because of ex-ante concerns that the other partner might opportunistically appropriate the knowledge that results out of such interaction, while it is a serious concern of collaboration in firms' core technological fields, it is less a problem in their non-core technological fields. Therefore, we hypothesize:

H 3: *Compared to collaboration in their core technological fields, firms benefit more from collaboration in their non-core technological fields.*

3.4 Collaboration Outcome in Related and Distant Non-Core Technologies

Besides the differences of collaboration in core and non-core technologies, within non-core technologies themselves, there may also be differences between firms' related and distant non-core technological fields. Compared to unrelated non-core technologies, when firms collaborate in related non-core technological fields, they likely have more opportunities to find the right and willing partners, and have necessary absorptive capacity to benefit from collaborations (Cohen and Levinthal, 1990). In contrast, collaboration outcome may be negatively affected if collaboration is conducted in firms' distant non-core technological fields. First, the firm may have very little absorptive capacity to enable effective learning in their unrelated non-core technological fields. It is often noted that a firm's absorptive capacity to a large extent depends on the knowledge it accumulated in a specific field (Dodgson, 1989; Cohen and Levinthal, 1990). If the firm has not yet developed a sufficient level of knowledge in a specific field, it will then turn out to be extremely difficult for the firm to absorb externally acquired knowledge into its existing technological fields. As it is observed, many mergers and acquisitions (M&As) that are conducted outside of the firm's existing main business are not successful in achieving good performance (Duysters and Hagedoorn, 2000). Similarly, compared to collaborating in those related non-core technological fields where the firm has a better understanding about the underlying knowledge and mechanisms, collaborations conducted in those unrelated non-core technological fields in which their future development is still largely uncertain, may not pay off.

Second, collaborating in firms' related non-core technological fields may also open up a range of new opportunities for innovations and knowledge (re-) combinations within the firm. Via their linkages and immediate references to the core technological fields of the firm, collaborations conducted in the firm's related non-core technological fields allow for knowledge synergies and cross-fertilization among different knowledge streams both within the firm, and between the firm and its external partners. Therefore, we hypothesize:

H 4: Compared to collaborations in their distant non-core technological fields, firms benefit more from collaborations conducted in their related non-core technological fields.

4. Data and Sample

To test our hypotheses, we use a unique dataset on research projects which are conducted by a large multi-national multi-divisional European-based manufacturing company. The company adopts a global R&D structure which is typical for large technology-based companies (von Zedtwitz and Gassmann, 2002). Research projects are conducted in central R&D laboratories and are initiated by either Corporate Research– the central R&D unit of the firm, or by one of the firm's business units. Corporate Research overviews the R&D activities of the firm as a whole, and mainly sponsors research projects that are highly explorative, have a long-term orientation and are of strategic importance to the firm. Business units, on the other hand, being restricted by the need to show (quick) returns on R&D investments and a regular evaluation of business achievements, mainly sponsor research projects that are application-oriented and have a relatively shorter time window.

The R&D laboratories execute research projects and transfer the research outcomes to the business units that express their interest in taking up these outcomes for further development and commercialization. Each project is evaluated on a yearly basis from its start to termination (or to the latest year of data collection— 2010, if it is ongoing). From the beginning of a research project, there is annual information on its R&D partnerships, project practices (full-time equivalent researchers, project management, project sponsoring units and recipient business units). After excluding the observations that have missing data, we have information on 876 research projects. Our dataset is a cross-sectional dataset that contains 876 observations. Financial performance is measured as total performance, and the explanatory variables are constructed as stock variables (e.g. partnership variables and full time equivalent researchers) or take average values over the course of research projects. More details on the construction of the different variables are provided below.

4.1 Dependent Variable and Empirical Method

We use two dependent variables in this analysis.

***Collaboration Propensity*.** The first dependent variable is collaboration propensity. Here we use the observed collaboration behavior of the project and test possible influential factors that lead to the (un-)adoption of collaboration behaviors. The first set of regressions is based on Logit analysis. Projects' choice of being "open" is measured as a 0/1 variable. "0" indicates that the project is closed, and "1" means the project has established collaborative partnerships during its lifetime.

***Project Financial Performance*.** Based on analyzing collaboration behavior of the project, we take financial performance as a second dependent variable. Financial performance is the most frequently used measure of the performance of research projects (see Cooper et al., 2004, for a review of project-level performance indicators). Financial performance is measured as the total revenues that are generated by the "transferred" outcomes of a research project to one or multiple business departments, being conducted either in an open or closed manner. R&D partners share development costs and risks, but they also share innovation revenues (Belderbos et al., 2010). The dependent variable is the part of financials the focal firm earns through the revenues generated via internal and external paths to markets (e.g. licensing or IP sales). Financial performance is a continuous variable that takes an average value of 10,4 million euro, and ranges between 0 and 920 million euro. The variable is truncated at a value of 0. To account for the truncation, Tobit regressions are used (McDonald and Moffit, 1980; Greene, 2000). We control for heteroskedasticity by using robust standard errors.

4.2 **Independent Variables**

R&D Collaborations. We have annual information on the R&D collaboration practices of the research projects. More specifically, we know– for all project years– whether a research project is in collaboration with partners or not. The *R&D partnership* variable gets a value of "1" if there is a R&D partnership with external partners in at least one of the project years. Out of the 876 research projects, 325 (37.1%) are "closed" projects, and 551 (62.9%) are "open" projects where the research team collaborated with external partners. Of all the projects, 119 (13.6%) projects are conducted in the firm's core technological fields, 205 (23.4%) are in the firm's related non-core technological fields, and 552 (63.0%) are in the firm's unrelated non-core technological fields. Below, we explain how we divide the research projects into those that are related to core technologies and those that are related to non-core technologies.

Technological fields of the Firm. We distinguish between three types of technological fields of the firm, namely, core technological fields, related non-core technological fields, as well as unrelated non-core technological fields. We first distinguish between core and non-core technological fields. In calculating firms' core technological fields we adopt two criteria: 1) *Patent Share*: the shares of the firm's total patenting in each of the technological fields (at IPC-4digit level), that is, a relative importance for the firm of competencies in each of the technological fields. 2) *Revealed Technology Advantage*: the shares of the firm in total patenting in each of the technological fields, divided by the firm's aggregate share in all the fields (Patel and Pavitt, 1997). In other words, these two criteria measure the absolute importance of the firm to these technological field, as well as the relative importance of the firm to these field of technological competence, after taking account of the firm's total volume of competencies. Following Patel and Pavitt (1997), for the first criterion, *Patent Share*, we use a 3% patent share (at the IPC-4digit level) of the firm in the technological field of all patents filed in that technological field as the cutting point of firm's high/ low patent share. A patent share that is equal to, or more than, 3% among all the patents filed in that technological field is considered as high. For the second criterion, *Revealed Technology Advantage*, we use 2.0 as the cutting point of firm's strong/ weak revealed technology advantage, that is, the firm's technological fields with a patent share (among all patents filed by all patent applicants) at least double the size of the firm's overall patent share in all technological fields, are considered as of high revealed technology advantage. Combining the two criteria together, the technological fields that are of both high patent share and high revealed technology advantage are defined as "core technological fields" of the firm (for a detailed graphical explanation, please refer to Figure 3). We did the calculation on a yearly basis, therefore, the core/ non-core technological fields of the firm is identified yearly. As a research project may last for several years, we take the classification of its technological fields (core/ non-core) at the start of the project as the classification of the research project. For robustness check, we also use 5% patent share as the cutting point of the firm's core/ non-core technological fields[4], which gives similar results.

[Insert Figure 3 About Here]

After classifying a project to core or non-core technological fields, we further distinguish between firm's related non-core fields and unrelated non-core fields. Based on Leten et al. (2007), we measure the technological relatedness of two technology classes via comparing the observed numbers of citations between these classes with expected numbers of citations, under the hypothesis of random occurrence of technology classes on cited patents. Let N_j be the total number of patents that are classified in technology class *j*, with $T = \sum_j N_j$. making no specific assumptions about the form of the random distribution of technology classes across cited patents, this gives the following expression for the expected number of cited patents of technology class *j* in citing patents of technology class *i* (E_{ij}): $E_{ij} = O_i * (N_j / T)$. A measure of technological relatedness is then calculated as follows: $R_{ij} = (O_{ij} + O_{ji}) / (E_{ij} + E_{ji})$. This leads to the creation of a symmetric matrix of relatedness measures for each pair of distinctive technology classes. The interpretation of R_{ij} is straightforward: if $R_{ij} > 1$, then technologies *i* and *j* are more related than could be expected on the basis of random citation patterns (Leten et al., 2007). Citation data in European Patent Office (EPO) is used for this paper. We calculate the pairwise patent citations of each two technology classes, which results in an indicator with a value larger than 1 (meaning more observed citations than expected citations between the two technology classes) representing high relatedness between the two technology classes, and a value smaller than 1 (meaning less observed citations than expected citations between the two technology classes) denoting low relatedness between the two technology classes. Thus, the non-core technological fields which share high levels of technology relatedness with the firms' core technological fields are considered as "related non-core technological fields", while the non-core technological fields which share low levels

[4] For the cutting point of revealed technology advantage, at least in our sample, 2.0 is quite consistent.

of technology relatedness with the firm's core technological fields are considered as "unrelated non-core technological fields". For robustness check, we also use 1.5 as the cutting point of technological relatedness in this paper, which gives similar results.

For a distribution of different project technological fields, please refer to Table 2 (overall) and Table 3 (yearly).

4.3 **Control Variables**

There are several factors that may influence project performance. We operationalize on a number of variables to control for possible confounding effects at the project level in this paper.

Project Resources. We use the number of full time equivalent researchers (FTE) working on a R&D project as a proxy of project size and internal resource endowment. This information is available on a yearly basis. In line with the R&D collaboration variables, this variable is calculated as a cumulated variable over the past years. Moreover, this variable is highly correlated with project costs, and thus we use it as an alternative to the cost of the project.

Project Technological Fields. We use a set of dummy variables to denote the technology fields in which R&D projects are executed. We have followed a two-step process to classify R&D projects into technological fields. First, for projects that have made patent applications, we use the technology class information on the patent applications. If a patent contains multiple technology classes (IPC4-digit level), a project is assigned to multiple fields. Second, the remaining projects are assigned manually to IPC technology classes by using information on the project content from the project titles and descriptions. To reduce the probability on misclassifications, we work at the level of IPC 4-digit classes. Technology classes with a low number of projects in our sample are grouped together in a rest category.

Project Technical Strength (Firm Patent Stock). This variable represents the technological strength of the company in the technology fields that are relevant for the R&D project. It measures to what extent the company has a strong technical expertise in the technological field(s) of the R&D project. These competences are expected to be (at least partly) accessible to the project team. This variable represents the previous 5-year patent stock of a project, which is measured based on the total number of the relevant 4-digit IPC code (5 years prior to the project year) of the patent applications the firm has made in EPO. The technological fields of a project are identified based on its 4-digit IPC code of the firm's patent stock. We have collected patent data for the sample firm at the consolidated level, including both the parent firm and their majority-owned subsidiaries. The consolidation was done on a yearly basis (2003-2010) to take into account changes in the firm group structure due to acquisitions, mergers, green-field investments, spin-offs and divestments. Based on the technological fields of each research project, we extracted the relevant patent stock in the same technological fields of the firm five years prior to project origination. We also calculated previous 3 years and 10 years patent stock as robustness checks.

Project Management. It is argued that successful projects are the ones that have implemented stage-gate processes in a more systematic way than the rest (Cooper, 1990; Kahn et al., 2006; Griffin, 1997). Following previous studies, in this paper we introduce the variable "project management maturity" (PMM) indicating to which extent the projects has followed a formalized management process. This indicator is evaluated on a yearly basis with a scale from 0 to 5.

# of Projects Under Management. The more projects a project leader is actively managing, the less time and energy he may devote to each individual project, which may affect project outcomes. Projects that receive more attention from their project manager may enjoy timely feedback, and receive more managerial support, and be ultimately more successful. In this study, we use number of projects that the project leader is managing concurrently during the project's life span as a proxy for (a possible lack of) managerial attention.

Corporate Research. In this study, research projects can be initiated from two types of sponsor units, i.e. corporate research, or the business groups which are in different business divisions. We control for the differences between project sponsors by adopting a dummy variable with value "1" representing a project initiated by corporate research, while "0" suggesting that a project is sponsored by business divisions.

Project Transfer. A first condition for a R&D project to generate financial returns is a transfer of the project results to one, or multiple, business departments. We use a dummy variable (0/1) to indicate whether a R&D project has generated a transfer.

Sponsor Departments. R&D projects can be initiated by corporate research (49% of projects) or any of the business departments (51% of projects). As explained before, R&D projects that are initiated and sponsored by different departments are likely to differ in characteristics. We therefore add a set of 11 dummies that indicate the sponsor departments.

Project Initiating Years. Finally, we control for the year in which the project started. The "project originating year" may signal the macroeconomic situations at a particular point in time, but it may also embody the effects of changes in corporate level strategy on the R&D projects. We use a range of dummy variables to control for effects related to specific external and internal conditions when R&D projects were initiated.

Descriptive statistics and correlations for the variables are provided in Table 1. As mentioned above, most of the research projects have open innovation partnerships (62,90%). 31.74% of the research projects generate transfers. None of the reported correlations are high. The variance inflation (VIF) score is 1.5, which is well below 10; hence multi-collinearity is not an issue in our analyses. In general, our sample projects spreading among a wide range of 25 "core" technological fields (at IPC-4 digit level, Pavitt & Patel definition), which are clustered into 15 broad technological fields (at IPC-3digit level) and 4 general technological areas (at IPC-1 digit level). For more details, please refer to Table 2 and Table 3.

[Insert Table 1 About Here]

[Insert Table 2 About Here]

[Insert Table 3 About Here]

5. Empirical Results

5.1 Collaboration Propensity and Technological fields

The results of the regression analyses on collaboration propensity and technological fields are shown in Table 4. Collaboration activities in research projects are measured by 0/1 dummy variable, and all the five models test the propensity to collaborate of the project. The main independent variables: core technological fields, related non-core technological fields as well as unrelated non-core technological fields are mutually exclusive. Model 1 is the baseline model which includes only the control variables. Research projects that are initiated by corporate research and are equipped with a larger number of project resources (FTE) are more likely to adopt R&D partnerships in their innovation activities. Furthermore, the more projects sharing the same project leader (larger number of research projects under management), the more likely they adopt R&D partnerships. Controlling for different technological fields of the firm and its patent stock in the relevant technological fields does not seem to influence project's propensity to collaborate. Finally, the sets of dummy variables controlling for the sponsoring departments, technological fields and initiating years are jointly significant.

[Insert Table 4 About Here]

We now look at projects' collaboration propensity in different technological fields of the firm. The "Core Technological fields" variable is added to Model 2. The results of the other variables remain unchanged when including this variable. The coefficient of the Core Technological fields variable is positive and significant. Hence, Hypothesis 1 is not supported: The likelihood to set up R&D partnerships is higher when in the firm's core technological fields. In Model 3, collaboration propensity in firms' related non-core technological fields is added into the model. We do not find a significant relation between collaboration propensity and firms' related non-core technological fields. This means, on average, firms' collaboration propensity in their related non-core technological fields is not significantly stronger (or weaker) than its other technological fields. Therefore, Hypothesis 2 is not supported. In Model 4 we test firms' collaboration propensity in their distant non-core technological fields. For this set of regression, we find a negative and significant effect of the collaboration propensity and firms' distant non-core technological fields. The negative coefficient confirms Hypothesis 3: There is less collaboration conducted in firms' distant non-core technological fields than the others. Finally, in Model 5, we test for the relative effect of firms' collaboration propensity in their technology core, and related technology non-core fields. The baseline category in this model is collaboration propensity in firms' distant technology non-core fields.

5.2 Collaboration Outcome and Technological fields

Table 5 and Table 6 show the financial outcome of engaging (or not) into R&D collaborations in firms' different technological fields. In Table 5, we split the sample into three mutually exclusive groups: namely, firms' core technological fields, related non-core technological fields, and distant non-core technological fields. Project financials is the dependent variable. Since the dependent variable is a continuous and truncated at "0", Tobit techniques are used. Model 1, 3, 5 are baseline models for each different technological fields, Model 2, 4, 6 are models added with open innovation partnerships. The negative and significant coefficient in the result of technology core fields shows that open innovation partnerships in firms' technology core fields actually are not paying off, and such collaborations also seem to negatively influence firms' corporate research. However, when looking at firms' related non-core technological fields (Model 4), open innovation partnerships then play a positive and rather significant role, which means, open innovation partnerships pay off in collaborations conducted in firms' related non-core technological fields. Finally, Model 6 shows the result of establishing open innovation partnerships in distant non-core technological fields, which also shows a positive effect, but not significant. In Table 6, we created interaction terms of R&D collaborations and different technological fields of the project and ran regressions again on the full sample. Findings in Table 5 are confirmed: although firms do better in their core technological fields, conducting R&D collaborations in those fields in general hampers their performance (Model 2). On the other hand, firms have a high possibility to suffer from failures in innovations conducted in their related non-core technological fields, while leveraging external expertise in R&D collaborations help them to improve their performance (Model 3). Maybe due to limited absorptive capacity, or because of the "technology threshold", collaborating in firms' distant non-core technological fields does not pay off (Model 4). The above findings are consistent when are pulled into a complete regression model, where collaborations in firm's distant non-core technological fields is the baseline (Model 5). In sum, Hypothesis 4 is supported, that compared to collaboration in their core technological fields, and firms benefit more from collaboration in their non-core technological fields, in particular, related non-core technological fields.

[Insert Table 5 About Here]

[Insert Table 6 About Here]

5.3 Robustness Check

We conducted various robustness checks, using different cutting points of core/non-core technologies and technological relatedness of two technology classes (for the criteria that we used, please refer to Table 7)[5]. In general, a vast majority of innovation activities of the firm are conducted in the core and related non-core technological fields. According to different combinations that we use, these two technological fields together account for between 70% ~ 90% of the firm's overall R&D activities (based on Pavitt and Patel definition of core technologies).

[Insert Table 7 About Here]

The first set of robustness checks are related to collaboration propensity. Where we first separate the general collaboration variable "open innovation" (whether or not in collaboration with any type of external partners) into more finely-grained types of collaborations, based on the type of partners that are involved in the partnership (market-based or science-based). When breaking down collaboration into different types of partnerships, it is interesting that openness in core technological fields is more relevant to market-based partners, than to science-based partnerships. It seems it is indeed the technological excellence of the firm in a certain technological fields that drives its partnership establishment with externals. In contrast to the significant finding of collaboration propensity with market-based partners, the propensity of collaboration with science-based partners seem to be less clear. As expected, (may be) driven by the learning effect, firms links up more with science in their relatively weak technological fields (distant non-core). Firms also collaborate more with science in their core technological fields, albeit to a lesser extent compared to in their distant non-core technological fields. However, unlike the strong effect as what we've found for collaborations with market-based partners, both effects with science-based partners are not that significant.

We also tried to replace the "core/ non-core" concept with more extreme cases, that is, 1) whether the technological field is completely new for the firm, and 2) whether the technological field is completely unrelated to the firm's core fields. For the former, we denote those technological fields with no any prior patent applications as *New Technological fields* of the firm; and for the latter, we indicate those technological fields with technology relatedness of "0" to the firm's core technological fields as *Unrelated Non-Core Technological fields*. We run logit regressions using each of them as independent variable respectively, and we use different types of collaborations (general collaboration, with market-

[5] Results are omitted because of limitation of space. The result tables are available upon request.

based partners, with science-based partners) as dependent variables. What we find is that for those new technological fields, firms tend to leverage collaborations as a means for new technology development. In more details, while the propensity with market-based partners is high, such propensity with science-based partners is although positive, but insignificant. On the contrary, for firms' unrelated non-core technological fields, collaboration propensity with all three types of partnerships are low. Hence, combining the findings, it then turns out to be that firms can leverage partnerships in developing their new technological fields (as long as it has some relatedness with its core technologies), while it is particularly hard for them to develop technologies that are completely irrelevant to their core technologies.

The second set of robustness checks are related to collaboration outcome. We did robustness checks based on the combinations of different levels of core technologies and different levels of technology relatedness. First, we use a higher cutting point for defining project core technological fields, where we raise the criteria of being a core technological field to patent fields that account for equal to or more than 5% in firms' total patent shares (instead of 3% in the previous setting). We then also use a different level of technology relatedness, where we set the cutting point of being in a "related technological fields" as 1.5 (instead of 1 in the previous settings). The analysis results based on these different criteria both show similar results. Due to limited space, the results of other similar combinations are omitted, which all give similar results.

Finally, following the categories as mentioned before, we did also robustness checks on the collaboration outcome in firms *New Technological fields* and *Unrelated Non-Core Technological fields*. In line with previous chapters, open innovation partnerships are positive and significant to project financials. We find that conducting R&D activities in new technological fields per se brings negative financials, but open innovation helps to overcome such negative effect. Interestingly, there is a positive financial effect of R&D activities conducted in unrelated non-core technological fields, where open innovation partnerships do not seem to help much.

6. Discussion and Implications

In this paper we aim to examine 1) In which technological fields firms have higher propensity to collaborate with external partners; and 2) What are the collaboration outcomes of these choices. We distinguish between three types of technological fields of the firm: core technological fields, related non-core technological fields, and distant non-core technological fields, and compare firms' collaboration propensity and collaboration outcome in these different technological fields, respectively. In exploring these issues, this paper sheds light on collaboration decisions and their outcome, particularly to the internal organizational activities of innovative firms.

The findings are thought provoking. We find that although firms collaborate more in their core technological fields, it is collaborations conducted in their non-core technological fields (more precisely, related non-core technological fields) that benefit them the most. In terms of collaboration propensity, we find that, at least for research projects, there is a surprisingly low collaboration propensity in their non-core technological fields, which is contradictory to some existing suggestions (e.g.: Chesbrough and Schwatz, 2007). A possible explanation is that, because the establishment of R&D partnerships is essentially a process of mutual choice from both partners, therefore the focal firm also needs to be considered as desirable and attractive to its potential partner as well. It seems a certain level of "technology threshold" exists for firms that wish to establish external R&D partnerships. Projects that are below such a threshold (e.g.: distant non-core technological fields or even unrelated non-core technological fields) seem to suffer from difficulties in establishing R&D partnerships with external partners, thus show a low collaboration rate. Another explanation may be that in non-core technological fields of the firm, strong ties (thus fewer ties and also harder to establish) will be preferred by the focal firm because the firm will learn more through some very dedicated ties in their distant non-core technological fields as it is so difficult to learn; While in core technological fields of the firm, loose ties (thus more ties and may be easier to establish) will be preferred by the focal firm, because loose ties with partners help the firm to explore new technological fields and potential technological opportunities. Future research may explore into details on these issues. Nevertheless, based on our research findings, it is suggested that in order to benefit from R&D collaborations, it is useful for those distant non-core technological fields to firstly develop their technology capabilities to a certain level (i.e. beyond the technology threshold) or develop familiarities with their existing core technologies (higher level of relatedness), instead of trying to rashly start R&D partnerships from scratch with low technology capabilities. In terms of collaboration outcome, our study shows that despite a high collaboration propensity in firms' core technological fields, it is collaborations that are conducted in firms' non-core technological fields (in particular distant non-core technological fields) that benefit them the most. Hence, the additional gains of collaboration in firms' core technological fields may not offset the potential loose of knowledge leakage and spillover in such fields.

Our study contributes in different ways to the literature. Open innovation as a field of research needs hard empirical evidence to explore how project management activities and decisions may influence project outcomes. Most existing literature adopts a lens looking at external factors, while with considerable shortage of looking at the intra-firm organizational behaviors and activities of the firm. Our study thus enriches this literature stream and provides new insights on organizing intra-firm activities (namely, decisions on collaborations and firms' technological fields) for better collaboration outcomes. Moreover, in the literature stream of open innovation, "openness" is considered as a simple construct (whether or not in collaborations and with whom), we propose that openness should be shaped according to the competences of the firm. The type of technologies is a very important contingency factor to keep in mind when studying open innovation, its behaviors and performances.

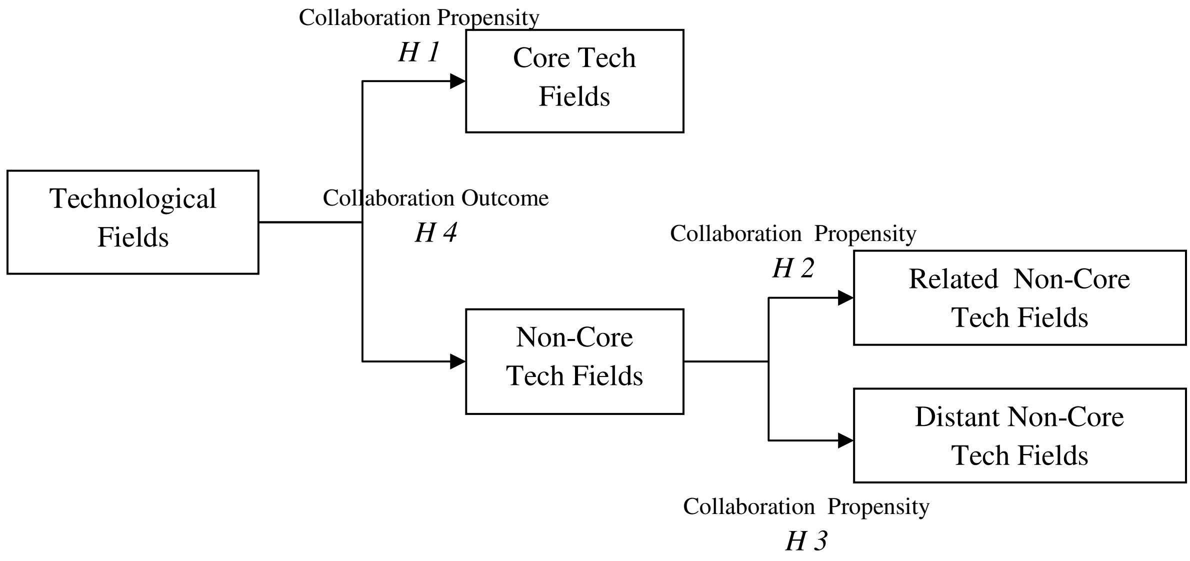

Figure 1 Technological Fields of the Firm
(Hypotheses and Conceptual Framework)

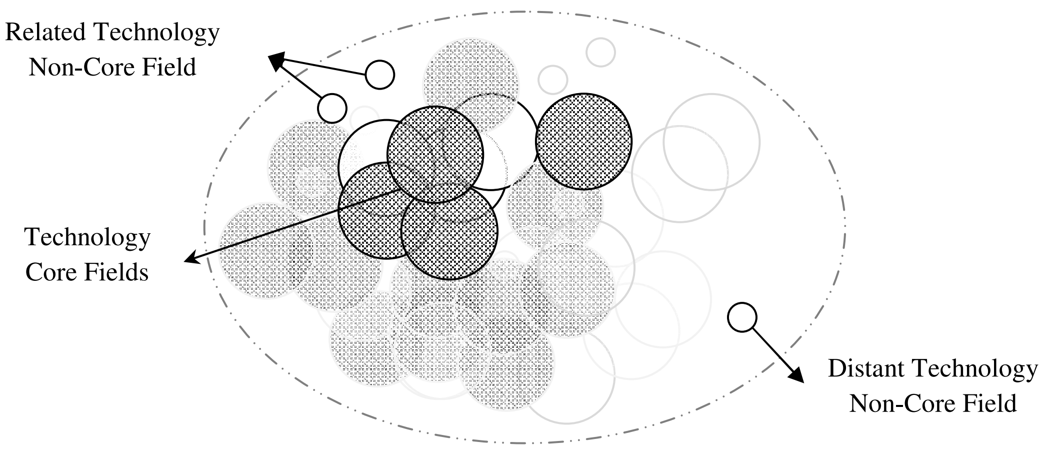

Figure 2 Technological Fields of the Firm (Cont.)

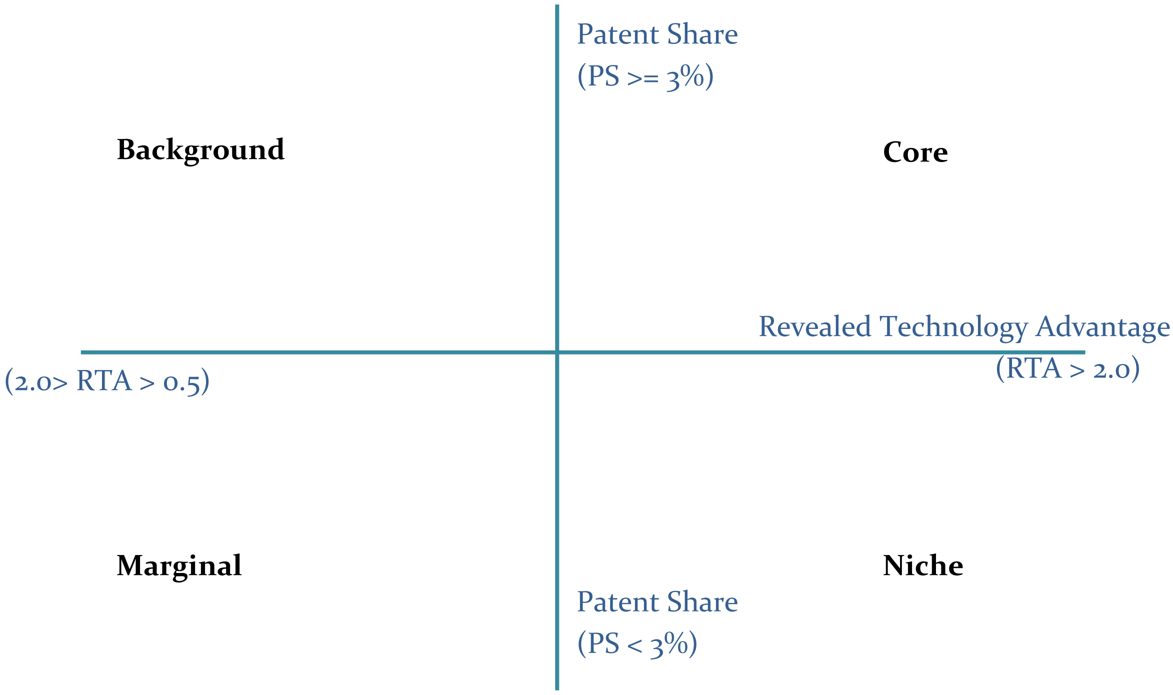

Figure 3 Classification of Firms' Technological Profiles

Source: Patel and Pavitt, 1997

Table 1 Descriptive Statistics and Correlations

	mean	s.d.	1	2	3	4	5	6	7	8	9	10
1. Project Financial Performance	4,082	36,562	1,000									
2. R&D Collaborations	0,629	0,483	0,044	1,000								
3. Core Technology Fields	0,136	0,343	0,021	0,174	1,000							
4. Related Non-Core Technology Fields	0,234	0,424	0,010	0,212	-0,219	1,000						
5. Distant Non-Core Technology Fields	0,650	0,477	-0,016	-0,307	-0,519	-0,673	1,000					
6. Corporate Research	0,495	0,500	-0,032	-0,033	-0,033	0,046	-0,004	1,000				
7. # Projects under Management	19,414	10,917	0,082	0,045	-0,013	0,004	0,056	-0,089	1,000			
8. Project Resources	4,510	4,978	0,033	0,314	0,309	0,432	-0,566	0,009	-0,067	1,000		
9. Project Transfer	0,317	0,466	0,164	0,229	0,166	0,133	-0,234	-0,180	0,040	0,291	1,000	
10. Firm Patent Stock	4,898	2,530	0,035	0,070	0,261	0,005	-0,229	-0,052	-0,072	0,125	0,181	1,000

(Number of observations = 876 Projects)

Table 2 Distribution of Core/ Related Non-Core/ Distant Non-Core Technological Fields

	Number	Category	PS> 3% Relatedness> 1	PS>5% Relatedness> 1.5
Technological fields in our sample (at IPC-4 digit level)	118	Core	25	17
		Related Non-Core	72	62
		Distant Non-Core	21	39
Projects in our sample	876	Core	342	234
		Related Non-Core	441	491
		Distant Non-Core	93	151

Table 3 Yearly Evolution of Core/ Related Non-Core/ Distant Non-Core Technological Fields (Sample Firm)

Year	PS> 3% Relatedness> 1			PS> 5% Relatedness> 1.5		
	Core	Related Non-Core	Distant Non-Core	Core	Related Non-Core	Distant Non-Core
2003	18	39	9	11	40	15
2004	15	25	3	11	23	9
2005	17	22	6	15	19	11
2006	14	36	7	10	34	13
2007	10	21	3	8	18	8
2008	6	19	3	5	15	8
2009	3	7	3	3	6	4

Note:

- A downsizing of the firm's technological fields is ongoing in recent years.
- Here we only show the technological fields in our sample, which is in proportion of, but not, the whole technological population of the firm.

Table 4 Logit Regressions on Collaboration Propensity

VARIABLES	Model 1	Model 2	Model 3	Model 4	Model 5
Core Technology Fields		0.508*			0.654**
		(0.305)			(0.328)
Related non-Core Technology Fields			0.156		0.351
			(0.245)		(0.269)
Distant non-Core Technology Fields				-0.572**	
				(0.253)	
Corporate Research	1.490**	1.549**	1.502**	1.631**	1.595**
	(0.629)	(0.640)	(0.634)	(0.655)	(0.651)
Project Resources	0.310***	0.292***	0.298***	0.250***	0.261***
	(0.034)	(0.035)	(0.037)	(0.0419)	(0.0412)
Firm Patent Stock	0.0090	-0.0011	0.0096	-0.00199	-0.00274
	(0.0323)	(0.0325)	(0.0323)	(0.0324)	(0.0325)
# Projects Under Management	0.044***	0.045***	0.044***	0.0453***	0.0448***
	(0.011)	(0.012)	(0.011)	(0.0117)	(0.0120)
Sponsor Units	*included*	*included*	*included*	*included*	*included*
Technology Fields	*included*	*included*	*included*	*included*	*included*
Year Dummies	*included*	*included*	*included*	*included*	*included*
Constant	-5.180***	-5.300***	-5.178***	-4.744***	-5.474***
	(1.319)	(1.351)	(1.323)	(1.361)	(1.489)
Observations	876	876	876	876	876
Log Likelihood	-484.7	-483.2	-484.46	-481.80	-482.29
Pseudo. R-squared	0.161	0.164	0.161	0.166	0.165

Robust standard errors in parentheses:
*** p<0.01, ** p<0.05, * p<0.1

Table 5 Tobit Regressions on Technological Fields and R&D Collaboration Outcomes

VARIABLES	Core Technology Fields		Related Non-Core Technology Fields		Distant Non-Core Technology Fields	
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
R&D Collaborations		-93.50***		1,058***		32.75
		(8.888)		(29.61)		(27.54)
Corporate Research	-21.86***	-18.06***	-142.1***	-238.9***	-134.0***	-100.5***
	(5.261)	(5.822)	(22.43)	(22.52)	(32.10)	(32.86)
Project Resources	6.132***	7.951***	-7.604***	-7.290***	13.83**	11.31*
	(0.450)	(0.456)	(2.275)	(2.300)	(6.012)	(6.293)
Firm Patent Stock	69.42***	80.93***	8.193*	25.72***	14.90***	14.63***
	(1.275)	(1.254)	(4.706)	(4.866)	(4.562)	(4.656)
# Projects Under Management	3.413***	4.942***	30.43***	38.47***	-0.302	-0.712
	(0.152)	(0.152)	(0.522)	(0.532)	(0.660)	(0.671)
Project Transfer	405.9***	400.3***	1,196***	1,319***	1,801***	1,832***
	(9.212)	(9.013)	(28.71)	(29.61)	(31.20)	(31.78)
Sponsor Units	*included*	*included*	*included*	*included*	*included*	*included*
Technology Fields	*included*	*included*	*included*	*included*	*included*	*included*
Year Dummies	*included*	*included*	*included*	*included*	*included*	*included*
Sigma	58.52***	54.91***	169.9***	163.5***	269.9***	269.3***
	(2.139)	(1.935)	(9.928)	(9.527)	(13.57)	(13.82)
Constant	-1,061***	-1,165***	-3,439***	-5,268***	-1,867***	-1,894***
	(9.212)	(9.013)	(28.71)	(29.61)	(31.20)	(31.78)
Observations	123	123	210	210	555	555
Log Likelihood	-73.45	-72.02	-73.21	-72.18	-148.1	-148.1
Pseudo. R-squared	0.268	0.282	0.247	0.258	0.194	0.194

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 6 Tobit Regressions on Technological Fields and R&D Collaboration Outcomes (Cont.)

VARIABLES	Model 1	Model 2	Model 3	Model 4	Model 5
R&D Collaborations		48.51***	28.37*	69.11***	39.21**
		(16.23)	(15.86)	(17.19)	(16.71)
Core Technology Fields		68.54***			48.00***
		(16.15)			(16.87)
Related Non-Core TF			-1,170***		-1,206***
			(19.83)		(21.96)
Distant Non-Core TF				58.78***	
				(17.11)	
Collab.& Core TF		-66.59***			-67.08***
		(16.78)			(17.38)
Collab. & Related Non-Core TF			1,145***		1,168***
			(19.83)		(21.96)
Collab. & Distant Non-Core TF				-29.52*	
				(17.49)	
Corporate Research	-29.13*	-18.52	-1.387	3.632	4.202
	(15.69)	(16.22)	(15.75)	(16.28)	(16.19)
Project Resources	2.841**	1.925	1.793	3.242***	3.311***
	(1.133)	(1.197)	(1.157)	(1.141)	(1.238)
Firm Patent Stock	14.82***	13.59***	13.11***	14.96***	13.24***
	(2.479)	(2.557)	(2.449)	(2.610)	(2.546)
# Projects Under Management	7.813***	7.730***	7.128***	7.612***	8.029***
	(0.323)	(0.334)	(0.325)	(0.346)	(0.333)
Project Transfer	1,376***	1,375***	1,632***	1,386***	1,348***
	(17.24)	(17.68)	(16.93)	(18.41)	(17.66)
Sponsor Units	*included*	*included*	*included*	*included*	*included*
Technology Fields	*included*	*included*	*included*	*included*	*included*
Year Dummies	*included*	*included*	*included*	*included*	*included*
Sigma	222.2	221.7***	220.6***	221.2***	220.6***
	(7.410)	(7.555)	(7.554)	(7.882)	(7.547)
Constant	-2,071***	-2,104***	-2,292***	-2,165***	-2,092***
	(17,24)	(17.68)	(16.93)	(18.41)	(17.66)
Observations	876	876	876	876	876
Log Likelihood	-307.2	-306.9	-306.1	-306.8	-306.0
Pseudo. R-squared	0.172	0.173	0.176	0.174	0.176

Robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

Table 7 Different Criteria Adopted for Robustness Checks (N= 876 projects)

	Core Technology Fields (I) (Patent Share >= 3%)	Core Technology Fields (II) (Patent Share >= 5%)	Core Technology Fields (III) (Patent Share >= 10%)
Core Technology Fields	342 *(39.04%)*	234 *(26.71%)*	16 *(1.83%)*
Related Non-Core Technologies[1] (Technology Relatedness> 1)	441 *(50.34%)*	521 *(59.47%)*	425 *(48.52%)*
Medium Related Non-Core Technologies[2] (Technology Relatedness>= 1.5)	431 *(49.20%)*	491 *(56.05%)*	389 *(44.41%)*
Fairy Related Non-Core Technologies[3] (Technology Relatedness>= 2)	415 *(47.37%)*	473 *(54.00%)*	380 *(43.38%)*
Very Related Non-Core Technologies[4] (Technology Relatedness>= 5)	266 *(30.37%)*	265 *(30.25%)*	296 *(33.79%)*

Note:

- A downsizing of the firm's technological fields is ongoing in recent years.
- Criterion 1, 2, 3, 4 are inclusive, not mutually exclusive.

Reference List

Ahuja, G. (2000). The duality of collaboration: Inducements and opportunities in the formation of interfirm linkages. *Strategic management journal*, *21*(3), 317-343.

Auster, E. R. (1992). The relationship of industry evolution to patterns of technological linkages, joint ventures, and direct investment between US and Japan. *Management Science*, *38*(6), 778-792.

Belderbos, R., Carree, M., & Lokshin, B. (2004). Cooperative R&D and firm performance. *Research Policy*, *33*(10), 1477-1492.

Belderbos, R., Faems, D., Leten, B., & Looy, B. V. (2010). Technological Activities and Their Impact on the Financial Performance of the Firm: Exploitation and Exploration within and between Firms. *Journal of Product Innovation Management*, *27*(6), 869-882.

Bower, J. L., & Christensen, C. M. (1995). *Disruptive technologies: catching the wave*. Harvard Business Review Video.

Brusoni, S., & Prencipe, A. (2001). Unpacking the black box of modularity: technologies, products and organizations. *Industrial and Corporate Change*, *10*(1), 179-205.

Bruton, G.D., Oviatt, B.M., & White, M.A. (1994). Performance of acquisitions of distressed firms. *Academy of Management Journal*, 37: 972-989.

Caloghirou, Y., Kastelli, I., & Tsakanikas, A. (2004). Internal capabilities and external knowledge sources: complements or substitutes for innovative performance? *Technovation*, *24*(1), 29- 39.

Carroll, G. R. (1985). Concentration and specialization: Dynamics of niche width in populations of organizations. *American Journal of Sociology*, 1262-1283.

Cassiman, B., & Veugelers, R. (2002). R&D cooperation and spillovers: some empirical evidence from Belgium. *The American Economic Review*,*92*(4), 1169-1184.

Chesbrough, H. 2003. Open Innovation: The New Imperative for Creating and Profiting from Technology, Boston, Harvard Business School Press.

Chesbrough, H., & Schwartz, K., 2007, Innovating Business Models with Co-development Partnerships. *Research-Technology Management*, 50(1), pp. 55-59.

Christensen, C. M., 1997, The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail. *Harvard Business Press*.

Cohen, W. M. & Levinthal, D. A. 1990. Absorptive Capacity: A New Perspective on Learning and Innovation. *Administrative Science Quarterly,* 35**,** 128-152.

Cooper, R. G., Edgett, S. J., & Kleinschmidt, E. J. (2004). Benchmarking best NPD practices-1. *Research-Technology Management*, *47*(1), 31-43.

Daft, R. L. (1978). A Dual-Core Model of Organizational Innovation.*Academy of management journal*, *21*(2), 193-210.

Danneels, E. 2002. The dynamics of product innovation and firm competences. *Strategic Management Journal*, 23, 1095-1121.

Das, T. K. & Teng, B.-S. 2001. Trust, Control, and Risk in Strategic Alliances: An Integrated Framework. *Organization Studies,* 22**,** 251-283.

Dekker, H. C. (2004). Control of inter-organizational relationships: evidence on appropriation concerns and coordination requirements. *Accounting, Organizations and Society*, *29*(1), 27-49.

Dodgson, M. (Ed.). (1989). *Technology Strategy and the Firm: management and public policy*. Longman.

Doz, Y. L. (1996). The evolution of cooperation in strategic alliances: initial conditions or learning processes?. *Strategic management journal*, *17*(S1), 55-83.

Doz, Y. L., & Hamel, G., 1998, Alliance Advantage: The Art of Creating Value Through Partnering. *Harvard Business Press*.

Duysters, G., & De Man, A. P., 2003, Transitory Alliances: An Instrument for Surviving Turbulent Industries? *R&D Management*, 33(1), pp. 49-58.

Duysters, G., & Hagedoorn, J. (2000). Core competences and company performance in the world-wide computer industry. *The Journal of High Technology Management Research*, *11*(1), 75-91.

Enkel, E., Gassmann, O. & Chesbrough, H. 2009. Open R&D and Open Innovation: Exploring the Phenomenon. *R & D Management*, 39(4), pp. 311-316.

Eisenhardt, K. M., & Martin, J. A. (2000). Dynamic capabilities: What are they? *Strategic Management Journal*,21 (10–11), 1105–1121

Escribano, A., Fosfuri, A., & Tribó, J. A. (2009). Managing external knowledge flows: The moderating role of absorptive capacity. *Research Policy*, *38*(1), 96-105.

Faems, D., Van Looy, B., & Debackere, K. (2005). Interorganizational Collaboration and Innovation: Toward a Portfolio Approach*. *Journal of product innovation management*, *22*(3), 238-250.

Faems, D., Janssens, M., & Van Looy, B. (2007). The initiation and evolution of interfirm knowledge transfer in R&D relationships. *Organization Studies*,*28*(11), 1699-1728.

Fisher, S. R., & White, M. A. (2000). Downsizing in a learning organization: are there hidden costs?. *Academy of Management Review*, 244-251.

Galunic, D.C. and Rodan, S.A. (1998), ``Resource recombinations in the firm: knowledge structures and the potential for Schumpeterian innovation'', Strategic Management Journal, 19(12), 1193-201.

Gavetti, G. (2004). *Kodak and the Digital Revlotion*. Harvard Busness School.

Granstrand, O., Patel, P., & Pavitt, K. (1997). Multi-technology corporations: Why they have'distributed'rather than'distinctive core'competences.*California management review*, *39*(4), 8.

Grant, R. M., 1996, Toward a Knowledge-based Theory of the Firm. *Strategic Management Journal*, 17, pp. 109-122.

Grant, R. M., & BADEN-FULLER, C., 2003, A Knowledge Accessing Theory of Strategic Alliances. *Journal of Management Studies*, 41(1), pp. 61-84.

Greene, William H. 2000. Econometric analysis. 4th edition. Upper Saddle River, NJ: Prentice Hall.

Griffin, A., & Page, A. L. (2003). PDMA success measurement project: recommended measures for product development success and failure.*Journal of Product Innovation Management*, *13*(6), 478-496.

Hagedoorn, J. (1995). Strategic technology partnering during the 1980s: trends, networks and corporate patterns in non-core technologies.*Research Policy*, *24*(2), 207-231.

Hagedoorn, J. 2002. Inter-firm R&D partnerships: an overview of major trends and patterns since 1960. *Research Policy,* 31**,** 477-492.

Hamel, G., 1991, Competition for Competence and Interpartner Learning within International Strategic Alliances. *Strategic Management Journal*, 12(S1), pp. 83-103.

Hamel, G (1994). "The Concept of Core Competence," in Hamel, G and Heene, A (eds.), Competence-Based Competition, The Strategic Management Society, Sussex: John Wiley and Sons, 11-33.

Hamel, G., Doz, Y. L., & Prahalad, C. K., 1989, Collaborate with your Competitors and Win. *Harvard Business Review*, 67(1), pp. 133-139.

Heiman, B. A., & Nickerson, J. A. (2004). Empirical evidence regarding the tension between knowledge sharing and knowledge expropriation in collaborations. *Managerial and Decision Economics*, *25*(6-7), 401-420.

Hoskisson, R.E., & Hitt, M.A. 1994. Downscoping: How to tame the diversified firm. New York: Oxford University Press.

Inkpen, A. C., & Tsang, E. W. (2007). 10 Learning and Strategic Alliances.*The Academy of Management Annals*, *1*(1), 479-511.

Ireland, R. D., Hitt, M. A., & Vaidyanath, D. (2002). Alliance management as a source of competitive advantage. *Journal of management*, *28*(3), 413-446.

Kale, P., & Singh, H. (2007). Building firm capabilities through learning: the role of the alliance learning process in alliance capability and firm-level alliance success. *Strategic Management Journal*, *28*(10), 981-1000.

Katila, R., & Ahuja, G. (2002). Something old, something new: A longitudinal study of search behavior and new product introduction. *Academy of Management Journal*, *45*(6), 1183-1194.

Katz. R. and Allen. T. (1982). Investigating the not invented here (NIH) syndrome: A look at the performance. tenure and communication patterns of 50 R&D project groups. *R&D Management*. 12. (1). 7-19.

Keupp, M. M., & Gassmann, O. (2009). Determinants and archetype users of open innovation. *R&d Management*, *39*(4), 331-341.

Knudsen, M. P. (2007). The Relative Importance of Interfirm Relationships and Knowledge Transfer for New Product Development Success*. *Journal of Product Innovation Management*, *24*(2), 117-138.

Kogut, B. (1991). Joint ventures and the option to expand and acquire.*Management science*, *37*(1), 19-33.

Kogut, B., Shan, W., & Walker, G. (1992). The make-or-cooperate decision in the context of an industry network. *Networks and organizations*, 348-65.

Laursen, K., & Salter, A. (2005). Open for innovation: the role of openness in explaining innovation performance among UK manufacturing firms.*Strategic Management Journal*, *27*(2), 131-150.

Lei, D., Hitt, M. A., & Bettis, R. (1996). Dynamic core competences through meta-learning and strategic context. *Journal of management*, *22*(4), 549-569.

Leonard-Barton, D., 1992, Management of Technology and Moose on Tables, *Organization Science*, 3(4), pp. 556-558.

Leten, B., Belderbos, R., & Van Looy, B., 2007, Technological Diversification, Coherence, and Performance of Firms. *Journal of Product Innovation Management*, 24(6), pp. 567-579.

Levinthal, D. A., & March, J. G., 1993, The Myopia of Learning. *Strategic Management Journal*, 14(S2), pp. 95-112.

Madhok, A., & Tallman, S. B. (1998). Resources, transactions and rents: managing value through interfirm collaborative relationships. *Organization science*, *9*(3), 326-339.

March, J. G. (1991). Exploration and exploitation in organizational learning.*Organization science*, *2*(1), 71-87.

McDonald, J. F., & Moffitt, R. A. (1980). The uses of Tobit analysis. *The review of economics and statistics*, *62*(2), 318-321.

Mowery, D. C. (1988). *International collaborative ventures in US manufacturing*. Ballinger Pub Co.

Mowery, D. C., Oxley, J. E., & Silverman, B. S. (1998). Technological overlap and interfirm cooperation: implications for the resource-based view of the firm. *Research policy*, *27*(5), 507-523.

Nelson, R. R., & Winter, S. G., 1982, An Evolutionary Theory of Economic Change, Belknap press.

Patel, P., & Pavitt, K., 1997, The Technological Competencies of the World's Largest Firms: Complex and Path-dependent, But Not Much Variety. *Research Policy*, 26(2), pp. 141-156.

Patel, P., & Vega, M. (1999). Patterns of internationalisation of corporate technology: location vs. home country advantages. *Research Policy*, *28*(2), 145-155.

Penrose, E. T. 1959. The Theory of the Growth of the Firm, 3rd edition. Oxford University Press, Oxford, UK.

Powell, W. W., Kogut, K. W. & Smith-Doerr, L. 1996. Inter-organizational Collaboration and the Locus of Innovation: Networks of Learning in Biotechnology. *Administrative Science Quarterly*, 41, 116-145.

Prahalad, C. K., & Hamel, G., 1990, The Core Competence of the Corporation., *Harvard Business Review*, May-June, pp. 79-91.

Reich, R. B., & Mankin, E. D.,1986, Joint Ventures with Japan Give Away Our Future, *Harvard Business Review*, 29, pp. 78-86.

Rivkin, J.W., 2001. Reproducing Knowledge: Replication without Imitation at Moderate Complexity. *Organization Science* 12, pp. 274–293

Rothaermel, F. T. & Deeds, D. L. 2006. Alliance Type, Alliance Experience and Alliance Management Capability in High-technology Ventures. *Journal of Business Venturing*, 21, pp. 429-460.

Rumelt, R.P., 1974, *Strategy, Structure, and Economic Performance, Division of Research*, Harvard Business School, Boston.

Shan, W., Walker, G., & Kogut, B. (1994). Interfirm cooperation and startup innovation in the biotechnology industry. *Strategic management journal*,*15*(5), 387-394.

Song, J., Almeida, P., & Wu, G. (2003). Learning–by–Hiring: When Is Mobility More Likely to Facilitate Interfirm Knowledge Transfer?.*Management Science*, *49*(4), 351-365.

Tether, B. S. (2002). Who co-operates for innovation, and why: an empirical analysis. *Research policy*, *31*(6), 947-967.

Tsai, K. H. (2009). Collaborative networks and product innovation performance: Toward a contingency perspective. *Research Policy*, *38*(5), 765-778.

Teece D.J., Pisano, G., Shuen, A., 1997, Dynamic Capabilities and Strategic Management. *Strategic Management Journal*, 18(7), pp. 509–533.

Teece, D. J., 1998, Capturing Value from Knowledge Assets. *California Management Review*, 40(3), pp. 55-79.

Teece, D. J., 2007, Explicating Dynamic Capabilities: The Nature and Micro-foundations of (Sustainable) Enterprise Performance. *Strategic Management Journal*, 28(13), pp. 1319-1350.

Tripsas, M., Schrader, S., & Sobrero, M. (1995). Discouraging opportunistic behavior in collaborative R & D: A new role for government. *Research Policy*, *24*(3), 367-389.

Tushman, M. L., & Romanelli, E. (1985). Organizational evolution: A metamorphosis model of convergence and reorientation. *Research in organizational behavior*.

Tushman, M. L., & Anderson, P. (1986). Technological discontinuities and organizational environments. *Administrative science quarterly*, 439-465.

Tushman, M., & O'Reilly, C. (1996). Evolution and revolution: Mastering the dynamics of innovation and change. *California Management Review*, *38*(4), 8-30.

Vanhaverbeke, W., Gilsing, V., Beerkens, B., & Duysters, G., 2008, The Role of Alliance Network Redundancy in the Creation of Core and Non-core Technologies. *Journal of Management Studies*, 46(2), pp. 215-244.

Vanhaverbeke, W., Gilsing, V., & Duysters, G. (2012). Competence and Governance in Strategic Collaboration: The Differential Effect of Network Structure on the Creation of Core and Noncore Technology. *Journal of Product Innovation Management*.

Vega-Jurado, J., Gutiérrez-Gracia, A., Fernández-de-Lucio, I., & Manjarrés-Henríquez, L. (2008). The effect of external and internal factors on firms' product innovation. *Research Policy*, *37*(4), 616-632.

Von Zedtwitz, M., & Gassmann, O. (2002). Market versus technology drive in R&D internationalization: four different patterns of managing research and development. *Research policy*, *31*(4), 569-588.

Zahra, S. A., & George, G. (2002). Absorptive capacity: A review, reconceptualization, and extension. *Academy of management review*, 185-203.

Zhang, J., & Baden-Fuller, C., 2009, The Influence of Technological Knowledge Base and Organizational Structure on Technology Collaboration. *Journal of Management Studies*, 47(4), pp. 679-704.

Zirger, B. J., & Maidique, M. A. (1990). A model of new product development: an empirical test. *Management Science*, *36*(7), 867-883.