Essays on complementarities in R&D activities:

Implications for innovation management and for firm performance

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Contents

Introduction

During the last decades, it has been observed that competition in business environments has largely been knowledge-based (Almeida, Phene and Grant, 2003; He and Wong, 2004). Companies make an important effort to produce knowledge with potential applications before their rivals. In order to be successful in this form of competition, firms need to search for new opportunities that lead them to be on the leading edge of innovation. Since knowledge creation implies the development of effective search strategies (Katila and Ahuja, 2002), the way firms organize their R&D activities becomes particularly relevant. This is the case, since the organization of the R&D function grounds the search process through which firms find and apply new solutions for improving the performance of their innovation activities (Pisano, 2000).

Studies on innovation management have started to indicate that success in innovation critically depends on the degree of openness observed in the organizational design of R&D activities (Quinn, 2000; Chesbrough, 2003; Laursen and Salter, 2006). This literature widely recognizes that the shift from closed innovation models to more open options has helped firms reach competitive advantages in the production of new knowledge (Dyer and Singh, 1998; Rosenkopf and Almeida, 2003). This holds true since use of external knowledge often allows firms to identify missing capabilities (Mowery, Oxley and Silverman, 1996), learn about new technological opportunities (Powell, Koput and Smith-Doerr, 1996), recombine knowledge for developing new capabilities (Kogut and Zander, 1992), and to boost internal search activities (Rosenkopf and Almeida, 2003).

Despite the insightful ideas emerging from previous studies, more research is needed in order to improve our understanding of the ways in which internal and external sources of technologies interact with each other along the process of knowledge creation. For instance, studies on learning alliance have shown that firms can learn by interacting with their partners (Powell, et al., 1996; Lane and Lubatkin, 1998; Rosenkopf and Almeida, 2003). Nevertheless, little is known about the direct and indirect channels by which specific types of alliances may leverage internal learning sustained by the firm’s intramural R&D activities. Several literatures on technology and innovation have started to demonstrate that the joint adoption of internal and external R&D activities has a positive impact on knowledge creation (Arora and Gambardella, 1990; Veugelers and Cassiman, 1999; Cassiman and Veugelers, 2006; Laursen and Salter, 2006; Gomes-Casseres, Hagedoorn and Jaffe, 2006). However, less attention has been paid to the examination of specific conditions that favor the presence of complementarities between internal and external sources of knowledge in a given performance measure.

This current PhD dissertation intends to tackle some of the aforementioned issues. In general, this thesis aims to *improve our understanding of how alternative sources of technology gain leverage from each other in order to enhance the firm's innovative performance*. In order to achieve this goal, the thesis addresses several research questions, which are treated by three interrelated studies. The next paragraphs describe in more detail the content of each study. Finally, the main contributions of the thesis are highlighted.

The structure of this research

The first paper of this dissertation examines the production of complementarities between internal and external R&D activities. As firms can combine their own R&D with alternative modes of R&D alliances along the continuum between "hierarchies" and "markets", the study analyzes alternative organizational designs that a firm may implement to leverage its R&D activities in knowledge creation. In particular, this paper addresses the following research questions: (i) Do alternative organizational designs of internal and external R&D activities have the same capacity to generate complementarities? (ii) What role do specific external R&D activities play in determining knowledge creation? Although the assessment of complementarities in R&D has been widely investigated by other studies (e.g., Mowery, 1983; Arora and Gambardella, 1990; Cassiman and Veugelers, 2006; Schmiedeberg, 2008; Love and Roper, 2009), less attention has been paid to determining the role of different types of external technology sourcing in leveraging the firm's own R&D activities.

In order to answer these questions, I elaborate on previous studies on organizational learning (e.g., Cohen and Levinthal, 1990; von Hippel, 1994; Anand and Khanna, 2000;

Lenox and King, 2004; Rothaermel and Alexandre, 2009); I suggest that the production of inter-organizational complementarities in R&D depends on the knowledge provision linked to the external sources strategy that a firm chooses to leverage for its internal R&D activities. In particular, this paper suggests the hypothesis that the adoption of hybrid forms, such as research collaboration, induces more the execution of intramural R&D and the production of complementarities, compared to the adoption of contract-based arrangements, such as R&D outsourcing. This hypothesis rests on the fact that the use of research collaboration imposes higher learning requirements, and in that sense, depends more on the firm's absorptive capacity.

Nonetheless, the paper argues that the firm's absorptive capacity has to be formed by a diverse knowledge background to favor the creation of complementarities in R&D. In this regard, I examine the role of collaborative and contract-based arrangements in enhancing the diversity of the firm's knowledge background. Particularly, the study provides arguments indicating that knowledge diversity raises more intramural R&D productivity by the adoption of research collaboration than by the adoption of R&D outsourcing. This research indicates that the implementation of research collaboration allows firms to do so by better preventing the emergence of locked-out effects that may impair the production of complementarities in R&D.

In order to test the hypotheses previously described, this study uses a panel of Spanish manufacturing companies for the period of 1998-2002. The empirical design of this paper comprises of two parts. The first part examines the drivers that lead firms' choices on internal and external R&D activities, while the second one evaluates the presence of complementarities between alternative combinations of internal and external R&D activities. The results of this study support the hypothesis that complementarities between internal and external R&D activities depend on whether firms leverage their own R&D by choosing research collaboration or R&D outsourcing. In particular, the findings show that, while combinations between intramural R&D and research collaboration generate strong complementarities in knowledge creation, the joint adoption of intramural R&D and R&D outsourcing reduces the firm's innovative performance. These results are in line with prior studies on learning alliance that the co-development of R&D activities in inter-organizational contexts, rather than the acquisition in markets of R&D, is an effective strategy to reinforce the contribution of intramural R&D to the process of knowledge creation (Mowery, et al., 1996; Gomes-Casseres, et al., 2006).

From examining the drivers leading the firms' choices on R&D, this study also shows that, compared to the use of R&D outsourcing, the adoption of research collaboration relates more to the use of innovation management mechanisms and to the presence of growing technological opportunities. These findings confirm that research collaboration is a demanding form of learning, and in that sense, its use further induces the accomplishment of intramural R&D. One implication of these results is that the presence of complementarities between internal and external R&D activities depends on the scope of learning associated with each type of alliance. As learning is determined by the difficulty in managing knowledge provision in alliances (von Hippel, 1994; Anand and Khanna, 2000), the results show that differences in the production of complementarities may well correspond to the fact that the use of research collaboration has a broader capacity to induce learning than the use of R&D outsourcing. Finally, this paper provides a discussion about the potential implications for innovation management derived from the reported differences in the production of complementarities.

In the second paper of this research, I examine the organization of the firms' search strategies along the process of technological innovation. As examined in the first study, success in the process of knowledge creation requires that firms integrate internal and external search activities appropriately. However, knowledge search also implies the ability to synchronize activities that differ from each other in terms of their categorization along the exploration-exploitation dimension. Drawing on March (1991), the firm's search strategies that relate to the discovery and learning of new knowledge are aligned with "exploration", while those that address the learning of current knowledge are associated with exploitation. By viewing the firm's search strategies in terms of both "where they take place" and "which type of learning they promote", this paper provides a complete picture regarding the problem of how to organize these strategies. As is discussed in this study, the reduction of tensions and the production of complementarities emerging from the integration of dissimilar search strategies are at the center of this problem.

Some studies have started to examine how firms combine exploratory and exploitative search activities to increase knowledge creation (Katila and Ahuja, 2002; He and Wong, 2004; Greve, 2007; Andriopoulos and Lewis, 2009). In this sense, ambidexterity in exploration and exploitation is pointed out as an effective strategy to integrate these activities. In the context of this dissertation, ambidexterity is understood as the firm's ability to conduct exploratory and exploitative technological search simultaneously, which are widely recognized as activities aligned with different goals (Raisch and Birkinshaw, 2008). Despite its relevance to innovation management and firm performance, few studies have examined the organization of exploration and exploitation in technological search that take place across the firms' boundaries (Rothaermel and Alexandre, 2009).

In this study, I suggest that, as firms expand their search activities outside their boundaries, new organizational forms emerge to accommodate differing search activities in technological innovation. This involves firms facing a set of alternative strategies that range from the adoption of specialized patterns of search in either exploration or exploitation to the adoption of alternative modes of ambidexterity. An inspection of the organization of knowledge search in different industries confirms that firms apply heterogeneous arrangements for their search activities. While firms in the semiconductor industry rely extensively on the formation of R&D alliances to perform their knowledge search (Lavie and Rosenkopf, 2006), firms in the chemistry industry tend to internalize their search activities. Alternatively, firms in the bio-pharmaceutical industry have a predisposition to combine specialized search activities across their organizational boundaries (Arora and Gambardella, 1990; Rothaermel, 2001; Hoang and Rothaermel, 2010). This fact leads us to the following research questions: (i) How do firms organize their explorative and exploitative technological activities across their organizational boundaries? (ii) What are the consequences associated with the adoption of different models of organizational search?

To investigate these issues, I present a taxonomy that describes alternative strategies that a firm may implement to organize its technological search activities. In particular, this study assumes that firms execute exploratory and exploitative search strategies by choosing the following options: i) not to undertake any strategy, ii) to adopt a "single" implementation, or iii) to adopt a "simultaneous" implementation of exploration and exploitation. As these choices are made inside and outside the firms' boundaries, the overlap of the internal and external choices generates three generic models of organizational search: the "ambidextrous", "specialized" and the "diversified" models. Furthermore, the paper provides a fine-grained description for these models of organizational search by distinguishing alternative modes of ambidexterity, specialization and diversification in the implementation of exploratory and exploitative search.

From an empirical perspective, the second study of this thesis draws on new data for the technological activities of manufacturing firms in Spain, surveyed between 2002 and 2006. With this dataset, the paper examines the performance consequences of applying alternative models of organizational search, and compares their capacity to produce complementarities in terms of a given measure of innovative performance. In particular, the empirical comparison of the capacity of the proposed models to generate complementarities shows that the coordinated implementation of specialized search strategies across the firms' organizational boundaries gives leverage to each other in innovative performance. Conversely, the data do not support the hypothesis sustaining the existence of complementarities of other models (ambidextrous and diversified models). The implication deriving from these results is that differences in the production of complementarities may be associated with differences in the way in which firms reach a balance for differing search strategies, which vary in their technological profile and in their organizational form.

Additionally, since firms' choices in matters of organizational search are viewed as endogenous variables, this paper examines the drivers affecting them and identifies the importance of the firms' absorptive capacity and diversified technological opportunities in determining these choices. These results confirm that the first factor is a combinative capability that enables firms not only to integrate internal and external search activities, but also to articulate explorative and exploitative search, and that the second factor is a pull-force driver that leads firms to combine their search activities across organizational boundaries, in the attempt to harness knowledge diversity.

Given the results of the second study, in the third paper of this thesis, I examine the use of inter-organizational ambidexterity as a method for balancing exploration and exploitation occurring in technological search. As the R&D function of a firm sustains the knowledge search that is required for technological innovation, this study focuses the attention on the way firms organize their exploratory and exploitative R&D activities. In this context, inter-organizational ambidexterity is viewed as a method of R&D organization, in which firms separate exploratory from exploitative R&D activities by allocating them across their organizational boundaries. Given the potential effects of this balance strategy on the way a firm innovates, I further investigate the main consequences associated with the adoption of inter-organizational ambidexterity in R&D.

As recognized by prior studies on R&D management (e.g., DeSanctis, Glass and Ensing, 2002; Chiesa and Frattini, 2007), the integration of exploration and exploitation in the R&D function is a process that may be fraught with tensions. On the one hand, the use of exploratory and exploitative R&D activities is identified as a requisite for a firm to compete successfully in the short-term and to enhance its innovativeness in the long-term (Rothaermel and Alexandre, 2009). On the other hand, the execution of exploration and exploitation in R&D pursues different objectives, requires alternative organizational capabilities, and leads to different outcomes. As the resources devoted to conducting exploratory and exploitative R&D are limited, their organization causes tensions due to the presence of competing views concerning the activities around which a firm should arrange its R&D function (DeSanctis, et al., 2002).

Drawing on previous works on organizational learning (e.g., Grant and Baden-Fuller, 2004; Lavie and Rosenkopf, 2006; Lavie, Stettner and Tushman, 2010), I hypothesize that a firm tends to balance its exploratory and exploitative R&D tasks by specializing in one of them internally while accessing the other through their alliances. In doing so, the firm avoids developing and maintaining dual structures for accommodating contradictory R&D tasks. In this way, managers can alleviate tensions in the allocation of the firms' resources. However, as prior studies recognize (Lavie and Rosenkopf, 2006; Lavie, et al., 2010; Lin, Yang and Demirkan, 2007; Vurro and Russo, 2009), exploration and exploitation occurring in an alliance can be defined in several domains. In order to allow for this fact, I propose that firms mitigate tensions in the organization of differing tasks by combining their own exploratory (exploitative) R&D activities with exploitative (exploratory) alliances, which are defined in terms of the "function" and “geographic” domain. The former domain refers to the purpose that an alliance serves along the innovation value chain, while the latter domain refers to the geographic scope that an alliance achieves along the innovation process. With this characterization, the paper offers a broader perspective that describes the firms’ balance behavior for the case of differing R&D tasks that occur in inter-organizational contexts.

While alliances provide firms with a range of knowledge integration mechanisms, its use should contribute to the articulation of differing R&D activities that come about in an inter-organizational environment. As documented by other studies (e.g., Tushman and O'Reilly, 2007; Raisch et al., 2009; Jansen et al., 2009), ambidexterity leads to a superior performance when exploration is buffered from exploitation, and when these activities are subsequently integrated during knowledge creation. From these considerations, the paper proposes that the use of alliances allows firms to reach the benefits of inter-organizational ambidexterity. In this direction, I assess the innovative performance implications of alternative models which combine their internal exploration (exploitation) in R&D with external exploitation (exploration), defined in the function and geographic domains, respectively.

From an empirical angle, I examine the previously described hypotheses by using data on the technological activities of a sample of Spanish manufacturing companies, surveyed for the periods of 2003-2005 and 2005-2007. Regarding the firms’ balance behavior, the empirical analysis reveals that firms tend to balance internal exploration (exploitation) in R&D with external exploitation (exploration) in the geographic domain. On the other hand, the data does not support the hypothesis that firms balance internal exploration (exploitation) in R&D with external exploitation (exploration) in the function domain. These findings suggest that a balance behavior depends on the domain that’s used to characterize the external search in the firms’ alliances.

Regarding the performance implications, the findings show that the use of inter-organizational ambidexterity produces complementarities in terms of innovative performance, when firms balance their internal exploration (exploitation) in R&D with external exploitation (exploration) in the geographic domain. In addition, these complementarities are stronger than those are in models where firms adopt the same type of activity across their organizational boundaries. Conversely, the results show weak complementarities when firms implement internal exploration (exploitation) in R&D with external exploitation (exploration) in the function domain. It is also observed that firms implementing exploration (exploitation) in their R&D with external exploration (exploitation) in the function domain obtain strong complementarities in terms of innovative performance. Seeing that inter-organizational ambidexterity brings complementarities only when external exploration-exploitation is defined in the geographic domain, this paper provides alternative explanations for contextualizing these results.

Contributions

Taken together, previously described studies contribute to existing literatures in the following ways. Compared to prior studies on complementarities in R&D (e.g., Arora and Gambardella, 1990; Cassiman and Veugelers, 2006; Leiponen, 2005b; Belderbos, Carree and Lokshin, 2006; Love and Roper, 2009), this thesis provides a more comprehensive picture regarding the way in which firms implement their R&D activities so as to maximize innovative performance. In particular, the thesis goes beyond the assessment of complementarities by examining the role of certain factors in favoring the production of these complementarities. On the one hand, this thesis identifies that certain types of knowledge provision in R&D alliances are elements that widely contribute to forming complementarities between internal and external R&D activities. On the other hand, this thesis is among the first in showing that combinations of specialized R&D activities along the exploration-exploitation dimension largely contribute to bringing inter-organizational complementarities in R&D.

From an empirical perspective, this thesis improves the evaluation of complementarities in R&D by implementing methods that allow for the effects of unobserved heterogeneity. As recognized by other studies (e.g., Athey and Stern, 1998; Mohnen and Röller, 2005; Leiponen, 2005b; Cassiman and Veugelers, 2006), the empirical evaluation of complementarities is problematic because the existence of unobserved factors can affect the estimation of the parameters which are used to determine the type of interaction prevailing between R&D activities. In particular, the estimation may lead either to asserting complementarities between two R&D activities when in fact they are independent, or to concluding the absence of complementarities when they are actually complementary. The use of count-data-panel techniques (Blundell, Griffith and Windmeijer, 2002) and treatment-outcome models with endogenous treatments (Deb and Trivedi, 2006) are considered, for properly handling the presence of unobserved heterogeneity in the assessment of complementarities.

Compared to other studies on organizational search (e.g., Rosenkopf and Nerkar, 2001; He and Wong, 2004; Lavie and Rosenkopf, 2006; Rothaermel and Alexandre, 2009), two contributions have to be highlighted. Firstly, this thesis extends the arrays of models of organizational search by proposing a new taxonomy that describes alternative arrangements that a firm may implement for organizing its exploratory and exploitative search activities. In this regard, this research adds to this literature by analyzing the performance consequences of using these models and by examining the factors that favor the firms' search choices. In doing so, the current dissertation provides new insights regarding the capacity of alternative forms of ambidexterity and specialization in exploration and exploitation to produce inter-organizational complementarities in terms of innovative performance. Secondly, by defining the function and geographic domain that characterize the exploration-exploitation in R&D alliances, this research contributes to this literature by examining the role of different forms of external search activities in leveraging the intramural R&D of a firm.

Chapter One

The organizational designs of R&D activities and their performance implications[♣]

1.1 Introduction

It has been long recognized that successful in innovation depends on the firm's ability to combine old and novel sources of knowledge (Kogut and Zander, 1992; Rosenkopf and Nerkar, 2001; Katila, 2002). When these sources give each other leverage in the innovation process, they are complementary in the sense that using one of them raises the returns of using the other (Milgrom and Roberts, 1990). The formation of complementarities in the production of knowledge acquires an important strategic nature, as they show that firms have found knowledge associations that raise their innovative performance. Recent studies on innovation management point to the implementation of open innovation models as an effective strategy to reach complementarities in knowledge creation (Cassiman and Veugelers, 2006; Rothaermel and Alexandre, 2008). This holds true since these models span firms' search outside their boundaries, provide new technologies and capabilities, and facilitate inter-organizational learning (Chesbrough, 2003; Rosenkopf and Almeida, 2003; Laursen and Salter, 2006).

However, implementation of open innovation models requires that firms combine several R&D activities. Each combination in turn leads to different organizational designs for these activities. In some cases, firms may achieve original knowledge associations by joining their own R&D with hybrid organizational forms, such as strategic alliances and joint venture arrangements. In other cases, firms may obtain novel knowledge combinations adopting together in-house R&D and contractual forms, such as licensing arrangements and R&D outsourcing. If so, this raises the following question: what organizational design should firms choose to maximize knowledge creation?

[♣] Forthcoming in *Industry & Innovation* as Lucena, A. The organizational designs of R&D activities and their performance implications: empirical evidence for Spain.

In this paper, I propose that the answer to this question rests on the type of knowledge provision derived from the external sourcing strategy that a firm chooses to leverage its intramural R&D. Alliances along the continuum between "hierarchies" and "markets" provide knowledge that varies depending on two factors: its complexity in terms of inter-organizational transfer, and its effectiveness in improving intramural R&D productivity. By using a rich panel of Spanish manufacturing firms for 1998-2002, this study provides evidence consistent with the premise that alliances differing on these factors have a different capacity to induce the adoption of intramural R&D, and subsequently, the production of complementarities. Surprisingly, how differences in external knowledge provision affect the formation of complementarities between internal and external R&D activities remains relatively unexplored in the extant literature on the subject[1]. Rather, previous works have focused on the interaction effects that may arise from combining multiple types of alliances (e.g., Arora and Gambardella, 1990; Belderbos et al., 2006; Love and Roper, 2009); on the investigation of the interrelation of contract-based arrangements and intramural R&D (Mowery, 1983; Veugelers and Cassiman, 1999); or on how knowledge acquisition in markets and intramural R&D leverage each other in terms of innovative performance (Cassiman and Veugelers, 2006).

With the aim of extending the previous literature on complementarities in R&D, the current research focuses on the following questions: (i) Do alternative organizational designs of internal and external R&D activities have the same capacity to induce complementarities? (ii) What role do specific alliances play in determining inter-organizational complementarities in R&D? The analysis of these questions becomes relevant if we are to understand how a firm can best arrange its internal and external R&D activities to reach the maximum leverage among them in knowledge creation. Furthermore, comparing complementarities that arise from various combinations of internal and external R&D activities enables the identification of important differences in the way these activities interrelate to each other. This fact provides a more comprehensive picture regarding the manners by which different types of R&D alliances shape innovative performance.

[1] A number of studies have compared the capacity of different R&D alliances to produce inter-organizational learning (e.g., Mowery et al., 1996; Gomes-Casseres et al., 2006). However, these studies do not assess the effect that intramural R&D may have on the contribution of alliances to inter-organizational learning.

This research contributes to the previous literature on the following aspects. This work is not only among the first in comparing complementarities derived from the combination of intramural R&D with different types of alliances, but it also conducts this evaluation using panel data analysis. Compared to cross-sectional studies on the subject (e.g., Cassiman and Veugelers, 2006; Love and Roper, 2009), the current paper assesses for complementarities in R&D allowing for the effects of unobserved heterogeneity, which has been recognized as a limitation of prior research (Athey and Stern, 1998; Leiponen, 2005b; Miravete and Pernias, 2006). Furthermore, the use of a longitudinal sample of companies improves the assessment of complementarities in R&D by accounting for the presence of well-documented feedback effects that characterize the innovation–R&D adoption relationship. In particular, this study allows for the feedbacks that arise from the dynamic nature of the link between innovation and R&D adoption (Blundell, Griffith and Van Reenen, 1995; Martínez-Ros and Labeaga, 2002), and from the fact that organizational design choices are essentially predetermined variables that may be correlated with the unobserved heterogeneity (Leiponen, 2005b). Altogether, this study provides a robust evaluation on complementarities in R&D, presenting reliable conclusions about the capacity of the compared organizational designs to enhance innovative performance.

To the best of my knowledge, only Schmiedeberg (2008) has conducted a comparative study of the complementarities between different combinations of internal and external R&D strategies, but for a cross-section sample of firms. On the other hand, Leiponen (2005b) uses panel data analysis for assessing complementarities between technical skills, innovation and R&D collaboration. However, the study about the role of different types of external R&D sources in determining the returns of technical skills is not addressed in her study.

The layout of the paper is as follows. Next section presents the theoretical foundations for studying the production of complementarities derived from alternative combinations of internal and external R&D activities. Subsequent sections describe the data, methodology, and results of the study, as well as the concluding remarks.

1.2 Theoretical framework

Organizational designs in which firms combine internal and external R&D activities bring not only benefits in terms of diverse knowledge, but also difficulties associated with the integration of such knowledge across organizational boundaries (Tortoriello and Krackhardt, 2010). Firms implementing these organizational designs need to develop communication channels for improving knowledge sharing and to ensure assimilation of heterogeneous sources of knowledge, some of which may be far from their technological base. Furthermore, the acquisition of external R&D is a knowledge-based transaction that may be fraught with complexity and contractual problems (Pisano, 1990; Anand and Khanna, 2000). Taken together, these issues may lessen the interaction of a firm's own R&D with external sourcing of knowledge, thus limiting the scope of inter-organizational learning (Leiponen, 2005a).

Although the combination of internal and external R&D is costly in terms of knowledge integration, an important stream of works has documented the existence of complementarities between R&D activities implemented across the firms' boundaries (e.g., Mowery, 1983; Veugelers and Cassiman, 1999; Cassiman and Veugelers, 2006; Schmiedeberg, 2008). To justify the presence of such complementarities, the majority of these studies built on the Cohen and Levinthal's (1989) notion of absorptive capacity (henceforth, ACAP), defined as the firm's ability to recognize, assimilate, and exploit external knowledge. According to previous research, accumulated experience in conducting R&D internally puts the firm in a better position to understand R&D performed by external actors. In particular, the ACAP contributes to forming complementarities in R&D by enabling firms to identify partners who best fit their technological background, and to improve communication with those having needed problem-solving capabilities. Additionally, it is argued that high levels of ACAP shape the firm's expectation on the importance of emerging technological opportunities to its innovation activities. If new opportunities are detected, the firm will aspirate to learn from them, which results in further incentives to be involved in new R&D projects (Lavie and Rosenkopf, 2006; Rothaermel and Alexandre, 2009).

However, production of complementarities in R&D requires that the firm form its ACAP from a diverse stock of knowledge. When sharing a similar and specialized knowledge background, sub-units within a firm can improve communication effectiveness, facilitating knowledge assimilation across intra-organizational boundaries. Indeed, internal communication efficiency contributes to reinforcing the firms' inward-looking ACAP (Cohen and Levinthal, 1990). However, a lack of a diverse knowledge background also makes the firm less receptive to acquire an external source of knowledge. Less diversity in the firm's stock of knowledge affects its outward-looking ACAP (Cohen and Levinthal, 1990), which may result in the emergence of the *Not Invented Here* syndrome (Almeida, Dokko and Rosenkopf, 2003; Laursen and Salter, 2006). In the context of our study, previous arguments imply that firms with a less diverse technological background will focus their search effort on a restricted number of technological trajectories. If this search behavior is persistent, firms will see a reduced capacity to create novel knowledge associations, together with their possibilities to produce complementarities in R&D.

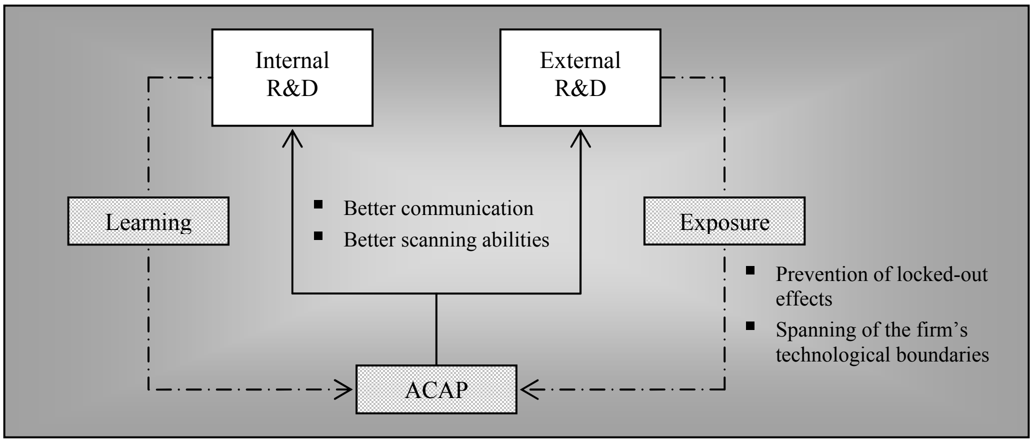
Drawing on the learning alliance literature (Mowery et al., 1996; George et al., 2001; Rosenkopf and Almeida, 2003), in this study I propose that organizational designs in which firms combine internal with external R&D help them to enhance diversity of their knowledge background, thus improving their ACAP effectiveness in producing complementarities[2]. This holds true as involvement in external R&D increases the exposure of the firm's own R&D to heterogeneous sources of knowledge that, in turn, contributes to forming a technological background in areas different from prior knowledge accumulation (Mowery et al., 1996; George et al., 2001; Faems, Van Looy, and Debackere, 2005). Furthermore, information provision from external links shapes ACAP by revealing the benefits of implementing new managerial practices that may improve R&D performance in knowledge creation. In that regard, Henderson and Cockburn (1998) show evidence indicating that wide connections with external actors drive the pharmaceutical companies' abilities to recognize and exploit technological opportunities. Lenox and King (2004) suggest that R&D laboratories connected to external actors are better prepared to identify the value of adopting new R&D practices.

[2] Although the role of external sources of knowledge in shaping ACAP is widely recognized in previous studies on organizational learning (e.g., Nicholls-Nixon, 1995; Cockburn and Henderson, 1998; George et al., 2001), the influence of diverse external knowledge in reinforcing the ACAP effectiveness to form complementarities remains relatively unexplored in the extant literature.

Rothaermel and Alexandre (2009) propose that joining internal and external R&D prevents search behavior that overemphasizes internal search and lessens the external exploration of new technologies. See Figure 1.1 for a diagrammatic explanation of previous ideas. Taken together, prior arguments lead to the following hypothesis:

Hypothesis 1.1*: Organizational designs, in which firms combine internal and external R&D activities, produce complementarities in terms of knowledge creation.*

Figure 1.1. Sources of complementarities in R&D



However, the intensity of these complementarities may differ depending on the external R&D activity chosen by a firm to leverage its own R&D. In particular, here I study the interaction of intramural R&D with two particular forms of alliances, research collaboration and R&D outsourcing. The former includes intentional arrangements formed among firms and external actors to co-develop innovation activities, while the latter refers to projects and services contracted in the markets for technology. While research collaboration and R&D outsourcing provide a distinct type of knowledge, these alliances can be distinguished by the fact that the adoption of each one imposes different learning requirements and generates different external knowledge exposures. Therefore, I expect that such differences explain variation in the intensity of complementarities derived from alternative combinations of internal and external R&D activities. To investigate this fact in more detail, the following paragraphs present a description about the type of knowledge provision resulting from the adoption of R&D outsourcing and research collaboration, respectively.

Knowledge provision in R&D outsourcing is achieved by exchanges of knowledge in the technology markets. In terms of von Hippel's theory (1994) on the allocation of information and problem-solving capabilities along the innovation process, I posit here that R&D outsourcing is often an *iterative form of learning* in that codified knowledge about technology adoption moves successively between the adopting-firm and the market R&D providers[3]. This generates an interaction mode in which a firm links to its R&D providers by sending them codified information about technical problems and by receiving technological solutions in terms of blueprints, manuals, or technological packages from them. Exchanges of codified knowledge advance until the providers' technological solutions fit the firm's technical needs. An important implication of this characterization is that these exchanges of knowledge limit the firm to learning just from the problem-solving capabilities previously codified by its R&D providers, but not from others elements embedded in their technological expertise (Lane and Lubatkin, 1998; Kale, Singh and Perlmutter, 2000).

Alternatively, research collaboration is an *interactive form* of learning, in which the firm and its partners gain knowledge from a conjoint involvement in R&D activities. As interaction proceeds, participants share resources intentionally, but may also reach knowledge involuntarily spilled out by the others (Singh, 2005). When knowledge spillovers refer to context-specific information (e.g., partners' expertise and specific practices for the functioning of particular R&D projects), research collaboration further provides the firm with tacit sources of knowledge (Lane and Lubatkin, 1998; Almeida, Dokko and Rosenkopf, 2003). In terms of knowledge provision, research collaboration then allows the firm to obtain not only standard forms of knowledge, but also knowledge hardly definable outside the R&D collaboration context (Powell et al., 1996; Mowery et al., 1996).

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[3] Since R&D outsourcing is often an arm's length transaction, it can be argued that its involved learning does not necessarily take place as an iterative exchange of knowledge. In the context of this study, I consider that arm's length transactions suppose the lowest level of iteration among partners, in that providers' solutions fit the firm' technical problems immediately. However, in many other situations, firms and their R&D providers exchange information successively on the progress of a technology implementation (Weigelt and Sarkar, 2009). For instance, the firm may need additional information to solve emerging technical problems, while providers may require the firm's feedback to improve technology implementation. In other cases, technology solutions acquired by firms come with bundled additional services, such as training or consulting support (Arora, 1996). This fact usually results in new exchanges of information between firms and providers.

Comparing knowledge provision derived from the external R&D activities under consideration, the following conclusions can be drawn. Firstly, learning from research collaboration is more demanding than learning from R&D outsourcing since the former provides knowledge that is more complex in terms of its tacitness. Learning from tacit knowledge requires that the firm have well-develop skills in prospecting its potential outcomes and in transforming contextual into codified information for enabling knowledge assimilation (Kale, Dyer and Singh, 2002; Todorova and Durisin, 2007). As widely recognized by previous studies on organizational learning (e.g., Cohen and Levinthal, 1990; Arora and Gambardella, 1994; Anand and Khanna, 2000), the greater the degree of external knowledge complexity is, the greater the amount of ACAP necessary to handle the involved learning process. This fact implies that firms adopting research collaboration to learn from outside knowledge will have more incentives to reinforce their ACAP, which in turn will lead them to invest more in internal R&D activities.

Secondly, learning from research collaboration enhances a firm's exposure to heterogeneous knowledge more than learning from R&D outsourcing does. This is because research collaboration allows firms to learn from knowledge with a more complex composition (e.g., codified as well as tacit knowledge). In research collaboration, interaction enables participants to learn about multiple aspects, such as lacking technologies, managerial practices, or about partners' skills and capabilities (von Hippel, 1994; Doz, 1996; Kale et al., 2000). Instead, since R&D outsourcing involves successive exchanges of knowledge about technology implementation in markets, the firm is restricted to learning from codified knowledge, but not from other aspects underlying the production of the transacted knowledge. Therefore, compared to R&D outsourcing, the adoption of research collaboration enhances the exposure to varied and complex knowledge, better preventing the emergence of locked-out effects (Tidd and Trewhella, 1997; Rosenkopf and Nerkar, 2001). These arguments imply that research collaboration is more effective than R&D outsourcing in shaping the firm's ACAP, and subsequently, in stimulating its involvement in new R&D activities. Taking into account the previous discussion, I hypothesize that:

Hypothesis 1.2*: Complementarities emerging from the joint adoption of in-house R&D and research collaboration are stronger than complementarities emerging from the joint adoption of in-house R&D and R&D outsourcing.*

The next section describes the methods implemented in this study to test the previously described hypotheses, paying attention to the treatment of recognized difficulties associated with the empirical evaluation of complementarities in R&D.

1.3 Empirical analysis

To test for previous hypotheses, I implemented two alternative methodologies. First, I used the method of Arora and Gambardella (1990) to infer complementarities in R&D from conditional correlation coefficients[4]. These correlations come from a model in which the firm's choices on R&D are determined by observed firm and industry-specific factors. This is advantageous since this method also allows examining differences in factors that drive these choices, which in turn is informative about differences in factors influencing complementarities. Second, I tested directly for complementarities by assessing the performance effects of alternative organizational designs for R&D. To do so, I first specified a knowledge production function as being determined by exclusive combinations of the R&D activities in question. Drawing on previous empirical studies on complementarities (e.g., Mohnen and Röller, 2005; Leiponen, 2005b; Cassiman and Veugelers, 2006), I tested for the presence of supermodularity of this function as a method to assess complementarities in R&D[5].

1.3.1 Conditional correlation analysis

Here, I aim to assess complementarities between the firm's adoption choices of alternative combinations of internal and external R&D activities. Let $X = \{x_{RD}, x_{RC}, x_{RO}\}$ be the set of R&D activities under consideration, where "RD" represents in-house R&D, and "RC" and "RO" represent research collaboration and

[4] The idea behind this analysis is that under complementarities, the adoption of two strategies should be positively correlated. This implication is based on the *revealed preference principle*; that is, the fact that firms have chosen to adopt strategies together is potentially informative about the joint returns generated by them (Arora and Gambardella, 1990; Athey and Stern, 1998).
[5] Topkis (1998) and Milgrom and Roberts (1990) show that the presence of supermodularity implies the existence of complementarities.

R&D outsourcing, respectively. For any $x_k \in X$, an activity "k" is adopted when $x_k = 1$ and not when $x_k = 0$. To infer complementarities from conditional correlation coefficients, I first regressed firms' choices of R&D activities on a set of both firm-specific and industry-specific factors[6]. Since X includes three R&D activities, my model has three equations. Finally, I estimated the correlations between residual terms derived from each equation. These correlations are conditional on the observable factors included in the analysis. For modeling the firm's adoption choices on each x_k, I implemented a multivariate probit model for pooled data (Cappellari and Jenkins, 2003). These choices are determined simultaneously according to the following specification[7]:

$$x^*_{k,it} = Z_{it}\beta^k + u^k_{it}\ ,\ x_{k,it} = 1\left[x^*_{k,it} > 0\right];\quad \forall k = \text{RD, RO, RC}$$

$$E\left[u^k\right] = 0,\ V\left[u^j\right] = 1;\ \forall k,j = \text{RD, RO, RC} \qquad (1.1)$$

$$\text{Cov}\left[u^k, u^j\right] \neq 0;\ \forall k \neq j$$

Z contains controls for observed firm and industry characteristics, while u^k represents residuals corresponding to equation k. In this context, positive conditional correlation coefficients are consistent with Hypothesis 1.1. Further, a comparison between conditional correlations provides information to identify cases in which complementarities are stronger (Hypothesis 1.2). Nonetheless, the influence of unobserved factors can affect conditional correlations, which may lead either to assert complementarities between two R&D activities when in fact they are independent, or to conclude the absence of complementarities when they are actually complementary (Athey and Stern, 1998; Miravete and Pernias, 2006). Therefore, despite the informative power of model (1.1) in describing drivers of choices of R&D, conclusions regarding the presence of complementarities should not be exclusively based upon the conditional correlation analysis.

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[6] Firm-specific factors include variables, such as "firm size", "number of patents", and dummies reflecting the "use of innovation management", the "introduction of new products", or "new processes". Industry-specific factors include indicators, such as "industry-export intensity", or a proxy for "industry technological opportunities". See Table 1.2 for a complete description of each variable.

[7] One advantage of this specification is that it takes into account potential interdependencies in the adoption of R&D activities (Gomez and Vargas, 2009). When interdependencies exist, covariances between residuals will be statistically different from zero (Arora and Gambardella, 1990).

1.3.2 Knowledge production analysis

In this case, complementarities are inferred directly by assessing the effects that the firms' organizational choices in R&D have on knowledge creation. To this end, I estimated a knowledge production function in which the following issues were explicitly considered. First, knowledge creation is regarded as a dynamic process in that past performance in the production of knowledge determines current performance (Blundell, et al., 1995). This implies that experience in knowledge creation may explain persistent unobservable differences among firms in their capacity to produce knowledge (Martínez-Ros and Labeaga, 2002). Second, the relationship between knowledge creation and R&D adoption is examined allowing for potential correlation between unobservable firm-specific characteristics (e.g., managerial skills or the firm's knowledge background) and organizational choices in R&D[8]. Finally, the firm's organizational choices in R&D are viewed as predetermined variables (Leiponen, 2005b), which allows for the presence of feedback effects in the sense that knowledge produced by the firm in the past may have an impact on its current organizational choices[9].

The number of innovations commercialized by a firm in a given period characterizes knowledge creation, denoted here by K_{it}. Since this proxy is a non-negative integer variable, I considered the extant literature on count-data models to choose the specification that allows better for previously described issues (e.g., Hausman, Hall and Griliches, 1984; Montalvo, 1997; Blundell, et al., 2002). In particular, I implemented the model of Blundell, et al., (2002), who present a linear feedback specification for a dynamic count-data-panel process. This option produces estimates for the effects of the firm's organizational choices on knowledge creation, in which a fixed-effect specification is implemented, and in which organizational choices in R&D are regarded as predetermined variables.

[8] For instance, if the manager's aptitude to promote technological exploration is high, organizational designs with external links will probably be adopted more than others will (Rosenkopf and Nerkar, 2001).
[9] Success in previous innovation activities may raise the firm's aspiration levels, and subsequently, its willingness to be engaged in new R&D projects (Cohen and Levinthal, 1990).

Hence, in this study knowledge produced by the firm "i" at year "t" is determined as follows:

$$K_{it} = \gamma K_{it-1} + e^{\beta_0 + \sum_j \omega_j d_{jit} + \mathbf{W}_{it}^{'}\alpha + \eta_i + \varepsilon_t} + u_{it} \qquad (1.2)$$

The lag of the dependent variable, K_{it-1}, linearly comes into the model. A positive value for γ will indicate that the innovation behavior of firms is persistent. In this model, d_{jit} corresponds to binary variables that represent firm i's organizational choices at time "t", and where "j" is the set of organizational designs available to firm "i" (See Table 1.1 for a description of this set). **W** includes both firm and industry potential predetermined variables. In the model, η_i represents firm specific-effects, while ε_t represents time specific-effects. Finally, ω_j and $\boldsymbol{\alpha}$ refer to parameters associated with the firm choice variables (d_{jit}) and control potential predetermined variables (**W**), respectively.

Table 1.1. Organizational designs for R&D

Organizational Designs	The j^{th} combination (x_{RD} x_{RC} x_{RO})
No Adoption Setting	(000)
In-house R&D only	(100)
Research Collaboration only	(010)
R&D Outsourcing only	(001)
In-house R&D along with Research Collaboration	(110)
In-house R&D along with R&D Outsourcing	(101)
Research Collaboration and R&D Outsourcing	(011)
In-house R&D with both External R&D Activities	(111)

Note: x_k is a binary variable that is equal to one when the firm adopts the activity "k". The set "k" includes RD = in-house R&D, RC = research collaboration, and RO = R&D outsourcing.

Then, I tested for complementarities by examining the existence of supermodularity of K. Using the estimates of ω_j, the conditions for which K is supermodular in X are defined as follows:

Supermodularity on x_{RD} and x_{RC}	$\begin{cases} \omega_{(110)} - \omega_{(100)} \geq \omega_{(010)} - \omega_{(000)} \\ \text{and} \\ \omega_{(111)} - \omega_{(101)} \geq \omega_{(011)} - \omega_{(001)} \end{cases}$	(1.3.1)
Supermodularity on x_{RD} and x_{RO}	$\begin{cases} \omega_{(101)} - \omega_{(001)} \geq \omega_{(100)} - \omega_{(000)} \\ \text{and} \\ \omega_{(111)} - \omega_{(011)} \geq \omega_{(110)} - \omega_{(010)} \end{cases}$	(1.3.2)
Supermodularity on x_{RC} and x_{RO}	$\begin{cases} \omega_{(011)} - \omega_{(001)} \geq \omega_{(010)} - \omega_{(000)} \\ \text{and} \\ \omega_{(111)} - \omega_{(101)} \geq \omega_{(110)} - \omega_{(100)} \end{cases}$	(1.3.3)

Note that the supermodularity of K implies the idea of complementarities between decision variables in X, since the adoption of R&D activities separately does not raise knowledge the same as implementing all of them simultaneously.

From the procedure developed by Kodde and Palm (1986), I tested for conditions (1.3.1)–(1.3.3) under the null hypothesis, taking each pair at a time, and considering that the test for supermodularity is a one-sided test of a given pair of inequalities[10]. To this end, I computed a distance measure that was subsequently compared with both upper and lower bounds, as provided by Kodde and Palm (1986). The decision rule applied establishes that: if the distance value is below the lower bound, the null is not rejected; if the distance value is above the upper bound, the null is rejected. Values for the distant test falling between the bounds show that the test is inconclusive. Note that a test for sub-modularity (substitution between R&D activities) can be conducted in a similar way. In this case, it is necessary to reverse the inequalities in (1.3.1)–(1.3.3) and impose them as restrictions to be met under the null.

By following a procedure similar to that of Leiponen (2005b), I tested for the hypothesis of strict supermodularity as a method for assessing complementarities. For each pair, I first tested for the presence of supermodularity, and then for the presence of sub-modularity, both under the null. Non-rejection of the first and rejection of the second is considered as evidence about the presence of strict supermodularity. This fact indicates

[10] Restrictions in (1.3.1)–(1.3.3) can be also tested under the alternative hypothesis (Kodde and Ritzen, 1988). When testing each pair of inequalities under the null, the testing problem is that inequalities have to be satisfied simultaneously, while under the alternative there are no restrictions.

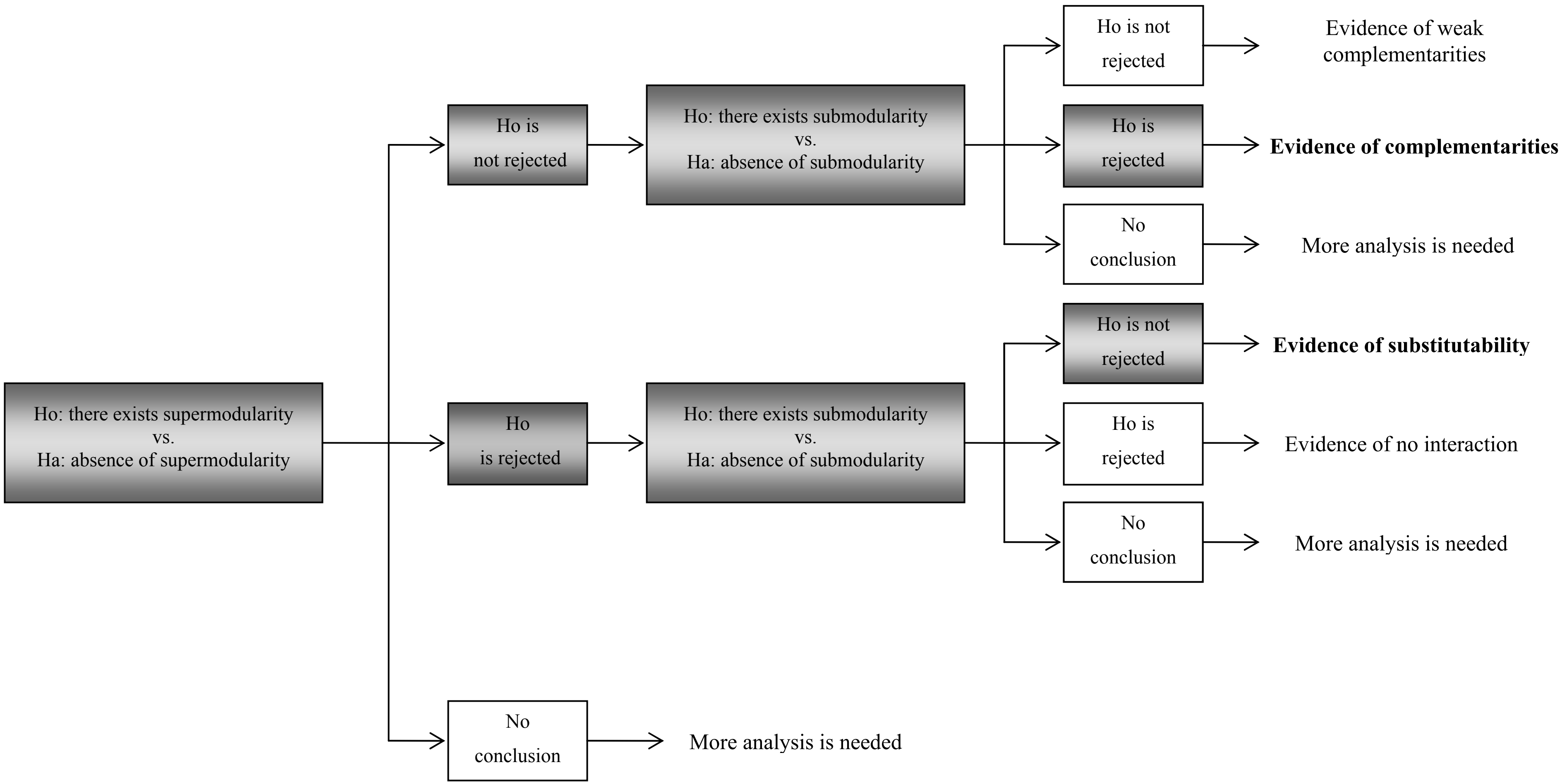
the existence of complementarities. Alternatively, non-rejection of the first with non-rejection of the second points to the presence of both supermodularity and sub-modularity, which is interpreted here as evidence that complementarities are weak. Finally, rejection of both supermodularity and sub-modularity is regarded as evidence that there is no interaction between the R&D activities under consideration. Figure 1.2 describes the testing strategy followed in this paper in detail. In order to complement the testing-procedure previously described, I followed Kodde and Ritzen (1988), shifting the test in such a way that the inequality testing problem (e.g., there is no interaction at all) is defined under the null against the alternative hypothesis that supermodularity (or sub-modularity) exists[11].

1.3.3 Data and variables

The analysis in this paper makes use of the *Spanish Survey of Business Strategies* (henceforth, ESEE) conducted by the Public Enterprise Foundation and the Spanish Ministry of Science and Technology since 1990. Every year, the survey collects information on an average sample of 1800 companies. This is an unbalanced panel as some companies stopped providing information for reasons, such as mergers, closure, or liquidation. Therefore, to preserve representativeness, new companies are included in the survey each year. The survey is exhaustive for firms with more than 200 workers. In the case of companies with between 10 and 200 workers, a stratified random sample by industry and size intervals is gathered. The data used in the current study covers the period 1998–2002.

[11] Under this reformulation, non-rejection of the null hypothesis provides evidence indicating that there is no interaction between the R&D activities under consideration.

Figure 1.2. Hypothesis testing strategy



Attention is placed on Spanish manufacturing firms in the ESEE with complete information on their technological activities. Observations for those firms involved in any acquisition and for firm experiencing changes in their legal forms during the period of study were excluded. Additionally, no gaps in the individual time series are allowed[12]. Fulfillments of these requirements result in a balanced panel with 1034 observations for each year[13]. This data include companies whose principal economic activity is listed in one of the two-digit manufacturing industries of the "Classification of Economic Activities in the European Community".[14]

Dependent variables

In the case of model (1.1), the R&D adoption behavior of firms is characterized by three binary variables that indicate if a firm conducts in-house R&D, R&D outsourcing, or research collaboration, respectively. Regarding the latter, I built this variable aggregating the information of the survey in which firms state whether they participated in joint-venture arrangements and in R&D collaboration with universities, competitors, suppliers, or clients. As commented above, knowledge creation in model (1.2) is measured in terms of the number of new products commercialized by a firm in each year.

Explanatory and control variables

Table 1.2 describes regressors included in models (1.1) and (1.2). As explanatory variables in model (1.2), I used dummies that indicate the adoption of R&D activities to build exclusive combinations that characterize alternative organizational designs for

[12] This requirement has to be fulfilled for estimating model (1.2) with the ExpEnd gauss routine (Windmeijer, 2002).

[13] A comparison of means between the unbalanced and unbalanced sample for some variables provides the following results. The null hypothesis of no differences in means for variables, such as "number of employees" and "value assets" is rejected at conventional levels. I found that means are statistically smaller for the balanced than for the unbalanced sample. For these variables, Box plots show that the balanced sample has much fewer outliers, compared with the unbalanced sample. This fact could explain the reported differences in means. A further comparison indicates insignificant differences in means for variables, such as "number of patent applications", "number of new products commercialized", or "industry export intensity". Finally, for the balanced sample, I classified firms by size and industry categories in order to examine how they differ in terms of variables such as, "number of patent applications", and "number of product innovations". Then, I compared the resulting differences to those observed in the data provided by the Spanish National Statistics Institute (INE) and in the unbalanced sample provided by Public Enterprise Foundation. I did not find substantial differences between the results derived from the balanced sample and those reported by these institutions.

[14] This classification is equivalent to the "International Standard Industrial Classification", ISIC.

R&D activities (see Table 1.1). On the other hand, I also included control variables that affect the R&D adoption behavior in model (1.1) and/or the innovative propensity of firms in model (1.2). In order to control for the fact that firms with different learning capabilities may differ in terms of their ability to generate complementarities, I considered the indicator, *Innovation Management*. This is a dummy variable that characterizes the firm utilization of management practices, such as the adoption of planning programs to address innovation activities, and the use of metrics to evaluate innovation outcomes. In model (1.1), it is hypothesized that the use of innovation management practices induces the firm's adoption of R&D activities. This holds true since these practices enable firms to detect the R&D activities required for achieving predetermined innovation objectives, and to assess better the contribution of these activities to the innovation process. In the case of model (1.2), I hypothesized that firms using innovation management mechanisms are better placed to harness learning rooted in the R&D, and then are those with a high propensity to innovate (Huergo, 2006). In addition, in model (1.2) I included the indicator, *Innovation Intensity*, measured here as the percentage of R&D expenditure to total sales. With this variable, I aim to control for the influence that differences in the technological efforts of firms may have on knowledge creation. In particular, it is expected that *Innovation Intensity* contributes positively to determining knowledge creation (Cassiman and Veugelers, 2006).

As suggested in the last section, firms with a high exposure to diverse external knowledge are those with more incentives to make R&D activities and with higher probabilities to produce complementarities in R&D. To control for these aspects, I incorporated the indicator *Technological Opportunities*, which represents external knowledge available to firms that may contribute to improving their technological performance (Cohen and Levinthal, 1989; Breschi, Malerba and Orsenigo, 2000). Particularly in model (1.1), it is hypothesized that *Technological Opportunities* encourage the adoption of R&D activities, since in industries with high investments in R&D, firms search more extensively to access new opportunities (e.g., Cohen and Levinthal, 1989; Veugelers, 1997; Laursen and Salter, 2006). To allow for a non-linear relationship between *Technological Opportunities* and the R&D adoption behavior, I also considered the quadratic term of *Technological Opportunities*. Additionally, in assuming the presence of diffusion spillovers, it is expected that the propensity to innovate in model (1.2) is also positively associated with a high presence of

Technological Opportunities (Klevorick et al., 1995; Cincera, 1997; Breschi et al., 2000).

Table 1.2. Variable description and descriptive statistics

Model	Variable	Description	Mean	S.D.	Min.	Max.
1-2	Innovation Intensity	Percentage of R&D expenditures to total sales	0.70	2.21	0	55.8
1-2	Innovation Management	Binary: 1 if the firm used plans to address its innovation activities and metrics to assess innovation outcomes.	0.23	0.42	0	1
1-2	Technological Opportunities*	Industrial R&D stock normalized by total industrial sales (measured at the level of two-digit NACE).	1.71	2.48	0.19	20.27
1-2	Number of Patents	Number of patents granted during the year	0.35	3.93	0	150
1-2	Process Innovation	Binary: 1 if the firm conducted process innovation	0.32	0.46	0	1
1	Product Innovation	Binary: 1 if the firm conducted product innovation	0.22	0.42	0	1
1-2	Industry Export Intensity	Total industrial exports normalized by total industrial sales (measured at the level of two-digit NACE)	0.29	0.14	0.03	0.91
1-2	Value of Total Assets	Logarithm of total value assets	13.95	2.32	5.09	19.72
1	Total Public Funds	Logarithm of public resources for financing R&D activities	1.02	3.33	0	16.99
2	Knowledge Creation	Number of new products commercialized	2.59	17.18	0	426
1	In-house R&D	Binary: 1 when the firm adopted R&D activities	0.28	0.44	0	1
1	R&D outsourcing		0.19	0.39	0	1
1	Research Collaboration		0.29	0.45	0	1
2	In-house R&D only	Binary: 1 when the firm adopted exclusive combinations of R&D activities	0.04	0.18	0	1
2	Research Collaboration only		0.03	0.19	0	1
2	R&D Outsourcing only		0.01	0.13	0	1
2	In-house R&D with Research Collaboration		0.09	0.28	0	1
2	In-house R&D with R&D Outsourcing		0.02	0.12	0	1
2	Research Collaboration and R&D Outsourcing		0.03	0.16	0	1
2	In-house R&D with both External R&D		0.13	0.34	0	1

* For each firm, I used the perpetual inventory method to determine R&D stock (Beneito, 2006; Morales, 2007). I first deflated the firm's R&D expenditures using an Industrial Price Index for durable goods, base 1998 (www.ine.es). Subsequently, for the first observation, I used the market capitalization formula: $K^{RD}_{it=1998} = R_{it=1998}/(g+\delta)$. I assumed that δ=0.3 (Martínez-Ros and Labeaga, 2002), and that g=0.4 (Beneito, 2006). Finally, R&D stock for firm "i" at period "t" is derived from $K^{RD}_{it} = (1-\delta)K^{RD}_{it-1} + R_{it-1}$. Finally, I aggregated individual R&D stock at the industry level (two-digit NACE).

To control for appropriability concerns (Kale et al., 2000; Baker, Gibbons and Murphy, 2002), I incorporated the variable *Number of Patents* granted to the firm in each year. In model (1.1), it is hypothesized that firms with strong patenting capabilities are less exposed to leakage of strategic information, and for that reason, they engage more in R&D activities. Likewise, patenting capabilities positively determine knowledge creation in model (1.2) because they allow firms to appropriate benefits from innovation. Alternatively, I included in each model the variable, *Industrial Export Intensity*. In so doing, I aim to control for the fact that the degree of internationalization of the industry where a firm operates likely affects its adoption R&D behavior as well as its propensity to innovate. In model (1.1), it is hypothesized that firms in export industries adopt R&D activities as a method to extend their search activities to distant geographic contexts (Rosenkopf and Almeida, 2003). In model (1.2), it is expected that firms operating in export industries innovate more in an attempt to compete effectively in international markets (Cassiman and Veugelers, 2006). Finally, I incorporated *Value of Total Assets* in both models as a proxy for firm size. In particular, this controls for differences in both R&D adoption behavior and the production of knowledge related to variations in the scale of operations (Henderson and Cockburn, 1996; Veugelers and Cassiman, 1999; Almeida, Dokko and Rosenkopf, 2003).

Model (1.1) also incorporated the following controls. Since adoption behavior may differ among innovative and non-innovative firms, I included two binary variables that state whether the firm conducted either product or process innovation. Furthermore, I incorporated the variable *Total Public Fund* received by the firm to finance R&D activities, which attempts to control for the influence of public financing extensively used in Spain to stimulate firms' R&D activities (Bayona, García-Marco and Huerta, 2001). Finally, I added a categorical variable into model (1.2) that states whether the firm conducted process innovation. In this way, I try to take into account potential complementarities between process and product innovation during knowledge creation (Martínez-Ros and Labeaga, 2002; Reichstein and Salter, 2006). Table A1 in the appendix contains the correlation matrix of previously described regressors.

1.4 Results

Table 1.4 shows the estimation of unconditional correlations (Spearman rank correlation). As expected, the adoption of internal and external R&D activities is positively correlated, being stronger in cases for which firms combine in-house R&D with research collaboration. Table 1.5 shows the estimation of both the multivariate probit model and the associated conditional correlations. It is worth mentioning that the likelihood ratio test for the null that choices on R&D activities are independent is strongly rejected (*p-value < 0.001*). After removing the effects of observable factors, correlations between internal and external R&D activities remain positive and statistically significant, giving support to Hypothesis 1.1. In favor of Hypothesis 1.2, the results indicate that the conditional correlation between in-house R&D and research collaboration is much larger than that observed in the case of in-house R&D and R&D outsourcing.

By examining the factors driving R&D adoption, it is observed that the majority of the estimates of the multivariate probit model have the expected signs. Consistent with Kale et al., (2002), the parameter for *Innovation Management* is positive and statistically significant in each equation, providing evidence that firms using management practices to address their innovation activities are prone to adopting R&D activities. The results indicate that *Technological Opportunities* has a positive and statistical, but diminishing effect on the adoption behavior of R&D activities. As expected, both product and process innovation are positively related to the likelihood of R&D adoption. As indicated by other studies (Bayona et al., 2001), financing in Spain has a positive and significant impact on R&D adoption behavior. In addition, firm size is a factor positively influencing the likelihood of adopting R&D activities. These results are compatible with other studies that indicate that large firms have advantages for using both internal and external sources of knowledge (Henderson and Cockburn, 1996; Veugelers and Cassiman, 1999).

Table 1.4. Results for the unconditional correlations

	In-house R&D	Research Collaboration	R&D Outsourcing
In-house R&D	–	–	–
Research Collaboration	0.710***	–	–
R&D Outsourcing	0.541***	0.586***	–

Coefficient significant at 1%***, 5%**, and 10%*.

Table 1.5. Regression results for the choice of R&D activities

Independent variables	**In-house R&D (x_{RD})**	**Research Collaboration (x_{RC})**	**R&D Outsourcing (x_{RO})**
Innovation Management	1.577† (0.064)	1.182† (0.061)	0.870† (0.060)
Industrial Technological Opportunities	0.220† (0.026)	0.132† (0.027)	0.068*** (0.025)
Industrial Technological Opportunities Squared	-0.018† (0.002)	-0.009† (0.002)	-0.003** (0.002)
Number of Patents	0.020 (0.018)	0.001 (0.008)	0.029** (0.012)
Process Innovation	0.095* (0.056)	0.319† (0.052)	0.131*** (0.053)
Product Innovation	0.629† (0.061)	0.482† (0.060)	0.263† (0.059)
Industry Export Intensity	0.085 (0.216)	0.095 (0201)	0.456** (0.203)
Total Public Funds	0.119† (0.014)	0.098† (0.010)	0.089† (0.008)
Value of Total Assets	0.191† (0.013)	0.230† (0.013)	0.169† (0.012)
Constant	-3.999† (0.064)	-4.567† (0.192)	-4.009† (0.185)
Time Dummies	(included)	(included)	(included)
Conditional Correlations			
ρ (x_{RD} and x_{RC})		0.548†	
ρ (x_{RD} and x_{RO})		0.316†	
ρ (x_{RC} and x_{RO})		0.471†	
Goodness of fit		$\chi^2(39) = 3060.86$***	
Log-pseudo Likelihood		-4494.4464	
Observation (NxT)		5170	

Robust standard errors in parentheses: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, † $p < 0.001$.

The results show important differences in factors determining the adoption of research collaboration and R&D outsourcing. As regards *Innovation Management*, it is observed that its effect is statistically stronger on the choice of research collaboration than on the choice of R&D outsourcing[15]. The degree of association between the adoption of external R&D activities and the use of innovation management practices are regarded here as a signal indicating the level of complexity involved in learning from external knowledge (von Hippel, 1994; Anand and Khanna, 2000). In line with this suggestion, the results show that research collaboration is a more complex form of knowledge provision than R&D outsourcing, as the former depends more on the implementation of knowledge management. As regards *Technological Opportunities*, it is observed that increasing opportunities induce more the adoption of research collaboration than the adoption of R&D outsourcing[16]. This fact supports the idea that access to technological opportunities favors more the implementation of specific mechanisms of knowledge transfer. These results are consistent with the premise that learning from increasing technological opportunities is a difficult task that needs closer interaction between the firm and external actors than that produced by the exchange of knowledge in markets for technology (Tidd and Trewhella, 1997; Kale et al., 2000). Taken together, these findings are consistent with the arguments used here to ground Hypothesis 1.2; that is; research collaboration and R&D outsourcing differ in the provision of knowledge derived from each one.

Table 1.6 shows the estimates of the parameters for the knowledge production function in model (2). Particularly, I used a GMM estimator using Chamberlain moment conditions for the linear feedback specification in model (2)[17]. Columns 1–4 show two-step GMM estimations, in which *Innovation Intensity* and *Innovation Management* were successively incorporated as two alternative specifications for the firm's learning capabilities, and in which the linear and quadratic term of *Technological Opportunities* were also included. In all cases, the existence of a first-order correlation of the residuals is observed, but there is no second-order autocorrelation, which shows that the model is

[15] The Wald test for the hypothesis that the estimate of *Innovation Management* in the research collaboration equation is equal to that observed in the R&D outsourcing equation is rejected at conventional levels.
[16] The Wald test for the hypothesis that the estimate of *Technological Opportunities* in the research collaboration equation is equal to that observed in the R&D outsourcing equation is rejected at conventional levels.
[17] Estimations were carried out with ExpEnd, a Gauss code for non-linear GMM estimations of count data models with endogenous regressors (Windmeijer, 2002).

well-specified (Windmeijer, 2002). Values of the dependent variable lagged two or more periods as well as values of the explanatory variables lagged one or more periods are used as valid instruments in the study (see note in Table 1.6). As shown by the extant literature on count-data-panel models (e.g., Montalvo, 1997; Cincera, 1997), successive past values for the dependent and explanatory variables prove to be valid instruments in the quasi-differenced GMM estimator, since these values correlate with predetermined regressors in the differenced model, but not with the fixed effect term. Table 1.6 also reports the Sargan-test of the over-identifying restrictions. This statistic provides a test for verifying if the instruments under consideration are appropriately orthogonal to the residuals.

As indicated by Table 1.6, in all cases, the Sargan-test confirms the validity of the instruments used in the estimation (via the Chamberlain moment conditions). The validity of the implemented instruments is particularly important in the context of this research, taking into account that previous cross-sectional studies on complementarities in R&D recognize clear limitations in finding suitable instruments when correcting for unobserved heterogeneity (e.g., Cassiman and Veugelers, 2006; Schmiedeberg, 2008; Love and Roper, 2009). However, as discussed by Leiponen (2005b), the capacity of panel data techniques to allow for the type of unobserved heterogeneity that affects complementarities requires the assumption that the unobserved firm characteristics keep constant over time. Therefore, the validity of my approach to treat unobserved heterogeneity is circumscribed to this assumption.

The results from model (1.2) show that organizational designs with internal and external R&D activities tend to have a greater impact on innovation propensity than those with just one R&D activity. This is consistent with the idea that the joint adoption of internal and external R&D activities enhances learning (Hypothesis 1.1). It is also observed that organizational designs based exclusively on research collaboration have a negative, statistical impact on innovation propensity, while organizational designs in which R&D outsourcing is adopted exclusively have a positive, statistical effect on knowledge creation. These findings suggest that learning from R&D outsourcing is possible even without the adoption of in-house R&D, while learning from research collaboration needs complementary skills in terms of in-house R&D.

Table 1.6. Regression results for the firm innovation performance

Independent variables	Model (a)	Model (b)	Model (c)	Model (d)
Lag of the Number of New Products	0.198† (0.012)	0.179† (0.009)	0.172† (0.010)	0.159† (0.009)
Innovation Intensity	0.002 (0.028)	–	0.053** (0.025)	0.022 (0.024)
Technology Management	–	0.264* (0.147)	0.504† (0.134)	0.395† (0.107)
Industrial Technological Opportunities	-0.161*** (0.055)	-0.209*** (0.064)	-0.196† (0.054)	-0.375† (0.073)
Industrial Technological Opportunities Squared	–	–	–	0.025** (0.010)
Number of Patents	0.017*** (0.005)	0.017*** (0.005)	0.019† (0.004)	0.016*** (0.005)
Process Innovation	-0.988† (0.065)	-0.968† (0.062)	-0.977† (0.064)	-1.033† (0.055)
Industry Export Intensity	1.710*** (0.593)	2.231† (0.590)	1.798*** (0.549)	2.218† (0.562)
Value of Total Assets	0.208† (0.052)	0.108 (0.078)	0.075 (0.080)	0.015 (0.103)
Time Dummies	0.198† (0.012)	0.179† (0.009)	0.172† (0.010)	0.159† (0.009)
Organizational design adoption				
In-house R&D only	1.487† (0.229)	1.500† (0.242)	1.549† (0.234)	1.626† (0.203)
R&D Collaboration only	-0.653** (0.322)	-0.888** (0.267)	-0.928† (0.255)	-1.224† (0.186)
R&D Outsourcing only	0.683*** (0.195)	0.474** (0.209)	1.043† (0.154)	0.894† (0.177)
In-house R&D with R&D Collaboration	1.244† (0.082)	1.234† (0.137)	1.132† (0.139)	1.110† (0.099)
In-house R&D with R&D Outsourcing	1.732† (0.293)	1.812† (0.295)	1.526† (0.304)	1.738† (0.289)
Both Types of External R&D	0.150 (0.219)	0.205 (0.207)	0.110 (0.176)	-0.154 (0.177)
In-house R&D with both External R&D	1.948† (0.201)	2.116† (0.220)	1.827† (0.219)	2.061† (0.193)
Tests for serial correlation				
First-order serial correlation	-2.423**	-2.526**	-2.468**	-2.544**
Second-order serial correlation	-0.044	-0.270	-0.203	-0.318
Overidentification test				
Sargan's test	108.7611	115.0891	112.1745	130.4854
Degree of freedom	101	101	109	117
P-value	0.2812	0.1599	0.3982	0.1859
Observation (NxT)	5170			

Notes: Parameters are two-step GMM estimators using Chamberlain moment conditions. Estimations assume that organizational choice variables and control variables should be taken as predetermined, and then past values of all the regressors are used as instruments. Lags values of the dependent variables are also included as instruments. A maximum of four lags are used.
Robust standard errors in parentheses: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, † $p < 0.001$.

The results from model (1.2) show that organizational designs with internal and external R&D activities tend to have a greater impact on innovation propensity than those with just one R&D activity. This is consistent with the idea that the joint adoption of internal and external R&D activities enhances learning (Hypothesis 1.1). It is also observed that organizational designs based exclusively on research collaboration have a negative, statistical impact on innovation propensity, while organizational designs in which R&D outsourcing is adopted exclusively have a positive, statistical effect on knowledge creation. These findings suggest that learning from R&D outsourcing is possible even without the adoption of in-house R&D, while learning from research collaboration needs complementary skills in terms of in-house R&D.

Regarding the estimations for the control variables, the results are as follows. Estimates on the lagged dependent variable are positive and statistically significant in accordance with the premise that highly innovative firms tend to be so in the future. This fact reveals the presence of a persistent effect in innovation (Martínez-Ros and Labeaga, 2002; Leiponen, 2005b). Likewise, the parameter for *Innovation Management* is positive and statistically significant in all cases. As shown in model (b) of Table 1.6, inclusion of this variable in the analysis makes the coefficient for *Value of Total Assets* no longer statistically significant, which is consistent with the findings of Huergo (2006). That is, the effect of firm size on innovation propensity includes a large part relating to the use of mechanisms for innovation management.

It is also observed that the effect of *Technological Opportunities* is negative and statistically significant in all cases, suggesting the presence of *competitive* rather than *diffusion* spillovers (Cincera, 1997). In order to verify the existence of a nonlinear relationship between *Technological Opportunities* and innovation propensity, I introduced *Technological Opportunities Squared* into model (d). Last column of Table 1.6 shows that the parameter for *Technological Opportunities* is negative and that the parameter for the squared term is positive, which implies that at low values of knowledge spillovers, additional *Technological Opportunities* have a negative effect on knowledge creation. At some level, the effect becomes positive, indicating that the presence of knowledge spillovers encourages knowledge creation. This finding suggests that *diffusion* spillovers prevail over *competitive* spillovers, once a certain threshold of *Technological Opportunities* is achieved. Parameters for the *Number of Patent* applications are positive and statistically significant in all cases, suggesting that firms' patenting capabilities incentive innovation propensity.

Unexpectedly, it is observed that the adoption of process innovation is negatively related to product innovation, which is not consistent with the presence of complementarities between these activities. Further experimentation with other specifications[18] reveals that the parameter for *Process Innovation* becomes negative once the lag of the dependent variable is included in the model. This could indicate that knowledge accumulation, characterized by K_{t-1}, reflects a part of the effects attributed to *Process Innovation*. Finally, it is observed that *Industry Export Intensity* is a relevant factor explaining innovation propensity, which is consistent with the premise sustaining that internationalization is a push-force inducing innovation.

Table 1.7 presents the values of the distance test used to assess complementarities[19]. Table 1.8 shows lower and upper bounds for various significant levels provided by Kodde and Palm (1986). Comparing distance measures in Table 1.7 with bounds in Table 1.8 leads to the following conclusions. There are complementarities in the case of the joint adoption of internal R&D and research collaboration, as suggested by the fact that strict supermodularity of the objective function is not rejected in any case. That is, supermodularity is not rejected while sub-modularity is strongly rejected. This result shows that internal R&D and research collaboration reinforce each other during the process of knowledge creation, giving support to Hypothesis 1.1.

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[18] Available from the author upon request.

[19] These values were obtained according to the procedure presented by Kodde and Palm (1986), in which a version of the Wald test is computed by minimizing a particular distance measure.

Table 1.7. Minimum distance values to be compared with the upper and lower bounds of the Kodde and Palm's test

Interaction	Combinations of R&D activities	Model (a)	Model (b)	Model (c)	Model (d)
Complementarity (Supermodularity under the null)	In-house R&D and Research Collaboration	7.6226e-009†	2.4732e-009†	6.0081e-010†	1.3194e-009†
	In-house R&D and R&D Outsourcing	1.318††	7.0283e-016†	10.813***	5.923**
	Research Collaboration and R&D Outsourcing	2.3706e-009†	8.7334e-011†	4.0554e-004†	1.8260e-009†
Substitutability (Sub-modularity under the null)	In-house R&D and Research Collaboration	8.507***	7.104**	26.078***	29.992***
	In-house R&D and R&D Outsourcing	1.7901e-010†	0.409†	1.4485e-010†	1.7891e-010†
	Research Collaboration and R&D Outsourcing	2.182†††	9.366***	6.039**	9.755***

Note: The use of asterisks indicates significant levels at which the null hypothesis is rejected. We adopt the conventional notation: 1%***, 5%**, and 10%*. Alternatively, the use of daggers indicates significant levels at which the null hypothesis cannot be rejected. In this case, we adopt the following notation: 25%†, 10%††, and 5% †††.

Table 1.8. Upper and lower bounds on the critical values of the distance test with two inequality constraints

Significant level α	0.25	0.10	0.05	0.01
Lower bound	0.455	1.642	2.706	5.412
Upper bound	2.090	3.808	5.138	8.273

Source: Kodde and Palm (1986).

For combinations between in-house R&D and R&D outsourcing, the results point to the existence of a substitution relationship. In all cases, sub-modularity is not rejected while the presence of supermodularity depends on the specification to be considered. In the case of model (a) and (b), the results point to the presence of weak complementarities, as both supermodularity and sub-modularity are not rejected. For these cases, I redefined the test so that under the null, no interaction is tested against supermodularity under the alternative[20] (see Kodde and Ritzen, 1988). In both settings, the null

[20] Results for cases in which the test is inconclusive are not shown here for space reasons, but they are available from the author upon request.

hypothesis cannot be rejected, thus, indicating these activities are independent. In the case of model (c) and (d), the test supports the existence of a substitution relationship, since supermodularity is rejected at 1% and 5%, respectively, while sub-modularity cannot be rejected at 25%[21]. Altogether, these results are interpreted as indicating that knowledge creation is weakly sub-modular in combinations for which firms adopt in-house R&D with R&D outsourcing. This fact reveals then the presence of a substitution relationship.

Finally, it is observed that the relationship between research collaboration and R&D outsourcing tends to be complementarity. For this combination, supermodularity in knowledge creation is not rejected while sub-modularity tends to be rejected. Since these activities are interrelated, it is of great importance not to ignore this fact when evaluating performance effects attributed to the joint adoption of internal and external R&D activities.

1.5 Discussion and conclusions

This study compares complementarities derived from alternative combinations of internal and external R&D activities, using an empirical design in which conditional correlations, as well as a dynamic knowledge production model were estimated from a panel of Spanish manufacturing companies. With this empirical design, the current study is among the first in correcting for the effects of unobserved heterogeneity that may affect the assessment of complementarities among R&D activities.

The results of this study strong support the proposed hypothesis that complementarities between R&D activities across organizational boundaries depend on whether firms leverage their intramural R&D by choosing research collaboration or R&D outsourcing. The findings indicate that while combinations between intramural R&D and research collaboration produce strong complementarities in knowledge creation, the joint adoption of intramural R&D and R&D outsourcing reduces the firm’s innovative performance. The evidence here shows that the co-development of R&D among partners, rather than the acquisition of R&D in markets, proves to be an effective

[21] While inequalities are tested under the null, note that the test is more demanding as the level of significance is greater.

mechanism in reinforcing the contribution of intramural R&D to knowledge creation. Although the current research employ a different approach, the results confirm the findings reported by prior research on inter-organizational learning that alliances, such as joint-ventures, are superior to contract-based arrangements in promoting inter-firm knowledge transfer (Mowery et al., 1996; Gomes-Casseres et al., 2006) as well as in generating learning-effects (Anand and Khanna, 2000). These findings expand previous literature as they show that participation in R&D collaboration contributes to shaping innovative performance particularly by leveraging in-house R&D. Previous studies on alliance learning rarely assessed this indirect effect of alliances on innovative performance.

In order to gain further insights into the role of external sourcing in forming complementarities, I examined the drivers leading firms' R&D adoption behavior. In particular, I found that compared with R&D outsourcing, research collaboration is related more to the use of innovation management practices and to the presence of increasing technological opportunities. As expected, these results support the proposition that research collaboration is a more complex form of knowledge provision, and in this respect, its adoption incentives are more in line with the firm's implementation of in-house R&D. By considering Anand and Khanna's (2000) suggestion that the potential of a firm's learning increases with the difficulty in managing knowledge provision in alliances, the findings of this research imply that such learning should have a broader scope in research collaboration than in R&D outsourcing. These results are relevant for the literature on complementarities in R&D, since they suggest that differences in the scope of learning associated with each of the external R&D activities under consideration may have a critical role in explaining differences in the way intramural R&D interacts with research collaboration and R&D outsourcing, respectively.

However, the finding showing a substitution relationship between in-house R&D and R&D outsourcing contrasts the results provided by Schmiedeberg (2008) and by Cassiman and Veugelers (2006). While the former study reports no evidence of complementarities for a sample of German firms, the latter supports the hypothesis of complementarities between these R&D activities for a sample of Belgian firms. Alternatively, in line with the literature on open innovation (Chesbrough, 2003), my results suggest that firms could improve their learning results by specializing in R&D core-activities internally or by acquiring in markets the R&D in which others have encoded knowledge expertise. Several features can be considered to explain divergences between my findings and those reported by the mentioned studies. For instances, differences across countries in the functioning and nature of markets for technology, or in the role of public policy in promoting innovation might explain discrepancies in the R&D adoption behavior (Mowery and Rosenberg, 1991). Furthermore, differences in methodology and data may result in contrasting conclusions. In this respect, important differences can exist, taking into account that the empirical design used here draws on longitudinal data for testing the hypotheses under question.

The findings of this paper have relevance for both innovation management and technology policy. As regards innovation management, the results provide indications on how firms can organize their R&D activities along their boundaries to obtain the best outcomes in terms of knowledge creation. The evidence provided by the study points to the adoption of research collaboration as the best option to enhance the returns of intramural R&D, although its benefits are only available to firms having technological and managerial skills. Alternatively, since R&D outsourcing has a positive effect on knowledge creation, it seems the right option to acquire knowledge in cases for which firms lack relevant technological assets, and for which markets for technology exist. Subcontracting of R&D may be also a suitable option in cases for which firms decide to focus their R&D effort in core R&D activities. As regards technology policy, this study supports the idea that promotion of public programs that stimulate research collaboration in sectors with high investments in R&D may cause positive externalities, considering the reinforcement effects that R&D collaboration may have on intramural R&D. Additionally, policies that improve the efficiency of markets for technology (e.g., by creating or developing property rights) may generate positive effects on the firm's innovative performance by favoring the diffusion and exploitation of available technologies. Nonetheless, one would expect that the effects of policies promoting R&D collaboration would outweigh those associated with the improvements in the functioning of markets for technology.

The results of this research are subject to some limitations, which at the same time, open new avenues for future research. As in other empirical studies on complementarities (e.g., Leiponen, 2005b; Belderbos, et al., 2006), the sample used here has few observations in some of the exclusive combinations of R&D activities under consideration. This fact may affect the estimation of critical coefficients, which could become less consistent and less significant. A larger sample of companies may contribute to mitigating this concern. On the other hand, given that the ESEE includes observations at the firm level, complementarities in R&D may be induced by economies of scope caused by the simultaneous development of several projects (Veugelers and Cassiman, 1999). However, the results are valid even after considering the effect of the variable *Innovation Management*, which controls for a firm's ability to manage several R&D projects simultaneously (Huergo, 2006). More research may contribute to verifying whether the production of complementarities between internal and external R&D activities takes place strictly at the organizational level or whether they can appear at the level of individual R&D projects. Finally, this study does not examine specific patters of interactions between internal R&D and research collaboration. Following the taxonomy developed by Choi, Poon and Davis (2008), complementarities can be classified into symmetric (R&D activities are mutually reinforcing) and asymmetric (one is reinforced by the other). In this regard, more research is needed to determine whether in-house R&D and research collaboration contribute symmetrically to knowledge creation, or if one of them plays a central role while the other acts more as a moderating R&D activity. Analysis of this feature is relevant for a better understanding of the characteristics underlying the architecture of organizational designs joining internal and external R&D activities.

Table A1. Correlation matrix

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. Knowledge Creation	1.00																			
2. Internal R&D Adoption	0.12	1.00																		
3. Research Collaboration Adoption	0.08	0.54	1.00																	
4. R&D Outsourcing Adoption	0.09	0.71	0.59	1.00																
5. Innovation Intensity	0.09	0.40	0.39	0.36	1.00															
6. Innovation Management	0.12	0.70	0.53	0.64	0.34	1.00														
7. Industry Technological Opportunities	-0.01	0.14	0.16	0.14	0.23	0.14	1.00													
8. Number of Patents	0.01	0.11	0.13	0.10	0.21	0.13	0.04	1.00												
9. Process Innovation	0.06	0.29	0.24	0.31	0.14	0.31	0.06	0.08	1.00											
10. Product Innovation	0.28	0.42	0.30	0.39	0.22	0.41	0.10	0.10	0.29	1.00										
11. Industry Export Intensity	0.01	0.16	0.16	0.16	0.15	0.16	0.49	0.01	0.10	0.08	1.00									
12. Value of Total Assets	0.07	0.49	0.42	0.51	0.23	0.47	0.11	0.10	0.27	0.23	0.14	1.00								
13. Total Public Funds	0.10	0.46	0.48	0.44	0.44	0.44	0.17	0.18	0.22	0.27	0.13	0.33	1.00							
14. Adoption of In-house R&D Only	0.03	0.31	-0.10	-0.12	0.04	0.10	0.00	-0.01	-0.01	0.08	0.01	0.07	-0.02	1.00						
15. Adoption of Research Collaboration Only	-0.02	-0.12	-0.10	0.30	-0.04	-0.05	-0.01	-0.02	0.05	0.00	0.00	0.10	-0.06	-0.04	1.00					
16. Adoption of R&D Outsourcing Only	-0.01	-0.08	0.27	-0.09	0.07	-0.04	0.02	-0.01	0.00	-0.04	0.06	0.01	-0.01	-0.03	-0.03	1.00				
17. Adoption of In-house R&D and Research Collaboration	0.04	0.51	-0.16	0.49	0.11	0.33	0.03	-0.01	0.14	0.19	0.06	0.20	0.07	-0.06	-0.06	-0.04	1.00			
18. Adoption of In-house R&D with R&D Outsourcing	0.01	0.21	0.26	-0.08	0.06	0.10	0.00	0.01	0.02	0.04	0.01	0.08	0.01	-0.03	-0.03	-0.02	-0.04	1.00		
19. Adoption of both Types of External R&D	-0.01	-0.11	0.34	0.27	0.04	0.09	0.02	-0.01	0.04	0.04	0.03	0.12	0.01	-0.03	-0.03	-0.02	-0.05	-0.02	1.00	
20. Adoption of In-house R&D with both External R&D	0.10	0.64	0.79	0.62	0.39	0.55	0.16	0.16	0.26	0.34	0.15	0.40	0.55	-0.08	-0.08	-0.05	-0.13	-0.05	-0.07	1.00

N=5170.

Chapter Two

The antecedents and innovation consequences of the firm's organizational search♣

2.1 Introduction

Innovation is the process by which firms must properly integrate various search activities to guarantee success in creating knowledge (Kogut and Zander, 1992; Katila and Ahuja, 2002). However, the combination of different search activities usually give rise to tensions in their implementation, since they have dissimilar objectives, require alternative organizational capabilities, and can lead to different results. Recent studies in the field of technology and innovation draw on March's (1991) notions of "exploration" and "exploitation" to characterize the pool of search activities encountered in the innovation process, and to examine the tensions emerging from their combined implementation (e.g., Rosenkopf and Nerkar, 2001; He and Wong, 2004; Lavie and Rosenkopf, 2006; Rothaermel and Alexandre, 2009). In these studies, search strategies related to the discovery of new knowledge are aligned with exploration, while those that address the learning of current knowledge are associated with exploitation.

Despite tensions in the implementation of dissimilar search strategies, an important stream of works (e.g., Katila and Ahuja, 2002; Nekar and Roberts, 2004; Sidhu, Commandeur and Volberda, 2007; Rothaermel and Alexandre, 2009) has found evidence showing that the adoption of the right combinations of alternative search strategies can produce important complementarities in terms of a given performance measure. In particular, the use of ambidextrous models of exploration and exploitation[1] is identified as an implementation strategy that leads firms to produce such complementarities (He and Wong, 2004; Rothaermel and Alexandre, 2009). Thus, it is widely recognized that both exploratory and exploitative search activities are needed in

♣ An earlier version of this research has been presented at the 2010 Academy of Management Conference held in Montréal, Canada. An abbreviated version of this paper has been published in the *Academy of Management Best paper Proceeding* of this annual conference.

[1] Ambidexterity is understood as the ability to execute activities that simultaneously pursued different aims (Tushman and O'Reilly, 1996). In the context of the current study, ambidexterity refers to the ability to conduct exploratory as well as exploitative search, which are widely recognized as activities aligned with different goals (March, 1991).

order for firms to enhance their innovation performance (March, 1991; Katila and Ahuja, 2002; Laursen and Salter, 2006).

Given the tensions and complementarities that can arise from the adoption of alternative search activities, previous studies have recognized that the ways in which firms choose to implement them is important to reach a better understanding of the performance consequences derived from different adoption scenarios. In that regard, researchers have examined tensions arising from the joint adoption of exploration and exploitation search activities (Stuart and Podolny, 1996; Chen and Katila, 2008). Furthermore, some studies have placed their attention on the study of the methods that firms follow to increase exploration activities that balance the firms' search strategies (Rosenkopf and Nerkar, 2001; Lavie and Rosenkopf, 2006), and on the performance evaluation of ambidextrous models of exploration and exploitation (Katila and Ahuja, 2002; Nerkar and Roberts, 2004; He and Wong, 2004). Recently, some have begun to study the performance consequences derived from models that combine ambidexterity in both exploration and exploitation and internal and external search (Rothaermel and Alexandre, 2009).

Despite the insights derived from previous works, the study about (i) different ways to ambidextrous models through which firms implement exploration and exploitation search activities along their organizational boundaries, and (ii) the assessment of the consequences derived from these modes of implementation remain relatively unexplored in the extant literature on innovation management. The study of these issues deserves more attention, since the adoption of ambidextrous models of exploration and exploitation search is just one of the options available to firms for reducing tensions and harnessing complementarities in the implementation of dissimilar search activities. While alternative models of organizational search emerge from the adoption of exploration and exploitation activities in an inter-organizational context, their performance evaluation become a relevant issue if we are to understand the firms' strategic behaviour in organizational search.

In order to tackle these issues, in this study I first draw on the organizational learning literature to build a typology that characterizes alternative models of organizational search. In this typology, firms can implement exploration and exploitation search, within and/or outside their boundaries, in two alternative ways: by using one strategy at a time or by using both strategies simultaneously. As a result, three models of organizational search are proposed: the ambidextrous, specialized and diversified model. Altogether, these models depict a range of strategies through which firms seek to mitigate tensions and boost complementarities associated with the implementation of exploratory and exploitative search activities. As a second step, I examine the innovation consequences derived from the strategies described in our typology, paying the attention to the production of complementarities that may emerge from each strategy.

This paper aims to make the following contributions to the literature on innovation management. In terms of firm innovative performance, the current study is the first to compare complementarities derived from the combinations of exploratory and exploitative search activities, occurring in both intra- and inter-organizational contexts. Although a number of studies have analyzed the link between ambidextrous models of exploration and exploitation search and their impact on performance (e.g., He and Wong, 2004; Rothaermel and Alexandre, 2009), the recognition of alternative models of organizational search, and their evaluation in terms of complementarities remains unaddressed in the extant literature on innovation management.

Finally, when examining the link between organizational search and performance, I consider firms' choices regarding models of organizational search to be endogenously determined. Specifically, I examine the role played by a range of factors, including a firm's absorptive capacity (henceforth, ACAP) and its diversity of technological opportunities, in determining its organizational search strategies. In so doing, the current study first improves the empirical assessment of complementarities under consideration by incorporating the role of factors that affect the firms' choices on organizational search (Athey and Stern, 1998; Leiponen, 2005; Miravete and Pernias, 2006; Cassiman and Veugelers, 2006). Furthermore, this research provides new insights about how the ACAP contributes to mitigating tensions derived from combining exploration and exploitation search activities across the firms' boundaries, as well as new evidence indicating how environments with diversified technological opportunities induce firms to combine different search strategies to harness external knowledge effectively.

The rest of this paper is organized as follows. Next section contains theoretical foundations used in the study to explain the innovation consequences of organizational search. Subsequent sections present the data, estimation methodology, results, as well as the concluding remarks.

2.2 Theoretical background

In some stages of the innovation process, firms seek to discover new opportunities, while in others firms seek to develop current opportunities. As is suggested by a number of influential studies, these search activities are to be found within and/or outside the firms' boundaries[2] (e.g., Powell et al., 1996; George et al., 2001; Rosenkopf and Almeida, 2003; Faems, et al., 2005). Thus, in order to organize their search strategies properly, firms must evaluate two potential sources of tension and complementarities; one associated with the combined adoption of exploratory and exploitative search, and the other related to the integration of internal and external search activities.

In the context of this study, internal search involves activities of research (exploration) and development (exploitation). The former refers to the research effort made by firms in seeking out new opportunities that might be exploited, while the latter refers to the research effort dedicated to improving the technologies by which firms can exploit existing opportunities (Danneels, 2002; Nerkar and Roberts, 2004; He and Wong, 2004). Similarly, external search may encompass the forming of alliances centered on activities of exploration and exploitation. The former include those external links in which partners seek novel sources of knowledge in order to create new products or patent new technologies. The latter refer to alliances where partners pool complementary resources that probably neither partner is willing to develop in-house (Koza and Lewin, 1998; Rothaermel and Deeds, 2004; Lavie and Rosenkopf, 2006).

2.2.1 Models of organizational search

Figure 2.1 presents a typology identifying alternative models for the undertaking of organizational search. It is derived from the options available to firms regarding how

[2] In line with Katila and Ahuja (2002), "search" is understood here as a form of learning in that it allows firms to solve problems and so to innovate.

they implement exploration and exploitation search within and outside their organizational boundaries. According to Figure 2.1, firms face three options when deciding how to put their search strategies into practice: i) "not to implement any strategy", ii) to apply a "single" implementation, or, iii) to opt for the "simultaneous implementation" of both exploration and exploitation search activities. When firms choose to implement overlapping strategies both internally and externally, the typology generates three generic models of organizational search: the "ambidextrous", "specialized," and the "diversified" model. The types of search models depicted in this typology are described in more detail below.

Figure 2.1. Models of organizational search

External Implementation				
	Simultaneous	External Ambidexterity	Type I Diversification	Radical Ambidexterity
	Single	External Specialization	Radical Specialization	Type II Diversification
	No Implementation	No search	Internal Specialization	Internal Ambidexterity
		No Implementation	**Single**	**Simultaneous**
			Internal Implementation	

Ambidexterity refers to those models of organizational search in which exploration and exploitation are conducted simultaneously. As recognized by several studies (e.g., March 1991; He and Wong, 2004; Gupta, Smith and Shalley, 2006; Rothaermel and Alexandre, 2009), these types of search activities are widely incompatible, since they compete for scarce resources, focus on different goals, and require alternative organizational capabilities. Despite these incompatibilities, ambidexterity can be achieved when knowledge creation is broken down into specialized activities that are carried out by autonomous and highly differentiated units, which interact along the innovation process (DeSanctis et al., 2002). For instance, in terms of their search strategies, Nokia Corporation and GlaxoSmithKline Plc commonly appear in the innovation management literature as cases of ambidextrous organizations (e.g. Birkinshaw and Gibson, 2004, Rothaermel and Deeds, 2004).

In this study, it is argued that ambidexterity can arise in three alternative scenarios. First, *internal ambidexterity* can occur at the firm level, so that a number of technological subunits within the firm specialize in exploration while others specialize in exploitation. Some companies keep their major R&D effort in-house despite the presence of important technological opportunities in their environment (Williams and Lee, 2009). Firms with well-developed learning capabilities usually innovate before their competitors, achieving then a "first-mover advantage". In this setting, firms may opt to perform the research and development of the emerging opportunities by themselves, keeping out their rivals from the exploitation of such opportunities (Katila and Chen, 2008), while protecting their innovations from knowledge leakage (Giarratana, and Mariani, 2009). Second, *external ambidexterity* can arise at the level of a firm's alliance portfolio, whereby some alliances are concerned with exploration while others focus on exploitation strategies. Some studies show that firms facing environments with disruptive changes in technologies and/or customer needs overcome obsolescence by opening their search activities extensively (Baden-Fuller, Targett and Hunt, 2000; Chesbrough, 2003; Ahuja and Katila, 2004). This idea indicates that the adoption of externally based models of search leads firms to a technological reposition (Rosenkopf and Nerkar, 2001, Holmqvist, 2007). Finally, *radical ambidexterity* can arise when firms adopt both an internal and external simultaneous implementation of exploration and exploitation search. Thus, boundary-spanning mechanisms for the organization of firms' search strategies are adopted, so that they widely integrate the search process rooted in their exploratory and exploitative alliances with that occurring in their corporate units with both a business (exploitation) and science (exploration) orientation.

By contrast, **specialization** refers to those models of organizational search where firms adopt just one search type at a time, be it exploration or exploitation. Chen and Katila (2008) document the use of specialization in the case of Pixar Animation Studios. By using short-films, Pixar first experiments with new technical features of a movie (exploratory search). After identifying successful ideas with potential applications, the company exploits them by using full-length films (exploitative search). Specialization can occur in one of two ways. On the one hand, firms opt for a given search type for any given period, switching from exploration to exploitation search strategies over time. This pattern relies on a punctuated equilibrium in that implementation is *sequential*

(Tushman and Anderson, 1986; Gersick, 1991). As suggested by previous research, this happens when exploration interrupts long periods of exploitation. In this setting, new technologies emerge sequentially from exploration search. Some of the new technologies become new paradigms, bringing new opportunities to be subsequently exploited.

On the other hand, organizations may choose to specialize *permanently* in exploration, while others make the same decision in favor of exploitation search. The emergence of modularity as an organizational form for R&D (Langlois and Robertson, 1992), the development of markets for new technologies (Arora, Fosfuri and Gambardella, 2004), and the creation of new institutional forms for governing exchanges of new technologies (Chesbrough, 2003) explain the increasing use of permanent specialization. For instance, in cases where firms *permanently* specialize in exploitation, the market for new technologies may strike a balance between exploration and exploitation, meeting the basic research needs of such firms with the supply of organizations specialized in exploration, i.e., universities and/or public research centers.

As in the case of ambidexterity, three models of specialization are proposed in this research. *Internal specialization* characterizes models of organizational search where firms implement either exploration or exploitation search strategies internally. In the case of temporary or permanent specialization, tangible and/or intangible resources for search activities are concentrated in the firms' technological subunits that focus on a given type of search. Riccaboni and Moliterni (2009) identifies two technological regimes, in which some "dedicated biotech companies" tend to specialize in early-research stages mainly targeted to product development (exploitation) while some others do so in the development of general-purposes platform technologies primary targeted to the discovery of new drugs (exploration). Alternatively, *external specialization* means that firms that adopt organizational boundary-spanning mechanisms for their search strategies choose to adopt only one type of strategy externally. In this case, the firm's alliance portfolio comprises of external links in which partners' assets align, temporarily or permanently, with either exploratory alliances or exploitative alliances. Compared with the external ambidexterity model, external specialization may be regarded as an incremental way of opening the search process of the firm in order to reach a technological reposition. Finally, *radical specialization* occurs in those settings in which firms combine internal and external specializations. Here again two possible arrangements for this form of implementation can be distinguished. The first corresponds to models of "inter-organizational specialization" as firms utilize the same type of strategy internally as that adopted externally. The second refers to models of "inter-organizational ambidexterity" as firms adopt a different strategy internally from that adopted externally. Although the two models involve a radical specialization (internal and external single implementation), they differ in the way firms combine their search activities.

Diversification, by contrast, involves a situation in which firms combine a simultaneous with a single implementation of strategies across their organizational boundaries. Unlike the other models, diversification means that firms necessarily span their organizational boundaries when combining alternative implementation strategies. Diversification can arise in two situations. *Type I diversification* describes a situation in which firms combine an internal single with an external simultaneous implementation. In this case, search activities are conducted by specialized technological subunits within firms in conjunction with a portfolio comprising exploration and exploitation alliances. Conversely, *type II diversification* occurs when firms choose an internal simultaneous together with an external single implementation. In this setting, the search performed by ambidextrous technological subunits within firms is combined with an alliance portfolio centered on either exploration or exploitation search. While type I diversification is a model of organizational search that joins different forms of external venturing (exploratory and exploitative), and in which knowledge creation occurs in a network of external actors, type II diversification is primary focused on a search process with an internal orientation[3], and in which external searching is rather used for scouting environmental opportunities. Small companies, with a strong portfolio of external venturing, probably lean toward a model of type I diversification, while large companies, with a remarkable tendency to internalize their R&D activities, lean toward a model of type II diversification (Schildt, Maula and Thomas, 2005).

Each category in Figure 2.1 should be interpreted as describing a tendency of a firm to organize its search activities around a particular model. This is the case, since it is

[3] Katila (2002) examines how firms search for knowledge internally, determining the innovative performance consequences associated with a process of internal search.

almost impossible to observe all the search activities of a firm. Rather, it is more likely to identify the search activities that tend to prevail within the organizational search adopted by the firm for its R&D activities (DeSanctis et al., 2002).

Drawing on the typology described above, the following step is to examine the innovation consequences associated with each search model, allowing for the drivers that affect the firms' decision to choose these models.

2.2.2 Performance implications of firms' search choices

As discussed in Figure 2.1, firms can conduct their knowledge search by implementing exploration and exploitation strategies in several ways. The use of previously described models of organizational search differ in that each one generates different tensions, which are associated with the joint adoption of exploratory and exploitative search, and/or with the integration of internal and external search activities (March, 1991; Rothaermel and Alexandre, 2009). However, the right combination of search activities may also produce complementarities in the sense that adopting one of them raises the returns of adopting the others (Milgrom and Roberts, 1990). The existence of complementarities implies that the combination of internal and external search activities may outweigh tensions involved in their joint implementation. This holds true as the exposure of the firm's internal search activities to those developed externally can provide fresh knowledge that helps firms to articulate better their search activities. Participation in external search enhances the sources of alternative knowledge available to firms, leading them to discover new forms of R&D organization and new links to put their solving-problem capabilities together. Collaboration in exploration and/or exploitation with other organizations creates access to information about i) new systems for solving conflicts emerging between research and development units, ii) new communication systems for improving the interaction between research and development divisions, and iii) new technical solutions to turn "inventions" into "innovations" (Cockburn and Henderson, 1998; Rosenkopf and Nerkar, 2001; Katila and Ahuja, 2002; Rothaermel and Alexandre, 2009).

Since firms may adopt alternative models of organizational search (ambidextrous, specialized or diversified), two questions deserve remain on the table: i) how can best firms organize their search activities to reach the maximum leverage among them in innovative performance, and ii) which are the drivers determining organizational search choices. To answer the first question, the attention is placed on comparing complementarities derived from the use of radical ambidexterity, radical specialization, and diversification of both types in terms of a given performance measure. In the context of this study, complementarities are defined in terms of a given performance measure, denoted by π. This function depends on the implementation strategy followed by a firm inside and outside its boundaries. Let I_j and E_j be indicator variables that define the mode of implementation adopted by the firm internally and externally, respectively. The sub-index "j" characterizes the implementation mode, which may imply a single or a simultaneous adoption of an exploratory and exploitative search. This variable is dichotomously defined in that it is equal to one when the firm adopts the implementation mode "j".

In order to formalize the notion of complementarity, the concept of supermodularity is considered (Athey and Stern, 1998; Mohnen, Röller, 2005; Cassiman and Veugelers, 2006). Therefore, the presence of supermodularity of π is used to define complementarities between alternative implementation strategies. For the purpose of this study, it is hypothesized that the organization of exploration and exploitation search activities produces complementarities when a firm combines either a "single" or a "simultaneous" implementation across its organizational boundaries. This occurs when the following condition holds:

$$\pi\left(I_j = 1, E_j = 1\right) - \pi\left(I_j = 0, E_j = 1,\right) \geq \pi\left(I_j = 1, E_j = 0\right) - \pi\left(I_j = 0, E_j = 0\right) \qquad (2.1)$$

When j = single, condition (2.1) allows us to examine whether the adoption of an internal single implementation produces a greater return as the firm also uses a single external implementation. This case allows us to assess complementarities associated with the use of a *radical specialization* model. Instead, when j = simultaneous, condition (2.1) allows us to inspect whether the adoption of an internal simultaneous implementation produce a greater return as the firm also draws on a simultaneous external implementation. In this instance, (2.1) allows us to examine the capacity of *radical ambidexterity* to produce complementarities.

Alternatively, since firms may combine a single with a simultaneous implementation across their organizational boundaries in different ways, other scenarios for the production of complementarities can arise. In this case, the following conditions have to be held:

$$\pi\left(I_j = 1, E_{-j} = 1\right) - \pi\left(I_j = 0, E_{-j} = 1\right) \geq \pi\left(I_j = 1, E_{-j} = 0\right) - \pi\left(I_j = 0, E_{-j} = 0\right) \quad (2.2)$$

When j = single, condition (2.2) defines complementarities corresponding to the combination of an internal single with an external simultaneous implementation. This situation is associated with the use *of type I diversification*. Alternatively, when j = simultaneous, condition (2.2) defines complementarities that emerge when the firm combines an internal simultaneous with an external single implementation. This condition allows the examination of complementarities corresponding to a *type II diversification* strategy.

Since “ambidextrous”, “specialized” and “diversified” models of implementation are viewed here as alternative methods to span exploration and exploitation search across the firms’ organizational boundaries, the determination of which one is more productive in terms of complementarities is appealing if we are to understand how firms manage tensions associated with the use of dissimilar search strategies. In so doing, the current study points to the problem of how firms should balance their exploration and exploitation search activities along the innovation process.

Finally, to answer the second question, it is considered that firms self-select the search model that represents the best fit with their learning and environmental conditions. Here, it is suggested that these choices are particularly affected by factors, such as the firms’ absorptive capacity (ACAP) and the level of diversity in their technological opportunities. The first factor is viewed as a combinative capability that enables firms not only to integrate internal and external search activities, but also to articulate exploratory and exploitative search. The second factor is regarded as a pull-force driver that induces firms to combine their search activities across organizational boundaries, in attempt to harness knowledge diversity.

The firm's ACAP

By using Zahra and George's (2002) approach, we can distinguish ACAP abilities aligned with upstream innovation activities (potential ACAP) from those aligned with downstream innovation activities (realized ACAP). In this study, I posit that a firm's ACAP is a combinative capability that favors the integration of dissimilar search strategies (Van Den Bosch, Volberda and De Boer, 1999; Danneels, 2004). This holds true because ACAP abilities are complementary to the extent that each is rooted in highly specialized activities along the innovation value chain (Henderson and Clark, 1990; Zahra and George, 2002). This in turn implies that a firm with high levels of ACAP is able to move technologies along this innovation value chain, because a firm's ACAP interconnects a range of diverse abilities in knowledge processing (i.e., potential and realized), favoring in turn the tendency to combine exploration with exploitation search (Rosenkopf and Nerkar, 2001; Katila and Ahuja, 2002; Rothaermel and Alexandre, 2009).

Diversity of technological opportunities

Drawing upon this idea that the environmental complexity can determine firms' incentives to engage in learning (Winter, 1984; Cohen and Levinthal, 1990; Anand and Khanna, 2000), I posit that firms respond to a high degree of diversity in their technological opportunities by combining alternative search strategies. From a technological perspective, environments with high diversification oblige firms to handle sources of information resulting from both upstream and downstream activities in knowledge creation (Rothaermel, 2001). While some of these sources comprise a pool of promising ideas, others form a pool of well-established ideas. Under these circumstances, firms face incentives to spread their search effort in exploration and exploitation activities in order to take advantage of the cross-fertilization effects derived from combining diverse ideas (Quintana-Garcia and Benavides-Velasco, 2008). From an organizational perspective, diversity in technological opportunities also leads firms to combine their internal and external search strategies. Diversity in technological opportunities pushes firms to extend their search effort beyond their boundaries in order to enhance learning (Mowery et al., 1996; George et al., 2001; Rosenkopf and Nerkar, 2001). Since the capacity of firms to search for diversified sources of information is limited (Rothaermel, 2001; Laursen and Salter, 2006), they may combine their search activities with those performed by external actors, thus enhancing their capacity to access multiple technological opportunities. As shown in previous studies (e.g., Rosenkopf and Nerkar, 2001; Almeida, Dokko and Rosenkopf. 2003), inter-organizational R&D collaboration allows firms to accomplish this objective.

Combining the ACAP and diversity of technological opportunities

In this study, it is argued that the firm's ACAP and the level of its diversified technological opportunities are self-reinforcing and have interactive effects on the firm's search choices. On the one hand, the exposure of firms to diversified technological opportunities can influence the productivity of their ACAP by preventing major core rigidities (Leonard-Barton, 1992; Quintana-Garcia and Benavides-Velasco, 2008). Diverse technological opportunities often provide knowledge that can help firms articulate much better the abilities that sustain their ACAP. Cockburn and Henderson (1998) illustrate this point for the case of the pharmaceutical industry. They suggest that technological opportunities in the scientific community boost a firm's abilities to recognize and take advantage of upstream developments (i.e., those produced by universities).

On the other hand, the firm's ACAP increases the quantity and/or improves the quality of the knowledge embedded in its technological opportunities (Katila and Ahuja, 2002; Almeida, Phene and Grant, 2003). This comes about because a firm's ACAP of s problem-solving capabilities that are required to articulate technological opportunities with its own stock of knowledge (Rosenkopf and Nerkar, 2001). Consequently, the higher the firm's ACAP, the greater are the possibilities it enjoys of turning diversified technological opportunities into useful knowledge for its innovation activities.

2.3 Empirical Analysis

In this section, I present the data and statistical methods used in assessing the performance consequences of the use of models described in the typology of Figure 2.1. In this study, I used a sample of Spanish manufacturing companies surveyed in a large-scale dataset. Previous research has tended to examine the link between knowledge search activities and performance for specific sectors, e.g., optical disks (Rosenkopf and Nerkar, 2001), robotics (Katila, 2002; Katila and Ahuja, 2002), pharmaceutical (Nerkar, 2003). Despite the insights provided by these studies, industry-specific characteristics may affect the performance assessment of the firms' search activities. Although recent studies have begun to examine multi-industry samples to study the consequences for innovation of organizational search (e.g., Laursen and Salter, 2006; Rothaermel and Alexandre, 2009), little attention is still given to undertaking an analysis of contextual variables that may affect firms' choices on organizational search, and as a result, their performance evaluation.

The empirical design used in this study contains two parts: one for analyzing the performance consequences and a second for examining the drivers for the organizational search. The former contains an outcome equation, in which a measure of innovative performance depends on both the firms' search choices and on a set of control variables. The latter includes a set of choice equations, in which search choices depend on a set of explanatory and control variables. As search choices are endogenous variables, I considered a research setting in which performance is determined by firms' search choices, as well as by factors that affect these choices.

2.3.1 Data and variables

The empirical analysis conducted in this paper draws on the *Technological Innovation Panel*[4] (henceforth, PITEC) conducted by the Spanish National Statistic Institute (INE), in collaboration with the Spanish Science and Technology Foundation (FECYT) and the Foundation for Technological Innovation (COTEC). The PITEC includes data on the technological innovation activities of all the main sectors in the Spanish economy,

[4] The PITEC is available at http://sise.fecyt.es/sise-public-web/

including services and manufacturing. In particular, it gathers information provided by the *Spanish Community Innovation Survey* (CIS) for the period 2003 to 2006, including new data about the technological profiles of the companies surveyed. Drawing on Rosenberg and Kline's model (1986), the PITEC collects information about the objectives of the innovation process, the sources of novel ideas, the obstacles associated with the innovation process, and an evaluation of the effects produced by innovations. Additionally, it provides new information, for example, about the qualifications held by and the gender of the firms' R&D personnel; outsourcing R&D activities classified by origin and type of partners; and the goals sought by firms' in-house R&D activities. In line with similar surveys elsewhere in Europe (i.e., SPRU survey), the PITEC follows the methodological rules laid down by the Oslo Manual (OECD, 1997)[5].

In order to preserve representativeness, the PITEC comprises of four samples. The first included data for large firms (with more than 200 employees), covering 73% of the large firms listed by the Spanish Central Company Directory, while the second included information about firms with intramural R&D expenditures. The third sample comprises of firms with fewer than 200 employees that report external R&D, but no intramural R&D expenditures. Finally, the fourth sample includes firms with fewer than 200 employees that report no innovation expenditures. In the case of the present study, I focus the attention on Spanish manufacturing firms in the PITEC for which complete information is available on their innovative activities for two consecutive periods, 2002-2004 and 2004-2006. As a result, the sample used below contains 3566 observations for each period. These data include companies whose principal economic activity appears in one of the two-digit manufacturing industries of the "Classification of Economic Activities in the European Community"[6].

Since the PITEC data are generated from self-reported information provided by the firms surveyed, the "common method bias" (Podsakoff and Organ, 1986) is a cause of concern. To mitigate this problem, I considered some of the remedies applied in other studies (e.g., Jansen, Van Den Bosch and Volberda, 2006; Rothaermel and Alexandre, 2009). Thus, at every opportunity, I separated the dependent and independent variables

[5] Contributions using data similar to the PITEC include, for example, (Lopez, 2008; Cassiman and Veugelers, 2006; Laursen and Salter, 2006; Reichstein and Salter, 2006; Leiponen, 2005; and Mohnen and Röller, 2005).

[6] This is equivalent to the International Standard Industrial Classification (ISIC).

by introducing a time lag. In the outcome equation, firm performance refers to the period 2004-2006, while the independent variables refer to the period 2002-2004. Similarly, in the set of choice equations, search choices refer to the period 2004-2006, while the remaining independent variables refer to the period 2002-2004. The two-year time lag used here is in line with previous studies based on similar samples (e.g., He and Wong, 2004; Jansen et al., 2006; Rothaermel and Alexandre, 2009). Nonetheless, in the outcome equation, performance and search choices refer to the same period, and here probably, the same respondents reported both. Despite this fact, they were obtained from different response formats, which help to mitigate the common method bias (Podsakoff et al., 2003).

2.3.1.1 Dependent variables

Performance. In the first part of the model, the outcome refers to a given measure of a firm's innovative performance. Since innovative performance is multidimensional (He and Wong, 2004, Sidhu et al., 2007; Rothaermel and Alexandre, 2009), I characterized it by using the reported evaluations provided by the firms surveyed regarding the effects derived from their innovations. On a four-point scale, they rated the extent to which their innovations in the period 2004 to 2006 had had a positive impact on the following aspects: (i) expansion of their market share, (ii) improvement in the quality of their products, (iii) increase in their product range, (iv) reduction in average labor costs, (v) improvement in production flexibility, (vi) increase in production capacity, (vii) reduction in average costs of raw materials and energy, (viii) reduction in the environmental impact of their production, and (ix) greater compliance with norms and regulations. For each of these aspects, I awarded a value of 1 if the firm in question rated the effect as strongly-important and 0 otherwise. Subsequently, I added the resulting codified variables so that each firm received 0 when its innovations had no impact and 9 when they were considered to have the maximum impact. This construct has a satisfactory degree of internal consistency (Cronbach's alpha = 0.74).

This measure of a firm's innovative performance provides a complementary approach to characterizing the outcomes derived from firms' search activities. One advantage of this measure is that it is not limited exclusively to codified forms of knowledge (i.e., patented inventions). Previous studies on innovation usually draw on patent data to characterize outcomes produced by firms' problem-solving capabilities (e.g., Rosenkopf and Nerkar, 2001; Katila and Ahuja, 2002). Despite their suitability for tracking knowledge creation, patents do not necessarily codify the entire knowledge generated by search activities (Laursen and Salter, 2006; Sidhu et al., 2007). A firm's patenting behavior may rather be a consequence of other strategies, such as, preventing possible hold-up problems in the market for new technologies, or blocking a competitor's entry (Gonzalez, 2006). Our measure is also an alternative to other studies in which sales attributable to new products characterize innovative performance (e.g., Cassiman and Veugelers, 2006; Laursen and Salter, 2006). Although this measure correlates with both patented and non-patented knowledge, it may overemphasize the effects of search activities related to product innovation, and understate those attributed to process innovation. The proposed measure avoids this limitation in that it includes an appraisal of the effects derived from both types of search (product and process innovation).

Firms' search choices. In the set of choice equations, combinations of varied search strategies represent alternative models of organizational search. In order to define the range of firms' search choices, I first need to characterize the exploration and exploitation search occurring inside and outside the firms' boundaries. I focused specifically on search strategies associated with the technological innovation activities conducted by the firms between 2004 and 2006. To this end, I used information from the PITEC concerning the objectives set by firms' intramural R&D. In the case of internal search strategies, I built on Rothaermel and Alexandre (2008), and used firms' expenditure on basic research as a proxy for exploration search and that dedicated to technological development as a proxy for exploitation search. In the PITEC, expenditure on basic research refers to that addressed explicitly to the pursuit of new knowledge but which does not necessarily lead to particular applications, while expenditure on technological development refers to that addressed to the pursuit of novel applications of existing knowledge that improve materials, products and/or technologies. In each case, I built a dummy so that a value of 1 is awarded when firms reported positive expenditure on the search activity in question.

In the case of external search strategies, I followed George et al., (2001), and used firms' R&D alliances as a proxy for exploration search, and the firms' obtained technologies via license/purchase as a proxy for exploitation search. In the PITEC, R&D alliances define agreements in which firms actively pursue innovative activities, though these are not necessarily intended to yield profits. Licenses and R&D outsourcing activities refer to those situations in which firms contract R&D services and/or technologies in the market to leverage their own R&D activities. Similarly, I built a dummy for each case so that a value of 1 is awarded when firms participate in the external R&D link under consideration.

From these dummies, I characterized alternative ways of conducting the organizational search. Table 2.1 presents a definition of the models described by Figure 2.1 in terms of their search strategies. The first column contains nine exclusive categories, including all possible combinations by which firms might implement their search strategies. The second column identifies models of organizational search for each exclusive category. Finally, the last column shows the set of observed search strategies used in defining each model.

Table 2.1. Exclusive categories that define models of organizational search

Type	Exclusive Combinations	Models	Search Strategies
1	No Implementation	No Adoption	No Technological Search
2	External Single Implementation	External Specialization	Either R&D Alliances or R&D Outsourcing
3	External Simultaneous Implementation	External Ambidexterity	Both R&D Alliances and R&D Outsourcing
4	Internal Single Implementation	Internal Specialization	Expenditure on either Basic Research or Development
5	Internal with External Single Implementation	Radical Specialization	Expenditure on either Basic Research or Development, and either R&D Alliances or R&D Outsourcing
6	Internal Simultaneous and External Single Implementation	Type I Diversification	Expenditure on both Basic Research and Development, and either R&D Alliances or R&D Outsourcing
7	Internal Simultaneous Implementation	Internal Ambidexterity	Expenditure on both Basic research and Development
8	Internal Single with External Simultaneous Implementation	Type II Diversification	Both R&D Alliances and R&D Outsourcing, along with Expenditure on either Basic Research or Development
9	Internal with External Simultaneous Implementation	Radical Ambidexterity	Expenditure on both Basic Research and Development, along with both R&D Alliances and R&D Outsourcing

2.3.1.2 Independent variables

The firm's ACAP. In line with Veugelers and Cassiman (1999), I used the surveyed firms' evaluations of the importance attached to internal sources of information in developing their innovation activities as a proxy for absorptive capacity (ACAP). On a four-point scale, firms evaluated information sources that originated from their own departments, employees and divisions between 2002 and 2004. I assume that firms reporting a high indicator have a high ACAP, since they were able to move information from its locus of origin to the sites of problem-solving capabilities. This reveals the firms' capacity to identify relevant information and apply it to the solving of problems. Accordingly, firms that are able to use internal information successfully for their innovation activities should be better prepared to reproduce this experience in similar contexts (i.e., from intra-organizational to inter-organizational contexts).

Diversity of technological opportunities. I employed PITEC data to determine the use made of external sources of information in the firms' innovation processes. The firms surveyed specified the extent to which they used ten different sources[7]. In line with Cohen and Levinthal (1989), these sources are seen as representing technological opportunities in that they characterize available information that might contribute to enhancing the firms' technological performance. In order to determine the degree of diversification of technological opportunities, I proceeded as follows. First, I conducted an exploratory factor analysis in order to classify the external sources evaluated by firms[8]. As a result, I identified three clusters: the first comprised sources of information related to institutions (e.g., universities and public research centers), the second was made up of sources originating from other firms (e.g., competitors and suppliers), and the third of sources related to formal forms of knowledge (e.g., conferences and journals). Second, I built dummies for each of the ten sources under evaluation. Each dummy takes a value of 1 when the firms stated that they used the source in question. I also added up the previous dummies corresponding to each cluster. Finally, I used a measure of diversity to define the degree of diversification of the firms' technological

[7] Sources under consideration include information arising from (i) suppliers, (ii) customers, (iii) competitors, (iv) consulting firms and/or private research centers, (v) universities, (vi) public research centers, (vii) technological centers, (viii) conferences, (ix) publications and journals, and (x) professional associations.

[8] Not shown here for reasons of space, but available from the author upon request.

opportunities. In line with other studies on innovation (e.g., Powell et al., 1996; Ahuja and Katila, 2004), I applied Blau's index (1977) in measuring diversification: $T_i = 1 - \sum_{k=1}^{3} \left(\frac{c_k}{C_i} \right)^2$. In this context, c_k represents the number of sources in cluster "k" used by firm "i", while C_i denotes the total number of sources used by firm "i".

Control variables. The firms' patenting capabilities may also affect their organizational search choices and their performance consequences. Firms with these capabilities may be more readily disposed to implement internal and external search activities jointly, since they are able to avoid any leakage of strategic information when interacting with external actors. To control for the effect of patenting on organizational search choices and on firms' innovative performance, I included in the analysis a binary variable (*Patent Application*), which is given a value of 1 when firms stated that they had applied for patents in the period 2002-2004. One factor that is often identified as constituting a point of difference in the way firms combine their innovative activities is the managers' perception of the constraints that might impede innovations (Athey and Stern, 1998; Veugelers and Cassiman, 1999; Lopez, 2008). In order to control for this aspect, I included a four-point scale variable (*Cost of Innovation*) that reflects self-reported assessment by firms concerning the importance of the costs of innovation activities as a factor inhibiting their execution for the period 2002-2004.

Search activities and their consequences may vary in line with the scale of the firms' operations (Winter, 1984; Katila and Ahuja, 2002; Almeida, Dokko and Rosenkopf., 2003). Therefore, I added to the model a binary variable (*Firm Size*), given a value of 1 when firms reported having more than 200 employees. Additionally, previous research shows that firms' willingness to implement exploration and exploitation search across their boundaries may depend on whether they form part of a multinational group (Veugelers, 1997; Nerkar and Roberts, 2004 Vanhaverbeke et al., forthcoming). To control for this feature, I included in the analysis a binary variable (*Business Group Affiliation*), given a value of 1 when firms reported that they belonged to a multinational group. Finally, I expect that firms acting in more technologically dynamic environments differ in their choices regarding search activities and in innovative performance, compared with those that operate in less dynamic technological environments (Ahuja and Katila, 2004; Jansen et al., 2006). I controlled for this fact by incorporating two binary variables within the model. In line with the OECD (1997), I classified firms according to the degree of technological intensity in the industries in which they operate. Next, I built a dummy given a value of 1 when firms operate in a sector classified as high-tech industries (*High-tech sector*), and another coded with 1 when firms operate in a sector classified as low-tech (*Low-tech sector*). With these dummies, I aim to control for other aspects of the technological regime not included in the analysis (Veugelers and Cassiman, 1999).

Exclusion Restrictions. In order to guarantee the robustness of the identification, I added variables to the choice equations that were not included in the outcome equation. Given the difficulties that have been documented in finding appropriate instrumental variables in surveys similar to the PITEC (e.g., Cassiman and Veugelers, 2006), I adopted some of the recommendations made by previous studies of strategy and performance (e.g., Athey and Stern, 1998; Hamilton and Nickerson, 2003). Specifically, I included two variables reflecting regulation and governmental policies that may differ across industries and that may affect search choices. Thus, I added, on the one hand, the number of public programs available for financing R&D activities (*Financing Sources*)[9] and, on the other, the number of markets (regions) to which a firm supplies their products (*Market Scope*)[10]. Some studies consider the first variable to be a critical element, modifying the incentives of Spanish manufacturing companies engaged in R&D activities (Bayona et al., 2001). The second variable seeks to characterize differences in trade policy and institutional characteristics that may affect the incentives of firms to supply their products to varied markets (regions). In order to allow for differences across industries, I followed previous studies on innovation (e.g., Cassiman and Veugelers, 2002; Lopez, 2008), and measured both variables at the industry level, defined at two-digit NACE. Table 2.2 displays descriptive statistics for the variables described above. In addition, Table A2 in the appendix shows the corresponding bivariate correlation matrix.

[9] These financing programs include local, governmental and European Union programs, as well as other EU programs.
[10] Firms can supply products to local, national and European markets, as well as markets in other countries.

Table 2.2. Descriptive statistics

Variable	Mean	S.D.	Min.	Max.
Performance	2.49	2.23	0	9
External Specialization	0.06	0.24	0	1
External Ambidexterity	0.02	0.15	0	1
Internal Specialization	0.25	0.43	0	1
Radical Specialization	0.17	0.37	0	1
Type I Diversification	0.12	0.32	0	1
Internal Ambidexterity	0.09	0.26	0	1
Type II Diversification	0.07	0.26	0	1
Radical Ambidexterity	0.05	0.23	0	1
Inward ACAP	0.80	0.27	0	1
Outward ACAP	0.51	0.21	0	0.67
Patent Applications	0.24	0.43	0	1
Cost as an Obstacle for Innovations	0.61	0.34	0	1
Business Group Affiliation	0.37	0.48	0	1
Firm Size	0.19	0.40	0	1
Low-tech Sector	0.09	0.29	0	1
High-tech Sector	0.09	0.29	0	1
Financing Sources*	0.56	0.13	0.21	1.5
Market Scope*	3.13	0.29	1.53	3.53

* Measured at the industry level (defined at two-digit NACE).

2.3.3 Statistical Methods

Since the proposed measure of firm performance is a non-negative integer variable (number of times that innovations are perceived as having a strongly positive effect) and the firms' search choices are viewed as a multinomial variable, I implemented the Deb and Trivedi model (2006) in the subsequent empirical analysis. This is a model of treatment (firms' search choices) and outcome (performance) with selection, in which the treatment is endogenous. Although the attention of this model is specifically focused on the effect of an endogenous treatment variable on outcome, we can harness the fact that this model also provides us with a characterization of the generating process of the treatment. This is informative about the role of factors in determining firms' search choices.

In the outcome equation, the observed *Performance* for firm "i" is denoted by y_i. It is assumed that values for this variable follow a negative binomial structure, in which the expected outcome is described by:

$$E\left(y_i \mid \mathbf{x}_i, d_{ji}, \ell_{ji}\right) = \mathbf{x}_i^{'}\beta + \sum_j \gamma_j d_{ji} + \sum_j \lambda_j \ell_{ij} \quad (2.3)$$

where $\mathbf{x}_i$ is a vector of exogenous variables, d_{ji} corresponds to binary variables representing the observed firm's search choices, where j denotes the set of search models described by Table 2.2. Alternatively, β and γ_j are parameters associated with the exogenous variables and firm choice variables, respectively. Finally, ℓ_{ji} denote latent factors that represent unobserved characteristics concerning firm i's choice of model of organizational search of type j. The λ_j represents factor loadings associated with the latent factors.

Alternatively, choice equations characterize the probability that firm "i" chooses the model of organizational search "j". Specifically, it is assumed that these probabilities are described by a mixed multinomial logit structure given as follows:

$$\Pr\left(d_{ji} = 1, \mid \mathbf{z}_i, \ell_{ji}\right) = \frac{\exp\left(\mathbf{z}_i^{'}\alpha_j + \delta_j \ell_{ji}\right)}{\sum_{k=0}^{J} \exp\left(\mathbf{z}_i^{'}\alpha_j + \delta_k \ell_{ki}\right)} \quad (2.4)$$

where $\mathbf{z}_i$ represents exogenous covariates while α_j are the corresponding parameters. As in the outcome equation, ℓ_{ji} are latent factors and δ_j are the corresponding factor loadings.

Whereas equation (2.3) describes innovative performance as a response to firms' search choices, I can test for the existence of complementarities by using the notion of supermodularity (Athey and Stern, 1998; Mohnen and Röller, 2005). To this end, I first defined the conditions for which innovative performance in (2.3) is supermodular in the space of the firms' implementation strategies (See Table 2.1). By using estimates of γ_j, these conditions are as follows:

Supermodularity on Internal and External Single Implementation	$\gamma_{type\ 5} - \gamma_{type\ 2} > \gamma_{type\ 4} - \gamma_{type\ 1}$	(2.5)
Supermodularity on Internal Single and External Simultaneous Implementation	$\gamma_{type\ 6} - \gamma_{type\ 3} > \gamma_{type\ 4} - \gamma_{type\ 1}$	(2.6)
Supermodularity on Internal Simultaneous and External Single Implementation	$\gamma_{type\ 8} - \gamma_{type\ 2} > \gamma_{type\ 7} - \gamma_{type\ 1}$	(2.7)
Supermodularity on Internal and External Simultaneous Implementation	$\gamma_{type\ 9} - \gamma_{type\ 3} > \gamma_{type\ 7} - \gamma_{type\ 1}$	(2.8)

In the context of this study, choice equations (2.4) characterize how the observable (i.e., *the firm's ACAP*) and unobservable factors (given by ℓ_{ji}) affect firms' search choices. In this way, I correct for endogeneity while estimating parameters γ_j, which has been described as a recurring problem in previous studies on complementarities (e.g., Athey and Stern, 1998; Leiponen, 2005; Miravete and Pernias, 2006; Cassiman and Veugelers, 2006).

2.4 Results

Table 2.3 shows the results for the estimates of both the outcome (first column) and choice equations (the remaining columns). Estimates were carried out using the Simulated Maximum Likelihood Method with 2000 simulation draws, based upon Halton sequences (Deb and Trivedi, 2006). The outcome equation was used to test for complementarities while the choice equations were used to examine the factor determining firms' search choices. In order to avoid potential multicollinearity, I mean centered the explanatory variables - *the firm's ACAP* and *diversified technological opportunities* - before creating their product interaction term (Aiken, West and Reno, 1991). As a starting point, I used the same group of independent variables for all the equations[11]. This means that, in the outcome equation, I included *the firm's ACAP*, *diversified technological opportunities* and their interaction effects as additional control variables. As recommended by Deb and Trivedi (2006), I also added exclusive

[11] Not shown here for reasons of space, but available from the author upon request.

restrictions to choice equations. Although this was not strictly necessary in this case[12], the inclusion of variables should provide a more robust identification.

Furthermore, I estimated a conventional multinomial logit model for the choice equations, and tested for the joint significance of the instruments in that model. By using the likelihood ratio, I found evidence that the fit of this model improves on including the instruments (*p-value* < 0.001). This indicates that these instruments are statistically suitable identifiers (Deb and Trivedi, 2006). I also confirmed that the instrumental variables had no explanatory power in the outcome equation. Finally, I investigated the independence of the irrelevant alternative (IIA) hypothesis by using both the Hausman and Small-Hsiao tests. In both cases, the results indicate that the IIA assumption is not violated[13].

2.4.1 Innovation consequences of organizational search

It is observed that models of organization search in which firms combine exploratory with exploitative search activities (inside and/or outside their boundaries) have a positive and significant impact on firms' innovation performance. As expected, since radical ambidexterity is the model that combines the largest number of search strategies, it is also the model with the most significant impact on innovation performance. Conversely, the models based on specialization, be it internal or external, are not statistically significant determiners of performance. By using the Wald test, I further conducted a comparison between the models in terms of their effects on performance. I found that the adoption of radical ambidexterity has a statistically greater impact on performance than that associated with the adoption of radical specialization (*p-value* < 0.001). I also found that the adoption of a type I diversification has a statistically greater effect on performance than that attributed to the adoption of a type II diversification (*p-value* = 0.077). Finally, it is observed that the null hypothesis establishing no differences between external and internal ambidexterity in terms of their effects on performance cannot be rejected at conventional levels. In order to identify any

[12] Deb and Trivedi (2006) point out that the parameters of the model are identified through nonlinear functional forms even when all the variables in the choice equations are included in the outcome equation.
[13] Not shown here for reasons of space, but available from the author upon request.

synergetic effects arising out of the combined adoption of implementation strategies (single and simultaneous), our next step is to test for the existence of complementarities.

In line with Athey and Stern (1998), I considered inequalities (2.5)-(2.8) as restrictions to be met in order for a firm's innovative performance to be supermodular in the space of firms' search choices. To this end, I applied the procedure developed by Kodde and Palm (1986)[14]. Accordingly, each restriction in (2.5)-(2.8) can be defined under the null or under the alternative hypothesis (Kodde and Ritzen, 1988). Thus, the test for complementarities has an *equality* under the null hypothesis (interpreted here as a signal of no interaction), and an *inequality* under the alternative (viewed here as evidence for supermodularity). I took each inequality at a time, considering the test for supermodularity to be a one-sided test. The rejection of the null in favor of the alternative is interpreted here as evidence of the existence of supermodularity in the firms' innovative performance in the pair of implementation strategies under consideration (see Table 2.3). When this is the case, I conclude the existence of complementarities.

Without losing generality, I normalized the coefficient $\gamma_{\text{type}\,1}$ to zero as in other empirical studies on complementarities (e.g., Leiponen, 2005; Belderbos, et al., 2006). The results for the test of complementarities are as follows. I find an interaction effect associated with the joint adoption of internal and external single implementation. That is, the null hypothesis establishing the equality, $\gamma_{\text{type}\,5} - \gamma_{\text{type}\,2} - \gamma_{\text{type}\,4} = 0$, is rejected (*p-value* = 0.052) in favor of the alternative, $\gamma_{\text{type}\,5} - \gamma_{\text{type}\,2} - \gamma_{\text{type}\,4} > 0$, defining the restriction that underpins supermodularity. This shows that a single implementation in one search type, *both* internally and externally, allows firms to yield additional returns in terms of innovative performance. Furthermore, in order to identify differences in complementarities associated with differences in the ways that firms combine their search strategies, I divided the firms into two groups using a radical specialization. The first group comprises of firms that adopt an inter-organizational specialization, while the second includes firms that use an inter-organizational ambidexterity. I then

[14] Although Kodde and Palm's (1986) procedure refers to combinations of several equality and inequality restrictions, our setting is, in fact, a particular instance of their general framework.

compared the complementarities associated with each group[15]. It is found that the null hypothesis is rejected (*p-value* = 0.071 for the first case, and a *p-value* = 0.085 for the second) in favor of the alternative sustaining supermodularity. Interestingly, the presence of complementarities, irrespective of the way firms combine internal and external specialized search strategies, suggests that the organizational dimension, rather than the technological dimension, is the main generator of such complementarities.

For the remaining inequalities, I find that the null hypothesis cannot be rejected at conventional levels. Accordingly, I do not find support for the hypothesis of complementarity in these cases. The lack of synergetic effects might be explained by the fact that, in a simultaneous implementation, the costs override the benefits derived from aligning opposing search strategies. This result is in line with Rothaermel and Alexandre (2008), who show that, after a particular threshold is reached, the returns of ambidextrous search models diminish. Likewise, other studies also suggest that the returns derived from multiple search strategies fall because of the limited capacity of managers to allocate their attention and resources to several search activities (e.g., Rothaermel, 2001; Laursen and Salter, 2006).

[15] Regression results for these cases are not shown here for reasons of space, but they are available from the author upon request.

Table 2.3. Regression results for the choice on searching and for firm innovative performance

Independent variables	**Performance**	**External Specialization**	**External Ambidexterity**	**Internal Specialization**	**Radical Specialization**	**Diversification (Type I)**	**Internal Ambidexterity**	**Diversification (Type II)**	**Radical Ambidexterity**
External Specialization	0.067 (0.057)								
External Ambidexterity	0.162† (0.045)								
Internal Specialization	0.059 (0.040)								
Radical Specialization	0.187*** (0.062)								
Diversification, Type I	0.287† (0.032)								
Internal Ambidexterity	0.161 (0.105)								
Diversification, Type II	0.238† (0.034)								
Radical Ambidexterity	0.383† (0.038)								
Inward-ACAP	0.441† (0.081)	0.121 (0.553)	0.829 (0.594)	1.099* (0.641)	0.876 (0.658)	1.051** (0.502)	1.177** (0.541)	1.058* (0.546)	1.056** (0.505)
Outward-ACAP	0.352*** (0.111)	0.834† (0.201)	1.265† (0.340)	0.291*** (0.111)	1.174† (0.143)	3.553† (0.231)	0.790† (0.225)	2.758† (0.314)	3.897† (0.237)
Inward-ACAP x Outward-ACAP	0.584† (0.103)	0.106 (1.175)	-0.153 (3.061)	1.261 (1.277)	1.093 (1.117)	4.622† (0.641)	0.536 (0.976)	2.179*** (0.756)	3.967** (1.805)
Patent Application	0.020 (0.020)	-0.243 (0.284)	0.234 (0.172)	0.120 (0.088)	0.368** (0.145)	0.542** (0.258)	0.672† (0.097)	0.999† (0.170)	1.094† (0.137)
Cost as an Obstacle for Innovation	0.059** (0.029)	-0.038 (0.150)	-0.638 (0.467)	-0.316* (0.171)	-0.369** (0.187)	-0.338 (0.210)	-0.038 (0.182)	-0.054 (0.162)	-0.169 (0.221)

Independent variables (Cont.)	Performance	External Specialization	External Ambidexterity	Internal Specialization	Radical Specialization	Diversification (Type I)	Internal Ambidexterity	Diversification (Type II)	Radical Ambidexterity
Business Group Affiliation	0.018 (0.029)	0.485 (0.368)	0.745** (0.290)	0.045 (0.187)	0.374 (0.282)	0.660*** (0.237)	-0.372** (0.180)	0.179 (0.183)	0.876† (0.181)
Firm Size	0.027 (0.042)	0.124 (0.265)	0.271 (0.200)	-0.774 (0.748)	-0.141 (0.765)	0.494 (0.762)	-0.415 (0.794)	0.059 (0.789)	0.290 (0.792)
Low-tech Sector	-0.035 (0.029)	0.090 (0.229)	-0.369 (0.232)	-0.336*** (0.098)	-0.320** (0.101)	-0.418 (0.333)	-0.089 (0.060)	-0.049 (0.113)	-0.055 (0.293)
High-tech Sector	0.012 (0.017)	0.100 (0.156)	0.430† (0.112)	-0.151 (0.201)	-0.068 (0.181)	-0.078 (0.226)	0.161 (0.193)	0.317 (0.289)	0.167 (0.385)
Industrial Level for Financing Sources		-1.065*** (0.392)	1.858 (1.600)	0.886* (0.505)	1.693† (0.275)	2.903† (0.363)	0.302 (0.726)	2.147† (0.311)	2.268† (0.700)
Industrial Level for Market Scope		0.447 (0.365)	0.225 (0.766)	0.443** (0.217)	0.065 (0.239)	0.112 (0.521)	0.350 (0.406)	0.525 (0.365)	0.198 (0.263)
Constant	0.681† (0.042)	-1.962 (1.276)	-3.553 (2.453)	-0.920 (0.947)	-0.734 (1.158)	-2.429 (1.902)	-1.581 (1.654)	-3.909** (1.677)	-3.628*** (1.361)
α (alpha)	0.433 (0.037)								
Log-pseudo likelihood	-14336.282								
Goodness of fit	$\chi^2(105) = 714.3$***								
Nº (observations)	3566								

Robust standard deviation in brackets. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, † $p < 0.001$.

The results corresponding to the control variables are as follows. In line with George et al., (2001), the estimates for the *Firms' ACAP* are positive and statistically significant, indicating that knowledge-processing capabilities have a direct impact on performance. I also found that the parameter *Diversified Technological Opportunities* is positive and statistically significant in determining performance. In line with Laursen and Salter (2006), this shows that external sources of knowledge complement traditional explanatory variables in explaining performance. Furthermore, I observe that the interaction effect of previous factors is highly significant statistically in their relationship with performance. Finally, I found that the parameter for C*ost of Innovation* is positive and statistically significant. This result is consistent with Veugelers and Cassiman (1999), who argue that managers' perception of obstacles impeding innovation captures their awareness of these obstacles rather than the effectiveness of these obstacles in inhibiting innovations. This argument is consistent with other studies showing that the firms' assessment of factors affecting innovations (motivators and inhibitors) is an important element of the firms' technology management with an impact on their degree of innovativeness (Kale, et al., 2002; Huergo, 2006).

2.4.2 The drivers of organizational search

I observe that the *Firm's ACAP* tends to be positively associated with those models in which firms combine exploration and exploitation search activities. In three instances, the ACAP relates to models involving combinations across the firms' boundaries. In the remaining cases, the ACAP is associated with internal search models, be they ambidextrous or specialized. These results lend partial support to the hypothesis that the firm's ACAP contributes to enhancing its possibilities of combining search activities. In the case of diversified technological opportunities, it seems that this variable is strongly associated with models centered on radical ambidexterity and diversification (types I and II). To a lesser degree, this variable is also associated with models in which firms combine external search activities (external ambidexterity) and with those in which firms combine specialized search activities (radical specialization). Despite its statistical significance, the effect of this variable is not as marked in those models in which firms use only one search strategy (i.e., no combination of search strategies). These results indicate that the *Diversity of Technological Opportunities* can account for the tendency of firms to combine exploration and exploitation search activities across their boundaries. Finally, the interaction between the firm's ACAP and diversified opportunities is strongly associated with models that combine the largest number of search strategies. Evidence for this lies in the fact that the effect of diversified technological opportunities on the probability of choosing a model based on radical ambidexterity or diversification (types I and II) increases with the level of the firm's ACAP.

The results regarding the estimates of the control variables are as follows. I found that firms with patent applications are more likely to combine internal and external search activities. This is consistent with the idea that firms with the capabilities to protect their innovations are more willing to conduct their search in inter-organizational environments. I observe that firms who see costs as an obstacle impeding innovations are less likely to choose a model based on a single internal implementation. This may be related to the fact that the opportunity costs of using models with an internal specialization (i.e., not experiencing economies of scope) may prevent firms from organizing their search strategies by using these models. Alternatively, firms affiliated to a multinational group are more likely to adopt models in which firms combine internal with external search activities (radical ambidexterity and type I diversification) or models in which firms open up their search strategies by including external ambidexterity. By contrast, firms affiliated with multinationals are less likely to adopt an internal ambidextrous model. I also observe that firms operating in low-tech sectors are less likely to choose models comprising internal search activities, such as internal specialization, radical specialization or internal ambidexterity. Alternatively, firms operating in high-tech sectors are more likely to adopt models based on external ambidexterity. Finally, with regard to industrial level variables, it is observed that sources for financing R&D activities determine positively the probability of choosing a model in which internal and external search activities are combined.

2.5 Discussion and conclusions

As firms pursue knowledge inside and outside their organizational boundaries, I have examined how they go about selecting their search strategies, based on March's (1991) dichotomy of exploration and exploitation. Specifically, I have argued that firms choose from among a range of implementation strategies that combine search activities in a variety of ways. Based on the overlap in firms' choices of internal and external search strategies, I have presented a new typology that recognizes three generic models of organizational search: ambidextrous, specialized, and diversified implementation models. I have then analyzed the respective performances of these models and examined the drivers of firms' search choices.

The findings regarding the performance of these knowledge search models make the following contributions to the innovation management literature. An empirical comparison of the capacity of the models in our typology to generate complementarities shows that the synchronized implementation of specialized search strategies across the firms' organizational boundaries has synergetic effects on performance, indicating the existence of complementarities. This conclusion holds regardless of how firms choose to combine their search strategies across their boundaries, i.e., by adopting either inter-organizational specialization or inter-organizational ambidexterity. In line with Rosenkopf and Nerkar (2001), our result demonstrates that the search activities being conducted in an inter-organizational context are an important source of complementarities. By contrast, the data do not support the hypothesis identifying the presence of complementarities in the case of other implementation arrangements. This reflects the fact that the cost of implementing ambidextrous search models outweighs any associated benefits. While any comparison of this nature should be treated with caution, the results do suggest that differences in the generation of complementarities may well correspond to differences in the way firms strike a balance in their adoption of search strategies that differ in their technological profiles (exploration vs. exploitation) and/or in their organizational forms (internal vs. external).

This paper has also provided new evidence concerning the role of firms' ACAP, their diversity in technological opportunities and the interaction of the two as drivers of their decisions to adopt a particular model of organizational search. As I allow for self-selection, I present an alternative method for characterizing the impact of these drivers on firms' innovative performances. In particular, the results indicate that these factors result in firms self-selecting models of organizational search that combine several search strategies (in particular models based upon radical ambidexterity, and types I and II diversification).

The results of the current research are subject to several limitations but, at the same time, new avenues of future research are opened up. Although conceived as panel data, the data used in the study essentially present a cross-sectional design. This prevents us from undertaking a dynamic analysis of the evolution in the elements comprising the organizational search of firms, imposing clear limitations on the scope of our research. More research is needed in order to characterize the influence of path-dependent decisions on current firm choices regarding their search strategies. Closely related to this, and constituting an attractive avenue of further research, is the question as to whether firms organize their search strategies by adopting the same model type over time, or rather by sequentially switching to alternative models (Chen and Katila, 2008). Research into these aspects might contribute to the literature by advancing our understanding of how previous search patterns determine firms' future choices of organizational search models, and of how firms achieve a balance in their search strategies over time.

Likewise, more research is required in order to examine how changes in the configuration of firms' technological opportunities can affect their choices regarding search strategies, and subsequently, their innovative performance. This aspect is important for understanding firms' incentives to adopt ambidextrous or specialized search models. For instance, Laursen and Salter (2006) document this question by showing that a firm's search strategies depend on the degree of novelty shown by its innovations. They argue that this relates to the degree of diversity shown by its technological opportunities. While incipient innovations tend to be associated with a narrow range of external sources of knowledge, mature innovations tend to be associated with a much broader range. This shows that the dynamic that underpins innovations determines the degree of diversity in a firm's technological opportunities, which in turn can affect a firm's choices regarding its search strategies.

Table A2. Correlation Matrix

Variables	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1. Performance	1.00																			
2. External Specialization	-0.04	1.00																		
3. External Ambidexterity	0.00	-0.04	1.00																	
4. Internal Specialization	-0.07	-0.14	-0.09	1.00																
5. Radical Specialization	0.01	-0.12	-0.08	-0.25	1.00															
6. Type I Diversification	0.08	-0.10	-0.07	-0.22	-0.19	1.00														
7. Internal Ambidexterity	-0.01	-0.09	-0.06	-0.18	-0.16	-0.14	1.00													
8. Type II Diversification	0.04	-0.08	-0.05	-0.17	-0.14	-0.12	-0.10	1.00												
9. Radical Ambidexterity	0.10	-0.07	-0.05	-0.15	-0.13	-0.11	-0.09	-0.08	1.00											
10. Inward-ACAP	0.15	-0.05	0.01	-0.01	0.00	0.05	0.02	0.04	0.05	1.00										
11. Outward-ACAP	0.13	-0.03	0.01	-0.10	0.00	0.12	-0.01	0.08	0.10	0.25	1.00									
12. Inward x Outward ACAP	-0.01	0.00	-0.02	0.01	-0.01	0.02	-0.02	-0.01	0.00	-0.34	-0.29	1.00								
13. Patent Application	0.06	-0.07	-0.01	-0.07	-0.01	0.05	0.02	0.09	0.10	0.10	0.12	0.01	1.00							
14. Cost of Innovation	0.03	0.00	-0.03	-0.01	-0.02	-0.01	0.03	0.02	0.00	0.02	0.10	-0.04	0.00	1.00						
15. Business Group Affiliation	0.06	0.02	0.05	-0.10	0.02	0.12	-0.10	0.01	0.11	0.11	0.07	0.00	0.08	-0.11	1.00					
16. Firm Size	0.05	0.02	0.04	-0.13	-0.01	0.13	-0.07	0.01	0.09	0.06	0.06	0.01	0.09	-0.11	0.44	1.00				
17. Low-tech Sector	-0.04	0.06	-0.02	-0.01	-0.02	-0.05	0.01	-0.02	-0.01	-0.04	-0.02	-0.01	-0.10	-0.03	-0.04	0.02	1.00			
18. High-tech Sector	0.04	-0.02	0.03	-0.02	-0.01	0.01	0.01	0.05	0.02	0.08	0.07	-0.01	0.03	0.03	0.01	-0.05	-0.33	1.00		
19. Industrial Level for Financing	0.02	-0.08	0.02	-0.01	0.02	0.08	-0.03	0.04	0.04	0.05	0.05	-0.02	0.04	0.07	0.04	-0.01	-0.31	0.23	1.00	
20. Industrial Level for Market Scope	0.04	-0.03	0.02	0.01	-0.01	0.02	0.00	0.04	0.02	0.07	0.04	-0.02	0.08	0.03	0.01	-0.01	-0.40	0.35	0.28	1.00

N= 3566

Chapter Three:

Balancing R&D activities across firms' boundaries: The performance implications of complementary search strategies

3.1 Introduction

The performing of research and development (henceforth R&D) activities underlies a process from which firms search the necessary knowledge to innovate (Pisano, 2000). Along this process, firms must integrate R&D tasks that differ from each other in terms of their orientation along the continuum between "science" and "business" (Hoang and Rothaermel, 2010; DeSanctis, et al., 2002). In addition, since resources devoted to performing these activities are limited, the organization of differing R&D may cause tensions that affect firms' organizational search choices, and subsequently their innovative performance. If so, this raises the following questions: (i) How do firms manage R&D activities that not only need different organizational capabilities, but also provide differing outcomes? (ii) How do firms strike a balance of the tensions that may emerge from synchronizing these activities? (iii) What are the key performance implications resulting from balancing such tensions? These questions are relevant for R&D management, since their answers contribute to improving the understanding of the strategies a company may execute for organizing their R&D activities.

To answer these questions, I argue in this research that science-orientated and business-orientated R&D activities may be characterized in terms of the March's (1991) lens of exploration-exploitation. Along the line of previous studies on technological innovation (e.g., He and Wong, 2004; Greve, 2007; Tushman and O'Reilly, 2007; Rothaermel and Alexandre, 2009), this characterization is helpful for identifying the sources that cause tensions in the organization of differing R&D activities. By considering the presence of these tensions, this research examines the role of ambidexterity as a method for organizing exploratory and exploitative R&D activities. On the one hand, I hypothesize that firms may buffer exploratory from exploitative R&D tasks by allocating them across their organizational boundaries. In particular, I examine whether firms develop a balance behavior in which exploration (exploitation) occurring internally in their R&D function is compensated for exploitation (exploration) occurring externally in their alliances. Going beyond, I define exploration-exploitation in firms' R&D alliances in terms of the function and geographic domain. This implies that firms' alliances are classified as either exploratory or exploitative depending on their function along the innovation value chain, and on their geographic scope. With this characterization, the current paper compares two methods of balancing exploratory and exploitative R&D tasks that come about along the firms' boundaries.

On the other hand, I hypothesize that a balance of exploratory and exploitative R&D tasks that separate them across the company's organizational boundaries brings complementarities in terms of a given performance measure. Drawing on earlier studies on ambidexterity (Raisch and Birkinshaw, 2008; Jansen, et al., 2009; Tempelaar, 2010; Hoang and Rothaermel, 2010), the presence of these complementarities links to the fact that ambidexterity in R&D across the firms' boundaries not only isolate conflicting activities, but also facilitates the integration of the knowledge sources emerging from the separated activities. Drawing on the learning alliance literature (e.g., Mowery, et al., 1996; Rosenkopf and Almeida, 2003), this study argues that R&D alliances contribute to reaching the benefits of ambidexterity by providing firms with a set of learning integration mechanisms that contribute to articulating the range of outcomes resulting from exploration and exploitation in R&D. This fact facilitates the linkage of exploration and exploitation across partners.

This study contributes to the extant literature on R&D management on the following aspects. Firstly, this research is among the first in examining how firms balance their exploratory and exploitative R&D activities across their boundaries by using a multi-industry sample of companies. Other studies have started to investigate the balance of exploration and exploitation across organizational boundaries by for the case of specific industries (Lavie and Rosenkopf, 2006; Vurro and Russo, 2009). Compared to earlier studies, the present research allows for industry-specific characteristics that may affect the search choices of firms and their innovation consequences. Secondly, in the examination of the balance problem, this research adds to previous studies by incorporating the geographic domain for defining exploration and exploitation that emerge in the firms' R&D alliances. In so doing, the study provides a more complex picture on the way firms balance tensions in the articulation of opposing R&D tasks.

Finally, the current research adds to the empirical literature on inter-organizational complementarities in R&D (e.g., Cassiman and Veugelers, 2006; Schmiedeberg, 2008; Love and Roper, 2009) by examining the interaction effects emerging from joining exploratory and exploitative R&D tasks across the firms' organizational boundaries. In this regard, this research proposes that the combination of internal and external R&D activities produces complementarities when the matched activities differ from each other along the exploration-exploitation dimension. This finding suggests that the association of specialized activities across the firms' organizational boundaries is a condition that favors the production of complementarities in R&D. To the best of my knowledge, only Hoang and Rothaermel (2010) have investigated how external exploration (exploitation) search moderates the firm's internal exploitation (exploration). However, these authors focus their attention only on the bio-pharmaceutical industry, and on external exploration-exploitation that occurs in the function domain.

The paper is organized as follows. Next section presents a theoretical basis for studying both the balance problem associated with the structure of exploratory and exploitative R&D activities, and the performance consequences deriving from the company's balance behavior. Subsequent sections describe the data for the empirical analysis, the estimation methodology, and results. Finally, discussion and conclusions are presented.

3.2 Theory and hypotheses

R&D is widely identified as a critical driver for innovation, and subsequently, for firm productivity (Blundell, et al., 1995). When assessing the relationship between R&D adoption and innovation, different stream literatures tend to treat R&D as a set of unified and homogeneous tasks. However, the implementation of R&D often supposes the implementation of a varied set of activities, which can be distinguished by the fact that each one has a direction on the continuum between "science" and "business" (DeSanctis, et al., 2002; Chiesa and Frattini, 2007). The existence of R&D activities with a different course has serious implications for understanding how firms choose the best way to organize such activities. This is the case, since R&D activities addressing different purposes require different organizational capabilities, operate under different mindsets, produce different organizational behavior patterns, and lead to inconsistent potential outcomes. Taken together, these differences may yield important tensions along the process whereby managers decide on the organizational design for R&D.

The March's (1991) lens of exploration-exploitation provides a helpful framework to characterize the range of contradictory tasks comprising the R&D function in firms, as well as to determine the sources of tensions emerging from the integration of such tasks. In this study, it is argued that those activities in the R&D function addressed to research purposes are conceived as "exploratory" in that they intend to discover new knowledge sources, experiment on novel knowledge connection, and then to increase the firm's knowledge-base diversity. Alternatively, activities in the R&D function directed to development purposes can be characterized as "exploitative" in the sense that they make use of current knowledge to improve and refine existing technologies, production processes and products of the firm.

The exploration-exploitation characterization allows us to determine the basics that an organizational design has to accomplish in order to accommodate alternative types of R&D. In particular, since exploratory activities in the R&D function pursue the creation of novel knowledge sources, they call for flexible organizational structures, decentralized decision-making processes, and informal mechanisms of coordination. Organizational designs with these characteristics fit well to exploratory R&D, since they promote: (i) the emerging of learning-from-failure strategies which are required to accommodate processes with a high rate of experimentation, (ii) the development of routines that allow researchers to be connected to others across different scientific disciplines, (iii) the formation of highly specialized teams, and (iv) the establishment of incentive schedules that encourage long-term commitments.

Alternatively, given that exploitative activities in the R&D function align with the development of the firm's existing knowledge bases, they need organizational designs that underscore formal mechanisms of coordination, control and fine-tuning practices, in which processes addressed to knowledge-variation reduction gain relevance as mechanisms to improve accountability and efficiency. Designs with these characteristics align with exploitative R&D, given that they encourage: (i) learning process focused on identification of weak points along the company's product development projects, (ii) routines that transfer knowledge effectively from the R&D function to the rest of corporate functions (e.g., production, commercialization, logistic), (iii) the creation of multi-functional teams, and (iv) the use of incentive systems that promote short-term commitments. Table 3.1 summarizes the characteristics of R&D with respect to the lens exploration-exploitation.

Table 3.1. Exploration and exploitation occurring in R&D

Exploration in R&D	Exploitation in R&D
▪ Highlights research and knowledge generation	▪ Emphasizes development and knowledge application
▪ Focuses on long-term results, such as radical innovation, new market entry, unrelated product diversification	▪ Focuses on short-term outcomes, such as incremental innovation, cost reduction, efficiency-enhancement
▪ Knowledge creation depends on science development	▪ Knowledge creation depends on business needs
▪ Calls for flexibility, informal coordination, and for a decentralization of the decision rights	▪ Calls for control, formal coordination, and for a centralized allocation of the decision rights
▪ Organizes R&D tasks around science	▪ Organizes R&D tasks around products and markets

Source: own elaborated

Organizational design choices for exploratory and exploitative R&D activities generate paradoxical situations, as the establishment of certain designs may lead managers to boost the implementation of some tasks to the detriment of others. For instance, organizational designs for exploratory R&D support basic research activities for pursuing long-term innovations, but favor less the development of those aligned with the short-term objectives, such as improving the speed of product introduction. Alternatively, designs for exploitative R&D encourage technology and product development activities, but support less those directed to the implementation of long-term targets, such as enhancing unrelated product diversification. The outcome of performing exploratory and exploitative R&D activities are necessary for the firm competitiveness and survival, but the use of alternative arrangements for accommodating both types of R&D activities is costly in terms of integration requirements as well as in terms of financial resources and managerial attention. As resources dedicated to the development of differing organizational designs for R&D are limited, competing views may exist regarding the activities around which firms should arrange their R&D function.

Recently, a burgeoning literature on technological innovation has started to recognize ambidexterity in exploration and exploitation as an effective strategy to deal with tensions derived from the joint adoption of these activities (e.g., He and Wong, 2004; Rothaermel and Alexandre, 2009; Andriopoulos and Lewis, 2009). In this literature, ambidexterity is conceived as the ability of a firm to conduct exploration and exploitation simultaneously in technological search (Raisch and Birkinshaw, 2008). In order to mitigate tensions, ambidextrous arrangements buffers exploration from exploitation within firms by allocating them to highly differentiated and loosely coordinated technological sub-units. However, ambidexterity is achieved only in those cases in which the resulting outcomes from these activities are properly integrated (Tushman and O'Reilly, 2007; Jansen, et al., 2009). In this direction, ambidexterity in R&D is defined here as the company' ability not only to execute differing R&D activities simultaneously, but also to integrate the evolving knowledge sources associated with each one.

However, case studies in R&D management also suggest that ambidexterity in R&D is such a difficult task due to the cost linked to mastering simultaneously exploratory and exploitative R&D within firms, and to the involved requirements in integrating the alternative outcomes derived from these activities, (DeSanctis, et al., 2002; Chiesa and Frattini, 2007). These studies also show an increasing trend of partitioning the R&D function into specialized activities, some of which are allocated to and interconnected by networks along firms' organizational boundaries (DeSanctis, et al., 2002). This tendency is consistent with the findings coming from the open innovation literature (Chesbrough, 2003; Laursen and Salter, 2006) that the integration of internal and external R&D has become relevant in order to understand the success of some companies in technological innovation properly. Taken together, these findings demonstrate the necessity to investigate the use of designs, in which firms avoid the described tensions of joining conflicting R&D tasks at the same time they profit from the knowledge sources generated by these tasks. Next section describes a design that allows firms to achieve these goals. In this respect, some hypotheses are derived about how firms balance their exploratory and exploitative R&D activities and about the effects on innovative performance associated with different balance strategies.

3.2.1 Inter-organizational ambidexterity for accommodating R&D

The current study examines alternative methods that link exploratory and exploitative R&D tasks across the firms' boundaries. In particular, this paper asserts that boundary-spanning strategies for performing R&D constitute effective strategies that mitigate tensions associated with the integration process of opposing R&D activities. In particular, I suggest that alliances provide firms with new ways for buffering exploratory from exploitative R&D, enabling them to reduce tensions described previously. For instance, a firm may opt for specializing in exploratory R&D tasks while forming alliances concentrated on exploitation as a method to complement its R&D effort. Alternatively, the firm can specialize in exploitative R&D activities internally at the same time as it forms R&D alliances with an exploration-orientation to balance its own R&D activities. In both instances, firms can relax constraints that affect their resource allocation choices relating to the arrangement of the R&D function, gaining access to critical resources available outside their boundaries. Moreover, by elaborating on previous learning alliance studies (e.g., Mowery, et al., 1996; Rosenkopf and Almeida, 2003; Gomes-Casseres, et al., 2006), this research asserts that the use of R&D alliances provides firms with a set of knowledge integration mechanisms that enable them to integrate the knowledge sources deriving from performing exploratory and exploitative R&D across their organizational boundaries.

Drivers leading the use of inter-organizational ambidexterity

Several factors can be considered to explain firms' tendencies to adopt inter-organizational ambidexterity as a method for organizing their R&D activities. Firstly, an increasing modularization of knowledge creation has facilitated the emergent of organizational designs in which the R&D function can be partitioned in highly specialized activities (Sanchez and Mahoney, 1996; Langlois, 2002). This feature enables firms to allocate specialized and contradictory R&D tasks across the firms' organizational boundaries. Secondly, the emergent and development of markets for technology allows firms to restructure their R&D function in such a way that they may benefits from the division of labor in knowledge production (Arora, et al., 2004). This is the case, since the development of these markets provides firms with a variety of new arrangements for organizing their R&D activities (e.g., strategic R&D alliances, R&D outsourcing, and joint ventures). This implies that firms may specialize internally in given R&D activities, while accessing in markets for technology those in which dedicated R&D providers hold accumulated and encoded expertise (Grant and Baden-Fuller, 2004). Thirdly, the development of property rights improves technology appropriation, and consequently, the firms' incentives to be involved in innovation activities across their organizational boundaries (Ceccagnoli, 2009). This holds true as the development of property rights reduces transaction costs, which enhances firms' predisposition to commercialize knowledge in markets for technologies.

The use of inter-organizational ambidexterity and the company's balance behavior

Implementation of inter-organizational ambidexterity in exploratory and exploitative R&D leads us to investigate to which extent this method constitutes a fruitful strategy to balance such activities. In the context of this study, it is hypothesized that inter-organizational ambidexterity in R&D is an effective balance strategy since this method not only alleviates the aforementioned tensions that characterize the articulation process of dissimilar R&D tasks, but also enables firms to integrate the outcomes produced by these tasks. Nonetheless, as recognized by recent studies on organizational learning, exploration and exploitation in alliances take place in several domains (Lavie and Rosenkopf, 2006; Lin, et al., 2007; Vurro and Russo, 2009). According to previous studies on alliance formation, exploration and exploitation can be defined in the function, structure or attribute domain. In a given alliance, exploration and exploitation in the function domain are defined based on the purpose of such an alliance along the innovation value chain (Koza and Lewin, 1998). In the case of structure domain, these activities are defined according to the network position of a firm's partners (Lavie and Rosenkopf, 2006; Lin, et al., 2007). Finally, regarding the attribute domain, exploration and exploitation refers to the level of differentiation existing between new and current partners in a firm's alliance portfolio (Lavie and Rosenkopf, 2006).

The presence of multiple domains reveals, however, that inter-organizational ambidexterity in R&D gives rise to a variety of strategies whereby a firm can strike a balance between exploration and exploitation in R&D. In order to shed light about the organization of exploration and exploitation in R&D activities, this paper hypothesizes that firms balance these activities by buffering them across their organizational boundaries and by considering that external search in R&D occurs in certain domains. Specially, the attention places on the balance of internal exploratory (exploitative) R&D activities in relation to two domains that describe external search in the firm's alliance portfolio: the function and geographic domain.

The characterization of the firms' alliances in the function domain has been widely investigated in other studies (e.g., Koza and Lewin, 1998; Faems, et al., 2005; Lavie and Rosenkopf, 2006). However, the use of this characterization of a company's alliances has not been used to analyze the balance of exploratory and exploitative R&D activities across its organizational boundaries. As regards the geographic domain, earlier studies have begun to examine how firms search for knowledge across geographic regions (Rosenkopf and Almeida, 2003; Ahuja and Katila, 2004), and how such search behavior contributes to enhancing performance (Ahuja and Katila, 2004; Sidhu, et al., 2007). However, to the best of my knowledge, no studies have conceptualized exploration and exploitation occurring in a firm's alliances in terms of the geographic domain, let alone have used such characterization to examine the balance problem of differing R&D activities. This study aims to fill this gap incorporating the geographic domain into the analysis of the balance of tensions in the organization of exploratory and exploitative R&D.

The next paragraphs describe the hypotheses for explaining the firms' balance behavior regarding the articulation process of opposing R&D activities across their organizational boundaries.

Balancing internal R&D with alliances in the function domain

Firms' alliances can be classified as exploratory and exploitative in the function domain taking into account the purposes they serve along the innovation value chain. In particular, exploratory alliances in this domain are formed with the purpose of conducting upstream innovation activities, such as knowledge discovery, detection and experimentation. Alternatively, Exploitative alliances in the function domain link partners whose actions aim at executing downstream innovation activities, such as technology development and commercialization (Rothaermel and Deeds, 2004; Faems, et al., 2005; Lavie and Rosenkopf, 2006).

Alliances' definition of exploration and exploitation in the function domain extends the space of possibilities that a firm can proceed when mitigating the tradeoffs of pursuing divergent R&D activities. For instance, a firm may concentrate its own effort on exploitative R&D activities at the same time as it fits complementary exploration activities by forming R&D upstream-alliances in the function domain. Alternatively, a firm may opt for mastering in exploratory R&D activities, compensating the necessity of exploitation by forming R&D alliances that align with downstream innovation activities in the function domain. In both cases, the firm buffers exploratory and exploitative R&D activities, thus avoiding the development and maintenance of dual structures for arranging contradictory R&D activities. This course of action mitigates tensions in the organization of R&D, enhancing the firms' incentives to separate exploratory and exploitative R&D activities across their organizational boundaries. As a result, in this study it is hypothesize that:

Hypothesis 3.1a: Firms tend to balance the intensity of their internal exploratory (exploitative) R&D activities by participating more in exploitative (exploratory) R&D alliances, in the function domain.

Balancing internal R&D with alliances in the geographic domain

R&D alliances that vary in geographic scope can be categorized according to the exploration-exploitation lens. Domestic R&D alliances make it possible the access of knowledge that is relatively close to that comprising a firm's technological background. As a result, learning from such alliances aligns well with activities, such as knowledge fine-tuning, refinement and development. According to preceding arguments, national alliances are arrangements that fit well to activities rooted in exploitation search. Instead, since international R&D alliances give prevalence to the access of knowledge that tends to be distant, compared to that accumulated in the local context of the firm, learning from these alliances focuses on activities, such as knowledge detection, trial, and variation. For that reason, international R&D alliances can be regarded as arrangements that align well with a search process anchored in exploration activities.

Given the characterization of alliances in the geographic domain, a firm faces a wide array of alternatives for balancing its exploratory and exploitative in R&D. In some instances, a firm can specialize internally in exploitative R&D tasks, such as technology development, knowledge refinement and technology commercialization balancing these activities with exploratory R&D alliances in the geographic domain. This may occur, for example, when the company brings knowledge derived from its development units to an entirely new geographic setting (exploration in the geographic domain), in the attempt to create new applications (Billington and Davidson, 2010). When applied research of pharmaceutical companies in leading countries is brought to downstream firms in follower countries, completely new knowledge applications can emerge, some of which may result in new drug development or different treatments.

In other instances, a firm can specialize internally in exploratory R&D while forming exploitative alliances in the geographic domain. Under these circumstances, domestic R&D alliances may provide access to local partners' expertise in advance development activities, which are needed to bring the firm's basic research outcomes into regional markets (Van Ark et al., 2008). This is evidenced, for example, in the case of the semiconductor industry, where most exploratory firms tend to be linked to regional knowledge networks as a way to gain access to supportive resources, such as technology commercialization and product development (Almeida and Kogut, 1997). Previous arguments show that firms may relax tensions on the process of resource allocation choices by balancing internal exploration (exploitation) in R&D with external exploitation (exploration) defined in the geographic domain of their alliances. Taken together, these considerations lead us to hypothesize that:

Hypothesis 3.1b: Firms tend to balance the intensity of their internal exploratory (exploitative) R&D activities by participating more in exploitative (exploratory) R&D alliances, in the geographic domain.

The balance behavior previously described has significant consequences in terms of firm innovative performance. With the aim to examine this premise, next section develops the arguments that link the use of an inter-organizational ambidexterity in exploratory and exploitative R&D to its innovative performance implications.

3.2.2 Performance implications

Balance behaviors described in preceding sections rest on the premise that exploration and exploitation activities occurring in R&D are two extreme of the same continuum. Thus, inherent tensions emerging from the integration of these activities encourage firms to adopt them separately. This fact involves that exploration and exploitation in R&D is regarded as rival and highly incompatible activities within the R&D function of firms. However, this paper suggests that the relationship between these R&D activities shifts from one of rivalry to one of complementarity in cases in which firms combine such activities across their organizational boundaries. In this setting, resource constraints precluding a joint adoption of exploration and exploitation in R&D are reduced, and subsequently, those are conceived like orthogonal activities in the sense that the adoption of one of them does not necessarily impede the adoption of the other (Gupta, et al., 2006).

The fact that exploratory and exploitative R&D tasks are regarded as orthogonal activities in inter-organizational contexts implies that a test for the beneficial effects of inter-organizational ambidexterity should be based on the assessment of the interaction effect of joining them on a given performance measure (Katila and Ahuja, 2002; He and Wong, 2004; Gupta, et al,, 2006). As a result, this study hypothesizes that the adoption of internal exploration (exploitation) in R&D along with external exploitation (exploration), defined in a given domain, produces complementarities in the sense suggested by Milgron and Roberts (1990). That is, an internal adoption of a given R&D task raises the returns of an external adoption of another R&D task.

The presence of complementarities between exploratory and exploitative R&D activities across organizational boundaries can be justified by the following drivers. Firstly, as suggested above, the allocation of differing R&D activities through alliances mitigate resource constraints that create tensions in the integration process of such activities. Secondly, the use of alliances in inter-organizational ambidextrous arrangements provides firms with mechanisms to facilitate the integration of exploration and exploitation in R&D, bringing the required knowledge sources together in order for a firm to be competitive, in the short-term, and innovative, in the long-term (Rosenkopf and Nerkar, 2001; Rosenkopf and Almeida, 2003). Thirdly, the relationship between specialized R&D activities in inter-organizational contexts enhances flexibility, shortens the life cycle of R&D projects, and contributes to reducing costs and risks involved in their joint execution (Grant and Baden-Fuller, 2004). Taken together, these arguments support the following hypotheses:

Hypothesis 3.2a: Firms that combine an internal specialization in exploratory (exploitative) R&D with exploitative (exploratory) R&D alliances in the function domain produces complementarities in terms of innovative performance.

Hypothesis 3.2b: Firms that combine an internal specialization in exploratory (exploitative) R&D with exploitative (exploratory) alliances in the geographic domain produces complementarities in terms of innovative performance.

Next section depicts the research design implemented in this study in order to test previously described hypotheses.

3.3 Empirical Analysis

In this study, I implemented two methodologies, one for the analysis of the firms' balance behavior, and another for the study of the performance consequences linked to such behavior. In the first case, I built measures for representing the amount of exploitation-exploration in R&D activities occurring within firms and in R&D alliances. By using regression analysis, I examined the relationship between these measures after controlling for both firm and industry-specific characteristics. In the second case, I specified an innovative performance function as being determined by exclusive combinations of internal and external R&D activities that represent models of inter-organizational ambidexterity. I tested for the presence of supermodularity of this function as a method for assessing the existence of complementarities among the combinations of R&D activities leading to inter-organizational ambidexterity.

3.3.1 Data

The empirical analysis of this study draws on the data provided by *The Technological Innovation Panel*[37] (henceforth, PITEC), which is conducted by the Spanish National

[37] The PITEC is available at http://sise.fecyt.es/sise-public-web/

Statistic Institute (INE) in association with the Spanish Science and Technology Foundation (FECYT) and the Foundation for Technological Innovation (COTEC). The PITEC includes data on the technological innovation activities of all the main sectors in the Spanish economy, including services and manufacturing. In particular, it collects information provided by the Spanish Community Innovation Survey (CIS) for the period of 2003-2007, including relevant information about the technological profiles of the companies surveyed. Drawing on Rosenberg and Kline's model (1986), the PITEC collects information about the objectives of the innovation process, the sources of fresh ideas, the obstacles associated with the innovation process, and an analysis of the effects produced by innovations.

An important characteristic of the PITEC for the present study is that these data classify alliances in terms of their geographic scope across national borders and their purposes along the innovation value chain. In addition, the PITEC gathers unusual information about the rationale underlying the surveyed firm's expenditures in R&D. For instance, this dataset allows researchers to describe the aims of the firms' expenditures in R&D, distinguishing which portion of such expenditures is dedicated to basic research, applied research and to development activities. Finally, as the PITEC gathers information about a varied number of Spanish industries, its use makes it possible to account for industry-specific characteristics that may affect the company's balance behavior, as well as the performance consequences of such behavior.

In the case of the present study, I pay the attention to Spanish manufacturing firms in the PITEC for which complete information is available on their innovative activities for two consecutive periods, 2003-2005 and 2005-2007. These data include companies whose main economic activity appears in one of the two-digit manufacturing industries of the "Classification of Economic Activities in the European Community"[38].

3.3.2 Variables

The PITEC contains data generated from self-reported information provided by the firms. In this setting, the results of the study may be affected by the "common method

[38] This is equivalent to the International Standard Industrial Classification (ISIC).

bias" problem (Podsakoff and Organ, 1986). In order to deal with this concern, I considered some of the remedies usually applied by other studies on technological innovation (e.g., Jansen, et al., 2006; Rothaermel and Alexandre, 2009). In particular, whenever possible, I separated the dependent and independent variables by introducing a time lag. In the analysis of the balance behavior, measures of exploration-exploration refer to the period of 2005-2007, while the control variables refer to the period of 2003-2005. Similarly, in the analysis of the performance implication of the firm balance behavior, firm performance refers to the period of 2005-2007, while the independent variables refer to the period 2003-2005. In cases for which the introduction of lags between the dependent and independent variables was not an option, both types of variables were obtained from different response formats. This strategy helps to relieve the common-method bias (Podsakoff, et al., 2003).

Dependent variables

In line with Hypotheses 3.1a and 3.1b, an increase in internal exploratory R&D should produce a reduction in external exploration that occurs either in the function or in the geographic domain. Thus, external exploration in each domain is regarded as the dependent variable in the subsequent analysis. I operationalized exploration-exploitation in each domain as a combined continuum by taking into account the information from the PITEC concerning the surveyed firms' participation in R&D alliances.

Exploration in the function domain. To build this variable, I proceeded as follow. I examined the configuration of the alliance portfolio of each firm, taking from the PITEC the set of binary variables describing R&D collaborations with agents, such as universities, public research institutes, private laboratories, clients, and suppliers. I applied the criterion of Faems, et al., (2005) that classifies such alliances depending on their purposes along the innovation value chain. Accordingly, alliances with universities, public research institutes and laboratories are regarded as exploratory activities, while alliances formed with supplier and clients are classified as exploitative activities respecting the function domain. From the set of binary variables corresponding to each group (exploratory and exploitative), I created the variable, f_i^k, which denotes the proportion of alliances of type "k" that the firm "i" forms along the innovation value chain. Finally, by following Lavie and Rosenkopf (2006), I calculated the weighted-average: $\sum_{k=1}^{2}\omega_k f_i^k$ for representing the variable *External Function Exploration*. In this context, ω_k denotes the weight associated with the category "k", such that $\omega_{explorative} = 1$, and $\omega_{exploitative} = 0$. The resulting variable ranges from 0 to 1, where high values indicate a tendency for function exploration while low values represent a tendency for function exploitation in the firm *i's* alliance portfolio.

Exploration in the geographic domain. In order to characterize exploration occurring in alliances with respect to the geographic domain, I applied the following procedure. From the set of binary variables representing R&D collaborations of the surveyed firms, I examined the partner location for each alliance. Then, I classified firms' alliances in three categories: (i) those established with Spanish partners, (ii) European partners[39], and (iii) with partners in other regions[40]. From this classification, I created the indicator g_ℓ^i, which represents the proportion of alliances the firm "i" forms with partners in the region "ℓ". Finally, I calculated the weighted-average: $\sum_{\ell=1}^{3}\omega_\ell g_\ell^i$ for representing the variable *External Geographic Exploration*. In this instance, ω_ℓ stands for the weight corresponding to the category ℓ, such that: $\omega_{Spain} = 0$, $\omega_{Europe} = 0.5$, and $\omega_{Other} = 1$. According to previous weights, European alliances are regarded here as a combination of exploration and exploitation. This is the case since these arrangements suppose that Spanish firms cooperate with partners operating in other countries that may differ greatly from Spain, but that share with it a similar regulation framework, institutions and common markets. The proxy for external exploration in the geographic domain ranges between "0" and "1", in such a way that high values point to a tendency for geographic exploration whereas low values indicate a tendency for geographic exploitation.

Innovative performance. In order to test Hypotheses 3.2a and 3.2b, I operationalized *Innovative Performance* in the following way. I paid the attention to the reported evaluations provided by the firms regarding the effects of their innovations. Using a

[39] This category includes partners in the European Union, in candidate countries to the accession to the European Union, and partners in Switzerland, Iceland and Norway.
[40] In this case, this category includes partners in US and Canada, and those in Asian, African and Latin-American countries.

four-point scale, firms declared the extent to which their innovations in the period 2005-2007 had produced a positive impact on the following features: (i) expansion of their market share, (ii) improvement in the quality of their products, (iii) increase in their product range, (iv) reduction in average labor costs, (v) improvement in production flexibility, (vi) increase in production capacity, (vii) reduction in average costs of raw materials and energy, (viii) reduction in the environmental impact of their production, and (ix) greater compliance with norms and regulations. For each of these aspects, I awarded a value of 1 when the firm under consideration rated the effect as strongly-important and 0 otherwise. Finally, I added up the resulting codified variables so that each firm received 0 when its innovations had no impact and 9 when they have the maximum impact. This construct has a convincingly degree of internal consistency (Cronbach's alpha = 0.76).

Independent variables

In the regression analysis concerning the firms' balance behavior; I employed the PITEC data to measure exploration occurring in the R&D function of firms. To do so, I examined the composition of the surveyed firms' R&D expenditures, focusing the attention on the share of such expenditures addressed to "basic research", "applied research" and to "development activities". In the PITEC, basic research refers to those activities that a firm conducts to pursue new knowledge sources, which do not necessarily lead to particular applications. Applied research refers to the set of specific activities directed to the generation of novel knowledge sources with the aim of reaching specific applications. Finally, technological development defines those tasks that utilize current knowledge sources to the pursuit of novel applications addressed to improving materials, products and/or technologies.

From the expenditures on these activities, I built the indicator, e_j^i, that characterizes the proportion of the R&D expenditures that the firm "i" dedicates to the activity "j". Finally, I calculated the weighted-average: $\sum_{j=1}^{3}\omega_j e_j^i$, which stands here for the variable *Internal Exploration in R&D*. In this occasion, the corresponding weights are given as follows: $\omega_{basic} = 1$, $\omega_{applied} = 0.5$, $\omega_{development} = 0$. There is no agreement in prior studies on technology and innovation regarding the orientation that the firm's applied research has in the continuum exploration-exploitation (Chiesa and Frattini, 2007). On the one had, applied research can be considered as exploration in that it is used for building new knowledge sources. On the other hand, applied research can be regarded as exploitation given that it leads firms to particular knowledge application. Given this duality, I assumed that applied research is a blend of exploratory and exploitative activities. The proxy of previously described ranges from 0 to 1, where high values point to a tendency for internal exploration in R&D while low values show a tendency for internal exploitation in R&D.

In the model examining the performance effects of using inter-organizational ambidexterity, I operationalized organizational design choices as follow. From the type of the internal and external R&D activities declared by each firm, I built a set of dummies so that a value of 1 is awarded when firms reported positive expenditures on a particular type of R&D (e.g., internal exploration, and internal exploitation). Similarly, I created dummies so that a value of 1 is awarded when firms declared to have participated in a particular type of alliance (e.g., exploratory, exploitative respecting each domain). From these dummies, I characterized alternative ways of achieving inter-organizational ambidexterity. For instance, it is considered that a firm adopting an internal exploration in R&D along with exploitative alliances in the function domain follows a model of inter-organizational ambidexterity. Likewise, it is considered that a firm draws on a model of inter-organizational ambidexterity when it combines an internal exploitation in R&D with exploratory alliances in the geographic domain. Table 3.2 depicts all the combinations characterizing designs for R&D in line with inter-organizational ambidexterity.

Control variables

By using additional information from the PITEC, I controlled for the firm and industry-specific characteristics that may affect both the firm tendency of conducting external exploration in a given domain, and the innovative performance consequences of using inter-organizational ambidexterity.

Table 3.2. The organizational designs for exploratory and exploitative R&D tasks

Type of Ambidexterity	Type	Exclusive Categories	Description
When external search is defined in the function domain	1	No Implementation	No R&D adoption
	2	Exclusive Internal Implementation	A single adoption of either exploration or exploitation in R&D
	3	Exclusive External Function Implementation	A single adoption of either exploration or exploitation in the function domain
	4	Inter-ambidextrous Implementation	A single adoption of a different type internally from that adopted externally
When external search is defined in the geographic domain	1	No Implementation	No R&D adoption
	2	Exclusive Internal Implementation	A single adoption of either exploration or exploitation in R&D
	3	Exclusive External Geographic Implementation	A single adoption of either exploration or exploitation in the geographic domain
	4	Inter-ambidextrous Implementation	A single adoption of a different type internally from that adopted externally

Firms' skills. Regarding the analysis of Hypothesis 3.1a and 3.1b, I controlled for the effect that differences in the firm's skill bases might have on the firm's propensity to perform external exploration in a given domain. In line with previous studies on innovation and technology (Mohnen and Röller, 2005; Leiponen, 2005b; Lavie and Rosenkopf, 2006), I hypothesize that a company with high skilled employees will be in a better position to expand its exploration activities beyond its organizational boundaries. In this regard, I included the number of reported researchers with a PhD degree in the period 2003-2005 as a proxy of the firms' skill bases (*Number of Qualified Researchers*). As regards the evaluation of Hypotheses 3.2a and 3.2b, differences in terms of the firms' skill bases may explain innovative performance heterogeneity. As a result, I controlled for this feature when assessing the performance implications of the firm's balance behavior.

Diversity in the firm's technological opportunities. On the one side, environment with a variety of knowledge sources may encourage firms to expand their exploratory effort beyond their organizational boundaries, in the attempt to learn from emerging opportunities. On the other side, diversity in terms of technological opportunities leads firms to be exposure to new managerial methods and technologies, which may result in novel recombination of knowledge sources and in different ways of solving problems.

This fact may increase the productivity of the firm's innovation activities (Cockburn and Henderson, 1998; Laursen and Salter, 2006). To control for these issues in the empirical analysis, I built a measure of diversification (*Diversity in Technological Opportunities*), by using the PITEC data on the utilization made by firms of external knowledge sources in their innovation process during the 2003-2005 period. In particular, diversification was measured by the Blau's index (1977), according to the following formula: $1-\sum_{k=1}^{3}\left(\frac{c_k}{C_i}\right)^2$. In this context, ck represents the number of external knowledge sources of the type "k" used by the firm "i", while Ci denotes the total number of sources used by the firm "i". Particularly, "k" includes information coming from three sources: institutions (e.g., universities, public centers), other firms (e.g., supplier, competitors) and from formal sources (e.g., conferences, journals).

Firms' patenting propensity. Since firms exploiting their current knowledge bases intensively may suffer technological exhaustion, they are more likely to perform external exploration to avoid technological obsolesce (Ahuja and Katila, 2004). As patent propensity is positively correlated to the firm's capacity to exploit its knowledge bases, I included the variable number of patent applications made by a firm in the period 2003-2005 (*Patent Propensity*) as a way to control for this aspect. In addition, in order to control for differences in innovative performance related to the firm's patent propensity, I included this variable in the innovation performance function used by testing Hypotheses 3.2a and 3.2b.

Inhibitor factors for innovation. The managers' perception of the cost involved in the innovation process is an aspect that may inhibit a firm to participate in external exploration search. This perception may further affect the managers' choices along the innovation process, and as a result, the development of the firm's innovation activities. In order to control for this issue, I incorporated into the analysis a four-point scale variable (*Cost of Innovation*) that ranges the self-reported assessment of firms regarding the importance of cost of innovation activities as an element impeding their performance during the period 2003-2005. Another element with a capacity to inhibit external exploration as well as to affect the performance consequences of the firm's balance behavior is the presence of organizational inertia. In line with previous studies on organizational learning (e.g., March, 1991; Lavie and Rosenkopf, 2006; Greve, 2007), I hypothesize that such inertia discourages exploration activities, favoring more the exploitation of the current firm's knowledge base. In addition, inertia may affect the firm innovative performance by reducing exploration search that is needed to sustain disruptive innovations (March, 1991; Gupta, et al., 2006). In order to control for these aspects, I included a four-point scale variable (*Innovation Inertia*) that reflects the self-reported judgment of firms about the role that previous innovations played in discouraging the performance of additional innovation activities in the period 2003-2005.

Firms' operational drivers. In particular, the firm's motivation to conduct external exploration in a given domain, as well as the involved consequences of this behavior may vary according to the scale of the firm's operations (Almeida, Dokko and Rosenkopf, 2003; Rothaermel and Deeds, 2004; Lavie, Kang and Rosenkopf, 2010). To control for this fact, I added to the analysis a binary variable that gives a value of 1 when firms report having more than 200 employees (*Firm Size*). Additionally, prior studies innovation management indicate that the firm's disposition to carry out external search activities, and the performance consequences of the firm's balance behavior may be affected by the firm's affiliation to a multinational group (Almeida, 1996; Veugelers, 1997; Nerkar and Roberts, 2004). I controlled for this aspect by including a binary variable that indicates whether firms form part of a multinational company (*Business Group Affiliation).*

Finally, it is expected that firms operating in more dynamic technological environments differ in the inclination to perform external exploration and in their innovativeness, compared to those operating in less dynamic technological environments (Breschi, et al., 2000; Katila and Ahuja, 2002; Jansen, et al., 2006). To control for these issues, I classified firms according to the degree of technological intensity in the industries in which they operate (OECD, 1997). In that case, I built a dummy given a value of 1 when the firms operate in an industry classified as high-tech (*High-tech Industry*), and another coded with 1 when the firms operate in an industry classified as low-tech (*Low-tech Industry*).

3.3.3 Statistical methods

Methods for the analysis of the firm’s balance behavior

In this case, I applied a Tobit analysis since the measures of external exploration in the function and geographic domain are (double) censored (they range between 0 and 1). However, by inspecting the empirical distribution for these variables, it is observed that they are highly skewed. This fact entails that the assumption of normality of residuals in the standard Tobit model is not fulfilled in the context of this research. In order to mitigate this concern, I considered remedies applied in other studies (Laursen and Salter, 2006; Duysters and Lokshin, forthcoming). Thus, I implemented a log-transformation of the Tobit model with a multiplicative exponential error terms. This procedure assumes a lognormal distribution for the residuals of the Tobit model. Accordingly, the latent variable, $\text{Exploration}^{*}_{m}$, corresponding to the external exploration in the “m” domain is introduced here as a logarithmic transformation of the observed measure, Exploration_{m}. Specifically, the dependent variables in the analysis of the balance behavior of firms are defined as follow: $\text{Exploration}^{*}_{m} = \text{Ln}\left(1 + \text{Exploration}_{m}\right)$. Then, the models implemented in each case are described as follow:

$$\text{Exploration}^{*}_{m\,i} = \alpha_m + \gamma_m \,\text{Internal Exploration} + \mathbf{w}_{\mathbf{i}}^{'}\boldsymbol{\beta}_m + \varepsilon_{m\,i} \qquad (3.1)$$

Where the dependent variable is defined as

$$\text{Exploration}_{m\,i} = \begin{cases} 0 & \text{if Exploration}^{*}_{m\,i} \le 0 \\ \text{Exploration}^{*}_{m\,i} & \text{if } 0 < \text{Exploration}^{*}_{m\,i} < 1 \quad \forall m = \text{function, geographic} \\ 1 & \text{if Exploration}^{*}_{m\,i} \ge 1 \end{cases}$$

In this case, $\mathbf{w_i}$ is the vector of previously described control variables, while γ_m and $\boldsymbol{\beta}_\mathbf{m}$ are the parameters associate with the explanatory (*Internal Exploration in R&D*) and control variables ($\mathbf{w}$), respectively. Finally, $\varepsilon_{m\,i}$ stands for the error terms in the model corresponding to the domain “m”.

Methods for the analysis of the firm innovative performance

As regards the analysis of the performance effects of the firm's balance behavior, I applied a count data analysis since the proxy for innovative performance in this research is a non-negative integer variable (number of times that innovations are perceived as having a strongly positive effect). In general, this fact makes recommendable the use of either a Poisson or a Negative Binomial specification in order to model properly the relationships under consideration. However, given the context of this study, it can be argued that the firms' choices on alternative arrangements for their R&D activities are endogenous variables (See Table 3.2 for a description of these alternatives). When this is the case, the use of standard Poisson or Negative Binomial models will produce biased estimates (Windmeijer, 2002).

In order to handle this concern, I implemented the Deb and Trivedi (2006) model in the subsequent analysis of the performance consequences of the firms' balance behavior. In particular, the outcome variable (number of times innovations are perceived as highly influential) is characterized as being determined by a set of control variables and by endogenous covariates (organizational designs choices), which in this study is a multinomial variable (See Table 3.2). This specification allows us to assess the effect of the endogenous organizational choices on the firm performance, at the same time as it provides us with a characterization of the generating process of such organizational choices.

In the outcome equation, the observed *Innovative Performance* for firm "i" is denoted by y_i, which values follow a negative binomial specification:

$$E\left(y_i \mid \mathbf{w_i}, d_{mji}, \ell_{mji}\right) = \mathbf{w_i'\delta_m} + \sum_j \omega_{mj} d_{mji} + \sum_j \lambda_{mj} \ell_{mji}; \quad \forall m = \text{function, geographic} \qquad (3.2)$$

In this case, $\mathbf{w_i}$ is the vector of control variables described above, d_{mji} corresponds to binary variables representing the observed firm's choices on combinations between internal R&D and external search in the "m" domain, where "j" denotes the type of arrangements depicted by Table 3.2. Alternatively, $\boldsymbol{\delta_m}$ and ω_{mj} are parameters associated with the control variables and the set of organizational design choices of the firm “i”, respectively. Finally, ℓ_{mji} denotes latent factors that represent unobserved characteristics concerning firm i’s choice of the organizational design of type “j” and with respect to the domain “m”. The λ_{mj} represents factor loadings associated with the latent factors.

Alternatively, the model includes choice equations that characterize the probability that firm “i” chooses the organizational design of type “j” with respect to the domain “m”. Specifically, these probabilities are described by a mixed multinomial logit structure given as follows:

$$\Pr\left(d_{mji}=1,|\,\mathbf{z_i},\ell_{mji}\right)=\frac{\exp\left(\mathbf{z_i}'\boldsymbol{\rho}_{mj}+\eta_{mj}\ell_{mji}\right)}{\sum_{k=0}^{J}\exp\left(\mathbf{z_i}'\boldsymbol{\rho}_{mj}+\eta_{mk}\ell_{mki}\right)};\quad \forall m=\text{function, geographic} \qquad (3.3)$$

Where $\mathbf{z}_i$ represents the vector of control variables under consideration[41] while $\boldsymbol{\rho}_{mj}$ are the corresponding parameters. As in the outcome equation, ℓ_{mji} are latent factors and η_{mjk} are the corresponding factor loadings.

Since model in (3.2) describes innovative performance as a response to firms’ organizational choices, I tested for the existence of complementarities by using the notion of supermodularity (Athey and Stern, 1998; Topkis, 1998). To do so, I defined the set of conditions for which innovative performance in (3.2) is supermodular in the space of the firm’s choices strategies described by the Table 3.2. By using the estimates of ω_{mj}, these conditions are established as follows:

$$\omega_{m\ type\ 4}-\omega_{m\ type\ 3}>\omega_{m\ type\ 2}-\omega_{m\ type\ 1};\quad \forall m=\text{ function, geographic} \qquad (3.4)$$

By following Kodde and Ritzen (1988), and by taking into account the procedure implemented by Leiponen (2005), the test for complementarities has under the null the equality given by $\omega_{m\ type\ 4}-\omega_{m\ type\ 3}-\omega_{m\ type\ 2}+\omega_{m\ type\ 1}=0$ (interpreted here as a signal of no interaction), and under the alternative the strict inequality

[41] With the purpose of improving identification of the model, exclusive restrictions were added to the set of control variables.

$\omega_{\text{m type 4}} - \omega_{\text{m type 3}} - \omega_{\text{m type 2}} + \omega_{\text{m type 1}} > 0$ (viewed here as evidence of strict supermodularity). Then, the rejection of the null in favour of the alternative is considered as evidence indicating the existence of strict supermodularity in the firm's innovative performance. In this case, it is concluded the presence of complementarities.

It is worthwhile mentioning that the method for estimating parameters in (3.4) assumes that firms self-select by choosing the organizational design option that represents the best fit to their own skills and environmental conditions. In the context of this study, choice equations (3.3) characterize the process of self-selection by considering the observable (control variables) and unobservable factors (given by ℓ_{mj}) that affect firms' organizational choices. In this way, I aimed to allow for endogeneity while assessing complementarities under question, which is described as a frequent problem in previous studies on complementarities (e.g., Mohnen and Roller, 2005; Cassiman and Veugelers, 2006; Love and Roper, 2009).

3.4 Results

Table 3.3a and 3.3b present descriptive statistics and correlations for all the variables described above. A low correlation between the dependent variables in Table 3.3a ($r = -0.05$) reveals that the exploration-exploitation construct in the function domain is different from that defined in terms of the geographic domain. According to the mean values for the variables characterizing exploration-exploitation, it is observed a tendency for internal exploitation in R&D (*mean = 0.20*) and a strong tendency for external exploitation in the geographic domain (*mean = 0.05*). Consistent with the result provided by Lavie and Rosenkopf (2006), exploration and exploitation activities are evenly represented in the function domain (*mean = 0.48*).

3.4.1 Results for the firm's balance behavior

Table 3.4 shows the results for the estimates of the Tobit models that examine the firms' balance behavior. Models (1a) and (2a) include the control variables, with respect to the external search in the function and geographic domain, respectively. The rest of models incorporate the explanatory variable (Internal Exploration in R&D), in order to test

Hypotheses 3.1a and 3.1b. As regards the firm's balance behavior relating to the function domain, model (1b) shows that the parameter for *Internal Exploration in R&D* is positive and statistically significant (*p-value = 0.002*), indicating that firms focusing on internal exploration also reinforce external exploration in the function domain. In order to verify the existence of a nonlinear relationship between *Internal Exploration in R&D* and *External Function Exploration*, I added *Internal Exploration Squared* into model (1c). It is observed in model (1c) that the parameter for *Internal Exploration in R&D* keeps positive and statistically significant (*p-value = 0.012*) while the parameter for the squared term is negative but not statistically significant. Taken together, these findings suggest that firms are not inclined to balance their internal exploration in R&D by participating in alliances addressed to external exploitation in the function domain. Hence, results in models (1b)-(1c) do not provide support to Hypothesis 3.1a.

As regards the firms' balance behavior respecting the geographic domain, model (2b) reveals that the parameter for *Internal Exploration in R&D* is positive, but not statistically significant. As in the previous case, I incorporated the squared terms of this variable in order to verify the existence of a nonlinear relationship between the firm's propensity to explore internally in the R&D function and externally regarding the geographic domain. Results of model (2c) show that the parameter for *Internal Exploration in R&D* is positive and statistically significant (*p-value = 0.028*) and that the parameter for the squared term is negative and statistically significant (*p-value = 0.080*). This fact implies that, at low values of the *Internal Exploration in R&D*, firms underpin their internal exploration with external exploration in the geographic domain. At some level, the effect becomes negative, showing that firms balance their internal exploration effort in R&D with an external exploitation in the geographic domain. These results reveal that a tendency for balancing internal exploration (exploitation) and external exploitation (exploration) in the geographic domain prevails, once a given threshold is achieved. These results give support to Hypotheses 3.1b.

Table 3.3a. Correlation matrix (balance behavior analysis)

Variables	Mean	S.D	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Function Exploration	0.48	0.41	0.00	1.00	1.00													
2. Geographic Exploration	0.05	0.09	0.00	0.90	-0.05	1.00												
3. Internal Exploration	0.20	0.18	0.00	0.83	0.13	0.05	1.00											
4. Number of Qualified Research	39.38	25.63	0.00	100.00	0.13	0.03	0.22	1.00										
5. Diversity in Tech Opportunities	0.58	0.16	0.00	0.67	0.09	0.07	0.03	0.05	1.00									
6. Patenting Propensity	1.13	7.35	0.00	232.00	0.04	0.12	0.07	0.05	0.05	1.00								
7. Cost of Innovation	0.61	0.35	0.00	1.00	0.10	0.01	0.04	0.09	0.08	0.03	1.00							
8. Innovation Inertia	0.17	0.25	0.00	1.00	0.00	-0.05	-0.03	-0.08	0.03	-0.05	0.07	1.00						
9. Business Affiliation	0.49	0.50	0.00	1.00	-0.11	0.27	0.01	-0.13	-0.01	0.07	-0.14	-0.05	1.00					
10. Firm Size	0.29	0.45	0.00	1.00	-0.03	0.23	-0.08	-0.27	0.06	0.11	-0.12	0.01	0.43	1.00				
11. Low-Tech Sector	0.25	0.43	0.00	1.00	-0.04	-0.04	0.04	0.00	0.03	-0.04	-0.05	0.02	-0.04	0.00	1.00			
12. High-Tech Sector	0.13	0.33	0.00	1.00	0.07	0.05	0.10	0.11	0.03	0.11	0.06	0.00	0.00	0.00	-0.22	1.00		
13. Industrial Financing Sources	3.33	0.23	1.71	3.88	0.01	0.05	0.04	0.00	-0.02	0.03	-0.02	-0.02	0.04	0.03	-0.23	-0.05	1.00	
14. Industrial Market Scope	0.58	0.12	0.25	1.26	0.06	0.09	-0.06	0.09	0.05	0.06	0.09	-0.07	0.00	0.04	-0.20	0.48	-0.08	1.00

N = 972.

Table 3.3b. Correlation matrix (performance implication analysis)

Variables	Mean	S.D	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. Innovative Performance	2.36	2.25	0	9	1.00																	
2. Internal = 1 and Func = 0	0.36	0.48	0	1	-0.06	1.00																
3. Internal = 0 and Func = 1	0.04	0.20	0	1	-0.01	-0.15	1.00															
4. Internal = 1 and Func = 1	0.10	0.30	0	1	0.04	-0.27	-0.07	1.00														
5. Internal = 1 and Geo = 0	0.35	0.48	0	1	-0.06	0.98	-0.14	-0.26	1.00													
6. Internal = 0 and Geo = 1	0.04	0.21	0	1	-0.03	-0.15	0.72	-0.07	-0.15	1.00												
7. Internal = 1 and Geo = 1	0.11	0.32	0	1	0.04	-0.24	-0.07	0.69	-0.27	-0.07	1.00											
8. Number of Qualified Researchers	36.32	27.11	0	100	0.00	0.10	-0.07	0.03	0.10	-0.06	0.05	1.00										
9. Diversity in Tech Opportunities	0.52	0.21	0	0.67	0.13	-0.09	-0.02	0.06	-0.08	-0.02	0.07	0.03	1.00									
10. Patenting Propensity	0.65	4.76	0	232	0.06	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02	0.01	0.05	1.00								
11. Cost of Innovation	0.59	0.37	0	1	0.03	0.01	-0.01	0.00	0.02	-0.01	0.01	0.09	0.09	0.02	1.00							
12. Innovation Inertia	0.21	0.29	0	1	-0.05	-0.02	0.02	-0.01	-0.01	0.03	-0.01	-0.04	-0.01	-0.05	0.06	1.00						
13. Business Affiliation	0.36	0.48	0	1	0.07	-0.08	0.02	0.01	-0.11	-0.01	-0.07	-0.10	0.06	0.05	-0.13	-0.02	1.00					
14. Firm Size	0.22	0.41	0	1	0.07	-0.11	0.04	-0.02	-0.12	0.01	-0.06	-0.25	0.03	0.09	-0.14	0.02	0.44	1.00				
15. Low-Tech Sector	0.31	0.46	0	1	-0.04	-0.03	0.03	-0.02	-0.02	0.02	-0.01	-0.05	0.01	-0.04	-0.03	0.01	-0.03	0.06	1.00			
16. High-Tech Sector	0.10	0.30	0	1	0.03	-0.03	0.01	-0.01	-0.02	0.00	-0.03	0.13	0.06	0.06	0.03	-0.02	0.01	-0.02	-0.22	1.00		
17. Industrial Financing Sources	3.33	0.23	1.53	3.88	0.06	0.03	0.00	-0.04	0.03	-0.02	-0.03	0.00	0.02	0.03	0.01	-0.02	0.02	0.00	-0.19	-0.06	1.00	
18. Industrial Market Scope	0.56	0.13	0.13	1.26	0.02	-0.01	-0.03	0.03	0.00	-0.03	0.00	0.09	0.03	0.04	0.03	-0.03	0.03	0.01	-0.26	0.45	-0.05	1.00

N = 2617

Table 3.4. Regression results for the firm's balance behavior

Independent Variables	External Function Exploration[a]			External Geographic Exploration[a]		
	Model (1a)	**Model (1b)**	**Model (1c)**	**Model (2a)**	**Model (2b)**	**Model (2c)**
Constant	0.016 (0.108)	-0.014 (0.108)	0.063 (0.111)	-0.182† (0.032)	-0.185† (0.032)	-0.166† (0.032)
Number of Qualified Research[a]	0.090† (0.026)	0.075*** (0.026)	0.074*** (0.026)	0.014** (0.007)	0.012* (0.007)	0.011* (0.007)
Diversity in Tech Opportunities	0.362* (0.196)	0.352* (0.195)	0.344* (0.195)	0.122** (0.059)	0.123** (0.059)	0.119** (0.058)
Patenting Propensity	0.001 (0.001)	0.0002 (0.001)	0.0003 (0.001)	0.001† (0.0003)	0.001*** (0.0003)	0.001† (0.0002)
Cost of Innovation	0.119* (0.068)	0.113* (0.067)	0.111* (0.067)	0.005 (0.017)	0.005 (0.017)	0.003 (0.017)
Innovation Inertia	0.005 (0.104)	0.007 (0.104)	0.008 (0.104)	-0.067** (0.030)	-0.068** (0.030)	-0.067** (0.030)
Business Affiliation	-0.156** (0.051)	-0.164*** (0.051)	-0.163*** (0.050)	0.090† (0.016)	0.089† (0.016)	0.091† (0.016)
Firm Size	0.058 (0.049)	0.068 (0.050)	0.067 (0.050)	0.068† (0.015)	0.069† (0.015)	0.068† (0.015)
Low-tech Industry	-0.056 (0.054)	-0.067 (0.054)	-0.067 (0.054)	-0.012 (0.016)	-0.014 (0.016)	-0.013 (0.016)
High-tech Industry	0.080 (0.068)	0.065 (0.066)	0.068 (0.066)	0.023 (0.017)	0.020 (0.017)	0.023 (0.017)
Internal Exploration[a]	–	0.495*** (0.160)	0.661** (0.263)	–	0.055 (0.042)	0.164** (0.074)
Internal Exploration[a] Squared	–	–	-1.012 (1.266)	–	–	-0.646* (0.368)
Goodness of Fit	F(9, 963) = 4.16†	F(10, 962) = 4.66†	F(11, 961) = 4.29†	F(9, 963) = 19.93†	F(10, 962) = 18.11†	F(11, 961) = 18.03†
N (censored)		972 (594)			972 (624)	

Notes: External Function Exploration is double-censored and External Geographic Exploration is left-censored.
Robust standard errors in parentheses: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, † $p < 0.001$.
[a] Logarithm values.

The results corresponding to the control variables are as follows. In line with the absorptive capacity theory (Cohen and Levinthal, 1990), the estimates for the *Number of Qualified Researchers* is positive and statistically significant in all the models under considerations, indicating that the firms' skill bases positively contribute to enhancing external exploration in both domains. This results support the Lavie and Rosenkopf (2006) suggestion that the firm's absorptive capacity contributes to neutralizing tendencies for exploitation, favoring search activities dedicated to exploration. Likewise, *Diversity in Technological Opportunities* is another driver that favors the firm's tendency to reinforce external exploration in the function and geographic domain, providing support to the premise that a diverse technological environment favors the search for fresh sources of knowledge (Ahuja and Katila, 2004). In addition, the results show important differences in drivers determining external exploration in the function and the geographic domain. As regards the inhibitor factors, the perceived *Cost of Innovation* predicts the firm's tendency for external exploration in the function domain, but not in the geographic domain. Unexpectedly, in models (1a)-(1c) this factor appears as a push-force that induces firms to use their alliances to explore in the function domain. Consistent with Lavie and Rosenkopf (2006), the estimates for *Innovation Inertia* are negative and statistically significant in the models explaining external exploration in the geographic domain. However, this factor does not predict external exploration in the function domain. It is also observed that the estimates for *Patenting Propensity* is positive and statistically significant in the geographic domain, but not in the function domain.

Regarding the firm-operational drivers, the results show that *Business Affiliation* is a factor inducing external exploration, in the geographic domain, and discouraging external exploration, in the function domain. These findings are in line with those reported by other studies that point to the role of multinational companies as an element favoring knowledge transfer across national borders (Almeida, 1996; Almeida, et al., 2002). Finally, the findings show that the firm's scale operation relates positively with the external exploration in the geographic domain, but not with the external exploration in the function domain.

3.4.2 Results for the performance effects of the firm's balance behavior

Table 3.5 provides the results for the estimates of the performance models. Models (1d) and (2d) examine the performance implications derived from balancing exploration and exploitation across the firms' boundaries, taking into account that external search in these activities occurs in the function and geographic domain, respectively. Without losing generality, I normalized the coefficient $\omega_{\text{m type 1}}$ to zero as in other empirical studies on complementarities (e.g., Leiponen, 2005b; Belderbos, et al., 2006). Taking into account conditions defined by (3.4) as well as the estimates of models (1d) and (2d), the results for the test of complementarities are as follow. Regarding the function domain, the null hypothesis, $\omega_{\text{function type 4}} - \omega_{\text{function type 3}} - \omega_{\text{function type 2}} = 0$, cannot be rejected at conventional levels. These results are interpreted here as a signal indicating a lack of complementarities. The use of an inter-organizational ambidextrous model, in which external exploration-exploitation is defined in terms of the function domain, does not produce the expected benefits associated with the separation of conflicting activities. Therefore, these results do not support Hypothesis 3.2a. In contrast, when the test is conducted by taking into account that external exploration-exploitation occurs in the geographic domain, it is observed that the null hypothesis establishing the equality, $\omega_{\text{geographic type 4}} - \omega_{\text{geographic type 3}} - \omega_{\text{geographic type 2}} = 0$, is highly rejected (*p-value <0.001*) in favour of the alternative hypothesis that establishes the following inequality: $\omega_{\text{geographic type 4}} - \omega_{\text{geographic type 3}} - \omega_{\text{geographic type 2}} > 0$. Thus, results of model (2d) are in line with Hypothesis 3.2b, revealing that firms can profit from adopting internal exploratory (exploitative) activities in R&D along with alliances aimed to exploitative (exploratory) activities in the geographic domain. In this case, the results are consistent with the idea that alliances enable firms to integrate knowledge sources coming from exploratory and exploitative R&D activities that are arranged across their organizational boundaries (Rosenkopf and Almeida, 2003).

Table 3.5. Regression results for the firm innovative performance

Independent Variables	Model (1d)	Model (1e)	Model (2d)	Model (2e)
Constant	0.421*** (0.147)	0.429*** (0.145)	0.418** (0.127)	0.436† (0.127)
Number of Qualified Researcher	0.031 (0.021)	0.030 (0.024)	0.030 (0.023)	0.032* (0.019)
Diversity in Tech Opportunities	0.609† (0.077)	0.617† (0.064)	0.613† (0.062)	0.591† (0.078)
Patenting Propensity	0.004 (0.004)	0.004 (0.003)	0.004 (0.003)	0.004 (0.004)
Cost of Innovation	0.101*** (0.033)	0.113** (0.054)	0.126* (0.067)	0.082 (0.050)
Innovation Inertia	-0.150** (0.057)	-0.197† (0.047)	-0.192*** (0.056)	-0.147** (0.055)
Business Affiliation	0.059** (0.025)	0.066** (0.028)	0.079*** (0.027)	0.065*** (0.022)
Firm Size	0.123** (0.057)	0.117** (0.051)	0.121** (0.048)	0.124** (0.055)
Low-Tech Sector	-0.082*** (0.027)	-0.100 (0.025)	-0.113† (0.023)	-0.080† (0.022)
High-Tech Sector	0.011 (0.017)	-0.008 (0.011)	-0.021 (0.018)	0.019 (0.016)
Organizational designs				
Exclusive Internal Search	-0.057† (0.010)	-0.063† (0.012)	-0.058* (0.030)	-0.062** (0.029)
Exclusive External Search	-0.022 (0.170)	-0.021 (0.175)	-0.101 (0.112)	-0.104 (0.111)
Combined Search	0.017 (0.068)	0.106*** (0.042)	0.138 (0.130)	0.050† (0.010)
Complementarity test	$\chi^2(1) = 0.40$	$\chi^2(1) = 2.00$*	$\chi^2(1) = 17.03$†	$\chi^2(1) = 3.91$**
α (S.D)	0.543 (0.057)	0.539 (0.056)	0.550 (0.067)	0.563 (0.058)
Goodness of Fit	$\chi^2(39) = 206.63$†	$\chi^2(39) = 223.43$†	$\chi^2(39) = 272.98$†	$\chi^2(39) = 284.21$†
Observations	2490	2434	2345	2575

Notes: Models (1d) and (2d) examine the effect that inter-organizational ambidexterity, regarding the external search in function and geographic domain respectively, has on innovative performance. Models (1e) and (2e) examine the effect that inter-organizational specialization, regarding the external search in function and geographic domain respectively, has on innovative performance.
Robust standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, † $p < 0.001$.

Alternatively, models (1e) and (2e) extend the analysis by examining the performance effects derived from adopting methods in which firms specialize in either exploration or exploitation across their organizational boundaries. The idea of including these models into the analysis is to examine whether the balance behavior defined by Hypotheses 3.2a and 3.2b leads firms to a superior performance, compared to a firm's behavior based upon a specialization adoption of either exploration or exploitation. This comparison is done here in terms of the capacity of each option to bring complementarities in terms of innovative performance. Regarding the function domain, the results indicate that the increase on innovative performance of forming an alliance after making an internal R&D activity, compared to the increase of forming only an alliance, is larger when a company specializes in the same activities (exploration or exploitation) across its boundaries than when the firm adopts models of inter-organizational ambidexterity. This finding reveals that firms produce a superior performance specializing in either exploration or exploitation when extending the R&D beyond their boundaries. With respect to the function domain, this result is in line with the company's balance behavior analyzed previously by models (1a)-(1c) that firms performing R&D activities across their organizational boundaries tended to specialize in either exploration or exploitation.

In the case of the geographic domain, results of models (2d)-(2e) reveal that the increase on innovative performance of participating in a given alliance after making internal R&D, regarding the increase corresponding to forming only an alliance, is larger when a company uses inter-organizational ambidextrous arrangements than in the case in which the firm specializes in the same type of activity. In this setting, a balance of exploration and exploitation across boundaries leads firms to enhance innovative performance, compared to the alternative based on a specialization. Interestingly, this finding is consistent with the conclusion drawn from the firm's balance behavior examined by models (2a)-(2c) that firms performing R&D in an inter-organizational context tended to balance internal exploration (exploitation) and external exploitation (exploration), defined in the geographic domain. See Table 3.6 for summarizing the results of comparing specialization and ambidexterity.

Table 3.6. Inter-organizational specialization vs. inter-organizational ambidexterity in R&D

Specialization	Ambidexterity	Comparison
$\Delta_S = \omega_{\text{func type 4}} - \omega_{\text{func type 3}} - \omega_{\text{func type 2}}$	$\Delta_A = \omega_{\text{func type 4}} - \omega_{\text{func type 3}} - \omega_{\text{func type 2}}$	$\Delta_S > \Delta_A$
$\Delta_S = \omega_{\text{geo type 4}} - \omega_{\text{geo type 3}} - \omega_{\text{geo type 2}}$	$\Delta_A = \omega_{\text{geo type 4}} - \omega_{\text{geo type 3}} - \omega_{\text{geo type 2}}$	$\Delta_A > \Delta_S$

Finally, the estimations for the control variables in models described by Table 3.5 provide the following results. Unless model (2e), the estimates for the Number of Researchers is positive, but not statistically significant in all the models, indicating that the firm's skill bases do not affect innovative performance directly. However, an inspection of the results in the estimation of the mixed multinomial logit models of equations (3.3)[42] reveals that the Number of Researchers is a significant factor for explaining the firm's choices on the method implemented for organizing exploratory-exploitative R&D tasks. In line with Laursen and Salter (2006), the results indicate that Diversity in Technological Opportunities faced by firms positively contributes to improving innovative performance. The estimates for the Cost of Innovation are positive and statistically significant in all the models, unless the case of model (2e). This is consistent with Veugelers and Cassiman (1999), who argue that managers' perception of costs impeding innovation captures their understanding of these impediments rather than the effectiveness of these obstacles in inhibiting innovations. As expected, the parameters for the Innovation Inertia are negative and statistically significant in all cases. In the case of the firms' operating drivers, it is observed that the affiliation to a multinational group and the size of a company are factors that positively contribute to determining the firm innovative performance. Finally, it is observed that the fact that a firm operates in a low-tech industry negatively affects its innovative performance.

3.5 Discussion and conclusions

This paper examines how firms balance exploration and exploitation that take place in R&D activities. In particular, I hypothesize that firms tend to separate these activities across their organizational boundaries as a method to mitigate the serious tensions deriving from their joint implementation. The balance of exploratory and exploitative R&D activities across the firms' organizational boundaries is conducted by defining them in the function and geographic domain, respectively. This feature makes it possible to compare two different methods of buffering incompatible R&D activities. By using a multi-industry sample of Spanish companies along the periods 2003-2005 and 2005-2007, this study is among the first in examining the use of inter-organizational ambidexterity in exploration and exploitation as a method for balancing these activities, and in assessing the performance effects resulting from this balance behavior.

[42] Not shown here for reason of space, but available upon request from the author.

This study provides evidence that firms are inclined to balance internal exploration (exploitation) with external exploitation (exploration) in R&D. This finding is consistent with the premise that an inter-organizational separation of contradictory R&D tasks is adopted by firms as an effective strategy to reduce tensions associated with the organization of R&D. This behavior is well observed in the case in which firms balance their internal exploration (exploitation) in R&D with external exploitation (exploration) characterized in terms of the geographic domain. Additionally, the empirical analysis reveals that that previously described balance behavior has a positive effect on the firm innovative performance. In particular, the presence of complementarities in this case shows that firms not only avoid critical tensions by separating specialized R&D activities across their organizational boundaries, but also benefit from the integration of the resulting knowledge sources linked to these activities. These results add to previous studies on technology and innovation by providing further evidence that a balance of exploratory and exploitative in R&D along the firms' organizational boundaries produces the beneficial effects of ambidexterity.

Nonetheless, the present study also provides evidence revealing that firms do not tend to balance internal exploration (exploitation) in R&D with an external exploitation (exploration) in terms of the function domain that characterizes their alliances. Moreover, it is observed that a balance of internal exploration (exploitation) in R&D and external exploitation (exploration) in the function domain of the firms' alliances does not bring complementarities in terms of innovative performance. In this case, the findings suggest that an inter-organizational separation of exploration and exploitation in R&D is not an effective strategy for coping with the trade-offs associated with the articulation of these activities.

Taken together, prior results indicate that a company's balance behavior, as well as its innovative performance consequences, is determined not only by an inter-organizational separation of conflicting activities, but also by the domain used for defining the exploration and exploitation linked to R&D. The observed differences in the production of complementarities deserve more attention in the future research on organizational designs for R&D. A potential explanation for these results is that internal exploration-exploitation in R&D can be also defined in various domains (Lavie, Stettner and Tushman, 2010). Let us assume that the measure of the internal exploration-exploitation in R&D observed in this study refers to the function domain. In effect, it can be argued that firms' distribution of their R&D expenditures in basic research and development activities may well correspond to a definition of exploration and exploitation in the function domain. Under these circumstances, a firm combining internal exploration in R&D with external exploitation in the geographic domain would be also combining two ways of separating conflicting R&D activities (across organizational boundaries and across domains). Alternatively, a firm combining internal exploration in R&D with external exploitation in the function domain would be just separating conflicting activities across its organizational boundaries, but not across domains. Under these circumstances, the results reported by this study imply that the combination of an inter-organizational separation and a domain separation are a more effective balance strategy, compared to the adoption of just an inter-organizational separation. By assuming that R&D within firms is defined in the function domain, the reported findings not only would confirm those of Lavie, Kang and Rosenkopf (2010) that a domain separation is an effective strategy to improve performance, but also would extend this conclusion to the circumstances in which a separation occurs across the firm's organizational boundaries.

The results of this study have relevance for both R&D management and technology policy. As regards R&D management, the results provide evidence indicating how firms can balance tensions in the organization of differing R&D activities in order to achieve a superior innovative performance. In particular, the evidence reported by this study points to the adoption of exploratory (exploitative) alliances in the geographic domain as the best way to increase the returns of exploitative (exploratory) R&D tasks conducted internally by a firm. These findings inform managers about the importance of international alliances as a way to enhance the productivity of exploitation R&D activities, as well as about the role of domestic alliances in boosting exploratory R&D activities developed by firms. As regards technology policy, this study reveals the importance of promoting public programs that encourage the formation of innovative regions, such as knowledge-intensive districts, or regional clusters that complement the exploration efforts in R&D made by native firms. As suggested by the results of this study, knowledge expertise accumulated in these regions can enhance the productivity of the research basic activities of domestic firms. In addition, policies that promote the internationalization of the R&D activities of native firms may also produce positive effects in terms of their innovative performance. As indicated by this study, firms may increase innovative performance by applying the outcome of their development activities abroad as a way to open new avenues from exploration in R&D activities.

The results of this study are subject to some limitations. Firstly, the impossibility of distinguishing alternative domains in which exploratory and exploitative R&D occur inside firms restricts the scope of the current research. In line with other studies on international business strategies (Almeida, 1996; Almeida et al., 2002), more research is needed in order to conceptualize, for example, the geographic and function domain that may delimitate exploration and exploitation in the R&D function within firms. This conceptualization would allow us to analyze the role of a domain separation as a method for balancing tensions in the organization of the firm's internal R&D, as well as the effectiveness of buffering competing R&D activities across domains and firms' organizational boundaries simultaneously. Finally, the definition of alternative domains for representing the exploration-exploitation phenomenon in R&D function would also allows us to investigate whether alternative methods for separating exploratory and exploitative R&D activities complement from each other in terms of a given performance measure. Secondly, the PITEC still provides data for building a cross-sectional design, which limits the possibilities of conducting a dynamic analysis of the balance behavior of firms. Although prior studies have started to uncover the role of time in explaining how firms balance tensions of articulating exploration and exploitation (Lavie and Rosenkopf, 2006; Venkatraman, Lee and Iyer, 2007), more research is needed to investigate potential interactions on performance of joining a sequencing separation with an inter-organizational separation of exploratory and exploitative R&D activities.

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