Universitat Politècnica de València
Departamento de Organización de Empresas

DETERMINANTS OF AND RETURNS TO INNOVATION ACTIVITIES WHICH SPAN ORGANIZATIONAL BOUNDARIES: EMPIRICAL STUDIES ON A PANEL OF SPANISH FIRMS

Ph.D. Dissertation

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To Flo

To my many mentors, coaches, and role models

Individually, we are one drop.
Together, we are an ocean.

\- Ryunosuke Satoro

ABSTRACT

Determinants of and Returns to Innovation Activities which Span Organizational Boundaries: Empirical Studies on a Panel of Spanish Firms

Firms interact increasingly with agents that are external to their organizational boundaries in order to create new product and process innovations. The three empirical studies comprising this dissertation explore the determinants of and returns to externally-oriented innovation activities. All three studies estimate econometric models on a panel survey of Spanish firms.

Study 1 investigates the determinants that predict whether manufacturing firms use internal means, collaboration, or external development as the main mode of new product development. Drawing from constructs based in transaction cost theory, the resource-based view, and industrial organization theory, the results illuminate the nature of collaboration and contracting and differences in the governance of innovation. First, market uncertainty tends to lead firms into collaborative but not external development, while firms are more likely to collaborate under conditions of technological uncertainty. Second, we find an inverted u-shaped relationship with the likelihood of collaborative development and a negative relationship with external acquisition as a function of internal R&D capacity, and therefore of firm resources. This reflects a tension between the 'need' (or lack thereof) to find external sources of innovation and the search for 'complementary' sources of innovation afforded by higher internal research capacities. Finally, contrary to theory the importance of spillovers at the industry level has no predictive power while higher use of appropriability mechanisms favours internal development.

Study 2 examines the firm-level innovation performance effects of R&D cooperation and contracting with universities. We find that both interaction mechanisms are important for new product development in a sample of manufacturing firms. However, the results

indicate that R&D cooperation with universities predicts product innovation with a high degree of novelty, whereas R&D contracting with universities predicts product innovation that is less novel. These results shed light on the nature of R&D cooperation and contracting and contribute to a growing literature on the role of university interactions in commercial product innovation.

Study 3, set in the context of low-tech sectors, consists of a comparative analysis that hypothesizes how the returns to pecuniary and non-pecuniary external sourcing activities differ along two dimensions: (1) product and process innovation and (2) manufacturing and service industries. It finds that the pecuniary acquisition of intangible intellectual property is more important for product innovation, while the acquisition of knowledge embodied in artefacts is a stronger predictor for process innovation. Likewise, the 'breadth' of non-pecuniary sourcing is more important for product innovation, but returns to the 'depth' of external sourcing are higher for process innovation; further, the analysis reveals that this positive effect of external sourcing is subject to decreasing returns when the firm overextends external search. Overall, returns to external innovation activities are higher for firms in service industries than for firms in manufacturing.

Keywords: open innovation; new product development; process innovation; panel econometric analysis; collaboration; acquisition; R&D contracting; manufacturing; service industries; boundaries of the firm

RESUMEN

Determinantes y beneficios de las actividades de innovación que trascienden las fronteras organizativas: Estudios empíricos de un panel de empresas españolas

Las empresas se relacionan cada vez más con agentes que se encuentran fuera de sus fronteras organizativas con el objetivo de desarrollar innovaciones tanto de productos como de procesos. Los tres estudios empíricos que componen esta tesis exploran los determinantes y beneficios de las actividades de innovación orientadas hacía el exterior. En los tres estudios se estiman diferentes modelos econométricos basados en un panel de empresas españolas.

El primer estudio investiga los factores que determinan que las empresas manufactureras elijan entre el desarrollo interno, la colaboración o el desarrollo externo como estrategia para el desarrollo de nuevos productos. A partir de constructos derivados de la teoría de los costes de transacción, la visión basada en recursos y la teoría de la organización industrial, los resultados destacan las diferencias existentes entre la colaboración y la contratación como modos de gobernanza de la innovación. En primer lugar, los resultados muestran que la incertidumbre de mercado tiende a llevar a las empresas a la colaboración pero no al desarrollo externo; mientras que las empresas son más proclives a colaborar bajo condiciones de incertidumbre tecnológica. En segundo lugar, los resultados ponen de manifiesto una relación en forma de U-invertida entre la capacidad de I+D de la empresa y la probabilidad de colaborar (en comparación con el desarrollo interno) y una relación negativa con la adquisición externa, reflejando una tensión entre el “efecto de la necesidad” de encontrar fuentes externas de innovación cuando la capacidad interna es baja, y el “efecto de la complementariedad” entre estas capacidades internas y la aptitud para beneficiarse de estas fuentes externas. Finalmente, y en contraste con la teoría, los spillovers industriales no tienen un efecto

significativo sobre la gobernanza de la innovación; mientras que un mayor uso de los mecanismos de apropriabilidad favorece el desarrollo interno.

El segundo estudio examina los efectos que tiene sobre el desempeño innovador de las empresas la cooperación y la contratación de actividades de I+D con un agente de particular importancia: las universidades. El estudio señala que los dos mecanismos de interacción son importantes para el desarrollo de nuevos productos en una muestra de empresas manufactureras. No obstante, los resultados indican que la cooperación con universidades predice las innovaciones de producto con un alto grado de novedad, mientras que la contratación de servicios de I+D con estos agentes predice innovaciones de producto menos novedosas. Estos resultados arrojan luz sobre la naturaleza de la cooperación y la contratación y contribuyen a una literatura creciente sobe el papel que tienen las interacciones que suponen un mayor componente relacional en la innovación de producto.

El tercer estudio, enmarcado en el contexto de los sectores de baja tecnología, analiza los beneficios de la actividades de adquisición externa de conocimiento (pecuniarias y no pecuniarias) y cómo éstos difieren en dos dimensiones: 1) innovaciones de producto y procesos, 2) industrias manufacturera y de servicios. Este estudio encuentra que la adquisición pecuniaria de propiedad intelectual es más importante para la innovación de producto, mientras la adquisición de conocimiento incorporado en las maquinarias y equipos tiene una mayor influencia sobre la innovación de procesos. Igualmente, la "amplitud" de la adquisición no pecuniaria de conocimiento es más importante para la innovación de producto, mientras que la "profundidad" de la adquisición de conocimiento es más importante para la innovación de proceso. Además, el análisis revela que el efecto positivo de la adquisición externa de conocimiento está sujeto a rendimientos decrecientes cuando la empresa amplia mucho la búsqueda externa. En general, los beneficios de las actividades de innovación externa son mayores para las empresas de servicios que para las empresas manufactureras.

Palabras Clave: Innovación abierta; desarrollo de nuevos productos; innovación de procesos; análisis econométrico de panel; colaboración; adquisición; contratación de I+D; industria manufacturera; servicios; fronteras de la empresa

RESUM

Determinants i beneficis de les activitats d'innovació que travessen les fronteres de l'organització: estudis empírics sobre un panell d'empreses espanyoles

Les empreses interactuen cada vegada més amb agents externs a les fronteres de l'organització amb la finalitat de crear nous productes i innovacions de procés. Els tres estudis empírics que composen aquesta tesi exploren els determinants i rendibilitat de les activitats d'innovació orientades a l'exterior. En els tres estudis es fa ús de models economètrics sobre la base d'una enquesta de panell de les empreses espanyoles.

L'estudi 1 investiga els factors determinants que predeixen si les empreses manufactureres utilitzen la via interna, la col•laboració, o el desenvolupament extern com el principal mode de desenvolupament de nous productes. Sobre la base de la teoria dels costos de transacció, la visió basada en els recursos, i la teoria de l'organització industrial, els resultats destaquen les diferències entre col•laboració i contractació com a modes de governança de l'innovació. En primer lloc, la incertesa del mercat empenyen les empreses a la col•laboració però no als desenvolupaments externs; mentre que les empreses s'inclinen més a col•laborar en condicions d'incertesa tecnològica. En segon lloc, ens trobem amb una relació en forma d'U invertida entre la capacitat d'I+D de l'empresa i la probabilitat de col•laborar, i una relació negativa amb l'adquisició externa, la qual cosa reflecteix una tensió entre l '"efecte de necessitat" i l' "efecte de complementarietat". Finalment, contràriament a la teoria sobre la importància dels "spillovers" industrials no tenen un efecte significatiu sobre la governança de l'innovació, mentre que un major ús dels mecanismes d'apropiació afavoreix el desenvolupament intern.

L'estudi 2 examina, a nivell d'empresa, els efectes de la col•laboració i els contractes amb un agent econòmic de particular importància: les universitats. Trobem que els dos mecanismes d'interacció són importants per al desenvolupament de nous productes en

una mostra d'empreses manufactureres. No obstant això, els resultats indiquen que la cooperació en R + D de amb universitats prediu la innovació de productes amb un alt grau de novetat, mentre que la contratació de serveis de R + D prediu innovacions de producte un menor grau de novetat. Aquests resultats aporten llum sobre la naturalesa de la cooperació i la contractació d'R + D i contribueixen a una creixent literatura sobre el paper de les interaccions associades a un major component relacional en l'innovació de producte.

L'estudi 3, ubicat en el context de sectors de baixa tecnologia, analitza els beneficis de les activitats d'adquisició externa de coneixement (pecuniàries i no pecuniàries) i cóm difereixen en dues dimensions: (1) innovacion de productes i processos (2) manufactura i les indústries de serveis. L'estudi determina que l'adquisició pecuniària de la propietat intel•lectual intangible és més important per a l'innovació de productes, mentre que l'adquisició de coneixements incorporats en maquinària i equjipament és té una influència més gran sobre l'innovació de processos. De la mateixa manera, l'"amplitud" de les fonts no pecuniàries és més important per a li´nnovació de producte, però la "profunditat" de l'adquisició de coneixement és més important per a les innovacions de processos. A més, l'anàlisi revela que l'efecte positiu de l'adquisició externa de coneixement està subjecta a rendiments decreixents, quan l'empresa amplia molt les activitats de de recerca externa. En general, els rendiments de les activitats d'innovació externa són més alts per a les empreses en les indústries de serveis que per a les empreses manufactureres.

Paraules clau: innovació oberta, desenvolupament de nous productes, innovació de processos, anàlisi economètrica de pannel, col•laboració, adquisició, contractació de R + D, fabricació, indústries de serveis, límits de l'empresa

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CHAPTER 1

INTRODUCTION

Innovation is a source of economic growth, technological progress, and the competitive advantage of firms and nations (Nelson and Winter, 1982; Porter and Stern, 1999; Schumpeter, 1934). Consequently, innovation has received much attention from policy makers and the academic community such that now the subject contains a voluminous literature covering a wide range of topics (Fagerberg, Mowery and Nelson, 2006; Fagerberg and Verspagen, 2009).

One aspect that has been highlighted as particularly important regards the organization of a firm's technological innovation process with respect to the external environment (Almirall and Casadesus-Masanell, 2010; Chesbrough, 2003; Linder, Jarvenpaa and Davenport, 2003; Pisano, 1990; Robertson and Langlois, 1995; Tellis, 2008; von Hippel, 1988). Although it has long been recognized that firms cannot innovate in a vacuum and routinely access external sources of knowledge (Freeman, 1991; Trott and Hartmann, 2009), the recently popularized model of *open innovation* has sparked heightened interest in the flow of knowledge across firm boundaries (The Economist, 2007; Fredberg, Elmquist and Ollila, 2008; Lichtenthaler, 2011).

The question of innovation and firm boundaries can be split broadly into two streams of literature (e.g. Jones, Lanctot and Teegen, 2001; Stanko and Calantone, 2011). The first examines firm governance behaviour and seeks to explain why firms follow certain internal or external innovation strategies. For example, these studies examine the factors driving firms into activities such as technological alliances or R&D outsourcing

(Bayona, García-Marco and Huerta, 2001; Kaiser, 2002; Mol, 2005; Narula, 2001; Robertson and Gatignon, 1998; Tether, 2002) and further analyze with which kinds of external agents the firm interacts (Belderbos *et al.*, 2004; Laursen and Salter, 2004; Miotti and Sachwald, 2003; Tether and Tajar, 2008). Accounting for why firms make certain innovation governance decisions provides policy makers with a richer understanding of economic behaviour. Likewise, understanding innovation governance behaviour serves managers by helping them to recognize the circumstances that shape their own decisions and those of collaborators and competitors.

The second stream of literature looks at the returns to (or effects of) various innovation strategies and the conditions that may moderate their effectiveness (Fey and Birkinshaw, 2005)[1]. In other words, this research investigates aspects of firm and innovative performance as a function of internally- and externally-oriented innovation governance modes and sources of knowledge (e.g Amara and Landry, 2005; Boudreau, 2010; Faems *et al.*, 2010; Laursen and Salter, 2006; Mol and Birkinshaw, 2009; Reichstein and Salter, 2006; Vega-Jurado *et al.*, 2008). The utility of this knowledge is clear: policies can be developed to promote those activities most effective at reaching intended innovation outcomes. Equally for firms, managers can pursue appropriate strategies by matching scarce resources to intended outcomes in order to achieve returns to innovation activities.

This dissertation investigates innovation activities that span firm boundaries along these two streams of literature (predicting firm behaviour and its consequences for innovative performance) in three separate empirical studies[2]. The remainder of Chapter 1 provides a brief overview of the research problems and the studies. Chapter 2 reviews innovation theory broadly in order to provide a definition of innovation outcomes and an understanding of the innovation process; this is followed by a discussion of the characteristics of knowledge and its creation. Chapter 3 describes the data used in the

1 A related third stream of economic literature considers the determinants, such as firm size and industry structure, of why firms choose to invest in innovation activities in the first place (e.g. Klepper, 1996; Rosenberg, 1990; Veugelers and Cassiman, 1999). However, this line of research is out of the scope of this dissertation since the analyses are limited to a sample of innovation-oriented firms.

2 The terms innovation ‘activities’, ‘strategies’, ‘decisions’, and ‘behaviours’ are used interchangeably, as is often found in the literature.

three studies, which is a panel survey of Spanish firms, and discusses the use of similar datasets in innovation research. It also gives an overview of the Spanish national context with an eye on the characteristics of the national innovation system and economy. Chapter 4 explains the rationale of modern econometrics in management research and the quantitative methodology applied to each study. Chapters 5, 6, and 7 are Studies 1, 2, and 3, respectively. Finally, Chapter 8 complements this introductory chapter by summarizing the combined findings of the studies and offering suggestions for future research.

1.1 Firm boundaries and innovation: research objectives and overview of studies

There is both anecdotal and empirical evidence that firms are indeed increasingly looking outside organizational boundaries for sources of technological innovation (Chesbrough, 2003; Hagedoorn, 2002; Mol, 2005; Poot, Faems and Vanhaverbeke, 2009; Rigby and Zook, 2002; van de Vrande *et al.*, 2009). This naturally raises two questions: Why and under what conditions do firms use particular external strategies for technological innovation? And what are the returns to these externally-oriented innovation activities regarding different aspects of innovative performance?

The objective of this dissertation is to contribute to our understanding of firm boundary behaviour and innovative performance across these two broad questions. In doing so, it identifies specific open research issues in the literature and addresses them in three empirical studies. I take the approach of 'dissertation as product', whereby the goal is to develop research skills through the process of producing scientific research in discrete publishable format (Krathwohl, 1988). As such, the three studies have been submitted into the peer review process[3]. Each is an individual article in its own right and thus contains its own introduction, theory, results, and conclusions. Since the scientific enterprise is inherently collaborative in nature, Studies 1 and 2 are developed with one and two colleagues, respectively. The first four chapters of the dissertation and the conclusion put the articles into their greater context.

[3] Per the norms of the university, the three studies each retain the format and styles particular to the respective journals to which they have been submitted. This includes the format of the bibliography. Chapter numbers have been added to the subsections, tables, and figures for clarity.

1.1.1 Study 1 – The determinants of cooperation and acquisition as modes of new product development

Study 1 examines the determinants that predict whether manufacturing firms use collaboration with (ally) or acquisition from (buy) external agents (as opposed to internal means [make]) as the main mode of new product development. Study 1 draws from three established theoretical perspectives used to explain firm boundary behaviour: transaction cost economics (TCE), the resourced-based view (RBV), and industrial-organization theory (IOT) (Hagedoorn, Link and Vonortas, 2000). We hypothesize how constructs from these theoretical perspectives predict innovation governance behaviour taking the characteristics of collaboration and contracting into account. In particular, drawing from TCE, we explore how different forms of environmental (technological and market) uncertainty determine boundary behaviour (Robertson and Gatignon, 1998). From resource-based theories, by exploring behaviour as a function of internal R&D capacity we investigate the tension between the 'need effect' predicted by resource-dependence theory (Dias and Magriço, 2011; Finkelstein, 1997; Pfeffer and Salancik, 1978) and the 'complimentary effect' predicted by RBV (Barge-Gil, 2010; Das and Teng, 2000). Finally, from IOT we explore the appropriability regime and importance of knowledge spillovers as industry-level predictors of make-buy-ally behaviour (e.g. Amir, Evstigneev and Wooders, 2003; Belderbos *et al.*, 2004; Veugelers and Cassiman, 2005). This paints a complex picture of firm innovation governance behaviour.

Study 1 aims to make several contributions. First, with the exception of two related works (Barge-Gil, 2010; Robertson and Gatignon, 1998)[4], the innovation literature has generally examined firm knowledge sourcing decisions rather than the modes actually used by firms to innovate. This could fail to link adequately boundary behaviour with innovation outcomes since firms may engage external sources for any number of reasons. In contrast, our dependent variable measures directly how new products were developed. Second, by considering boundary-spanning collaboration and arms-length acquisition in general terms, the measures we use are independent of the specific

[4] However, these two studies explore determinants of internal or collaborative development while leaving out the third mode – acquisition.

channel, placing the analysis squarely on the boundaries of the firm. Third, the article provides additional empirical evidence for several important theoretical perspectives of the theory of the firm using a robust panel analysis on a large sample of manufacturing firms. Finally, the study aims to help resolve often conflicting findings in the literature by considering fundamental differences between collaboration and acquisition along several theoretical perspectives.

1.1.2 Study 2 – The degree of novelty of product innovation: returns to R&D cooperation and contracting with universities

Study 2 and Study 3 look at the returns, in terms of different aspects of innovative performance, to external 'open' innovation activities. Study 2 narrows the generic product development strategies in Study 1 by considering R&D collaboration and contracting with a specific external partner: universities. The role and evaluation of university research in commercial innovation has emerged as an important topic over the past decades (Acs, Audretsch and Feldman, 1992; Molas-Gallart and Castro-Martinez, 2007; Salter and Martin, 2001). Among the many channels through which firms can interact with universities (e.g. technology licensing, researcher mobility, training programs, etc. [Bekkers and Bodas Freitas, 2008; D'Este and Patel, 2007]), collaboration and contracting have been highlighted as specially relevant for open innovation studies due to the 'high-relational' nature of the linkages (Perkmann and Walsh, 2007). Furthermore, some authors suggest that, due to fundamental differences between the two channels, the type of knowledge generated and transferred through these two channels can differ substantially (Cassiman, Di Guardo and Valentini, 2010; Fey and Birkinshaw, 2005; Lucena, 2011). Still, while many studies examine returns to collaboration with universities, R&D contracting remains understudied as an interaction mechanism. To this end, Study 2 theorizes on these two interaction mechanisms by empirically evaluating not only whether they predict firm innovative performance but also how the novelty of the new products differ.

Study 2 thus addresses several gaps in the literature. Many studies consider partner type or interaction channel while seldom linking the differences between both with the nature of innovative outcome. Perhaps as a result, previous research has uncovered multiple and even contradictory findings regarding the effect of university research on commercial innovation. Relatedly, as with the other studies in this dissertation, we apply panel econometric techniques to the analysis. These techniques control for many sources of unobserved heterogeneity, such as the proximity to a university or the tendency for more innovative firms to interact more with universities in the first place. Our approach demonstrates some of the subtleties involved and provides potential theoretical explanations for the different outcomes. In this regard, Study 2 contributes to a growing body of empirical work evaluating both the impact of university interactions on firm innovativeness and the nature of returns to firm governance decisions.

1.1.3 Study 3 – A comparative analysis of the returns to pecuniary and non-pecuniary modes of open innovation

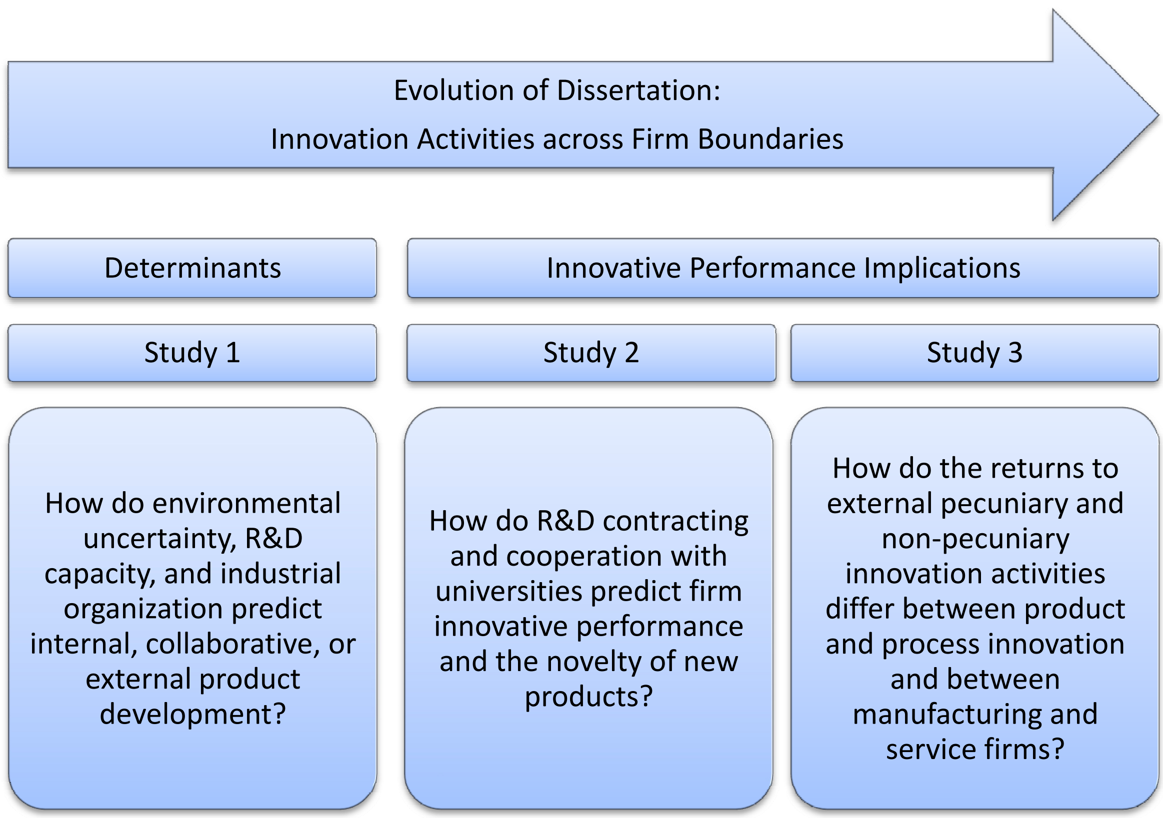
Study 3 broadens the scope of the research in the first two studies by considering how returns to several innovation activities differ according to the innovation output (product or process innovation) and sector (manufacturing or services). Following a survey of extant open innovation literature, Dahlander and Gann (2010) identify two main modes of inbound open innovation: 'pecuniary', which involves acquisition from the marketplace, and 'non-pecuniary', which involves scanning the environment for ideas and knowledge. The analysis in Study 3 further distinguishes between the pecuniary acquisition of *intangible* intellectual property and of knowledge *embodied* in artefacts, and between the *breadth* and *depth* of non-pecuniary sourcing. This differentiation makes Study 3 one of the first quantitative papers to directly compare these dimensions of innovation activities. In this way, Study 3 investigates not only returns to these dimensions of open innovation activities in terms of direction and significance, but also hypothesizes how the magnitudes of the returns differ according to innovation outcome and characteristics of the innovating agent.

Study 3 makes several contributions. It includes aspects which have not received much attention in the study of firm boundaries and innovation, namely process innovation, service firms, and low-tech sectors (Chesbrough and Crowther, 2006; Chesbrough and Spohrer, 2006; Drejer, 2004; Niehaves, 2010). Like most countries, low-tech sectors and service firms constitute much of the Spanish economy. Likewise, process innovation (and the sources thereof) is viewed as central to making productivity gains, a key economic issue in Spain (Vivero, 2002). Study 3 provides a starting point to bring these important factors into the discussion from both a theoretical and analytical perspective.

Next, a highly-cited article from Laursen and Salter (2006) finds evidence of an inverted-u relationship between external sourcing and innovative performance, whereby decreasing returns set in when firms overextend the breadth and depth of external search. Study 3 re-examines these important findings using a different methodology and broader set of innovation outcomes, thereby providing further empirical support and theoretical justification.

A final shared contribution among the three studies is methodological in nature. The studies apply advanced econometric models in the empirical estimations taking advantage of the panel structure of the data to account for many sources of unobserved heterogeneity; this is discussed in more detail in Chapter 4. Figure 1.1 summarizes the research questions of each study in the line of the dissertation.

Figure 1.1: Scope and research questions of the three studies in the dissertation



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CHAPTER 2

THEORETICAL BACKGROUND

As each of the three studies includes its own specific literature review, this chapter provides broader context on innovation theory. This includes a definition of the dimensions of innovation considered in each of the dissertation's three studies and an overview of how our understanding of the innovation process has changed over time. This chapter then provides a definition of the nature of knowledge and its production.

2.1 Defining innovation

An important distinction is made between invention and innovation: invention is the first occurrence or first discovery, whereas innovation occurs when an invention is carried into practice (Fagerberg, Mowery and Nelson, 2006). That is, innovation has both the conditions of novelty and use, such that an invention or a new idea has been exploited, adopted, or implemented (Alegre, Chiva, and Lapierda, 2005). Innovation can either be understood from the perspective of (1) the outcome of a process or (2) as a process itself[5]. If we see innovation as an outcome, we can differentiate types and categories of innovation. When understood as a process, we focus on the inputs and the ways of organizing the process from the conception of an idea through to implementation or commercialization.

[5] Indicators in the literature consider 'inputs' into the innovation process, such as R&D, and the 'results' (or outcomes) of the process, such as new products or new processes (Alegre, Chiva, and Lapierda, 2005).

2.1.1: Innovation as an outcome

Schumpeter (1934) originally defined five types of innovation:

(1) introduction of a new good or improvement of an existing good (product);

(2) introduction of a new production method (process);

(3) opening a new market, including entering a new export market (market);

(4) use of a new source of supply or raw materials (input);

(5) creation of a new type of industrial organization (organization).

This comprehensive definition includes new artefacts or new ways of doing things as outcomes. In each case, innovation denotes a change resulting in some measure of improved characteristics or performance in relation to the current environment. Schumpeter's notion of the difference between first creation and the productive application of knowledge still offers the fundamental definition of innovation today.

Subsequent to Schumpeter, authors have categorized innovation outcomes into many useful typologies and dichotomies, albeit the terminology has become somewhat fragmented and confounded (Chandy and Prabhu, 2011; Danneels and Kleinschmidt, 2001; Garcia and Calantone, 2002; Marxt and Hacklin, 2005). Generally, these typologies can be grouped loosely to describe (1) what is being changed or what output is achieved, such as new products, improved processes, or management practices, and (2) the nature of the systemic changes relative to whatever the innovation supersedes. Related to the second dimension are definitions that attempt to capture the degree of novelty or broader implications of the innovation.

Pavitt (2006: 86) terms the embodied results of the commercial innovation process 'artefacts', which include "products, systems, processes, and services". So despite a nearly infinite number of possibilities, the categories that describe what is being innovated (at least from the perspective of the firm) have remained close to Schumpeter's original definition. The most basic distinction is between the firm's revenue-generating products and the means by which they are produced, i.e. 'product and production' or 'product and process' innovation (Edquist, Hommen and McKelvey, 2001; Schmookler, 1966). Generally speaking, new products generate revenue from the market, whereas process improvements [6] increase production efficiency and manufacturing (or service delivery) capabilities within the firm (Abernathy and Utterback, 1978; Simonetti, Archibugi and Evangelista, 1995). Naturally, product and process innovation are not always separate since a firm must often re-organize and refine production in order to be able to produce and deliver new products (Damanpour and Gopalakrishnan, 2001; Kraft, 1990; Utterback and Abernathy, 1975).

'Product', in terms of what the firm ultimately sells to customers, includes packaged goods (such as Windows OS, iPods, and Barbie dolls) and product services (such as house cleaning, back massages, and financial accounting). The distinction between product and service innovation as outputs is often blurred and depends on the context. A product in the sense of a physical good which one can buy in a store and take home is straightforward enough. However, firms can often differentiate between service products – packages which customers purchase to fulfil some need – and services that are involved in the delivery or support of their main products – e.g. customer support, installation and repair, etc. In comparison to most product goods, services are generally characterized as highly intangible, inseparable, perishable, and unique (Fitzsimmons and Fitzsimmons, 2000; Schleimer and Shulman, 2011), implying a different innovation process leading to a new service (Barras, 1986).

In addition to product (both as good and service) and process innovation, the literature often considers innovations in the various ways of organizing business and marketing products. For example, following Schumpeter's definition, a firm can simply reach new customers for an existing product or deliver the product to customers in innovative ways without changing the product itself or the processes used to produce it. Thus scholars have investigated innovation in management practices (Birkinshaw, Hamel and Mol, 2008; Damanpour, 1991; Mol and Birkinshaw, 2009), the firm's business model (Chesbrough, 2010; Gambardella and McGahan, 2010; van der Meer, 2007), and how products and services are marketed and delivered (Amara, Landry and Doloreux, 2009; Levitt, 1960; Simmonds and Smith, 1968). In this context, the organization of innovation

[6] In Schumpeter's original definition, process innovation was not only "the introduction of a new production method" but also something that "can exist in a new way of handling a commodity commercially" (1934), i.e. a way of doing.

activities is itself subject to innovation (Berkhout *et al.*, 2006; Henderson, 1994; Igartua, Albors and Hervas, 2010; Michel, Brown and Gallan, 2008; Terziovski and Morgan, 2006; Thomke and von Hippel, 2002).

In summary, innovation output can be considered along a number of categories. The most important in the innovation literature are, broadly, product innovation (changes to what the firm produces), process innovation (changes to how the firm operates), and innovation of the organization and management practices of the business (Tether and Tajar, 2008). The next subsection looks at terminology used to describe the novelty or 'innovativeness' of the output. A brief overview of the dimensions of innovation output analyzed in this dissertation then follows.

Nature and degree of innovativeness

As a dimension of describing an innovation outcome, the degree of 'innovativeness' attempts to capture not only the degree of novelty but also the increase in value and wider disruption induced by the innovation; it relates to the effect that the innovation has on the status quo relative to individual agents (e.g. firms, customers, competitors)(Alegre, Chiva, and Lapierda, 2005; Chandy and Prabhu, 2011). Understanding innovativeness and the sources thereof is important because more revolutionary, pioneering innovations have greater consequences for firm competitive advantage and the well-being of society (Achilladelis, Schwarzkopf and Cines, 1990; Foster, 1986; Sorescu, Chandy and Prabhu, 2003).

However, measuring innovativeness is a difficult task since it doesn't always translate directly to newness or immediate commercial success[7] (Danneels and Kleinschmidt, 2001). In fact, the ultimate impact and success of an innovation is contingent upon a number of external factors, such as the availability of complementary assets and the systemic environment of the innovation (Teece, 1986). This has resulted in a plethora of related terms and constructs in the literature all striving to capture dimensions of innovativeness from different perspectives (Garcia and Calantone, 2002).

[7] For example, although Clairol's 'Touch of Yogurt' shampoo was a truly original idea and DuPont's patented leather substitute 'Corfam' a technological novelty, both were commercial flops (Haig, 2003). On the other hand, 'Coke Zero' is a commercial success without being anything newer than Diet Coke in a different bottle.

Nevertheless, all these constructs share a notion of some degree of (successfully implemented) newness, improved value or superior performance from the previous state of affairs. This is reflected in what are perhaps the most commonly encountered terms in the literature: *incremental* innovations, which involve many small improvements, and *radical* innovations, which entail substantial changes and discontinuities (Freeman and Soete, 1997; Tushman and Anderson, 1986). Radical innovation is also termed 'pioneering', 'discontinuous' or 'breakthrough' innovation by various authors (Garcia and Calantone, 2002). Chandy and Tellis (1998: 475) define radical innovation as "new products that (1) incorporate substantially different technology and (2) can fulfill key customer needs better than existing products", a definition which includes the important and ambitious aspect of coupling new technology with market conditions (Freeman and Soete, 1997).

However, although the incremental-radical distinction is a central theme in the innovation literature and provides us with many useful insights, it is also incomplete in some aspects and often fails to capture the true nature of the changes involved (Henderson and Clark, 1990). Given the ambiguity and measurement difficulties of radical innovation identified in the literature (and indeed the rareness and high standards an innovation must meet to be classified as truly radical) (Garcia and Calantone, 2002), we avoid the use of these terms in the studies (Study 1 and Study 2), instead opting to speak of the 'degree of novelty' (defined below). The next section discusses the measures used in the three studies.

Innovation outcomes in this dissertation

I review output and innovativeness here because the studies in this dissertation investigate and compare both of these dimensions. Study 1 and Study 2 explore product innovation, while Study 2 considers additionally the degree of novelty of product innovation and the commercial impact of new products within the firm[8]. In particular, two dependent variables in Study 2 measure the percentage of firm sales from products which are new to the firm and new to the market. These two measures come from

[8] The dependent variable in Study 1 is the mode used to produce new products, placing the analysis on product innovation. However, Study 1 also controls for the novelty of new products as a right-hand side variable.

standardized innovation surveys (presented in Chapter 3) and have been utilized extensively in the literature (e.g. Faems *et al.*, 2010; Laursen and Salter, 2006; Mairesse and Mohnen, 2002; Monjon and Waelbroeck, 2003). Because these two variables include actual firm sales, they capture, to some extent, whether the firm achieved some commercial success or not from new products, at least in terms that are relative to the individual firm. Although it can be difficult for managers to estimate the share of sales from innovative products (Marsili and Salter, 2005), it can still be argued that this a more sensitive measure than simply whether a firm introduced a new product innovation (i.e. dummy or count measures) because, unfortunately, the failure rate of newly introduced products across industries varies typically between 30-90% within the first year after launch (Cooper and Kleinschmidt, 1987; Crawford, 1977).

Additionally, as discussed above, Study 2 interprets these two variables in terms of the novelty of product innovation and avoids the terminology of incremental versus radical innovation given some limitations in our dataset. Note that many authors interpret 'significantly improved' and 'new to the firm' as two levels of incremental innovation and 'new to the market' as more radical innovation (Laursen and Salter, 2006; Marsili and Salter, 2005; Monjon and Waelbroeck, 2003), a classification scheme which follows closely 'high', 'medium', and 'low' innovativeness defined in Kleinschmidt and Cooper (1991). These studies often draw from related datasets that differentiate between the three levels. However, in our dataset, the variable for more 'incremental' innovation subsumes those products both significantly improved and those new to firm, which makes it difficult to separate incremental improvements of existing product lines from products that are the results of imitation or learning from external sources.[9] The interpretation of products which are new to the firm's market is less problematic since it measures a higher degree of novelty and, in the very least, 'uniqueness'. For these reasons we consider that the variables 'new to the firm' and 'new to the market' adequately capture lower to higher degree of innovation novelty, respectively.

[9] Still, imitation could mean significant change for that particular firm, even if the technology itself is not all that new to the market. For example, a firm in the automobile industry which switches from producing diesel engines to electric ones already available on the market faces daunting obstacles, albeit less daunting than the firm which pioneers electric engines.

Study 2 also includes the number of firm patent applications as an innovation output; this is essentially a robustness check for the novelty of knowledge generated. Although patents have a long history of being used as indicators of scientific and inventive – and by proxy, innovative – output (Archibugi and Planta, 1996; Griliches, 1990), the commercial value of patents is debatable (Acs, Audretsch and Feldman, 1992). Still, patents can serve as a proxy for the novelty of knowledge generated, as long as we keep in mind that appropriability and protection strategies particular to certain industries can strongly influence patenting behaviour.

Study 3 again looks at product innovation by differentiating between products in manufacturing industries and those in service industries (product as a good and product as a service); however, Study 3 also includes process innovation in the analysis. Even more, the dependent variables in Study 3 include aspects of product and process innovation that are somewhat novel in the innovation studies using similar datasets because they are defined more broadly. These two dependent variables are composites of questions measuring the effects of innovation, broadly, on products and processes, such as a greater range of products, penetration into new markets, and the effect of process innovation on variables such as labour costs and production flexibility. To date, most studies on innovation evaluate, for example, the number of new products or dimensionless dummy variables indicating simply whether the firm introduced a process innovation or not. Thus the dependent variables in Study 3 attempt to capture a broad dimension of product innovation performance (see Alegre, Lapierda, and Chiva, 2006, and Alegre and Chiva, 2008, for a similar validated measure of 'product innovation efficacy'). The exact definitions and measurements of the innovation outcome variables are presented in detail in each respective study of the dissertation.

2.1.2 The process of innovation[10]

What are the means by which the innovations described above come into being? And how does the organization of this process predict the degree of 'innovativeness' of the

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[10] I note that this dissertation studies the innovation process from the perspective of the agent (i.e. the firm) rather than from the perspective of the artefact (i.e. tracing the history of individual product or process innovations). This approach provides broad generalizations for firms but often fails to capture the path dependent, idiosyncratic nature of technological change and innovation (see e.g. Rosenberg, 1994).

outcome? These are difficult questions to answer since firm-level innovation processes are contingent upon a number of factors, such as the industry, type of innovation, and even historical period (Pavitt, 2006). In general though, the process of innovation involves problem-solving activities that may culminate in embodied technologies and disembodied knowledge (Dosi, 1982). Given that there is great diversity in these problem-solving activities, there are still some generalizations common to the process, although our understanding of the innovation process has changed somewhat over the decades (Fagerberg, 2003).

Before Schumpeter's definition of innovation, most economists treated the market as static and at some equilibrium (Nelson and Winter, 1982). Schumpeter proposed that the 'creative destruction' induced by innovation – i.e. the process whereby a new innovation displaces established methods, products, and firms through its superior performance – is the driving factor behind long-term economic growth (Schumpeter, 1942). In hypothesizing about how these technological changes emerge into the system, a distinction is commonly made between 'Schumpeter Mark I' and 'Schumpeter Mark II' patterns of innovation (Malerba and Orsenigo, 1996). In Schumpeter Mark I, small entrepreneurs act as the engines of innovation, displacing large incumbents and disrupting markets by introducing new technologies (Schumpeter, 1934). Mark I treats innovation as somewhat exogenous to the system, with new technologies entering into established markets and disturbing the equilibrium (Freeman, 1991a). In later writings, referred to as 'Mark II', Schumpeter suggests that the industrial R&D laboratory is central to innovation (Schumpeter, 1942)[11]. This leads to the Schumpeterian hypothesis that "a market structure involving large firms with a considerable degree of market power is the price that society must pay for rapid technological advance" (Nelson and Winter, 1982: 278). In reality, both patterns of Schumpeterian innovation occur in the economy (Winter, 1984). Environmental conditions may favour one mode over another depending on factors such as the industry structure, opportunity, appropriability

[11] In-house corporate R&D emerged in the late 19th century in German chemical firms and slowly spread to other industries and nations (Freeman, 1997), making it somewhat of an emerging process in Schumpeter's time. Nowadays R&D is performed primarily by three actors: firms, governmental labs, and universities (Niosi, 1999).

conditions, and nature of the underlying technological base (Breschi, Malerba and Orsenigo, 2000).

More recently, various authors have put forth notions of a 'Schumpeter Mark III' innovation model[12]. This broadly addresses the increasingly interactive nature of innovation and the importance of networks and shared intellectual capital between actors in an innovation ecosystem (Carayannis and Ziemnowicz, 2007). In essence, Mark I involves individual entrepreneurs; Mark II emphasizes the development capabilities of large corporations; Mark III introduces "networking among firms and knowledge institutions into the picture" (Lundvall, 2005: 7). Although the term Schumpeter Mark III is not widely adopted in the literature, I invoke it here to illustrate that the process of innovation at the macro level is now understood as an interactive process between a number of actors.

Generations of innovation models

Like the evolution of the Schumpeterian understanding of innovation and change at the macroeconomic level, the literature has seen several generations of industrial innovation models more specifically focused on the level of the economic agent (Berkhout *et al.*, 2006; Niosi, 1999; Rothwell, 1994; Roussel, Saad and Erickson, 1991). Each generation has its own peculiarities in terms of how it is understood by academe and policy makers and implemented by firms. In the *linear model* of innovation (Kline and Rosenberg, 1986: 285-288), results from basic research are fed downstream into development, production, and finally marketing (roughly: science – technology – production). This model is in line with the Chandlerian view of the vertically-integrated firm in the Post WWII United States (Chandler, 1977). The linear model calls attention to new scientific discoveries from basic research which lead to new technologies and products. Thus Schumpeter's idea of innovation can be characterized as 'technology push' from R&D into the market (Schumpeter, 1934). Later thinking envisioned a linear process of innovation and technological change from a 'demand-pull' perspective, whereby entrepreneurs and researchers responded to market opportunities with

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[12] This was not suggested by Schumpeter himself in his work, but is taken as a convenient term by some modern-day researchers to describe the natural evolution of our understanding of the innovation process.

increased inventive effort (Schmookler, 1966)[13]. Although conceptually simple, both of these perspectives fail to account for complex economic factors that shape technological change (Dosi, 1982). Kline and Rosenberg argue that this model does not incorporate important feedbacks and the interactive nature of innovation. They introduce the *chain-linked model* of innovation (also termed the *interactive model*). This model accounts for the synergistic nature of technology-push, market-pull, and knowledge characterized by the complexity of feedback loops and interactions occurring between different actors and activities (Kline and Rosenberg, 1986: 289-294). This model stresses that innovation is an interactive, path-dependent process with many actors at different levels[14].

More recently, the literature has seen various approaches akin to the interactive and 'Schumpeter Mark III' view of the innovation process. All these approaches stress the need for firms to interact with external actors in the innovation process and that the sources of innovation are varied. Already in the early 1990s Freeman (1991b) points to a (then 'recurrent') interest in networks of innovators and external sources of knowledge. Likewise, von Hippel's (1988) work shows that the sources of innovation are certainly not bound within a firm's R&D department and instead depend on complex interactions between firm and agents such as suppliers and users. In this way, while the evolution of the linear models into an interactive model focussed on feedbacks mostly between R&D and other functional divisions within the firm, in more recent models "technological alliances with users, suppliers and competitors increase the non-linear flows by incorporating information generated outside the firm" (Niosi, 1999). Many authors noted the increasing propensity for firms to access external agents and put forth evidence of a new emerging model in the innovation process (Granstrand *et al.*, 1992; Jones, Lanctot and Teegen, 2001; Rigby and Zook, 2002; Rothwell, 1994). In summary, our understanding of the innovation process in the modern era emphasizes the creation and flow of knowledge over firm boundaries and among many actors.

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[13] Perhaps the adage 'necessity is the mother of invention' applies here.

[14] Despite obvious shortcomings and perhaps due to its conceptual simplicity, the linear model of innovation still influences policy in many regions (Fernandez de Lucio, Mas-Verdu, and Tortosa-Martorell, 2010)

Open Innovation and the Antecedents of a 'Paradigm Shift'

Nevertheless, the most popular and recent of these approaches is *open innovation*, originally defined as "the paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology" (Chesbrough, 2003c: xxiv). Open innovation asserts the purposeful management of the inflow and outflow of IP and knowledge with external actors (Chesbrough, 2003b), such that useful IP is that for which a viable business model can be found, regardless of its origin or final destination (Chesbrough, 2006). This model suggests that the 'open' paradigm contrasts with the past century's 'closed' industrial R&D model, where the central R&D departments of large vertically-integrated firms were self reliant, inward looking, and built upon internal economies of scale under the control of management (e.g. Chandler, 1990)[15].

Chesbrough (2003a: 36) asserts that internal R&D is "no longer the strategic asset it once was" due to a number of erosion factors leading to the demise of the 'closed' innovation model. Proponents go so far as to call the emersion of an open innovation model – and with it the economic patterns of the production and use of knowledge – a "new paradigm in the sense of Kuhn"[16] (Gassmann, Enkel and Chesbrough, 2010: 214). All these next-generation and networked innovation ideas put forth over the past two decades cite various reasons for the increasingly external orientation of firms and the evolution of the ever more distributed innovation process (Antonelli, 2008; Cantwell and Molero, 2003; Chesbrough, 2003c; Dahlander and Gann, 2010; Dodgson, Gann and Salter, 2006; Lakhani and Panetta, 2007; Lane and Probert, 2007; Langlois, 2003; Lerner and Tirole, 2002; Mol, 2005; Rigby and Zook, 2002; Rothwell, 1994). Some of the primary reasons given are:

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[15] As pointed out in the Introduction and Study 3, this portrayal of a closed-open dichotomy has received some criticism by others who point out – as shown above – that organizations have always been open to the environment and have always systematically used external sources of innovation (Dodgson, Gann and Salter, 2008; Trott and Hartmann, 2009). Nevertheless, open innovation has clearly explicated a point of concern for managers and captured great interest.

[16] Kuhn's work describes the conditions of a scientific revolution, whereby an existing dominant paradigm of scientific production and organization is replaced with a new one (Kuhn, 1962).

- The increasing complexity and interdisciplinary nature of R&D and technology. It is not feasible for any one firm to be competent across all areas of discovery and technology.
- The rising costs of R&D. This is partly as result of the increasing complexity noted above and also less 'low hanging fruit' in terms of basic discoveries[17].
- Shorter product lifecycles. This can result in less revenue after a product enters the market, making it more difficult to justify large investments in internal R&D.
- Globalization. Expertise and knowledge assets are increasingly dispersed around the globe. Globalization also means more and diverse competition along a number of technological and market fronts.
- Growing job mobility among knowledge workers. Previously, many corporate scientists had a job for life. In the current economic environment however, employees regularly move not only to new companies but also new geographies, taking their expertise and experience with them.
- A marked increase in the availability of venture capital and other funding for innovation. Related to increased mobility, this means employees can exploit their ideas and knowledge in their own firms.
- A stronger intellectual property (IP) regime. This allows firms, in the case where IP can be protected, to exert greater control over their innovations and actually increases the tradability and appropriability of certain technologies.
- The rise of the Internet and information technology. This facilitates not only collaboration but also the diffusion of knowledge.
- Generally, the rise of the 'knowledge economy', in which knowledge, rather than economies of scale and production, provides the basis for growth, differentiation, and competitive advantage.

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[17] This may be especially true for certain industries like pharmaceuticals that spend more and more to produce new compounds (e.g. Nightingale & Martin, 2004).

Whether or not a radically new open paradigm shift actually exists, these studies come at a time when firms are purposefully opening firm boundaries in the innovation process. For example, the Managing Director of Telefonica's R&D business unit recently stated that their innovation strategy is based on open innovation and that without it the firm would be unable to achieve the technological innovations needed to compete[18]. Handset manufacturer Nokia displays prominently the message "Nokia Research Center is actively engaging in Open Innovation through selective and deep research collaborations with world-leading institutions"[19]. Consumer goods giant Proctor and Gamble has publicized its open innovation strategy through numerous articles and conferences, claiming to have the goal of roughly 50% of new products developed externally to the firm (Huston and Sakkab, 2006, 2007). Whether it is simply rhetoric or complex environmental factors driving its uptake, actively managing the flow of knowledge with external actors is a primary concern of practitioners.

2.2 Knowledge and its production

The previous section proposes that various factors, especially the increasing complexity of technological and scientific knowledge, have resulted in an innovation process that is progressively dispersed and specialized, conditions under which an open innovation approach seems logical and even requisite[20]. However, although the open innovation model is conceptually simple, in reality a firm can interact with external agents through a number of avenues. Furthermore, external knowledge does not necessarily come in discrete packages that can be simply brought into the firm and directly applied; technological knowledge comes in many forms, and the ability to absorb external knowledge depends on the characteristics of the knowledge and the firm (Mangematin

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[18] "Nuestro proceso está basado en un modelo de innovación abierta en el que la colaboración con terceros es un elemento clave." Carlos Domingo, La Catedral Innova, Gobierno de España, 21/12/2010. http://www.lacatedralonline.es/innova/caleidoscopio/7781-la-adopcion-de-la-innovacion-abierta-ha-convertido-a-la-propiedad-intelectual-en-un-aspecto-clave-de-nuestra-estrategia

[19] Accessed August 2011: http://research.nokia.com/open_innovation

[20] Chesbrough seems to present open innovation as a matching of technology to business model, with the assumption that the technological knowledge can be transferred discretely across firm boundaries. However, innovation often results from complex combinations of knowledge that are locus and context specific.

and Nesta, 1999). When firms do indeed look to external sources for the knowledge necessary to innovate, it is natural to ask what is exactly being created or transferred across firm boundaries? How does the type of interaction facilitate the creation and diffusion of knowledge outputs and affect their nature? And what role do the characteristics of the agents and environment play in knowledge creation? These kinds of questions gave rise to a strain of literature examining the economics of knowledge, including its characteristics, tradability, appropriability, and production (Arrow, 1962), with particular emphasis on the interaction between public sector (university) research and commercial businesses (Antonelli, 2008; Jaffe, 1989; Nelson, 1959). Understanding the production and characteristics of knowledge is helpful for understanding the three studies in this dissertation. Various conditions in the environment and characteristics of the firm and interaction mechanisms lead firms to organize the innovation process in particular ways (Study 1). Likewise, these conditions and characteristics mean that certain ways of organizing the innovation process are more conducive towards achieving particular types of innovation outcomes than others (Study 2 and Study 3). This section introduces descriptions of knowledge and its production and transfer. First, it defines several fundamental dimensions of knowledge. Next, it discusses views of how the firm integrates, combines, and creates knowledge in order to innovate. Finally, it briefly discusses knowledge creation and transfer in the three studies in the context of the characteristics of the external agent and interaction channels.

Dimensions of knowledge

Like depictions of innovation, knowledge is often discussed along a number of dimensions. One of the most popular is the differentiation between *explicit* and *tacit* knowledge. Explicit knowledge can be externalized, stored, and transferred in forms such as written manuals, diagrams, and other media through a process of codification (Nonaka, 1991). On the other hand, tacit knowledge is "personalized knowledge that is hard to formalize and communicate and deeply rooted in action, commitment and involvement in context" (Nonaka, 1994: 16). Michael Polanyi summarized this elegantly as "we know more than we can tell" (Polanyi, 1966: 6). Useful knowledge is more than awareness and possessing information ('knowing what'); it is also an innate ability to apply it to useful means ('knowing how'). Knowledge not explicitly codified or tacitly performed can also be *embodied* in artefacts, ranging from something as simple as a hammer to complex software programs and electronic components (Baetjer, 1998). Embodied knowledge is the output of an innovation effort at some point in time, and these artefacts can be put to productive use by others who need no knowledge of how that artefact is produced (Flowers, 2007). Over time, use of such artefacts generates disembodied (or tacit) knowledge as users gain experience applying the artefact (Rosenberg, 1982: 124). For example, a firm can purchase a piece of advanced production machinery (embodied knowledge) from an external supplier; subsequent use of that machinery results in learning by doing (disembodied knowledge) on the part of the firm. Therefore, even when embodied knowledge is transferred from one agent to another, the recipient must still engage in some degree of learning through its application.

Knowledge creation in the firm through interaction with external agents

Since knowledge varies in its form, locus, and complexity, it also varies in its transferability and manner of creation. This means that different organizational forms and interaction mechanisms can ease or hinder the process of bringing together sources of information in the problem-solving process. Factors other than the nature of the knowledge affecting its transfer and generation include the characteristics of the recipient, the external agent, and the interaction mechanism (Bozeman, 2000; Frenz and Ietto-Gillies, 2009). Although the studies in this dissertation do not explicitly consider innovation across firm boundaries as a 'technology transfer' problem because new knowledge is created and combined in the interaction process rather than wholly transferred, understanding the characteristics of the agents involved, interaction mechanisms, and nature of knowledge is a useful approach.

Starting with the characteristics of the firm, the ability to value, assimilate, and commercialize external knowledge is termed *absorptive capacity* (Cohen and Levinthal, 1989, 1990; Zahra and George, 2002). Absorptive capacity has generated much research interest and a number of proposals to extend and define the construct (Lane, Koka and Pathak, 2006), most of which confirm the link between a firm's ability to utilize external knowledge sources and its current knowledge stock and internal R&D resources (Veugelers, 1997). In this sense, an internal R&D department that produces nothing itself can still generate value through its ability to exploit knowledge from the external environment (Vermeulen, 2010). Taking the capability perspective, other organizational factors in addition to prior knowledge and R&D departments determine absorptive capacity. Organizational forms and the ability to combine knowledge (‘combinative capabilities’) determine absorptive capacity (Van Den Bosch, Volberda and de Boer, 1999), as do the systems of formalization and social integration (Vega-Jurado, Guiterrez-Gracia and Fernandez de Lucio, 2008). Within the context of open innovation, building absorptive capacity to capitalize on external knowledge is considered by some as a precondition to open innovation (Spithoven, Clarysse and Knockaert, 2010).

Relatedly, a strain of the resource-based view posits that firms exist as institutional forms for integrating the knowledge necessary to carry out complex production (or service) functions (Grant, 1996; Nonaka, 1991). Knowledge generation as a process of evolutionary learning occurs via both internal processes (e.g. reorganizing, accidents, experiments) and from interactions with external sources (e.g. acquisitions, joint ventures, new employees) (Kogut and Zander, 1996). Organizational knowledge and innovation result from continuous interaction and conversion between tacit and explicit knowledge (Nonaka, 1994). In the open innovation paradigm, knowledge and IP are continually brought into and sent out of the firm and transformed in the process. This idea of combination and transformation stems from Schumpeter, who placed much emphasis on innovation occurring as the result of ‘new combinations’ of existing knowledge (Schumpeter, 1934). This suggests that successful firms focus on a strategy of recombinant innovation, finding new markets and new products from existing knowledge (Hargadon, 2005). The combination and recombination of existing knowledge leads to an increase in variability that can result in failures but also breakthroughs since "innovation is always a recombination of existing resources" (Fleming, 2001). Accessing external sources of knowledge increases the variability to which the firm is exposed and increases the chances of truly novel combinations (Metcalfe, 1994). Combinations of knowledge may be technical in nature, but also include aspects such as market knowledge, manufacturing capabilities, etc. (Schumpeter, 1934). According to the logic of open innovation, it is clear that acquisition of external knowledge leads to a recombination within the firm before commercialization or implementation. This recombination of internal with external knowledge and assets can be purely related to production and marketing, such as utilizing existing complementary assets like distribution channels, or occur on a technological level, for instance the inclusion of a technological component into a larger system. In any case, the capabilities and resources of the firm play a central role in the ability to use and transform external knowledge.

In contrast to studies on absorptive capacity, the literature investigating how the characteristics of the external agent influence knowledge creation and innovative performance tends to focus on the characteristics of one particular partner at a time and is thus somewhat fragmented (Un, Cuervo-Cazurra and Asakawa, 2010: 673-674) [21]. Still, some studies consider the potential to pool the resources of the firm and external agent (Das and Teng, 2000) or the barriers to collaboration stemming from appropriation concerns and alignment of objectives (Cassiman and Veugelers, 2002; Enkel, Kausch and Gassmann, 2008; Lee, 2011). Some more general factors addressed include the external agent's breadth of knowledge and the ease of accessing that knowledge (Un, Cuervo-Cazurra and Asakawa, 2010) and the explorative or exploitative orientation of the interaction based on the external agent's resources and complementary assets (Faems, Van Looy and Debackere, 2005).

But perhaps the most important aspect addressed in this dissertation is how the interaction mechanism between a firm and external agents facilitates the nature of knowledge transferred or created[22]. There are a vast number of channels and mechanisms through which firms can interact with external agents (e.g. D'Este and Patel, 2007; Dahlander and Gann, 2010; Schartinger *et al.*, 2002; van de Vrande, Vanhaverbeke and Duysters, 2011; Vega-Jurado, Gutierrez-Gracia and Fernandez-de-Lucio, 2009). These include, to name a few, informal and formal partnerships or collaboration (Hagedoorn, Link and Vonortas, 2000); in-sourcing of technological licences and machinery (Santamaría, Nieto and Barge-Gil, 2009; Tsai and Wang, 2007); acquisitions and mergers (Christensen, 2011; Dyer, Kale and Singh, 2004); observation and gathering technological intelligence (Lichtenthaler, 2003; Veugelers, Bury and

[21] If 'absorptive capacity' describes the ability of the receiving firm to value and utilize external knowledge, might a construct akin to 'emissive capacity' describe an organization's ability to find, transmit, and exploit knowledge via external agents or external routes to market?

[22] The literature on differences in particular interaction channels and external agent characteristics is discussed in more detail in the respective studies of this dissertation.

Viaene, 2010); and collaboration and contracting (Fey and Birkinshaw, 2005; Frenz and Ietto-Gillies, 2009; Lucena, 2011). Each channel varies, importantly, in terms of the direction and level of iterative communication between agents, ranging from none (e.g. purchase of knowledge embodied in machinery or intelligence activities), to largely unidirectional (e.g. a university providing requested knowledge outputs back to a contracting firm), to highly iterative and open ended (e.g. cooperative research projects).

Through investigating the determinants of whether firms use collaborative or external modes of product development, Study 1 further reviews the literature to hypothesize on the fundamental differences between these two (collaboration and contracting) broad interaction mechanisms and the interplay with internal R&D and environmental factors that leads to the creation of new knowledge (in this case, knowledge outputs embodied in new products). Study 2 examines the interaction mechanism by differentiating between arms-length R&D contracting, on the one hand, and R&D cooperation on the other. As the literature review and findings in Study 2 show, these two interaction channels are different in terms of the communication patterns and seem to lead to differences in knowledge output. Further, Study 2 touches on the characteristics of the external agent by considering universities in depth and including commercial agents (suppliers, competitors, and commercial R&D labs) as external partners in the analysis. Study 3 differentiates explicitly between knowledge embodied in tangible artefacts (machinery, software, etc.) and knowledge in the form of intangible IP (patents etc.), as well as different external non-pecuniary knowledge sourcing activities. Study 3 hypothesizes on how the different nature of the knowledge inputs result in different innovative outputs.

To summarize, the intention of this chapter was to review the broader theory behind the constructs and literature included in the dissertation's three studies. It elaborated some of the assumptions inherent in the studies and provided definitions for several of the underlying concepts. It also presented an overview of the evolution of our understanding in innovation studies leading up to current theories. First, within the broader definition of innovation as the successful implementation of new ideas and technologies that generate greater value, one can understand innovation both as an outcome and a process. Innovation as an outcome can further be defined in terms of the resulting output (e.g. new products, process innovation, etc.) and its innovativeness or degree of novelty (e.g. incremental or radical innovation). In terms of understanding innovation as a process, this chapter reviewed how academic thinking has evolved from a linear view of the innovation process to an interactive one with iterative flows of knowledge among a network of agents. The final section of this chapter reviewed some fundamental aspects of knowledge and its creation. The three studies (Study 1, 2, and 3) continue the literature review here by building upon specific theory relevant to each study's narrower aims.

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CHAPTER 3

DATA AND THE SPANISH NATIONAL INNOVATION SYSTEM

This chapter provides an overview of the dataset used in the three empirical studies, which is a panel survey of innovation activities and outputs within Spanish firms, as well as an overview of similar surveys used by researchers and policy makers. It then provides some context on the characteristics of the Spanish economy and national innovation system.

3.1 Data source: a panel survey of Spanish firms

The interest in the economics of innovation and technological change led to a marked increase in relevant data sources (Encaoua *et al.*, 2000: 2). While the resourceful researcher may be able to draw from any number of potential sources to investigate innovation-related phenomena (e.g. patent databases, product catalogues, etc.), many governments have implemented innovation-specific national surveys (Archibugi and Planta, 1996). The aim of these innovation surveys is to provide basic data and indicators on innovation activities that can be used for policy analysis. The national innovation surveys are largely based on recommendations from the Oslo Manual, which the OECD developed as “proposed guidelines for collecting and interpreting technological innovation data” (OECD, 2005). Within the European Union, the national innovation surveys are collectively termed the Community Innovation Survey (CIS). The first CIS was administered in 1993, while similar surveys were conducted in other OECD countries, e.g. by StatsCanada (Survey of Innovation) or by the US National Science

Foundation (Manufacturer's Innovation Survey) (Cooper and Merrill, 1997: 30-32). Although the main purpose of national innovation surveys is to construct indicators and scoreboards for policy aims, they additionally provide researchers with remarkably rich and detailed data suitable for econometric analyses (Mairesse and Mohnen, 2010).

Although all are based on the Oslo Manual, each country designs and implements its own version. This means that there may be differences between countries regarding the questionnaire itself, the frequency of administration, and the laws mandating participation, which can make direct comparative studies difficult (Mairesse and Mohnen, 2010). An additional limitation of survey data is that the firms are often anonymized or access to the data is restricted and bureaucratic, making it difficult to supplement survey data with information from additional sources without complex matching exercises (Frenz and Ietto-Gillies, 2009). Despite these limitations, Laursen and Salter (2006) identified over 60 academic studies that draw from CIS data, a number which has increased much over the past several years.

A subset of the Spanish CIS, the PITEC (Panel de Innovación Tecnológica[23]), focuses on the collection of detailed data from more R&D-active private sector enterprises. The PITEC differs from many other national innovation surveys because firm participation is mandated by law (Leyes 4/1990, 13/1996, and article 10.1 of the LFEP). This ensures a large, consistent sample size and may limit problems associated with respondent selection bias. The data is collected by a joint effort of the Spanish National Statistics Institute (INE), the Spanish Foundation for Science and Technology (FECYT), and the Foundation for Technical Innovation (COTEC). The datasets are provided, with the questionnaires and detailed description of variables and changes, by the FECYT[24]. The PITEC is organized as a panel data set, with a consistent data collection methodology over a number of time periods. The unit of analysis (i.e. each observation) is the single enterprise, whether part of a larger group or independent. In addition to the innovation variables, data on the type of enterprise (i.e. private national, public, private national with international ownership) along with basic data on the firm’s size, industry, etc. is provided.

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[23] ‘Panel of Technological Innovation’

[24] http://icono.fecyt.es/

At the time of this dissertation, six waves of the PITEC were available (from 2004-2009)[25]. However, each of the three studies draws from different waves of the PITEC. This happened for two reasons. First, the wording of the question from which I construct the dependent variables in Study 3 changed in the 2008 survey. Therefore, Study 3 is only able to analyze data from 2004-2007. The second reason is that Study 1 was submitted into the review process before the FECYT released the 2009 wave of the survey. The data was made available in time for Study 2 to incorporate six waves from 2004-2009.

3.2 The Spanish economy and national innovation system

National Innovation System (NIS) can be defined as the network of actors inside the borders of a nation state that are involved in the production, transfer, and application of economically useful knowledge (Lundvall, 1992). From this perspective, the organization and interactions between firms and institutions determine the innovative performance of a nation's firms and ultimately economy (Nelson, 1993). Fundamental factors within a NIS go beyond firms and their strategies to include inter-organizational networks, education systems, legal institutions, sources of financing, governmental policies, and so forth (Groenewegen and van der Steen, 2006). Still, particular emphasis is placed on understanding knowledge flows between firms and sources of public R&D, particularly universities (Mowery and Sampat, 2006; OECD, 1996). Consideration of the concept of NIS is particularly relevant given the focus of this dissertation on knowledge flows across the boundaries of the firm between a network of public and private agents (Metcalfe, 1994). Furthermore, it is easy to see how the national and even the regional contexts should be considered before making generalizations of research findings to other economies. The remainder of this section describes some general characteristics of Spain's economy and NIS.

Spain is the 2nd largest country in the European Union in terms of area and 5th largest in population, currently making it the world's 12th largest economy. Following the emergence from a dictatorship in 1975 and accession to EU membership in 1986, the

[25] The panel includes data for a smaller sample of firms in 2003 that is unfortunately not possible to include due to significant changes in the wording and structure of the subsequent surveys.

country enjoyed a very successful sixteen-year period of uninterrupted economic growth until the global economic crisis of 2008[26]. In terms of the NIS however, Spain still lags behind other nations in many innovation indicators such as public and private R&D spending and innovation output[27], with Spain's investment in R&D one of the lowest in Europe (Science, 2004). Historically, Spain invests just over 1% of GDP in R&D, which trails substantially leading European countries like Finland (3.5%) and Germany (2.5%) and the OECD average (2.3%). On a general index of innovation indicators, Spain ranked 32nd in the world (Dutta, 2011). Aside from budgetary issues, the system has shortcomings to overcome such as weighty bureaucracies, slow adoption of new information technologies, lack of qualified technical personnel in firms, and deficiencies in public science base practices like the endogamous practice of hiring faculty graduating from the same department (FECYT, 2005; OECD, 2007).

Spain's overall national policy places the improvement of innovation capabilities and the implementation of new technologies in the center of its vision for economic growth and productivity improvement (OECD, 2007). At least until the recent economic crisis and forced austerity measures (Alvarez *et al.*, 2010), the Spanish NIS has shown signs of steady improvement over the past decade, and the government has indicated its intent to reach goals set out by the EU's Lisbon treaty and Europe 2020 targets of 3% investment of GDP in R&D ("Europe 2020 Flagship Initiative: Innovation Union," 2010). Out of all OECD countries surveyed, Spain placed in the top three in terms of the increase in government R&D budgets from 2002-2007 with year-on-year increases well ahead of other countries[28] (OECD, 2008). Until the recent crisis, this was mirrored by well over a decade of remarkable growth rates.

One prominent characteristic of Spain's NIS is that it still relies heavily on public-sector research organizations, with the share of R&D spending by firms relatively low (Modrego-Rico, Barge-Gil and Nuñez-Sanchez, 2005; OECD, 2007); a high proportion of

[26] CIA World Factbook: https://www.cia.gov/library/publications/the-world-factbook/geos/sp.html

[27] OECD (2008), Statlink: http://dx.doi.org/10.1787/453782122762

[28] Statlink: http://dx.doi.org/10.1787/450583327300

Spanish firms simply do not invest in innovation or R&D activities[29]. Another notable characteristic of the Spanish system is the heterogeneity among regions. The provinces of Madrid, the Basque Country, Navarra, and Catalonia lead the rates of R&D investments amid regions with low levels of innovation and R&D investment, with other provinces, notably Valencia and the Balearic Islands, showing much improvement in regional performance indicators over the past decade (Hollanders, Tarantola and Lochky, 2009). Spain's public administration is highly devolved, with regional governments running their own budgets in important areas like education and health, among others. These regional differences extend beyond path-dependent idiosyncrasies to a patchwork of regional innovation policies (Fernandez de Lucio, Mas Verdu and Tortosa Martorell, 2010; Gomez Uranga, Zabala Iturriagagoitia and Fernandez de Lucio, 2008). Given the significance of regional factors in general and the features of the Spanish system in particular, controlling for the characteristics of the region is an essential part of any quantitative analysis of innovation. By exploiting the panel structure of the PITEC, the studies in this dissertation are able to control for many regional idiosyncrasies. Chapter 4 explains this methodological aspect in detail.

Finally, the panel dataset spans one of the most severe global economic crises of the modern era. The situation in Spain has been particularly severe, with unemployment going from a low of 8% in 2007 to over 19% in 2009[30] and the government forced into a number of austerity measures that include public support of R&D (Alvarez *et al.*, 2010). For a researcher, this presents both a methodological problem and an opportunity. The problem is that any sample of firms taken at a single point in time might be subject to spurious results due to the extraordinary crisis. The positive side for researchers (albeit likely not for firms) is that this kind of exogenous economic shock generates variability in the environment (for example, perceptions of market uncertainty studied in Study 1) which can be captured and controlled for using panel econometric techniques. When more waves of the PITEC become eventually available, future research could isolate and study the specific effect of the crisis on the R&D and innovation activities of firms.

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[29] That said, the PITEC captures a representative sample of those Spanish firms which are innovation-oriented, meaning the low incidence of R&D-active firms in Spain is a quality of the national context of the sample rather than the sample itself.

[30] Data from Eurostat, accessed via www.google.com/publicdata

Putting the idiosyncrasies of any nation aside, Spain is attractive to analyze. First, many studies on innovation stem from countries such as the United States and United Kingdom, places which have relatively advanced economies and a high concentration of high-tech industries and funding for innovation. This is not the situation of many countries in the European Union and indeed the world. Many countries are ‘innovation-followers’ with a relatively high weight of traditional industries and low-value-added services and few technologically leading firms.

Second, although perhaps understudied, culture is a predictor of management behaviour (Pfister *et al.*, 2011), especially when it comes to things like attitudes towards risk-taking and work practices associated with the ability to develop innovations (Tellis, Prabhu and Chandy, 2009). For example, Steensma *et al.* (2000) demonstrate that national culture traits directly influence the propensity of firms to form technology alliances. Cluster analysis of management practices and traits across countries tend to place Spain closely to other Latin European countries and further away from Northern European and North American countries (Ronen and Shenkar, 1985). These regions often share similar languages, religion, and cultural legacies. In this sense, results obtained from Northern European countries and the US and Canada may not apply universally, and the findings from Spain shed light on the Spanish context.

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CHAPTER 4

METHODOLOGICAL APPROACHES

As all three studies consist of empirical analyses, this section identifies the fundamental problem faced by quantitative management researchers when analyzing observational data and several methods to address it. In doing so, it reviews the rationale behind applied econometrics and the approaches taken to exploit the panel structure of the dataset. It then discusses the challenges, strengths, and limitations of the models. Detailed mathematical proofs for the models discussed can be found in the referenced works.

4.1 Econometrics in management research: confronting the selection problem

Like all social scientists, management researchers face the *selection problem* when working with observational data (Angrist and Pischke, 2009). Essentially, unobserved factors both drive individuals to self-select into a treatment condition and are responsible for differences between the two groups and any variables of interest. This is particularly a problem in management research because managers often make decisions to undertake certain strategies with expectations about the outcomes, leading to endogeneity in the statistical analysis (Hamilton and Nickerson, 2003). Under such conditions, it may be impossible for the researcher to tell whether a particular variable or some unobserved factor is responsible for differences in a variable of interest. Furthermore, the individuals in different groups normally differ along a number of dimensions, making them incomparable in the first place. A properly controlled experiment solves the selection problem through the process of random treatment (Duflo, 2002). Randomly assigning individuals to treatment and control groups ensures that any observed differences are due to the treatment rather than some underlying factors because it ensures that groups are comparable on average. Manipulation by researchers resolves any remaining questions about the direction of causality since the treatment is completely exogenous.

Unfortunately, management researchers are normally constrained to observational data due to feasibility or ethical concerns inherent in conducting randomized experiments at the level of the firm or the economy (Duflo, 2002). How, then, does one untangle the variables of interest from confounding factors? This is where the utility of econometrics comes in: econometrics provides varying approaches, or tools, for approximating experimental conditions and addressing the challenges of analyzing observational data (Wooldridge, 2000). Econometrics is defined as "studies involving the unification of economic theory, economic statistics (data), and mathematics (statistical methods)" (Mills and Patterson, 2009: 6). Econometrics approximates experimental conditions by conditioning out differences between treatment and control groups through the application of various mathematical techniques. By artificially making groups comparable, the aim is to estimate the counterfactual, i.e. what would have happened to a firm if it had not undertaken a certain strategy (Rubin, 1974). Although a statistical relationship in itself cannot logically imply causation, we can appeal to *a priori* or theoretical considerations regarding causation (Gujarati, 2003). This lack of shyness about causal inference and prediction is what differentiates econometrics from its sister field of statistics (Angrist and Pischke, 2009).

Though many researchers stop short of inferring causal relationships between variables from non-experimental data, econometrics still enables statistical inference and hypothesis testing, i.e. whether the relationship between a dependent variable and its covariate can be predicted consistently and said to differ statistically from some value (Gujarati, 2003). A significant test statistic allows a researcher to reject the null hypothesis and accept the proposed alternative hypothesis. In the case of management research, most of the time the null hypothesis is that the effect (or relationship) is zero.

While statistical hypothesis testing, reliable prediction, and determining causal effects are chief aims of econometrics, the degree to which the researcher is able to accomplish these goals depends on the nature of the data and the robustness of the applied techniques (Nichols, 2007). In other words, some econometric techniques are much more effective at determining causality and estimating the counterfactual than others. The selection of econometric approach is termed the *identification strategy*, which describes "the manner in which a researcher uses observational data (i.e. data not generated by a randomized trial) to approximate a real experiment" (Angrist and Pischke, 2009: 7). One can imagine a hierarchy of techniques, with a well-designed experiment at the top and array of other approaches underneath.

Perhaps the simplest method (and most commonly found in the innovation literature) is controlling-on-observables, often termed cross-sectional regression. Study 1 applies a controlling-on-observables model in addition to more complex panel treatment. In this method, a researcher takes a cross-section of observations at a single point in time and attempts to condition out differences by including control variables in the model. The econometrician holds each variable constant at the mean while removing the linear influence of each covariate on the dependent variable one at a time (Gujarati, 2003). The resulting estimated coefficients give the net effect of a covariate on the mean value of the dependent variable after removing the effect of the other covariates (or controls).

However, there are limitations to controlling-on-observables. Obviously, it is impossible to measure and include every conceivable variable. Many potentially important variables are left out of the regression model simply because they are not measurable or the data is missing. Management researchers refer broadly to these immeasurable yet important firm characteristics as *unobserved heterogeneity*, and missing controls results in *omitted variable bias* (under-controlling). On the other hand, even if a researcher did have hundreds or thousands of variables on hand, it does little good to include them all in a single regression. Over-controlling is as problematic as under-controlling. Many variables that are highly correlated with one another lead to multicollinearity, and including a variable that is correlated with the error term or caused by the variable of interest leads to endogenous, biased results (Duflo, 2002). This does not render cross-sectional studies futile since large samples and good controls can mitigate the extent of the bias, but it does limit the causal inferences which researchers can draw from such models[31].

4.2 Exploiting panel data to address the selection problem

Importantly, each study takes advantage of the panel structure of the data. Panel data is repeated observations on individuals over time, sometimes called longitudinal cross-sections. Aside from the importance of including the dimension of time – namely that it often makes little sense to speak of the causal effects of variables which do not change (Sobel, 1995) – panel data also allows one to control for much of the unobserved heterogeneity and selection bias which often plague controlling-on-observables studies[32]. That is, panel techniques exploit additional information in the panel to bring researchers closer to the determination of causal effects in observational data (Winship and Morgan, 1999). Two techniques of controlling for unobservables in panel data are fixed effects and random effects[33].

Fixed-effects models, as the name suggests, control for individual characteristics that are stable. For example, things such as the location and industry, brand name, proximity to a cluster, and corporate culture are all more-or-less constant for a firm over time. In a controlling-on-observables setting, our strategy would be to include control variables in the model for all these fixed factors. Fixed-effects models condition out permanent unobserved heterogeneity by estimating the variance within a firm over time, essentially using the individual as its own counterfactual and allowing each firm to have its own intercept. The fixed effects can be controlled for either by including dummy variables for each individual in the panel (*unconditional* fixed effects) or, especially in the case of large panels, by differencing out each individual's intercept (*conditional* fixed

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[31] However, other techniques – namely instrumental variables and regression discontinuity – can be applied to cross-sectional data in order to address the selection problem and can be superior to panel techniques. A discussion on these is out of the scope of this chapter.

[32] With some panel models, it is possible to compare *within* and *between* effects to gain an idea of the importance and extent of the firm heterogeneity (see Himmelberg and Petersen, 1994).

[33] Dynamic panel models, in which the lagged dependent variable is included as a covariate in the regression, is another method for addressing unobserved heterogeneity and state dependency over time (Angrist and Pischke, 2009; Baltagi, 2005).

effects [CFE])[34] (Maddala, 1987). For this reason it is also called the *within estimator*. In this way fixed effects "perform neatly the same function as random assignment in a designed experiment" (Allison, 2009). The main drawback of fixed-effects models is that it is not possible to estimate variables that do not change over time, should that be of interest to the researcher. A further downside is that, while fixed effects produce consistent estimates, the models are often inefficient. Also, like any regression approach, fixed effects can suffer from omitted variable bias since many important unobserved variables do change over time.

The second approach to panel data estimation is random effects (also called random-constant or variance component models). Random-effects models make the assumption that the unobserved variables are independent from and not correlated with the observed variables in the model (Baltagi, 2005). The unobserved heterogeneity is absorbed into a composite error term which is assumed to follow a designated distribution. This is also called the random intercepts model.

Fixed effects are not to be confused with random effects; they differ in several fundamental ways, the most important of which is the assumption of how the unobserved heterogeneity is distributed. Random-effects models make the strong assumption that the unobserved factors are randomly and independently distributed among the sample of firms. For example, in the PITEC, belonging to a group of firms is correlated with firm size, R&D collaboration behaviour, and innovativeness; if the variable for 'group' were unobserved and the variables for size and collaboration were included in the model, the unobserved heterogeneity (which now contains 'group') is no longer random: it is correlated with several covariates and the dependent variable. Conversely, fixed effects allow for correlation with the unobservables by absorbing it into firm-specific constants. Following the example, the variable for 'group' is fixed and therefore controlled for without introducing bias.

If the assumptions hold, random effects are the superior model. Random-effects models are more efficient, enable the estimation of static variables, and provide broader

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[34] Unconditional fixed effects are efficient but can be biased when the number of periods, *T*, is small (Katz 2001). In any case, the PITEC contains a very large *N* and small *T*, necessitating conditional fixed effects (CFE) in Study 2 and Study 3.

inferences into the entire population compared to fixed-effects models. That said, Study 2 and Study 3 use fixed-effects models because the random-effects assumption does not hold. Hausman (1978) developed a specification test which compares the fixed-effects with random-effects estimates to determine whether a systematic bias is present. For both studies the Hausman test indicates that the random-effects estimator is biased.

Despite the outlined potential for bias, Study 1 still applies both controlling-on-observables and random-effects models. Although both techniques have drawbacks if the assumptions are broken, the dependent variable in Study 1 takes one of three mutually-exclusive nominal and unordered values, which necessitates a multinomial logit (McFadden, 1974). This class of discrete choice model, whereby each actor follows one of a limited given set of possible behavioural outcomes, does not have a fixed-effect estimator. In this special case, we are able to control for some unobserved heterogeneity via the application of a more complex random-effects model, namely one that models a latent distribution for each outcome separately (Agresti *et al.*, 2000; Jain, Vilcassim and Chintagunta, 1994). The next section discusses this and the special challenges of controlling for unobserved heterogeneity when the dependent variables are not continuous.

4.3 The challenges of modelling limited dependent variables in a panel

All the models estimated in the three studies deal with dependent variables that are somehow limited. A *limited variable* is defined as one whose range of possible values is restricted, such as the case of discrete integers, categorical responses, or variables censored at some value (Maddala, 1983). In contrast to the exemplary continuous variable with a bell-shaped normal distribution, limited dependent variables depart from the Gauss-Markov assumptions appropriate for ordinary least squares (OLS) linear regression. Although limited covariates are relatively straightforward to interpret and estimate, limited dependent variables (LDVs) often call for special estimation techniques. These are various classes of non-linear models whose underlying mechanics mathematically transform the distribution into a linear one. The choice of model (e.g. Poisson, logit, etc.) depends on the distribution of the dependent variable. Although the use of non-linear parametric models is common enough in the management literature, the estimation challenges of LDVs are compounded when working with panel data (Maddala, 1987).

As noted above, we approach the estimation in Study 1 using both cross-sectional and random-effects multinomial logit models because of the unordered, discrete nature of the dependent variable. Thus we are faced with two sources of potential bias depending on the model: omitted variable bias from unobserved heterogeneity in the cross-sectional model, or violation of the assumption that the unobserved heterogeneity arises randomly in the random-effects model. For this reason, we estimate both models in order to get an idea of the extent of any bias while taking the limitations of both models into account. Further, we apply a more advanced case of the random-effects multinomial logit which mitigates at least some of the bias if the assumption is not met.

In a similar study based on PITEC data, Barge-Gil (2010) aims to control for unobserved heterogeneity in a multinomial logit using a random effects model. Barge-Gil's approach allows a single distribution of unobservables (i.e. a single random intercept) for the entire population of firms across three discrete outcomes. With one random term, the unobserved effects are assumed to be constant between alternatives (Haan and Uhlendorff, 2006). This approach with a single random term has an important difference from Study 1: Study 1 allows for separate random terms for each outcome (i.e. multiple random intercepts), such that the heterogeneity is assumed to vary between outcomes. In marketing jargon, this approach captures a 'latent preference' or 'latent response tendency' among individuals in the panel for one of the outcomes (Jain, Vilcassim and Chintagunta, 1994). It is a much more reasonable assumption that certain unobserved, latent variables are more closely related with each outcome individually rather than randomly distributed across the population as a whole. In organizational terms, this kind of model accounts better for latent variables such as firm capabilities. So although random effects models in general can lead to biased results when the assumptions are violated, the case of the multinomial logit with multiple random terms (or individual latent preferences) mitigates somewhat the extent of the bias. Unfortunately, the estimation of the model is much more challenging. Section 4.6 discusses computation in more detail.

The main dependent variables in Study 2 – the share of firm sales from innovative products – differ from the other LDVs since they are continuous. Since many firms do not realize sales from any innovative products, the distribution of the variable is left-censored at zero. Censored continuous variables present a special estimation problem. Either simply applying OLS or dropping the censored observations result in biased estimates (Breen, 1996). This led to the development of non-linear models such as the Tobit (Tobin, 1958). Many prominent cross-sectional studies apply the Tobit to the dependent variables used in Study 2 (e.g. Faems *et al.*, 2010; Laursen and Salter, 2006; Leiponen and Helfat, 2010). Unfortunately, there is no standard and consistent maximum likelihood estimator for the fixed-effects Tobit in panel data (Greene, 2004). This censoring leads to a non-trivial difficulty in accounting for permanent firm heterogeneity (Reitzig and Wagner, 2010).

Therefore, in Study 2 we approach the fixed-effects estimation of the censored continuous variables using three separate techniques: OLS, Poisson, and the semiparametric fixed-effects Tobit model (Angrist and Pischke, 2009; Gourieroux, Montfort and Trognon, 1984; Honoré, 1992, 2002; Santos Silva and Tenreyro, 2006). Each model makes a particular set of assumptions; by comparing all three techniques, one can be more certain that the results are not the artefact of bias introduced by the distributional assumptions of any one single model. A complete discussion of these three approaches is provided in Study 2.

Model VII in Study 2 (the number of firm patent applications) and the models in Study 3 estimate LDVs as well. These are log-transformed discrete count variables. However, in contrast to the difficulties associated with the panel estimation of LDVs described above, the estimation of count variables with fixed-effects is well established, straightforward, and consistent thanks to the properties of the fixed-effects Poisson (Cameron and Trivedi, 1998; Gourieroux, Montfort and Trognon, 1984; Hausman, Hall and Griliches, 1984).

4.4 The question of sample selection bias in panel data

Related to the general selection problem is *sample selection bias*. Sample selection bias occurs if "some potential subjects are more likely than others to be selected for the study sample" (Boslaugh and Watters, 2008). While the *selection problem* describes the inequality of individuals in observational data due to some kind of non-random, unobservable self-selection, *selection bias* relates to the process of sampling by the researcher, namely which observations are to be included in and excluded from the study. Ideally, the sample is representative of the entire population (whether or not the individuals in various 'treatments' are the same or not).

Vermeulen (2010: 11) provides an illustrative example of selection bias in the innovation literature:

> *Consider, for example, the popular notion that innovation projects require diverse, cross-functional teams. This notion exists because if we analyze some ground-breaking innovation projects, they were often staffed by such teams. However, [research] suggests that diverse, cross-functional teams also often created the biggest failures of all! However, such failures never resulted in any products. Therefore, if we (only) examine the projects which actually resulted in successful innovations, it seems the diverse cross-functional teams did much better.*

In other words, if we had seen the entire picture rather than only those cases with positive outcomes, we might reach entirely different conclusions. This kind of sample selection bias is very common in management research, especially in the media and popular business books from practitioners because they tend to focus on successful outcomes while ignoring failures (Denrell, 2003). One might even venture that, especially in its early days, the open innovation literature was vulnerable to such a selection bias; the case studies, articles, and conferences tended to highlight how the successful companies applied open innovation (or how ones failed because they didn't) with no indication of those companies who tried unsuccessfully or ended up with mediocre/negative consequences (or conversely those closed innovators who achieved above-average success). Only an inclusive empirical analysis or careful case study design could properly shed light on this question.

The studies in this dissertation restrict the analyses to firms that have made the decision to invest in innovation activities, termed *innovation-oriented* firms. This raises the suspicion of some kind of systematic sample selection bias. Dropping non innovation-oriented firms could result in a selection bias in most controlling-on-observables studies, depending on the research question and desired inferences. Likewise, including non innovation-oriented firms without correction would likely result in overestimation of the effects of various innovation strategies on performance[35]. For example, in Study 2 the decision to at least invest in innovation is likely accompanied by unobserved factors such as motivation, opportunity, allocation of funding, etc., which may have an effect on innovation performance. Per the selection problem, when firms engage in certain innovation strategies (such as cooperation with universities) only in the presence of some unobserved factors (such as motivation or opportunity), it becomes difficult to determine whether the innovation activity or unobservables lead to innovation performance.

In cross-sectional studies, the approach is generally to estimate these unobservables associated with selection into a condition and include this estimate as an additional term in the main model (Heckman, 1979). In this way Heckman (1979)[36] treats selection bias as an omitted variable problem. Although this approach has found widespread use in the innovation literature, the choice of which variables to use to estimate selection in the first stage and the potential for multicollinearity with the inverse mills ratio in the second stage can be problematic (Puhani, 2000).

Fortunately, fixed-effects analyses rarely suffer from this kind of selection bias (Vella, 1998)[37]. The unobserved heterogeneity is absorbed into the individual effect and captured through additional control variables such as period-specific dummies (Kennedy, 2003: 312). The solution in the studies in this dissertation is simply to drop those observations from the estimation in which the firms were not innovation-oriented; in this way, the average *within* innovative performance associated with the decision to invest in innovation is captured in the individual fixed effect. Alternatively, keeping all observations and including a dummy variable for the firm's decision to be innovation-oriented produces the same estimates, but with the loss of a degree of freedom due to

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[35] This is because the innovation activities would be highly correlated with the factors involved in the decision to invest in innovation, and therefore pick up much of the variance.

[36] James Heckman received the Nobel Prize in Economics in 2000 for this work on the selection problem.

[37] Also, I refer again to the fact that participation in the PITEC is mandated by Spanish law (see Chapter 3), mitigating the possibility of *respondent* sample selection bias.

the inclusion of the additional control variable. Several econometric techniques do address certain kinds of selection bias in panels, such as unbalanced attrition (Verbeek and Nijman, 1992), although these do not pose a problem in these studies taken from the PITEC.

Because it requires a multinomial logit, Study 1 does not have the luxury of letting fixed effects take care of any selection bias. Yet Study 1 only includes those firms in the analyses that introduced a product innovation, raising the question of selection bias. We approach this in two ways. First, the nature of the multinomial logit assumes the *independence of irrelevant alternatives* (i.i.a.). The i.i.a. assumption states that firm behaviour, given a set of alternative outcomes, is unaffected by the addition of other orthogonal options[38] (Cheng and Long, 2007). If we treat 'non-innovative' as a category in the multinomial logit and the i.i.a. assumption holds, it is irrelevant whether non-innovative firms are included or not – the multinomial logit merely reports parameters that reflect firm behaviour relative to the reference category. A diagnostic test including 'non-innovative' as a category in the cross-sectional multinomial logit (along with observations from non-innovative firms) reveals that the parameter estimates for the other categories do not change. Furthermore, by taking advantage of the panel structure of the data, unobservables in the selection are at least partly accounted for in the separate latent variables. Given that the computation time increases exponentially for each additional category in the random-effects model (Haan and Uhlendorff, 2006), including 'non-innovative' as a category only adds to the complexity of the study without bringing anything to the theory. Second, the research question itself addresses the factors that predict the development modes actually used by firms. We take care about the inferences which can be made from this study and follow precisely the approach used in the primary article from which we advance our paper (Robertson and Gatignon, 1998). Consequently, we do not consider selection bias a concern in Study 1, albeit for different reasons than in Studies 2 and 3.

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[38] The usual example to illustrate the *i.i.a.* is summed up nicely in a Haiku by Keisuke Hirano, University of Arizona:

Red bus or blue bus?
Multinomial logit
may lead you astray

4.5 The bootstrap: comparisons of the returns to innovation activities

Often management research considers the estimates in terms of direction and level of statistical significance while falling short of discussing magnitude (Shaver, 2008). In many cases however, magnitude matters. The magnitude of a coefficient can be interpreted as the return to a variable for a particular outcome. Generally, holding all other covariates constant, for each change in covariate X, the dependent variable Y changes, on average, proportionally to the coefficient, β; the larger the coefficient, the higher the return to that variable (or the bigger the 'effect' of the variable on the outcome). The empirical analysis in Study 3 addresses this econometric issue: how to compare statistically the magnitude of parameters between different subpopulations and outcomes.

For instance, Study 3 hypothesizes why returns to open innovation activities may be higher for a population of low-tech service firms than for one of low-tech manufacturing firms; there are theoretical reasons to believe this is the case, and therefore a statistical comparison of the parameters is required. Study 2 also applies this methodology to test whether the effect of internal R&D is larger for the development of highly novel product innovations than for more incremental ones. Different kinds of firms realize dissimilar returns to innovation activities, and particular innovation activities may only be relevant for particular outcomes. An interesting question is how the returns to particular innovation activities vary according to firm type or outcome. This is an important subject because policy makers and managers often want to maximize returns to their activities; it also helps us understand fundamental differences in the innovation process above and beyond simply saying that certain variables are 'significant and positive in magnitude'.

There are formal statistical methods for addressing these questions. In a standard regression model, the significance level of a parameter reports whether its distribution of estimated values is significantly different from zero. When comparing coefficients between subpopulations or outcomes in different regression models, the task is to determine whether the difference of the two estimated coefficients is significantly different from zero. As study 3 points out, a Chow test can normally be used in linear regression for this purpose (Chow, 1960). Unfortunately, a simple Chow test is not appropriate in the case of non-linear models like the Poisson. Other approaches, such as an incremental F-test or Wald test are useful only for comparing parameters within a single regression model rather than across different dependent variables (Laursen and Salter, 2006). The approach we take is to run separate regression models on each subpopulation and then to compare the resulting parameters (Hoetker, 2007). This approach is applicable not only between groups but also between dependent variables, so long as they are on the same scale.

The statistical method of comparison is the non-parametric bootstrap or 'pairs bootstrap' (Angrist and Pischke, 2009). Bootstrapping involves repeatedly estimating the model on randomly drawn subsamples with replacement back into the pool of observations. Bootstrapping provides a method to calculate a significance level for hypothesis testing through the comparison of confidence intervals (Efron and Tibshirani, 1998). The implementation of the procedure is described in the following section.

4.6 Practical considerations: estimation of the models

All models are estimated using the software package Stata 11. Stata has a number of unique features that make it widely adopted by applied econometricians (Baum, 2006; Rabe-Hesketh and Everitt, 2004). In addition to its specialization towards the needs of management researchers, Stata follows an open platform strategy that allows the research community to contribute user-written programs for specialized and current econometric techniques. The Stata Journal, a peer-reviewed publication, provides a forum for the development of new methodologies and the validation of user-written commands. This is an advantage since programming is often a barrier to the timely adoption of advanced econometric techniques (Honoré, 2002). Several of these programs, briefly described below, make the studies in this dissertation possible.

Study 1 applies two user-written programs available for Stata. The first is `GLLAMM`, an acronym for Generalized Linear Latent and Mixed Models (Rabe-Hesketh, Skrondal and Pickles, 2005; Skrondal and Rabe-Hesketh, 2003). GLLAMMs model latent variables in multilevel data, i.e. data clustered and correlated as many observations within a firm or industry (such as in the PITEC). Although modelling multiple random terms in the multinomial logit is attractive, it presents a computational problem. Because there is no solution to the integral when estimating the distribution of the firm-specific effects, the usual maximum likelihood or least squares-type estimators do not apply. Instead, researchers must rely on other methods such as quadrature or simulation to approximate the integrals, an approach which presents a significant computational difficulty due to the need to estimate multiple correlated dimensions (Malchow-Møller and Svarer, 2003). GLLAMM computes the distributions via a number of support points using adaptive quadrature. The solution is effective although the calculations are intensive; estimation time increases exponentially for each random effect and support point and linearly for each additional variable in the model (Haan and Uhlendorff, 2006). Consequently, the final model in Study 1 needed approximately 8 days of calculation time on a dual-core computer and proved too complex to compute via simulation.

The second routine in Study 1, `postgr3`, graphs the relationship between one of the covariates and the dependent variable (Mitchell and Chen, 2005). The technique is useful because it graphs the predicted main effects while accounting for the contribution of the remaining covariates in the model. Visually evaluating the relationship, especially in the case when the model predicts an inverted-u shape, is important in order to check that the predicted values fall within the range of actual observations (Shaver, 2006).

Study 2 applies `PANTOB`, a program which implements the semiparametric censored model with individual effects (the so-called 'fixed-effects Tobit' model) developed by Honoré (1992). Honoré provides a validation of `PANTOB` from a Monte Carlo experiment[39]. The management literature has applied `PANTOB` in several studies either as a main model (Gelos and Werner, 2002; Greve, 2008) or robustness check (Hutzschenreuter, Voll and Verbeke, 2011).

Studies 2 and 3 use a program for calculating robust standard errors in the CFE Poisson after Wooldridge (1999). The routine `XTPQML`[40] has since been incorporated as a formal option for the CFE Poisson (`XTPOISSON`) in Stata 11.1. This is an important

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[39] Results of the validation of `PANTOB` available here: http://www.princeton.edu/~honore/stata/pantob/Results%20of%20validation%20of%20PANTOB.pdf

[40] Simcoe, Tim (2007). XTPQML: Stata module to estimate Fixed-effect Poisson (Quasi-ML) regression with robust standard errors. RePEc: http://ideas.repec.org/c/boc/bocode/s456821.html

methodological option since the standard errors in the CFE Poisson often need adjustment to account for any over or under dispersion of the dependent variable. Such an option is not available for the related CFE negative binomial, which requires complex and less-robust bootstrapping procedures to correct standard errors.

In addition to the generally available user-written programs described above, Stata is programmable for individual needs. There are several methods of programming Stata, and Stata even contains its own matrix programming language, Mata™ (Baum, 2009). The non-parametric bootstrapping applied in Study 2 and Study 3 is a bespoke procedure created using Stata's programming capabilities[41]. The footnote contains the rough Stata code for the procedure[42].

4.7 Methodology in the context of innovation research

This chapter briefly introduced the fundamental selection problem which faces quantitative management researchers and gives an overview of econometric techniques for addressing it. In doing so, this chapter tied together the difficulties and approaches shared among the three dissertation studies.

The three studies in this dissertation are certainly not the first to exploit panel data in innovation studies at the level of the firm (e.g. see Boudreau, 2010; Lucena, 2011; Montoya, Zárate and Martín, 2007). In fact, some of the first applications of fixed effects in management research a quarter century ago were also important contributions to innovation studies (e.g. Hausman, Hall and Griliches, 1984; Jaffe, 1986). Other researchers use alternative techniques to address the selection problem, such as instrumental variables (Bascle, 2008; Eom and Lee, 2010) or even field experiments (Boudreau and Lakhani, 2010). Such closer approximations to experimental settings

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[41] I extend my thanks to Francesco Rentocchini and Africa Villanueva for help with the code.

[42]
```
program xtpois_compareB,eclass
tempname bxtdiff bxt_sv bxt_man
xtpoisson lprodeff_d `VARS’ if ltsvdum == 1, fe vce(robust)
matrix `bxt_sv'=e(b)
xtpoisson lprodeff_d `VARS’ if ltmandum == 1, fe vce(robust)
matrix `bxt_man'=e(b)
matrix `bxtdiff'=`bxt_sv'-`bxt_man'
ereturn post `bxtdiff'
end
bootstrap _b, reps(400) title(XTPoisson) nowarn: xtpois_compareB
```

produce reliable results, and it's been shown that controlling for heterogeneity through panel data may even contradict results obtained from cross-sectional studies (Himmelberg and Petersen, 1994; Mairesse and Mohnen, 2010; Shaver, 1998; Wagner, 2003). One contribution of this dissertation is the application of more robust methodologies to problems and variables that are encountered often in the innovation literature. The methodologies applied in Studies 1, 2, and 3 aim to contribute to a large body of quantitative studies.

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The Studies

Study 1: Disentangling the Roles of R&D Capacity and Environmental Uncertainty as Determinants of New Product Development Mode

Study 2: Accessing Knowledge Through Industry-University Interactions: The Effect of R&D Contracting and Cooperation on Product Innovation Novelty

Study 3: Modes of Open Innovation in Service Industries and Process Innovation: A Comparative Analysis

CHAPTER 5

STUDY 1:

DISENTANGLING THE ROLES OF R&D CAPACITY AND ENVIRONMENTAL UNCERTAINTY AS DETERMINANTS OF NEW PRODUCT DEVELOPMENT MODE[43]

Abstract

This paper investigates the determinants of new product development mode drawing on transaction cost economics, resource-based perspectives, and industrial organization theory. We analyse the boundary behaviour of a panel of Spanish manufacturing firms (N = 4646) which used internal, collaborative, or external development as the main way to innovate. We find that, among other factors, environmental (both market and technological) uncertainty and firm internal R&D capacity are instrumental in shaping the mode of new product development. First, under conditions of higher environmental uncertainty, firms tend to innovate through collaboration rather than based exclusively on in-house efforts. Second, our results indicate that the relationship between the likelihood of developing a new product collaboratively versus in-house follows an inverted U-shape as a function of internal R&D capacity, whereas the propensity for external development

[43] Developed with Jaider Vega-Jurado

follows a negative relationship. This reflects a tension between the 'need effect', on the one hand, and the 'complementary effect' on the other, and helps to reconcile some of the controversies in the literature related to the effect of R&D capacity on the exploitation of external knowledge sources. We discuss the managerial and policy implications of these findings.

Keywords: new product development, collaboration, outsourcing, boundaries of the firm, transaction cost economics, resource-based view

5.1 Introduction

Successful commercialization of new products is essential for firm survival and growth, and understanding the processes and organizational forms which drive new product development (NPD) is an important area of managerial and academic concern (Brown and Eisenhardt, 1995). Firms continuously face two principal questions: a) which product-market to enter? and b) which NPD strategy to use (Roberts and Berry, 1985)? The latter question is increasingly relevant. Traditionally, firms have developed new products primarily based on their internal resources, but in recent decades companies have gradually looked more and more outside their organizational boundaries to perform some of the design, development, and manufacturing activities in the product development process (Hagedoorn, 2002; Laursen and Salter, 2006). The shift toward accessing external knowledge and assets has been highlighted from different theoretical perspectives analysing how co-development and the acquisition of technologies can be used to mitigate the risk, cost, and complexity of product development. More recently, the open innovation paradigm emphasizes that firms should utilize outside sources to carry out product innovations and suggests that internal research and development (R&D) is no longer the strategic activity it once was (Chesbrough, 2007, 2003).

Along these lines, a large body of theoretical and empirical research has emerged which discusses the rationale behind collaboration with external agents and behind the acquisition of technology thorough the marketplace for the purpose of innovation (Vega-Jurado et al., 2009; Fey and Birkinshaw, 2005; Cassiman and Veugelers, 2002; Beneito, 2003). However, most of these studies focus on the firm's decision to source knowledge externally and rarely address the determinants of the development modes actually used by firms to bring innovations to market. Thus, although the literature provides diverse and sometimes conflicting evidence on the factors which promote engagement in technological collaboration or R&D outsourcing, our understanding of the factors that determine whether firms truly innovate in collaboration with other agents or through market procurement remains limited. The lack of systematic analysis on this issue is unfortunate considering that the means of knowledge acquisition does not necessarily equal the locus of innovation; firms may access external knowledge sources while retaining the core innovation processes in-house. Some recent studies based on large-scale surveys show that strategies such as R&D collaboration and R&D outsourcing have a limited effect on the success of product innovation (Tsai and Wang, 2009; Vega-Jurado et al., 2008).

In our view, more research is needed to identify the factors leading firms to innovate through the exploitation of external knowledge sources rather than based mainly on internal resources. This issue, which has important implications for both policy and management, has not been explored well in the literature from the perspective of innovation. Consequently, the empirical evidence is mostly anecdotal.

We tackle this issue empirically by distinguishing three different modes through which firms develop new products[44]: 1) internally (product innovation based mainly on internal efforts), 2) collaboratively (product innovation developed with other firms or institutions), and 3) externally (product innovation developed mainly by external firms or institutions).[45] By considering these modes, we analyze the factors that lead firms to base their product innovations on outside sources rather than internal development. In contrast to most previous work, we focus not on the determinants of external knowledge sourcing strategies but rather indirectly explore the importance of these strategies for actual product innovation output. Our unit of analysis is independent of the type of external source (e.g. university, another firm) or transfer mechanism (e.g.

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[44] These modes represent the three major NPD entry strategies stemming from the management and industrial organization literature (Millson & Wilemon, 2008)

[45] Note that we use external development and acquisition interchangeably.

formal collaboration contract, R&D outsourcing, inward technology licensing), which puts our study squarely on the boundaries of the firm.

Two studies in the literature address this topic in similar terms. The first is the research of Robertson and Gatignon (1998), which assesses the determinants of the innovation development mode from a transaction cost perspective. However, these authors examined only the dichotomy between internal and collaborative development and do not consider acquisition as an innovation mode. We take as our point of departure the challenge made by these authors when they suggest that future research should consider alternative modes of innovation development closer to technology acquisition in the marketplace. In our analysis we include external development to that effect. We also extend the Robertson and Gatignon study by considering a broader range of possible determinants of the innovation development mode. Robertson and Gatignon focus on the effect of three major factors stemming from transaction cost economics (TCE): asset specificity, external uncertainty, and behavioural uncertainty. We do not question their relevance as predictors of the innovation development strategy but suggest that they offer only a partial explanation of the phenomenon. Hence, following recent studies on the make, buy, and ally innovative behaviour of firms (Belderbos et al., 2004; Oerlemans and Meeus, 2001; Serrano-Bedia et al., 2010) we combine TCE with the resource-based perspectives and industrial organization theory (IOT) to try to disentangle the role of different firm characteristics (R&D capacity, size), environmental uncertainty (market and technological uncertainty), and industrial factors (knowledge spillovers, appropriability conditions) in the development mode. Note that, even in traditional studies on the determinants of external knowledge sourcing, the effect of these factors - especially those related to a firm's technological resources - is not well understood. Relatedly, we argue that the effect of internal R&D capacity varies according to the NPD strategy considered (collaborative or external development) and may even be determined by non-linear relationships.

The other related work is that of Barge-Gil (2010), which analyses the characteristics of firms that use collaboration as the main way to innovate. Sharing the context of Spanish manufacturing firms, our study extends Barge-Gil's research in two ways. First, we consider external development (as an NPD strategy) rather than collaboration alone. Secondly, our research untangles the relations between internal R&D capacity and the different sources of environmental uncertainty associated with each mode of product development.

Our analysis is based on a large-scale, cross-industry sample of manufacturing firms taken from five waves of the Spanish Innovation Survey. The use of panel data allows us to control for unobserved heterogeneity and spurious temporal effects and, therefore, offers a more generalized, broader empirical view of the phenomenon.

In the next section (Section 2) we review the theory on the factors determining the product development mode, from which we generate a set of six hypotheses. Section 3 describes the data source, defines the variables, and introduces the econometric approach. In Section 4, we present the descriptive characteristics of the sample and report the estimation results, also graphically presenting the predicted relationships. Sections 5 and 6 provide a discussion of the results and offer some implications, possible theoretical developments, and suggestions for future research.

5.2 Theory development and hypotheses

An important area in the management literature is the analysis of how the firm manages its organizational boundaries in order to acquire the technological knowledge required for its innovation activities (Fey and Birkinshaw, 2005). Authors have distinguished different modes of technology acquisition in the spectrum formed between hierarchical transactions within firms (*make*), forms of boundary-spanning shared development and collaboration (*ally*), and arms-length transactions in the marketplace (*buy*).

Regarding the last strategy, the literature addresses various modes including R&D outsourcing, inward technology licensing, acquisition of technologies embodied in machinery and equipment, and mergers and acquisitions (Dahlander and Gann, 2010). Studies on the “buy” strategy frequently are oriented towards analysis of the factors affecting the choice between internal and external knowledge sourcing (e.g. Veugelers and Cassiman, 1999; Veugelers, 1997; Narula, 2001) and even the verification of a complementary or substitutive relationship between them (Cassiman and Veugelers, 2006; Schmiedeberg, 2008). Although these studies do not address the conditions under which firms use external knowledge sourcing as the main mode of innovation (which this paper aims to do), the factors they consider as determinants of the general decision to outsource may also be useful to explain the firm's product development behaviour. These factors have been examined from three main perspectives: TCE, the resource-based perspectives (resource dependence theory and resource-based view), and IOT.

5.2.1 Transaction costs and environmental uncertainty

TCE proposes that firms decide whether to externalize their activities according to the criterion of minimizing the sum of production and transaction costs (Coase, 1937; Williamson, 1985). Production costs come from the coordination of in-house activities related to learning, organizing, and managing production (Das and Teng, 2000). Transaction costs stem from the efforts to access such activities through market acquisition and refer to the expenses incurred for a transaction (i.e. cost of information, renegotiation, and adaptation). The literature identifies the major sources of transaction costs as environmental uncertainty, behavioural uncertainty, and asset specificity. All these factors increase transaction costs because they lead to renegotiation and contractual updates (Mayer and Argyres, 2004; Williamson, 1985). Thus, generally speaking, the higher the uncertainty or asset specificity, the higher the transaction costs and, therefore, firms will organize their boundaries in order to minimize these costs (Wolter and Veloso, 2008).

Although TCE was not designed to explain innovation governance decisions, many researchers use the notions of uncertainty and asset specificity to explore the drivers of technological knowledge acquisition (Belderbos et al., 2004; Oerlemans and Meeus, 2001; Serrano-Bedia et al., 2010; Walker and Weber, 1984). In the specific context of product development strategy, Robertson and Gatignon (1998) use TCE to explain why alliance rather than internal development should be the product development mode. Based on Robertson and Gatignon's (1998) conceptualization we deal with the effect of environmental uncertainty on product development strategy.[46]

Environmental uncertainty refers to 'unanticipated changes in circumstances surrounding an exchange' (Noordewier et al., 1990, p. 82). This construct comprises two key dimensions: market uncertainty and technological uncertainty (Walker and Weber,

[46] We focus on environmental uncertainty since this is the only construct for which we have information from the Spanish Innovation Survey.

1984; Abernathy, 1978). Market uncertainty refers to fluctuations and unpredictability of demand; technological uncertainty refers to the firm's inability to forecast accurately technological requirements (Walker and Weber, 1984; Robertson and Gatignon, 1998). As previously noted, the higher the market and technological uncertainty, the greater the number of contingencies that the firm is required to deal with; therefore, in principle, it is more likely that the firm will select internal development as a governance mode. Nevertheless, although this proposition has been systematically supported in the literature, the empirical evidence is not conclusive with respect to the innovation governance implications of these factors (Stanko and Calantone, 2011). Along this line, Robertson and Gatignon (1998) suggest that market and technological uncertainty act in opposite directions, with the former promoting internal development and the latter favouring external sourcing. On the one hand, market uncertainty may cause changes to the development portfolio, adding complexity and expense to external development. Highly uncertain market environments will increase the probability of renegotiation or cancellation of the innovation contract, which will increase the transaction costs associated with both collaborative and external development, thus favouring internal innovation.

On the other hand, although technological uncertainty may also increase the transaction costs associated with external development – due to the problems of predicting technical requirements – the flexibility afforded by collaboration and market acquisition may compensate for these costs (Klein et al., 1990). Uncertainty arising from a fast pace of technological change may make internal development less attractive because internal capabilities may quickly become obsolete (Balakrishnan and Wernerfelt, 1986). For firms facing uncertainty stemming from lack of knowledge about technology, accessing the capabilities of other firms through collaborative development or acquisition may reduce uncertainty by filling in knowledge gaps and provide a viable development pathway (Steensma et al., 2000). Therefore, in conditions of high technological uncertainty, acquiring product innovations in the marketplace or developing them through strategic alliances may allow firms to introduce new products onto the market more quickly and provide first mover advantages (Robertson and Gatignon, 1998).

Based on these arguments, we propose the following hypotheses:

Hypothesis 1. The greater the technological uncertainty, the more likely that the firm will base its product innovation on collaboration with other agents or on external acquisition rather than internal development.

Hypothesis 2. The greater the market uncertainty, the less likely that the firm will base its product innovation on collaboration with other agents or on external acquisition rather than to internal development.

5.2.2 Firm resources

Although TCE is the framework traditionally used to study the innovation governance decision, it allows only a limited view of the phenomenon and neglects the role of the firm's resource base in sourcing external technology (Oerlemans and Meeus, 2001). Boundary decisions based on in-house and partner capabilities may differ from what traditional TCE would predict (Barney, 1999). In this sense, several studies in the strategic management literature incorporate the resource-based theory of the firm, suggesting that each firm possesses a unique set of organizational resources – such as a specific knowledge base, organizational practices, and dynamic capabilities - which represent the primary source of sustainable competitive advantage (Zott, 2003; Teece, 2007). These resources must be rare, valuable, non–imitable, and not-substitutable and constitute the main determinant of firm's performance (Barney, 1991). In the context of innovation, this suggests that the rationale for external technology sourcing is not cost minimization but the potential for value creation based on pooling resource bases (Belderbos et al., 2004).

Along these lines, two theoretical approaches explain the role of resources in the firm's innovation governance decisions: the resource-based view (RBV) (Dierickx and Cool, 1989; Das and Teng, 2000) and resource dependence theory (Pfeffer and Salancik, 1978; Finkelstein, 1997). Both approaches stress the role of internal assets as the prime driver of external knowledge acquisition. However, the former focuses on synergy and the acquisition of complementary resources, while the latter emphasizes internal resource scarcity and the need to survive (Dias and Magriço, 2011).

Specifically, the RBV argues that firms use external knowledge sources in order to leverage their superior resources via the complementary assets possessed by other firms or institutions (Teece, 1986; Kogut, 1988). The RBV considers the externalization of innovation activities as a mechanism to maximize firm value through the resources available in other institutions rather than as a cost-minimization strategy. This implies that technological collaboration and acquisitions are not only modes of coordination, but also activities where resources and know-how are needed and developed (Tyler and Steensma, 1995). Thus, firms with high levels of internal resources will tend to favour external knowledge acquisition due to their greater ability to appreciate and internalize valuable external knowledge. These firms also do not encounter difficulty in finding potential partners interested in accessing their resources. It can be argued that external knowledge acquisition is more common among firms that conduct in-house R&D or have relevant stocks of prior knowledge (Kamien and Zang, 2000). This idea is reminiscent of the notion of absorptive capacity, which stresses that in-house R&D activities contribute not only to innovations but also to the firm's ability to identify, assimilate, and exploit the knowledge generated by competitors and extra-industry sources (Cohen and Levinthal, 1990).

Resource dependence theory explains the role of resources in a different way. According to this view some firms are not able to generate all the resources they require; therefore, they must look for alternative ways to overcome this weakness. In this view, external knowledge sourcing is seen as a way to acquire the resources that firms lack but which are necessary for firm survival (Dias and Magriço, 2011). Thus, firms with low levels of R&D capacity can benefit significantly from external knowledge sourcing, whereas firms with highly developed R&D capabilities will find it less necessary and less effective to involve external agents in their innovation activities (Barge-Gil, 2010; Bayona et al., 2001; Santoro and Chakrabarti, 2002).

This view is supported by the idea of asset specificity, defined as 'durable investments that are undertaken in support of particular transactions' (Williamson, 1985, p. 55). According to TCE, investments in highly specific assets increase the risk of delays due to costly renegotiations or opportunism since the costs of switching suppliers and re-investing are high, meaning firms are more likely to integrate vertically. Asset specificity also predicts that firms are more likely to retain specialized and valuable assets within firm boundaries in order to avoid exposure to potential imitators and to capture the value generated by innovation (Stanko and Calantone, 2011). In the context of innovation in particular, asset specificity refers not only to traditional factors, such as investments in manufacturing plants and particular equipment, but also to accumulated tacit knowledge and experience captured in human capital (Lohtia et al., 1994; Audretsch et al., 1996). Therefore, higher R&D capacity implies higher levels of asset specificity and a lower propensity to engage in external technology development (Mol, 2005).

If we combine the theoretical findings from these approaches, two conflicting arguments arise. According to the RBV, we would expect a positive relationship between internal R&D capacity and any two of the strategies associated with external innovation development (collaboration or acquisition); however, resource dependency theory would predict the opposite outcome. These predictions can be labelled respectively as the 'complementary effect' and the 'need effect'.

In order to disentangle this issue, we argue that the effect of internal R&D capacity varies according to the NPD strategy considered (collaborative or external development) and follows non-linear relationships. First, we predict a curvilinear relationship between the firm's R&D capacity and the probability of developing an innovation through collaboration with external agents. We propose that firms with slightly higher levels of R&D capacity tend to develop products collaboratively compared to firms with lower levels of R&D capacity. This is due to the increasing levels of absorptive capacity, which allow the firm to benefit more from collaboration ('complementary effect'). In addition, although firms with higher levels of internal R&D make more attractive collaboration partners, their product innovation may require very specific knowledge assets, making collaborative development less attractive than internal development ('need effect').

Hypothesis 3. The relation between internal R&D capacity and the firm's propensity to develop product innovations in collaboration with external actors versus in-house follows an inverted U-shape.

In contrast to collaboration, we predict a negative relation between internal R&D capacity and the probability of acquiring innovations developed by other agents (external development). Although several authors suggest that firms need a certain level of related technological knowledge to allow them to benefit from technology discoveries of other firms (Tsai and Wang, 2009), we consider that, when faced with the decision between internal and external development, the 'need effect' outweighs the 'complementary effect'. Thus, firms with low levels of internal R&D capacity will be more likely to select external acquisition as the innovation development mode. These firms have little to offer potential collaborators in any kind of joint innovation project. They also lack the resources to develop innovations on their own, meaning that in order to introduce a new product, they need to commercialize innovations developed elsewhere.

Hypothesis 4. The relation between internal R&D capacity and a firm's propensity to develop product innovations through external acquisition versus internal development is negative.

5.2.3 Appropriability and public spillovers

IOT examines technology acquisition taking account of the effects of factors related to industry structure and focusing on the role played by spillovers and the appropriability regime (Belderbos et al., 2004; Veugelers and Cassiman, 2005). These two factors are closely related and, together, represent the knowledge flows in the industry in which the firm operates. Spillovers can be defined as those elements of knowledge which become part of the pool of publicly available information (Jaffe, 1986). Appropriability is the extent to which the results of innovative activities can be protected and are not easily diffused within the industry (Teece, 1986).

Spillovers may lead firms to choose externalization as the innovation governance mode in order to exploit the publicly available information in their own innovation processes (incoming spillovers). However, the firm's innovation activities may also generate information flows out of its boundaries into the public pool of knowledge (outgoing spillovers). These outflows of information arise as a result of imperfect protection mechanisms, thus limiting the appropriability of the innovation process (Teng, 2007). IOT argues that firms must manage these flows of information by maximizing incoming spillovers through cooperation or outsourcing while minimizing outgoing spillovers by exploiting protection mechanisms (Belderbos et al., 2004; Amir et al., 2003; Cassiman et al., 2002). The available empirical evidence confirms that incoming spillovers positively affect the firm's decision to collaborate with other institutions (Belderbos et al., 2004; Kaiser, 2002; Veugelers and Cassiman, 2005; López, 2008) or to outsource its R&D activities (Veugelers and Cassiman, 1999). At the same time, the existence of weak appropriation mechanisms negatively influences external technology contracting (Stanko and Calantone, 2011).

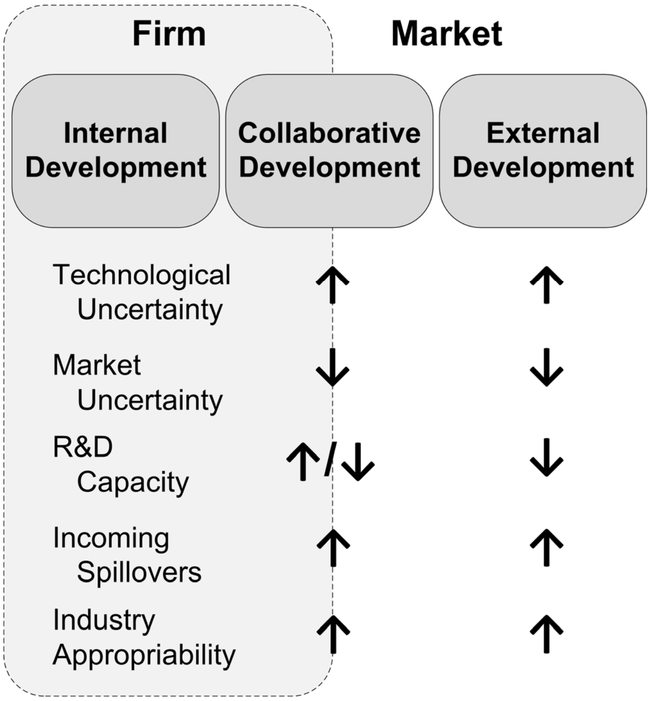
We therefore propose the following:

Hypothesis 5. The higher the level of incoming spillovers in the industry in which the firm operates, the more likely the firm will base its product innovation on collaborative or external development rather than on internal development.

Hypothesis 6. The higher the appropriability conditions in the industry in which the firm operates, the more likely the firm will base its product innovation on collaborative or external development rather than on internal development.

Figure 5.1 summarizes the predicted effect of each factor on the propensity for the firm to carry out product development collaboratively or externally, in relation to internal development.

Fig. 5.1.
Hypothesized effect of variables on the development mode, relative to internal development



5.3. Data and methodology

5.3.1 Data source

We conduct our analysis on data from the Spanish Technological Innovation Panel (PITEC), a survey of over 6,700 manufacturing firms over five periods from 2004-2008.[47] The PITEC is a subset of the national innovation survey of the Spanish National Statistics Institute (INE) that draws from more R&D active firms: roughly 86% of the firms in the PITEC are innovation-oriented. Spanish law mandates response to the survey, which mitigates respondent selection bias. The survey is based on the OECD Oslo Manual and closely resembles the Community Innovation Surveys in other countries, although it has the distinct advantage of being structured as a panel dataset.

Although the PITEC covers innovation-oriented firms that have not introduced a product innovation, we restrict our analysis to product innovators, which is in line with

[47] Although the panel starts with 2003, several of our key variables were first introduced in 2004.

Robertson and Gatignon (1998).[48] Also, due to the nature of our variable for R&D capacity, we exclude micro-firms from the analysis, that is, firms with 10 employees or less. Our final sample is 4,646 firms.

5.3.2 Variables

5.3.2.1 Dependent variable:

The dependent variable reflects the firm's mode of NPD. The categorical nominal variable INN_MODE takes one of three values indicating whether the innovation was developed (1) primarily by the firm itself (internal development), (2) in collaboration with external partners (collaborative development), or (3) primarily by external actors (external development). The values are mutually exclusive and vary by period.

5.3.2.2 Predictor variables:

The covariates of interest fall broadly into three categories related to (1) costs and environmental uncertainties, (2) internal R&D capacity, and (3) industry-level factors.

The first set of constructs measures the perceived costs and uncertainty faced by innovator firms. Firms rate several items on a Likert scale, ranging from 0 (not relevant) to 3 (highly important), to indicate the significance of each factor for the level of difficulty of innovation activities. First, we compute the variable COST as an average of three items ('lack of internal funding', 'lack of external funding', and 'cost of innovation too high') (Cronbach's $\alpha = 0.82$). Second, we take the item 'uncertainty respecting the demand for innovative products' as the measure of market uncertainty relating specifically to innovation (MARK_UNC). Third, firms scored the significance of 'lack of information about technology', which we use as our measure of technological uncertainty (TECH_UNC). Note that this last variable measures the endogenous dimension of technological uncertainty (i.e. uncertainty stemming from the individual firm's knowledge about technology) rather than exogenous uncertainty related to the nature of a particular technology (Robertson and Gatignon, 1998). Milliken (1987)

[48] That said, our model is robust to adding non-product innovators as a category in the multinomial logit or to a Heckman selection model for product innovation. In the interests of parsimony and to enable a more coherent theoretical discussion, we follow Robertson and Gatignon (1998) and focus on successful innovators only.

points out that managers experience uncertainty because of the perception of the lack of adequate information or the inability to access relevant data. The individual manager's perception of transaction cost factors has been shown to be a more powerful predictor of firm behaviour than more objective, global measures of the same construct (Love and Roper, 2005).

In order to measure R&D capacity we take the number of employees dedicated to internal R&D activities as a percentage of all employees (EMP_RD) (Negassi, 2004; Keupp and Gassmann, 2009; Audretsch et al., 1996). Due to the questionnaire design, this variable is broad enough to capture employees who dedicate at least some of their time to R&D activities from multiple departments or on a part-time basis. We prefer this measure to others commonly found in the literature, such as expenditure on internal R&D, because the number of firm employees and human capital is less susceptible to random fluctuations in firm revenue accounting (e.g. from large contracts) or R&D spending (e.g. based on one-off purchases of expensive equipment). Moreover, human capital may better reflect a firm's tacit knowledge and experience (Muscio, 2007).[49] Since we predict non-linear relationships, we include the squared term (EMP_RD_2) in the models.

The last set of variables reflects concepts from IOT to test Hypotheses H5 and H6. After Cassiman and Veugelers (2002), we include two contextual, industry-level variables in the analysis: use of legal protection mechanisms and importance of incoming spillovers. We build a measure of the average number of protection mechanisms used by firms on a per-industry basis – in particular patents, trademarks, copyrights, and registered industrial designs – as a measure of the appropriability regime.[50] The resulting variable (IPR_IND) ranges from 0 to 4. Firms rate the importance for innovation of public sources of knowledge – namely conferences, publications, and professional associations – on a four-point scale from 'not used' to 'highly important'. The variable SPO_IND is the

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[49] Note that the model is robust to different operationalisations of R&D intensity. However, we prefer this construct on theoretical grounds and also because it has the best explanatory power.

[50] The industry is defined at the NACE 2-digit sector level, and the mean is the average score of the firms in the sample.

industry average of these three items combined and ranges from 0 to 3 (Cronbach's α = 0.81).

5.3.2.3 Control variables:

Other firm and industrial characteristics which have been commonly employed as determinants of innovation behaviour from both IOT and RBV perspectives are firm size (Hagedoorn and Schakenraad, 1994), belonging to a business group (Belderbos et al., 2004; Tether, 2002), and technological intensity of the industry (Hagedoorn, 1993; Tether, 2002). The literature on firm resources suggests opposing arguments to explain their relationships with the make-buy-ally decision. These are similar to those used to explain R&D capacity and are related to the complementary and the need effects. For instance, it has been suggested that large firms, operating in technologically intensive sectors or belonging to a business group, are better suited to exploit external knowledge due to their higher levels of internal resources. However, it has also been argued that for these types of firms the need for external knowledge may be lower compared to small and independent firms in less R&D-intensive sectors. In our analysis we control for the above mentioned firm and industry characteristics with a set of three variables. First, a variable measuring the number of employees, log-transformed (LOGEMP), to control for firm size. Second, a dummy variable to indicate whether the firm belongs to a group of companies (GROUP). Third, two dummies for firms in high-tech or medium-tech industries (with low-tech industries serving as the reference category), based on the classification groupings in the Spanish NACE system (CNAE - Clasificación Nacional de Actividades Económicas).

Firms operating in international markets may also face pressure to innovate due to their exposure to more diverse competition; we use a dummy variable (INTERNATIONAL) to indicate whether the firm exports to markets outside of Spain.

Finally, we include a variable to control for the nature of the new product. The dummy variable NEW_TO_MARKET indicates whether the firm's product innovation is new to the market (as opposed simply to being new to the firm). This allows us to account for idiosyncrasies in the risk and complexity of the firm's innovation efforts since it is conceivable that products not yet tested in the market may be associated with higher levels of uncertainty. The variable also presents interesting possibilities for interpretation regarding the relative novelty of products associated with each product development mode, although we do not generate a formal hypothesis for this.

5.3.3 Econometric approach

Since the dependent variable takes one of three categorical values, we use a multinomial logit model, setting internal product development as the reference category (McFadden, 1974; Wooldridge, 2002). Given that the dataset contains repeated observations of the same firms over time, we apply two econometric approaches.

First, we estimate a cross-sectional (i.e. pooled or population-averaged) model and cluster the errors at firm level (Wooldridge, 2003). The use of repeated observations over time allows us to mitigate spurious temporal effects and provides us with a more general idea of firm behaviour.

Second, we take advantage of the panel structure of the data to control for unobserved heterogeneity via a random-intercepts multinomial logit model (Chintagunta et al., 1991; Hartzel et al., 2001). In this model, the unobserved heterogeneity is captured in firm-specific intercepts which follow an unknown distribution through the population. There exists only a random- (as opposed to a fixed-) effects estimator for the multinomial logit, which assumes that the unobserved variables captured in the random effects are uncorrelated with the covariates. Although this might seem to be a strong assumption given the diversity of the firms in our sample, estimating separate random effects for each outcome category provides a more flexible and reasonable estimate of the distributions of unobserved heterogeneity (Agresti et al., 2000; Jain et al., 1994). We estimate the model using the Stata package GLLAMM (Generalized Linear Latent and Mixed Models), which approaches the numerical integration by means of adaptive quadrature (Rabe-Hesketh et al., 2002; Rabe-Hesketh and Skrondal, 2008).[51]

[51] The computation time for this type of model increases exponentially with the number of integration points. This made estimation of our model computationally burdensome: even after sequentially seeding initial values prior to increasing in the number of integration points, the estimation time for the final model with 12 integration points exceeded 170 hours (see Haan and Uhlendorff, 2006).

We examine the cross-sectional and panel models together since there is often a trade-off between the omitted variable bias inherent in cross-sectional methods and the assumptions and estimation difficulties of random-effects models. However, both methods provide coefficient estimates that are comparable in terms of sign and magnitude with only minor differences in efficiency, giving us confidence about in the robustness of the models.

In order to visually evaluate Hypotheses 3 and 4, we use the Stata graphing command `postgr3`. The procedure plots the predicted main effects while holding each covariate at its conditional mean (Long and Freese, 2006). The resulting graphs show each predicted propensity to develop a product innovation, relative to internal development, as a function of internal R&D capacity (Mitchell and Chen, 2005).

Finally, we conduct several robustness checks. First, we consider the multinomial logit's assumption of the *Independence of Irrelevant Alternatives* (IIA) (Hausman and McFadden, 1984). Since the categories are inclusive based on theoretical grounds and IIA diagnostic tests are often of limited value in applied work with a small number of outcomes (Cheng and Long, 2007), we compare our estimations with a multinomial probit, which does not make the IIA assumption.[52] In any case, accounting for unobserved factors through random effects reduces potential bias from the IIA (Skrondal and Rabe-Hesketh, 2003). Next, to ensure that any overlap from analysing sequential periods does not bias the results, we estimate a model using two temporally distal waves of the survey (e.g. 2004 and 2007). Our results are consistent in both cases. Table 5.A.1 in the Appendix presents the results of these robustness checks.

5.4 Empirical results

5.4.1 Descriptive analysis

This section examines the characteristics of the firms in our sample. Table 5.1 presents the descriptive statistics and correlation matrix for the variables.

[52] Despite being unconstrained by the IIA assumption, the multinomial probit often suffers from identification problems, and its estimation is computationally intensive (Dow and Endersby, 2004).

Internal development is clearly dominant, with 85% of observed new products developed internally over the five periods (N = 13,919). Of the remaining instances, 12% stem from collaborative development (N = 2,011) and only 3% from external development (N = 523). The prevalence of internally developed innovations (85%) is comparable to the range of 72%-77% reported in Robertson and Gatignon (1998).

Mean R&D capacity in our sample is 10% ($\sigma = 0.13$) of employees involved in R&D activities. Although this may seem high compared to other commonly used measures (e.g. R&D intensity as spending over revenue), it is due to the construction of the variable and the restriction of the sample to those firms that have successfully introduced new products.

Apart from the positive correlations of less than 0.38 between each of the uncertainty and IOT measures, most of the variables have a correlation well below 0.1. The correlation matrix reveals no concerns about collinearity among the measures. The descriptive analysis of the transition probabilities between development modes within firms over time is perhaps more informative. Table 5.2 shows the percentage of firms that persist with one development strategy (diagonal) or switch between development strategies (left-to-right) from one period to the next. For example, a high proportion (94.6%) of firms that reported internal development also report internal development in the following period, whereas far fewer firms reporting collaboration continued to be collaborators for innovation (61.5%). These figures are interesting in highlighting first, that there is variability over time in the product development mode; most but not all firms tend to follow the same strategy year after year. Second, these changes in strategies are not equally distributed. For instance, firms that were collaborative innovators are more likely to move to other development modes in the next period, whereas internal innovators seem to remain mostly internal innovators.

Table 5.1
Descriptive statistics and correlations of variables

Variable	Mean (s.d.)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(1) Internal	0.85 (0.36)													
(2) Collaborative	0.12 (0.33)	-0.875*												
(3) External	0.03 (0.17)	-0.425*	-0.068*											
(4) R&D Capacity	0.10 (0.13)	0.020*	0.031*	-0.099*										
(5) Cost Obstacle	1.79 (0.88)	-0.020*	0.027*	-0.009	0.084*									
(6) Tech. Uncertainty	1.30 (0.85)	-0.037*	0.040*	0.001	0.021*	0.379*								
(7) Market Uncertainty	1.65 (0.97)	-0.026*	0.041*	-0.023*	0.045*	0.354*	0.369*							
(8) Incoming Spillovers	0.89 (0.10)	0.042*	-0.028*	-0.035*	0.141*	-0.009	-0.034*	0.016*						
(9) Ind. Appropriability	0.56 (0.12)	0.040*	-0.039*	-0.009	0.101*	0.005	-0.019*	0.021*	0.351*					
(10) Log Size	4.36 (1.20)	-0.012	0.015*	-0.004	-0.320*	-0.179*	-0.077*	-0.084*	-0.031*	-0.058*				
(11) International Market	0.85 (0.36)	0.009	0.021*	-0.058*	0.023*	-0.008	0.019*	0.037*	0.035*	0.044*	0.180*			
(12) Group	0.41 (0.49)	0.018*	0.000	-0.037*	-0.104*	-0.151*	-0.071*	-0.070*	0.022*	-0.035*	0.530*	0.105*		
(13) New to Market	0.57 (0.49)	-0.016*	0.049*	-0.058*	0.109*	-0.012	0.001	0.008	0.023*	0.018*	0.068*	0.046*	0.047*	
(14) High Tech	0.11 (0.31)	0.026*	-0.016*	-0.023*	0.259*	0.028*	-0.033*	0.000	0.405*	0.301*	-0.004	0.001	0.026*	0.049*
(15) Med. Tech	0.39 (0.49)	0.053*	-0.028*	-0.057*	0.074*	0.000	-0.009	-0.002	0.127*	0.019*	-0.044*	0.098*	0.027*	0.008
(16) Low Tech	0.50 (0.50)	-0.068*	0.037*	0.070*	-0.236*	-0.018*	0.029*	0.002	-0.379*	-0.208*	0.046*	-0.095*	-0.042*	-0.039*

Number of observations: 16,453 **Number of Firms:** 4,646 **Number of Periods:** 5 * significant at 0.05 level

Table 5.2
Transition probabilities between product development mode over five year period

	→ Internal, T+1	→ Collaborative, T+1	→ External, T+1	Totals
Internal, T	94.6%	4.5%	0.9%	85.2%
Collaborative, T	36.2%	61.5%	2.3%	11.8%
External, T	24.3%	8.1%	66.7%	3.0%

5.4.2 Econometric results

Table 5.3 presents the results of the multinomial logit regressions. All models use internal development as the reference category. The coefficient for each variable represents an increase or decrease in the probability of firms choosing an alternative relative to the reference category for each unit change in the predictor.

The results of the cross-sectional analysis are presented in Model I and those accounting for random effects in Model II. Both techniques result in coefficients that are comparable in terms of magnitude and sign, although with several minor yet predictable differences in the standard errors; as Skrondal and Rabe-Hesketh (2003) demonstrate, 'first choice' multinomial logit models with a limited number of alternatives and dominant outcome category can suffer from reduced efficiency. Also, random-effects models can produce inefficient standard errors due to deviations from the distribution of the heterogeneity (Agresti et al., 2004). We note that, following standard econometric theory, the coefficients from the random-effects model are generally larger in magnitude since failing to estimate random effects can bias cross-sectional estimates towards zero. Nevertheless, apart from slightly reduced efficiency, accounting for unobserved heterogeneity seems to have more predictive power as is evident from the markedly smaller log likelihood of the random-effects model.

Table 5.3
Pooled and random-effects multinomial logit results
(Reference category = internal development)

	Model I: Cross-Sectional				Model II: Random Effects			
Variable	**Collaborative**		**External**		**Collaborative**		**External**	
Tech. Uncertainty	0.091**	(0.042)	0.103	(0.073)	0.076	(0.058)	0.162	(0.125)
Market Uncertainty	0.088**	(0.038)	-0.108*	(0.064)	0.167***	(0.051)	-0.078	(0.106)
Cost	0.034	(0.044)	-0.008	(0.073)	-0.005	(0.061)	-0.095	(0.128)
R&D Capacity	2.292***	(0.615)	-19.039***	(2.464)	3.011***	(0.843)	-22.257***	(2.433)
$(\text{R\&D Capacity})^2$	-2.231***	(0.847)	18.261***	(2.364)	-2.920**	(1.162)	22.276***	(3.152)
Incoming Spillovers	-0.273	(0.446)	-0.578	(0.820)	-0.318	(0.743)	-2.097	(1.765)
Industry Approp.	-0.777**	(0.341)	0.252	(0.635)	-0.967*	(0.554)	1.653	(1.187)
Size	0.097**	(0.040)	-0.060	(0.066)	0.117*	(0.063)	-0.141	(0.136)
Group	-0.079	(0.091)	-0.440***	(0.168)	-0.034	(0.132)	-0.423	(0.295)
International	0.117	(0.098)	-0.326**	(0.157)	-0.039	(0.153)	-0.811***	(0.283)
New to Market	0.249***	(0.068)	-0.361***	(0.126)	0.375***	(0.092)	-0.315	(0.199)
High Tech	-0.312**	(0.150)	0.150	(0.327)	-0.579**	(0.249)	-0.862	(0.634)
Med Tech	-0.275***	(0.086)	-0.448**	(0.175)	-0.527***	(0.143)	-1.481***	(0.348)
Constant	-2.287***	(0.436)	-1.043	(0.801)	-4.228***	(0.718)	-4.754***	(1.635)
$\text{Var}(\gamma_j^2)$	-				9.742 (0.724)			
$\text{Var}(\gamma_j^3)$	-				24.931 (3.481)			
$\text{Cov}(\gamma_j^3, \gamma_j^2)$	-				7.535 (1.043)			
Observations	16,453				16,453			
Firms	4,646				4,646			
Log Likelihood	-8017.0054				-6325.2954			

*** $p < 0.01$ ** $p < 0.05$ * $p < 0.1$ Standard error in brackets.

5.4.2.1 Environmental uncertainty and cost

Our results provide weak confirmation for our hypotheses that firms experiencing technological uncertainty are more likely to engage in both collaborative and external development (H1), even when controlling for the newness of the product innovation, the technological intensity of the sector, and the firm's internal R&D capacity. Although technological uncertainly is statistically significant only in the cross-sectional model for the case of collaborative development, the signs and magnitude in Models I and II are in the predicted direction.

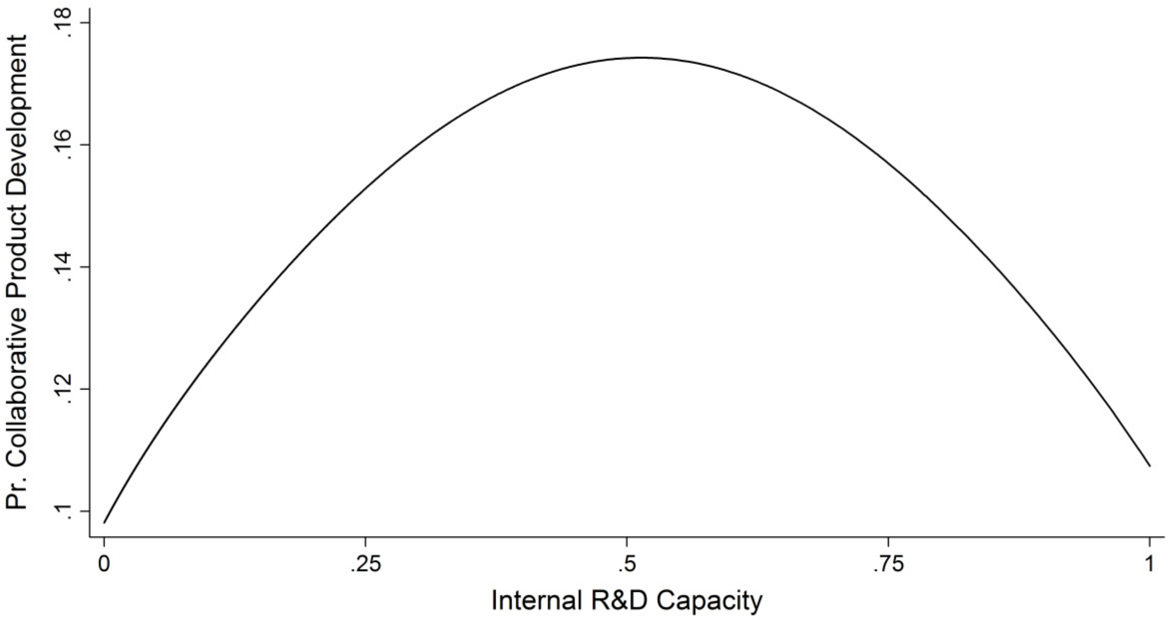
In contrast to our prediction (H2), the results from Models I and II indicate that there is a positive and significant relationship between market uncertainty and the probability of collaborative development. On the other hand, we find some support for market uncertainty having a negative effect on the propensity to engage in external development since the relationship is significant only in the cross-sectional model. Thus the dimensions of environmental uncertainty operate in different directions according to the development mode in question.

Also noteworthy is the lack of significance of the cost variable, which captures the financial cost of innovation activities. Although several authors highlight the cost advantage associated with externalization of innovative efforts (e.g.,Piachaud, 2002; Kumar and Snavely, 2004; Chesbrough, 2007), the empirical literature on the implications of this variable for the outsourcing decision is not conclusive. Some authors find a positive effect of high innovation costs on the propensity to collaborate (Veugelers and Cassiman, 2005), while others provide no clear empirical evidence to support this argument (Belderbos et al., 2004). Our results are in line with this second stream of empirical research and indicate that the effect of cost in determining the development mode is inconsequential. Therefore, although reduction of development costs may be an important driver for outsourcing or collaborative projects, it does not seem to determine the firm's main innovation strategy.

5.4.2.2 Internal R&D capacity

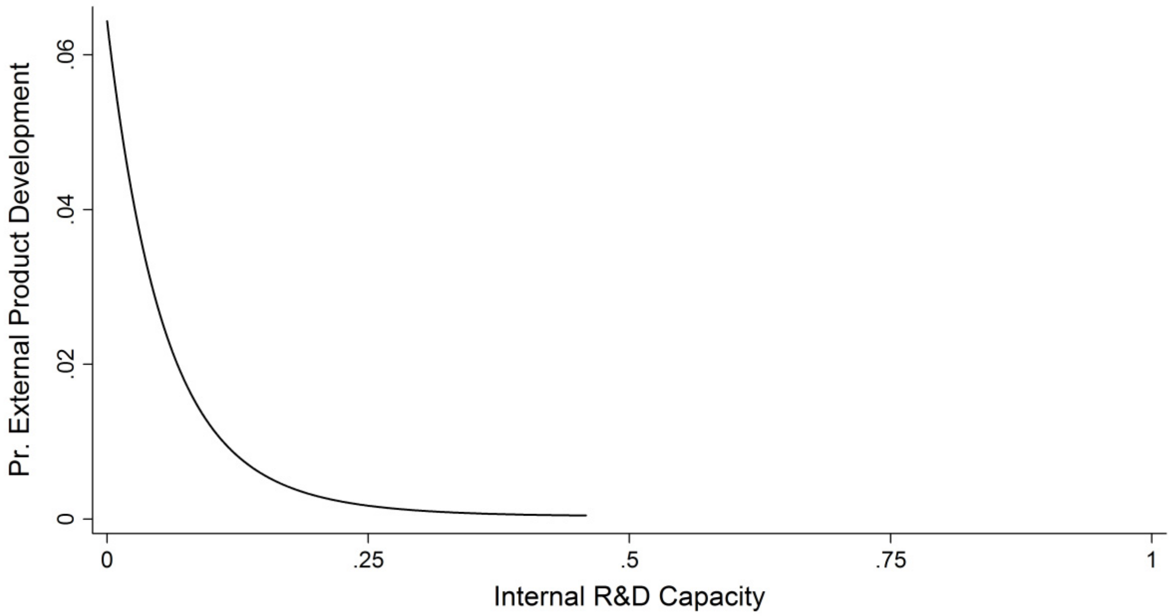
In line with Hypothesis 3, the models predict an inverted-U relation between internal R&D capacity and the probability of being a collaborative innovator. Figure 5.2 presents this graphically. Firms with slightly higher R&D capacity tend to adopt collaborative product development compared to firms with lower levels R&D capacity. However, insofar as firms develop a higher level of internal R&D capacity, collaborative development becomes less probable. That said, the inflection point (i.e. the point at which probability begins to decrease) occurs at a relatively high level of R&D capacity. In practice, only 2% of the firms in our sample have an (unconditional) R&D capacity greater than 50% of employees dedicating some of their time to R&D activities, these being generally smaller firms. However, within a reasonable range of R&D capacity around the mean, the model still predicts that the likelihood of collaboration is subject to positive and decreasing returns. In any case, this result not only contrasts the negative relation between R&D intensity and cooperative innovation found by Barge-Gil (2010), but also reveals a more complex underlying relationship and a fundamental tension between the 'need effect' and the 'complementary effect'.

Fig. 5.2.
Predicted relationship of collaborative new product development as a function of R&D capacity



We also find strong evidence for a negative relation between internal R&D capacity and the probability of being an external product developer (H4). That is, the greater the firm's internal R&D capacity, the lower the probability of acquiring and commercializing innovations developed externally to the firm. We graph this relationship in Figure 5.3. Although the squared term for R&D capacity is positive and significant, which would indicate a U-shape, in practice no observed firm with an R&D capacity higher than 45% engages in external development, leaving us with a negative relationship.

Fig. 5.3.
Predicted relationship of external new product development as a function of R&D capacity



5.4.2.3 Industry appropriability and incoming spillovers

In terms of the effect of incoming spillovers and appropriability conditions, the results do not support Hypotheses 5 and 6. In particular, incoming spillovers at the industry level have no significant predictive value for the type of product development in either model. This is not to say that spillovers are not important for product innovation, but merely that the presence of spillovers does not differentiate between the mode of product development followed by the firm. It could be that spillovers alert firms to potential collaborators and sources of external development while also providing knowledge that can be exploited via internal development.

Conversely, industry appropriability has predictive power which runs opposite to the direction predicted. The results show that higher average use of protection mechanisms in an industry predicts internal rather than collaborative development. In this case, the capacity to protect the results of innovation activities rather than to promote the externalization of these activities makes internal development the more attractive path for the firm. This result may be interpreted through the traditional Schumpeterian lens, which links higher levels of appropriability with greater innovative efforts, such that outgoing spillovers are reduced and the returns to investment in innovative activities increase.

5.4.2.4 Firm characteristics and product newness

Of interest, but not related to our central hypotheses, are the variables reflecting firm characteristics. First, in Models I and II we find that larger firms are more likely to develop innovations collaboratively but that size is not a significant predictor of external development. Second, firms in groups are less likely to use external development as a means to innovate. This may reflect that these firms have access to the resources of other firms in the same group, which gives fewer incentives to look further outside for avenues of product development (Belenzon and Berkovitz, 2010). Third, the geographical market in which the firm sells its products has no predictive power between internal or collaborative product development, although we find that internationally-operating firms are less likely to use external acquisition.

Although we make no inferences about the direction of causality, the estimated coefficients of the control variable for product newness are significant for both outcomes. Products that are new to the market are positively and significantly related to collaborative development compared to internal development. This is in line with research suggesting that firms may enter into product development alliances when they are attempting to develop pioneering technologies (Eisenhardt and Schoonhoven, 1996). Along the same lines, externally acquired innovations are less likely to be truly new, suggesting that these firms follow a more imitative strategy by acquiring innovations already available on the market.

5.4.2.5 Industry technological intensity

Finally, the industry dummies indicate that high- and medium-technology firms are more likely to use internal development (and less likely to develop products collaboratively or externally) as their main way to innovate, relative to low-technology industries. This result is in line with the results in Barge-Gil (2010). This is an intriguing finding since previous empirical studies show high-technology firms are more likely to access external knowledge sources and to engage in R&D collaborations (Vega-Jurado et al., 2009; Bayona et al., 2001). In this sense, our findings suggest that firms operating in these more technologically complex and fast-moving industries may be accessing external sources for various objectives, such as learning or exploration of new technological areas, while still maintaining the primary locus of innovation internally.

5.5 Discussion and implications

We proposed a number of hypotheses based on the theoretical literature on TCE, the resource-based perspectives, and IOT to account for new product development behaviour among firms and, in particular, whether new products are developed collaboratively or externally rather than internally. We predicted that collaborative and external development modes would be preferred to internal development as technological uncertainty increases and as industry spillovers and appropriability increase. We proposed also an inverted U-shaped relationship between R&D capacity and collaborative product development and a negative relationship between R&D capacity and external development. Our results support some of these predictions but also point out other unexpected associations.

Starting with the role of internal R&D capacity, our results support our initial hypothesis and help to reconcile the controversial arguments in the literature that we call the 'complementary effect' versus the 'need effect'. Our results point to the existence of a non-linear relationship between firm R&D capacity and the adoption of collaborative product development strategy compared to internal development. This implies that internal R&D activities make firms better suited to benefit from partners' resources; in other words, a certain level of in-house R&D capacity is needed for the firm to be able to exploit collaboration as a strategy for successfully achieving innovation. These results could be interpreted in terms of increased absorptive capacity derived from internal R&D (Cohen and Levinthal, 1990). Our results also show that, when the firm has a suitable technological base, it is more likely to search for and exploit complementary resources from other agents by committing to collaborative arrangements.

However, if the firm's in-house R&D capacities are high, the effect of absorptive capacity is reduced by the 'need effect.' In these conditions firms choose internal development, although this does not rule out firms still accessing external knowledge sources. One possible explanation is that those firms with sufficiently broad and deep technology bases have less need for external knowledge; therefore, they base their innovation activity on internal resources. Also, for these firms the costs related to collaboration as a way to innovate may exceed the potential benefits. The strong technological base of these firms may be more vulnerable to technology leakage if they engage in collaborative arrangements compared to firms with lower levels of internal R&D capacity. R&D intensive firms, which have made potentially valuable and costly investments, will want to protect these assets from imitation, making them less likely to develop products with external partners. Furthermore, firms with highly specific assets may find it more difficult to acquire technological knowledge from external sources required for their specialized product development activities.

Our results confirm also that internal R&D capacity has dissimilar effects on the different product development modes. In contrast to the inverted-U relationship for collaborative development, increased internal R&D capacity has a negative relationship with external development. As internal R&D capacity increases, firms are less likely to introduce product innovations developed externally. In this sense, compared to collaborative developers, external developers seem to be 'passive adopters' with low levels of R&D capacity.

In terms of environmental factors, our results show that uncertainty plays a complex role in determining the development mode. In contrast to the dominant view in TCE research, the effect of environmental uncertainty seems to be related more closely to strategic aspects than to cost considerations. This means that, although higher environmental uncertainty could impose higher transaction costs on external governance modes, firms will decide to pursue such a strategy if they have the flexibility required to deal with the uncertainty. The effect of uncertainty is greater in collaborative development since this development mode provides firms with greater capacity to share strategic assets as well as greater flexibility to manage transaction costs, compared to external acquisition. Thus, the evidence suggests that technological and market uncertainty are more likely to lead to collaborative product development compared to in-house development.

We point out that the above mentioned effect of market uncertainty contrasts with Robertson and Gatignon (1998). It is possible that successful collaborative development is motivated by the desire to diffuse market risk, perhaps by spreading costs and sharing the complementary assets of collaborative partners, and to access to required technological knowledge. In markets where it is difficult to forecast demand for innovative products, collaboration (especially with customers) may help firms to more clearly identify new market opportunities and emerging customer needs while reducing the likelihood of poor design in the early stages of development (Tsai and Wang, 2009).

Although the relationship between technological uncertainty, R&D capacity, and internal-versus-external technology sourcing behaviour is complex (Hoetker, 2005), our model seeks to integrate several strands in the literature by accounting for the non-linear effect of R&D capacity and disentangling several modes of realized product development.

There are several policy and managerial implications from this research. From a management perspective, the findings from this study could be used to guide decision making about the most suitable strategy to develop new products. For instance, our analysis indicates that in order to exploit collaboration as a way to innovate, firms need to possess a certain level of internal R&D capacity. In this sense, collaboration represents a means to leverage internal R&D rather than to replace R&D efforts. At the same time, firm R&D efforts are not only essential for developing new products internally but also for exploiting collaborative arrangements as an innovation strategy. What's more, if firms lack the R&D capacity required to carry out innovation projects by themselves or to benefit from collaboration, they can resort to external acquisition. However, in this case managers should be conscious that they are likely adopting an imitative development strategy which is likely to lead to product innovations that, although new to the firm, are already available on the market; without the right complementary assets, such innovations would not be a source of competitive advantage. Our results show that under conditions of high environmental uncertainty, many firms base product innovation on collaborative governance modes, which likely provide greater flexibility for managing market and technological risks.

The implications of this research for policy are that mechanisms promoting collaboration and networking between economic actors, although necessary, are not enough to encourage innovation. We have shown that internal capabilities are essential for collaborative development; therefore, the important role of fostering in-house R&D capacity should not be overlooked. Innovation policies should go beyond simply support for these relationships and establish mechanisms to enhance firms' internal R&D capacity. These kinds of interventions would be more effective because they would increase firms' abilities to develop products internally and also increase the probability of successful exploitation of collaboration arrangements.

Finally, in our model, cost is not a predictor of product development behaviour, although environmental uncertainty is. Therefore, policy or managerial tools aimed simply at reducing costs and ignoring the uncertainty faced by firms will likely have little impact on boundary behaviour.

5.6 Limitations and future research

This study has some limitations which point to areas for future research. First, since our dependent variable is self-reported, firms with high levels of R&D capacity might be more likely to report that innovations were developed primarily in-house due to pride, regardless of the contributions made by external actors (Robertson and Gatignon, 1998); Not Invented Here Syndrome is a well-noted phenomenon in corporate R&D departments (see e.g. Lichtenthaler and Ernst, 2006). More objective data could help to address such concerns. Second, our dependent variable may have limited value for evaluating multi-product firms, which may release multiple products developed through several modes. Research could explore the link between product type (e.g. strategic importance, technological complexity, newness) in multi-product firms and the development mode. Third, the aim of using such a large, diverse dataset is to allow broad inferences with wide-reaching policy implications. However, future research could delve into some of the idiosyncrasies and details of specific cases. Finally, national context and diverse cultural attitudes towards risk and cooperation have been shown to moderate the relationship between technological uncertainty and alliance formation (Steensma et al., 2000). Given that Spain, an innovation-follower country, has its own idiosyncrasies regarding innovation (see e.g. Fernandez de Lucio et al., 2010), future research could validate our model in a wider range of cultural contexts and situations since the effects may be stronger or weaker depending on the circumstances.

Despite these limitations, we believe that the results of this study could guide future work aimed at disentangling not just the characteristics of the firms that use external knowledge sourcing as the main strategy to develop new products but also the performance implications of different new product development strategies.

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5.8 Appendix

Table 5.A.1

Robustness checks: pooled multinomial logit with two temporally separate periods (2004 & 2007, Model III) and multinomial probit (Model IV).
(Base category = internal development)

	Model III Multinomial Logit, Separated Periods				Model IV Multinomial Probit			
Variable	**Collaborative**		**External**		**Collaborative**		**External**	
Tech. Uncertainty	0.070	(0.051)	0.120	(0.094)	0.068**	(0.031)	0.063	(0.045)
Market Uncertainty	0.085*	(0.046)	-0.173**	(0.081)	0.062**	(0.028)	-0.067*	(0.038)
Cost	0.051	(0.052)	0.077	(0.090)	0.023	(0.033)	0.009	(0.045)
R&D Capacity	2.557***	(0.735)	-18.710***	(3.057)	1.401***	(0.449)	-9.051***	(1.115)
$(\text{R\&D Capacity})^2$	-2.341**	(1.091)	18.276***	(2.861)	-1.315**	(0.610)	8.845***	(1.091)
Incoming Spillovers	-0.331	(0.484)	-0.738	(0.910)	-0.211	(0.326)	-0.400	(0.478)
Ind. Appropriability	-0.679*	(0.353)	0.258	(0.673)	-0.562**	(0.249)	0.157	(0.372)
Size	0.106**	(0.044)	0.020	(0.076)	0.068**	(0.029)	-0.039	(0.040)
Group	-0.104	(0.099)	-0.556***	(0.196)	-0.066	(0.066)	-0.259***	(0.096)
International	0.075	(0.117)	-0.339*	(0.190)	0.072	(0.071)	-0.221**	(0.098)
New to Market	0.174**	(0.080)	-0.355**	(0.147)	0.174***	(0.050)	-0.192**	(0.075)
High Tech	-0.230	(0.171)	0.031	(0.371)	-0.221**	(0.110)	0.036	(0.188)
Med Tech	-0.328***	(0.097)	-0.420**	(0.195)	-0.210***	(0.063)	-0.313***	(0.101)
Constant	-2.240***	(0.493)	-1.289	(0.924)	-1.777***	(0.317)	-1.050**	(0.479)
Observations	6,768				16,453			
Firms	4,285				4,646			
Log Likelihood	-3,312				-8,032.4165			

*** $p < 0.01$ ** $p < 0.05$ * $p < 0.1$ Standard error in brackets.

CHAPTER 6

STUDY 3:

ACCESSING KNOWLEDGE THROUGH INDUSTRY-UNIVERSITY INTERACTIONS: THE EFFECT OF R&D CONTRACTING AND COOPERATION ON PRODUCT INNOVATION NOVELTY[53]

Abstract

The role of universities in commercial product innovation has received considerable attention over the past decade. However, little is known about how the type of formal university-firm interaction predicts innovative performance and the degree of novelty of new products. This research differentiates two forms of firm high-relational interaction with universities: R&D contracting and cooperation. We exploit the panel structure of a dataset of 5,858 Spanish manufacturing firms with fixed-effects models to control for much of the unobserved heterogeneity, such as proximity to a university, that is inherent in industry-university relationships. We control for other innovation activities, namely internal R&D efforts and contracting and cooperation with commercial agents. The empirical analysis finds that, although both contracting and cooperation predict product

[53] Developed with Jaider Vega-Jurado and Liney Manjarrés-Henríquez

innovative performance, the two activities differ in the degree of novelty of new product outcomes. In particular, contracting to universities predicts the share of sales from products that are less novel (new to the firm), whereas cooperation with universities is a significant predictor of the share of sales from products that have a high degree of novelty (new to the market). Furthermore, we find that R&D cooperation with universities, but not contracting, predicts the number of firm patent applications, additional evidence that cooperation with universities generates knowledge that is more novel. The implications are that the codified nature and asymmetric scope of R&D contracting is more suitable for exploitative innovation, resulting in product innovation that is incremental in nature. On the other hand, the possibility to exchange and create tacit knowledge and the explorative nature of R&D cooperation provide firms with the opportunity to better access the broad knowledge base of universities, leading to product innovations with a high degree of novelty.

Keywords: R&D cooperation, R&D contracting, innovation, innovative performance, new product development, universities, product novelty

6.1 Introduction

The academic literature consistently emphasizes that firms rarely innovate alone and that the development of new products increasingly depends on the firm's capacity to access and exploit external sources of technological knowledge (Laursen and Salter, 2006). Thus innovation is recognized as a distributed and interactive process among a number of economic actors rather than the province of individual firms (Chesbrough, 2003; Tether, 2002).

Among the wide variety of agents with which firms can relate, universities have taken pride of place as partners, and academic research has come to be considered as one of the engines of industrial innovation (Henderson, Jaffe and Trajtenberg, 1998; Mansfield, 1998). Based on this belief, many OECD governments have launched, starting from the late 1970s, important initiatives to encourage greater interaction between universities and firms (OECD, 2003; DIUS, 2008). More recently, this has been reflected in the so-called 'third mission' of universities and greater efforts to measure the economic impact of such activities (Molas-Gallart and Castro-Martinez, 2007). Accordingly, the analysis of the effects of this kind of interaction has become an outstanding topic of interest for practitioners and policy makers.

However, despite this interest, tracing the effects of universities on industrial innovation has been a difficult task because of the wide spectrum of mechanisms through which knowledge may be exchanged as well as the complex set of factors that moderate the relationships between these agents (Ahrweiler, Pyka and Gilbert, 2011; Salter and Martin, 2001). University-industry links may involve a number of different organizational arrangements, ranging from collaborative research to temporary personnel exchanges. In this sense, our knowledge of the role of universities in industrial innovation is still limited since much of the existing research focuses on low-relational activities, such as patenting and licensing, while largely neglecting the linkages that are more intensive and used by firms more often, such as joint research and contract research (D'Este and Patel, 2007). This is especially true when it comes to the characteristics of the firm strategy for exploiting university knowledge and the use of systematic, large-scale empirical data to analyze it. As a result, multiple and even contradictory messages emerge from the empirical works carried out so far. Thus, while some studies show that university-industry links positively affect firms' innovative performance (Aschhoff and Schmidt, 2008; Lööf and Broström, 2008), others reveal an insignificant or even negative relationship (Miotti and Sachwald, 2003; Tsai and Wang, 2009).

In this paper, we argue that in order to disentangle the role of universities in industrial innovation, it is important to pay more attention to the specific characteristics of the interaction channel. In particular, we focus on two alternative formal arrangements with universities: R&D contracting and cooperation. According to Perkmann and Walsh (2007), these two types of links imply a higher level of relational involvement between universities and firms compared to other mechanisms such as mobility (e.g. academic entrepreneurship, human resource transfer) and transfer links (e.g. licensing of university-generated IP). Therefore, they may provide a better understanding of the interactive nature of innovation processes. As these authors point out, "in the context of open innovation, it is particularly the links with high relational involvement that are of interest, as they facilitate the building and maintenance of interorganizational relationships" (Perkmann and Walsh, 2007: 563).

The present study addresses the following questions: (1) Are (both types of) high-relational research interactions with universities (R&D contracting and cooperation) significant predictors of firm innovative performance? (2) If so, how do R&D contracting and cooperation with universities differ in terms of the novelty of product innovation and knowledge generated? In so doing this study makes several contributions to the literature.

First, while previous studies have focused on the impact of cooperation with universities on different measures of innovative performance, no detailed empirical evidence exists on the role of contract research; we have not found any study that simultaneously considers the effects of these two types of university-industry relationship on firm innovative performance[54]. This is surprising given that the differences between collaboration, as a hybrid form of boundary-spanning organization, and external contracting to the market are stressed in the management literature (Lucena, 2011; Narula, 2001; Powell, Koput and Smith-Doerr, 1996; Robertson and Gatignon, 1998). This study builds on a clear distinction between cooperation and contracting and thus sheds light on the process through which universities may influence innovation.

Second, this work is not only among the first to compare the effect of university-industry links derived from two types of relationships, but it also carries out the analysis using panel data. Many of the empirical studies on university-industry relationships have drawn mainly from survey data, especially those coming from the Community Innovation Surveys (CIS). The use of this kind of data has allowed researchers to consider large samples of firms belonging to different industrial sectors, thus gaining a broad view of the phenomenon. However, most of these studies have a drawback in that they are cross-sectional and employ a controlling-on-observables

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[54] A notable exception is the paper by Cassiman et al (2010), who investigate the project-level characteristics affecting the organization of links with universities. However, the focus of their work is more on the drivers of contracting and cooperation with universities rather than their effects on industrial innovation, which is the purpose of our current work.

estimation approach, which makes it difficult to account for certain sources of endogeneity (Leiponen, 2005; Lucena, 2011)[55]. This is especially important in our study since university-industry links and innovation outputs may be determined simultaneously or may depend jointly on other unobserved factors, such as proximity to a university (Mairesse and Mohnen, 2010). We control for much of the unobserved heterogeneity by exploiting the panel structure of the dataset, which is comprised of six waves of the Spanish Innovation Survey (see Methodology section for an explanation).

This article is organized in the following way. First, we discuss the potential effects of R&D contracting and cooperation with universities on firm innovative performance. We then move to a description of our research design followed by the presentation of the empirical results. We conclude by discussing the implications of our findings, the limitations of our study, and possible future research lines.

6.2 Literature review

Many academics, practitioners, and policy makers view universities and other publicly funded research organizations as important sources of scientific and technological knowledge for firms' innovation activities. The recent open innovation literature and other types of network perspectives toward industrial innovation (e.g. innovation systems, triple helix) point out that by linking with universities, firms can access specialized knowledge and skills that benefit their product innovations (Caloghirou, Kastelli and Tsakanikas, 2004; Laursen and Salter, 2004).

The above propositions, however, have not been clearly supported with systematic empirical research due, among other reasons, to the diverse nature of university-industry links. Schartinger et al. (2002), for instance, identify sixteen types of 'channels' or 'mechanisms' through which knowledge may be transferred between academics and industry personnel, grouped into four categories: joint research, contract research, mobility, and training. Using this classification as a starting point, Perkmann and Walsh (2007) suggest a more general typology by distinguishing university-industry

[55] See Eom and Lee (2010) for a discussion and application. They demonstrate that cooperation with universities increases the probability of firm innovation, but only when controlling for endogeneity, which they do using an instrumental variables estimation approach.

relationships from other mechanisms such as human mobility or technology transfer. According to these authors, while the former imply links with a high-relational involvement where university researchers and industry employees work together on a specific project, the latter are more generic as they do not necessarily require face-to-face contact between academics and industry users.

Perkmann and Walsh (2007) also point out that while empirical research has been especially prolific in the analysis of links with lower levels of relational involvement (by using data on patents, publications, licensing), the specificities and roles of inter-organizational relationships between firms and universities remain under researched. The higher-involvement relationships are precisely the focus of this paper: R&D contracting and R&D cooperation.

Although there is some debate in the literature on the existence of a sharp distinction between these two types of relationships (Barge-Gil, 2010), the organizational literature on the boundaries of the firm has stressed several differences between cooperation and contracting as innovation governance modes, which are equally applicable in the context of university-industry links.

From a transaction cost perspective, contracting represents a governance mode close to market structure, in which the firm opts to farm out to universities, entirely or partially, the development of an R&D project. In this kind of arrangement firms specify unilaterally what type of expertise they require (specific objectives and deliverables), and the academic researchers perform the assignment against payment (Perkmann and Walsh, 2007). In contrast, cooperation represents a hybrid governance mode between hierarchical transactions within firms and arms-length transactions in the market place. In collaborative arrangements both parties participate in the activities and contribute to the relationship by sharing knowledge and pooling resources (Hagedoorn, Link and Vonortas, 2000). Cooperation resembles markets in that the partners remain autonomous parties, driven by their own interests. However, cooperation also resembles a hierarchy in that the partners agree to make the decisions jointly, which leads to a greater capacity to face unanticipated circumstances when coordinated action from the parties is required (Cassiman, Di Guardo and Valentini, 2010; Croisier, 1998).

Due to these differences in the organization of the relationship, contracting and cooperation vary not only in terms of the firm's control and ownership of outcomes, but also in their capacity to ease the exchange of knowledge and/or resources between academics and industry employees. The nature of the partner interface – such as communication patterns and the governance structure – can ease or hinder the ability of the firm to access the university's knowledge (Sherwood and Covin, 2008). Therefore, it is reasonable to assume that the effect of university-industry relationships on industrial innovation is likely to differ across the type of agreement adopted for organizing the relationship. This aspect, however, has been neglected in the empirical literature, and most of the studies conducted so far tend to emphasize the role of collaborative networks or analyse the effect of university-industry relationships in a very generic way without specifying the type of link formed (Cassiman, Di Guardo and Valentini, 2010).

The following section presents a description of the characteristics of these two types of relationships as well as some empirical evidence from existing literature about their effects on firm innovative performance.

6.2.1 R&D contracting and university-industry cooperation as innovation strategies

The literature has documented a number of expected benefits of R&D contracting (Calantone and Stanko, 2007; Quinn, 2000). In general, it has been suggested that this strategy allows a firm to tap into knowledge and resources from external partners as well as to focus more on its internal core capabilities, thereby facilitating faster product development (Tsai and Wang, 2009). In the specific case in which the provider of R&D services is a university, the benefits of R&D outsourcing may be even higher since universities may provide different and complementary skills and resources with a large potential for learning (Un, Cuervo-Cazurra and Asakawa, 2010)[56]. Thus, many scholars have stated that while acquisition of external knowledge from agents within the supply-chain enables a firm to deepen its existing technological competence, drawing from research organizations provides a firm with the opportunity to explore new

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[56] Complementary knowledge may be defined as such knowledge that has a low degree of overlap or redundancy with the knowledge base of the firm (Knudsen, 2007).

technological areas and helps to broaden its technological knowledge base (Faems, Van Looy and Debackere, 2005).

Bearing in mind the above-mentioned aspects and the fact that in R&D contracting the activities are explicitly commissioned by the firm (by establishing specific objectives and outcomes), it is reasonable to expect a positive effect of this strategy on a firm's innovative performance. However, R&D outsourcing to universities may encounter some particular problems that may limit its success as innovation strategy. On the one hand, contracting may lead the firm to lose the capacity to develop the R&D activities internally, thus weakening its technological competences (Coombs, 1996). In addition, contracting may imply some extent of knowledge leakage from the firm, which in turn may compromise the distinctiveness of the innovative outcome. This is the case because firms usually allow the external provider access to their knowledge base in order to carry out the work effectively (Fey and Birkinshaw, 2005). On the other hand, scientific and technological knowledge from universities may be so complex in nature that it may be hard to assimilate and exploit via market arrangements (Nonaka, 1994). Further, problems of culture clashes and bureaucratic inflexibility may hinder the transfer of knowledge from universities to industrial firms (Knudsen, 2007; Spender, 1996). In these situations, more integrative strategies are required in order to facilitate the assimilation and exploitation of university knowledge. Cooperation, therefore, appears as an important technology acquisition alternative. By cooperating with universities, firms may not only share the risks and costs associated with basic research, but also build capabilities they would not get by simply contracting out the work to meet their needs (Colombo, 2003; Veugelers and Cassiman, 2005). Because of the close interaction during a collaborative agreement, not only the knowledge itself, but also the competencies of the partners can be shared (Fey and Birkinshaw, 2005). In this way, cooperation may be a more appropriate strategy to exploit a pool of different but complementary knowledge.

Nevertheless, despite the potential benefits of cooperation with universities, this strategy may also suffer some limitations as far as promoting innovation is concerned. In collaborative arrangements the objectives and outcomes are jointly defined by the partners and, taking into account the generation of output of high academic relevance primarily motivates university involvement, cooperation might be targeted at more basic research and be long-term oriented. In fact, there is a general belief that research partnerships between universities and firms are usually aimed at the development of basic research with no clear commercial application (Un, Cuervo-Cazurra and Asakawa, 2010). Thus, cooperation with universities may not directly influence the success of a firm's innovation output; rather, it may just be oriented to foster learning processes and capacity-building.

The empirical evidence on the effect of these two types of university-industry relationships is also not conclusive. In the case of R&D outsourcing, while a number of studies point to its benefits on firms' innovative performance, systematic empirical studies on its effectiveness remain scarce (Stanko and Calantone, 2011). Three exceptions are the papers by Tsai and Wang (2009), Vega *et al.* (2009), and Fey and Birkinshaw (2005), which explore the effect R&D outsourcing on technological innovative performance. In these studies R&D outsourcing is found to have no significant effect on technological innovation, although none of them distinguishes the outsourcing of R&D services to universities from R&D outsourcing to other agents.

Regarding cooperation, the empirical literature is more extensive but has produced contradictory results. Based on data for a large sample of Dutch innovating firms, Belderbos *et al.* (2004) find that firms that cooperate with universities in their R&D activities show higher sales growth due to new products than firms that do not cooperate. This result is in line with those in Lööf and Broström (2008) and Aschoff and Schmidt (2008), based respectively on the Swedish and German CIS, which find that cooperation with scientific agents (universities or research institutions) has a positive effect on the share of sales of products new to the market. In addition, based on a CIS dataset of 1,460 French firms, Monjon and Waelbroeck (2003) find that cooperation with universities (foreign rather than domestic) increases the probability of radical innovation.

The above studies all reinforce the idea that universities are likely to stimulate innovation in firms. However, there are studies that also use data from innovation surveys and come up with different conclusions. Miotti and Sachwald (2003), for instance, find that cooperation with public institutions has no significant effect on the share of turnover from innovative products. Tsai and Wang (2009) find a similar result in that collaboration with research organizations has a negative effect on improving innovative performance.

In sum, we can find different arguments to support opposite expectations about the success of R&D contracting and cooperation with universities as innovation strategies. On the one hand, R&D outsourcing has the potential to promote a faster innovation process, but due to the barriers arising from the cultural and organizational differences between firms and universities, several coordination and communication problems may emerge from this strategy thus limiting its impact on innovative performance. On the other hand, although cooperation may enable the firm to face coordination problems more effectively than technology acquisition via market procurement, the basic or fundamental nature of the research activities characterizing this kind of arrangement may make it difficult to obtain tangible outcomes, especially in the short term.

6.2.2 Novelty of the innovation outcome

So far we have discussed the effects of university-industry relationships taking into account the organizational form adopted for managing the relationship. However, the search for innovation can span not only organizational boundaries but also technological ones (Rosenkopf and Nerkar, 2001), leading to another dimension in the analysis: the degree of novelty of the innovation outcome. It is generally accepted that more novel innovations provide firms and society with greater benefits than ones which are incremental in nature, leading to a stream of literature on the sources of truly innovative products (Sorescu, Chandy and Prabhu, 2003) and the organizational conditions that enable their commercial success (Gatignon and Xuereb, 1997).

Along these lines, the literature review suggests that the benefits of university-industry relationships could be investigated by considering the explorative nature of interaction and the innovative result. Following March's (1991) dichotomy of exploration and exploitation, several researchers have addressed the analysis of R&D alliances by distinguishing between exploitative and explorative collaborations (Dittrich and Duysters, 2007; Faems, Van Looy and Debackere, 2005). While the former is oriented to enhancing existing competences, the latter is aimed at creating new ones. Thus, explorative collaborations are accepted to be especially successful in the creation of products with a high degree of novelty (e.g. market novelties) or in the development of new technology in the form of patents; exploitative collaborations are related more to the improvement of existing products. To a large degree, this idea also goes hand-in-hand with the distinction between complementary versus supplementary knowledge. While supplementary knowledge may fit better with the firm's current knowledge base and can be expected to improve existing organizational competences, complementary knowledge is more likely to provide new ideas that lead to the development of new projects and use of existing skills in different ways (Knudsen, 2007). Traditionally, universities have been considered a source of complementary knowledge for the firms and, therefore, collaboration with these agents is considered to be of a more explorative-oriented nature.

However, in the light of the discussion presented in the previous section, the question that emerges is how the organizational form adopted for managing university-industry relationships influences the explorative nature of this relationship. In this sense, the underlying premise in this work is that the type of relationship (contracting or cooperation) may have different effects on innovative performance according to the explorative nature of the innovation outcome. Since the literature on these effects is scarce, the present study does not state specific hypotheses but comments on the results.

6.3 Methodology

6.3.1 Exploiting panel data

The empirical analysis uses six waves (2004-2009) of the Spanish Technological Innovation Panel (PITEC). Like other Community Innovation Surveys, the PITEC is based on the OECD's Oslo Manual. The Spanish National Statistics Institute (INE) provides the data as a subset of more R&D active firms from the National Innovation Survey. The unit of analysis is the single enterprise, whether an independent firm or part of a group. We restrict the analysis to the manufacturing industry.

We exploit the panel structure of the data to account for unobserved heterogeneity by means of conditional fixed effects (CFE) models. Fixed effects are factors that remain constant over time yet may influence innovation and be particular to each individual firm, such as proximity to a world-class university, organizational structure, reputation and brand, industry, etc. (Allison, 2009). Accounting for fixed effects reduces omitted variable bias and, along with the inclusion of the dimension of time, provides researchers with a closer experimental approximation (Angrist and Pischke, 2009; Nichols, 2007). Essentially, each firm acts as its own counterfactual; this reduces many possible sources of endogeneity, such as the point that more prestigious firms may be more likely to cooperate with universities in the first place (Monjon and Waelbroeck, 2003). As Blundell *et al.* state, "unobservable permanent heterogeneity is an important feature of any empirical model of innovation activity" (1995: 333), and the importance of controlling for the aspects of firms which interact with universities in particular has been stressed in recent literature (Eom and Lee, 2010). We discuss the specific estimation approaches in the section below.

The survey asks firms whether they have introduced a new product or process, invested in innovation, or had ongoing or abandoned innovation activities during the period covered by the survey. A positive answer to one of these questions classifies a firm as *innovation oriented*. We use this selection criterion to restrict our analysis to the subsample of innovation-oriented firms. This decision was driven partly by the questionnaire design: only innovation-oriented firms fully complete all sections of the questionnaire, including those questions related to cooperation with external agents. Roughly 86% of the firms are innovation oriented. After deleting observations with missing values, we are left with an unbalanced panel of 5858 manufacturing firms over six periods[57].

6.3.2 Definition of the variables

Dependent variables

This paper uses three dependent variables to estimate the effect of university interaction mechanisms on innovative performance. A pair of variables measure the share of sales from product innovations that are new to the firm (INNFIRM) or new to the market (INNMARKET) (Faems et al., 2010; Laursen and Salter, 2006; Leiponen and

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[57] In a cross-sectional, controlling-on-observables analysis, dropping non innovation-oriented firms could result in a selection bias, while conversely including them without correction would likely lead to upwards bias in the estimations. Fortunately, selection bias is rarely a problem in fixed-effects estimation since the unobserved variables influencing selection are generally captured either in the fixed effect or through additional controls, such as year dummies (Kennedy, 2003: 312).

Helfat, 2010; Mairesse and Mohnen, 2002). These variables provide information on the novelty of product innovation and also how much of the firm sales such innovations account for. There is a fair amount of ambiguity in the literature surrounding terminology and definitions of what constitutes 'incremental' and 'radical' innovation (Chandy and Tellis, 1998; Garcia and Calantone, 2002). However, INNFIRM and INNMARKET are understood in the literature to capture the degree of product innovation from less to more novel, respectively (Laursen and Salter, 2006). The third variable is related to the patenting activity and measures the number of patent applications per firm in each period (LPATNUM). We log transform the variables (after adding 1) to account for skew and satisfy distributional assumptions in the models.

Altogether, these three variables allow us to explore the effect of university interaction on different dimensions of firm innovative performance and to evaluate the exploitative- or explorative-oriented nature of these kinds of relationships.

R&D contracting and cooperation variables

Our explanatory variables cover specific university interaction mechanisms, in particular R&D contracting and cooperation. Although the main objective is to analyse firm interaction with universities, we control for the effect of interaction with other agents on innovative performance. In addition to universities, we control for interactions with commercial actors consisting of other firms (competitors, suppliers, and commercial R&D laboratories). We group these commercial agents together because the R&D contracting variable does not distinguish between the three types of firms in the same level of detail as for cooperation.

To analyse the effect of cooperation we draw specifically on the responses to questions about cooperation with external agents for R&D and innovation activities. We define a set of two dummy variables indicating each of cooperation with universities (COOP_UNI) and commercial agents (COOP_COMM). In order to evaluate the effect of R&D outsourcing we draw on the responses to a question that asks firms to indicate expenditure on R&D services by different external agents. This information allowed the construction of two dummy variables specifying R&D contracting to universities (RD_UNI) and commercial agents (RD_COMM).

Control variables

Given that we account for fixed effects, we need only to control for variables that are subject to change over time. Stable firm characteristics, which are often included as controls in cross-sectional analyses, cannot be estimated nor included in the model. The result is a parsimonious model.

We control for changes in several firm-level variables, namely the firm size measured in the log of revenue (LSIZE) and a dummy indicating whether the firm has sales in international markets outside of the European Union (INTERNATIONAL). Note that the firm size and market, in general, are controlled for in the fixed effects; these variables control for changes in firm size, such as through a merger or layoff. We include a variable to measure the intensity of internal R&D activities. The variable LEMP_RD is the natural logarithm of the percentage of employees who dedicate at least some of their time to R&D activities (Belderbos et al., 2004; Faems et al., 2010).

We include dummy variables for each year. This two-way fixed-effects model controls for time effects and general economic conditions such as changing government policies, new general technologies, and the financial crisis (Baltagi, 2005).

6.3.3 Estimation approach

Because many innovation-active firms do not achieve sales from new products or apply for patents, these variables are censored at zero and non-negative. If the censoring is not accounted for, the estimates can be biased (Chay and Powell, 2001). Censoring of a continuous variable expressed as a proportion leads to a significant difficulty in accounting for firm-specific effects (Reitzig and Wagner, 2010). Although a Tobit model is the appropriate estimator in censored cross-sectional analyses, there is no sufficient CFE Tobit estimator (Greene, 2004)[58]. Therefore, we compare the results of several econometric approaches.

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[58] Although a sufficient estimator exists for the random-effects Tobit, random-effects make the strong assumption that the unobserved variables are uncorrelated with the independent variables in the model. A Hausman test confirmed that the random-effects assumption does not hold for our sample (Hausman, 1978).

We first estimate INNFIRM and INNMARKET using CFE ordinary least-squares (OLS) regression. Angrist and Pischke (2009) argue in favour of OLS over non-linear models; OLS does not depend on distributional assumptions of a latent variable and estimates the average effect of each covariate considering that the outcomes are actually zero for many firms. They contend that, while non-linear models in many cases provide accurate predictions regarding coefficient direction and significance within the bounds of true censoring, OLS is standardized, more parsimonious, and can be interpreted directly as average marginal effects.

Next, we estimate the models for INNFIRM and INNMARKET using the semiparametric fixed-effects Tobit (Honaré 1992). The method artificially trims the data and eliminates the fixed effects through differencing, resulting in a consistent estimator (Cameron and Trivedi, 2010: 808). The distribution of the errors in this method remains unspecified, and no distributional assumption is imposed on the unobservables (Honoré, Kyriazidou and Powell, 2000).

Finally, we estimate the continuous variables with the CFE Poisson[59]. The properties of the CFE Poisson both condition out fixed effects and account for censoring at zero. Even though INNFIRM and INNMARKET are not count data, the CFE Poisson is still applicable to continuous variables in log-log models because it is equivalent to the Generalized Method of Moments (GMM) estimator (Windmeijer and Santos Silva, 1997). The CFE Poisson is attractive because it (1) produces consistent estimates even with heteroscedasticity of unknown form due to omitted variables; (2) is robust to distributional failure and serial correlation; (3) is highly efficient; and (4) deals well with zero-censored variables (Santos Silva and Tenreyro, 2006). It gives consistent estimates under the relatively weak assumption that the conditional mean equals the conditional variance (Cameron and Trivedi, 1998)[60]. We calculate robust standard errors to adjust for any over or under dispersion (Cameron and Trivedi, 2010;

[59] In order to estimate a censored variable expressed as a percentage, Reitzig and Wagner (2010) rearrange the CFE Poisson equation such that the numerator becomes the dependent variable and the denominator enters the regression as a covariate. Rearranging our regression in this way produces essentially the same results as directly estimating INNFIRM and INNMARKET.

[60] This is a reasonable assumption: the unconditional mean is approximately equal to the within variance for both INNFIRM ($\mu = 1.55$, $\sigma^2 = 1.26$) and INNMARKET ($\mu = 1.08$, $\sigma^2 = 1.02$).

Wooldridge, 1999)[61]. Comparison of the estimates from the three approaches provides an idea of the extent of the censoring and confidence in the robustness of the results.

6.3.4 Descriptive statistics

Table 6.1 presents the definitions and descriptive statistics of the variables, which are reported prior to log transformation.

Table 6.1. Descriptive statistics and definitions of variables

Variable	Description	Mean (*within* s.d.)
INNFIRM	sales from products new to the firm / total sales	16.6% (20.4)
INNMARKET	sales from products new to the market / total sales	10.7% (16.3)
PATNUM	number of patent applications	0.780 (5.540)
RD_UNI	R&D contracting to universities (dummy)	0.096 (0.189)
COOP_UNI	cooperation with universities (dummy)	0.127 (0.202)
RD_COMM	R&D contracting to commercial agents (dummy)	0.210 (0.276)
COOP_COMM	cooperation with commercial agents (dummy)	0.212 (0.264)
EMP_RD	employees engaged in R&D activities / total employees	10.4% (9.10)
SIZE	total firm sales (millions of €)	57.0 (87.3)
INTERNATIONAL	product sales in an international market (dummy)	0.818 (0.179)

Note: Mean reported prior to log transformation. *Within* standard deviation in brackets.

Keeping in mind that the PITEC draws from a subset of R&D active firms in the national innovation survey, 12.7% of the innovation-oriented firms engaged in active cooperation with universities. The pattern of R&D contracting in our sample is comparable to cooperation but lower: 9.6% of firms contracted R&D to universities. Veugelers and Cassiman (2005) report a European average from CIS-III of 8.3% of innovative firms reporting cooperative agreements with universities, with the level of university cooperation (5%) in Spanish firms from the broader national innovation

[61] See Santos Silva and Tenreyro (2006) for a detailed discussion and application of the CFE Poisson to censored continuous variables.

survey generally lower than the European average. In comparison, studies on much smaller Spanish samples found that 25% of firms (N = 781) engaged in R&D collaboration with universities (Un, Cuervo-Cazurra and Asakawa, 2010) and that, in general, 19% contracted and 29% cooperated on R&D (N = 1,034) with any other actors (Lucena, 2011). In our sample, both contracting and cooperation with commercial actors is roughly 21%, although this variable captures a number of commercial partners. Thus our large sample seems fairly representative of firm behaviour found in typical innovation-oriented firms.

Although not presented in Table 6.1, 5.5% of firms both contracted R&D to and cooperated with universities concurrently. Stated differently, 43% of firms that cooperated with universities also report contracting R&D to universities. This indicates that firms do not approach these activities as substitutes for one another and may engage in both types of interaction for different purposes.

Regarding the innovative performance measures, firms report 16.6% of sales from products new to the firm and 10.7% of sales from products new to the market. Taken together, this innovation-oriented sample of Spanish firms reports 27.3% of sales from innovative products. This is roughly in line with other CIS-based studies, such as the European average of 35% in Mairesse and Mohnen (2002) and 23% in a sample of Belgian manufacturing firms (Faems, Van Looy and Debackere, 2005). The average number of patent applications per firm in each period is 0.78, with patenting activity limited to 17% of firms.

Table 6.2 reports the pairwise correlation matrix of the variables and reveals no concerns about multicollinearity. Internal R&D intensity is positively correlated with the R&D contracting strategies. All other innovation strategies show small but positive correlations with one another. In particular, the collaboration strategies are positively correlated. This result is in line with previous research showing that a firm which cooperates with one external agent is more likely to cooperate with other agents.

Table 6.2 Pairwise correlations of variables

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) INNFIRM									
(2) INNMARKET	0.066*								
(3) LPATNUM	0.053*	0.180*							
(4 RD_UNI	0.027*	0.061*	0.160*						
(5) COOP_UNI	0.048*	0.101*	0.178*	0.433*					
(6) RD_COMM	0.061*	0.090*	0.165*	0.208*	0.155*				
(7) COOP_COMM	0.072*	0.103*	0.129*	0.177*	0.404*	0.227*			
(8) LEMP_RD	0.132*	0.213*	0.142*	0.169*	0.166*	0.177*	0.117*		
(9) LSIZE	0.008	-0.007	0.148*	0.121*	0.151	0.124*	0.176*	-0.180*	
(10) INTERNATIONAL	0.053*	0.058*	0.092*	0.067*	0.078*	0.071*	0.080*	0.067*	0.287*

* significant at $p < 0.05$

Internal R&D intensity is positively related to cooperation. This latter result may be an indication of the twofold effect of internal R&D: the greater the effort expended on this activity, the better the ability of the firm to identify and use sources of scientific knowledge (Cohen and Levinthal, 1990). This is not to say that firms that do not cooperate with scientific agents do not perform in-house R&D, but rather that those that do cooperate are generally more active (Bayona, García-Marco and Huerta, 2001).

6.4 Results

Table 6.3 presents the regression results evaluating the effect of university contracting and cooperation of R&D activities on firm innovative performance and the novelty of new products. The explanatory variables of interest are the two formal mechanisms through which firms interact with universities. Models I, III, and V present the results of fixed-effects OLS, Tobit, and Poisson estimations of the sales from products new to the firm (INNFIRM), and models II, IV, and VI present results from products new to the market (INNMARKET). The results are similar across the three econometric approaches in terms of sign and significance, giving us confidence in the robustness of the findings. As standard econometric theory predicts, the CFE OLS estimates are biased downward compared to the FE Tobit due to the censoring. On the other hand, the coefficients from the CFE Poisson are similar to OLS since the CFE Poisson drops firms which never innovate in the six periods of our panel[62].

Overall, interaction with universities has a positive and significant effect on the innovative performance of firms. However, the two interaction mechanisms have different effects according to the degree of novelty of product innovation. University contracting is significant only for innovations new to the firm, while the opposite relationship is seen with university cooperation, which is highly significant only for innovations new to the market.

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[62] We also estimated the models using a CFE negative binomial, which is similar to the Poisson but introduces a term to adjust for any over- or under dispersion. The log likelihoods are identical to the CFE Poisson models (< 1% difference), confirming the Poisson's assumptions. In any case, the CFE negative binomial accounts for fixed effects only under very demanding conditions and cannot easily calculate robust standard errors (Guimarães, 2008; Reitzig and Wagner, 2010).

Table 6.3 Estimation results of university interaction and novelty of product innovation

	CFE OLS		FE Tobit		CFE Poisson		
Variable	**(I) INNFIRM**	**(II) INNMARKET**	**(III) INNFIRM**	**(IV) INNMARKET**	**(V) INNFIRM**	**(VI) INNMARKET**	**(VII) LPATNUM**
University Contracting	0.083** (0.041)	0.012 (0.040)	0.134** (0.066)	0.002 (0.078)	0.052** (0.026)	0.004 (0.032)	0.068 (0.043)
University Cooperation	0.058 (0.044)	0.118*** (0.042)	0.082 (0.069)	0.195** (0.079)	0.034 (0.027)	0.087*** (0.033)	0.096* (0.050)
Commercial Contracting	0.040 (0.031)	0.054* (0.028)	0.063 (0.050)	0.089 (0.058)	0.023 (0.019)	0.036 (0.023)	0.061 (0.039)
Commercial Cooperation	0.146*** (0.036)	0.138*** (0.033)	0.228*** (0.057)	0.269*** (0.066)	0.088*** (0.022)	0.116*** (0.027)	0.147*** (0.045)
Log Share R&D Employees	0.055*** (0.013)	0.084*** (0.011)	0.103*** (0.025)	0.196*** (0.028)	0.038*** (0.009)	0.078*** (0.011)	0.179*** (0.026)
Log Firm Size	0.019 (0.032)	0.026 (0.026)	0.035 (0.060)	0.045 (0.059)	0.013 (0.021)	0.013 (0.022)	0.166*** (0.047)
International	0.017 (0.050)	0.022 (0.044)	0.030 (0.100)	0.065 (0.118)	0.013 (0.036)	0.022 (0.046)	0.111 (0.075)
Year Dummies	Included	Included	Included	Included	Included	Included	Included
Observations	28933	28933	28993	28993	23239	18719	6914
Firms	5858	5858	5858	5858	4384	3472	1465
Log likelihood	-	-	-	-	-27830.94	-21649.44	-3888.40
F-test (12, 5857)	9.12	18.22	-	-	-	-	-
Chi^2	-	-	116.55	242.47	108.36	208.42	117.16
Prob > Chi2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

*** $p < 0.01$ ** $p < 0.05$ * $p < 0.1$ Robust Standard Errors in brackets. FE Tobit Bootstrapped Standard Errors in brackets

Cooperating with commercial partners is a significant and positive predictor of both types of product innovation. Conversely, contracting to other firms does not predict product innovation (except in for the case of the OLS estimation in Model II, where it is significant only at the 10% level). We include these only as controls and are unable to differentiate between the types of commercial R&D contracting partners. These results are generally in line with findings from other studies that show the limited impact of R&D contracting in general (Fey and Birkinshaw, 2005; Tsai and Wang, 2009; Vega-Jurado, Gutierrez-Gracia and Fernandez-de-Lucio, 2009) and importance of commercial technology alliance formation (Aschhoff and Schmidt, 2008; Faems, Van Looy and Debackere, 2005).

Model VII estimates the same set of covariates on the number of patent applications with CFE Poisson regression. Cooperation with universities and cooperation with commercial agents, along with internal R&D, are the only variables that predict patenting. R&D contracting to universities does not predict patent applications. The degree of the new knowledge generated and appropriability strategies are all possible explanations for this behaviour. First, patenting can indicate that the nature of the knowledge generated by these interactions is more explorative; this is in line with the findings from Models I-VI whereby cooperation with universities is significant for more novel product innovation. Second, patenting as an outcome may reflect attempts to appropriate and protect knowledge generated from a collaboration, or even legally ensure equal access to the intellectual property by both firms in the case of shared patent applications.

Unsurprisingly, internal R&D intensity consistently and positively predicts innovation outcomes. In any case, it is informative to compare the magnitude of the coefficient across the degree of product novelty in Table 6.3. Returns to internal R&D are higher for product innovations that are new to the market (Model VI) than for those that are merely new to the firm (Model V) as indicated by the larger coefficient. In order to test whether this is statistically significant, we use a non-parametric bootstrapping procedure with 400 repetitions on the difference in the estimated coefficients between dependent variables[63]. The difference is statistically significant ($p < 0.01$, $\chi^2 = 7.83$). This finding, which is in line with results from Laursen and Salter (2006), indicates that internal resources are more important for developing product innovation that is more novel.

6.5 Discussion and implications

Recently, researchers have emphasized the potential for universities as a source of external knowledge in firms' innovation processes. The purpose of this study was to examine the effectiveness of university-industry links as an innovation strategy, paying special attention to those interactions that imply a higher level of relational involvement – namely R&D contracting and cooperation - and taking into account the degree of novelty of the innovation outcome. Several important findings emerge from the analysis.

First, this research finds that high-relational interactions with universities positively predict firm innovative performance. In general, both R&D contracting and cooperation with universities appear as important strategies in order to introduce new products onto the market. This result is consistent with the open innovation literature and other types of network perspectives toward industrial innovation that highlight the prominent role of universities as innovation partners and their capacity to enhance firms' technological performance (Chesbrough, 2003; Laursen and Salter, 2004).

Second, and even more important, this research uncovers a distinction between the degree of novelty of innovation outcome resulting from R&D contracting and that from cooperation with universities: contracting predicts product innovations that are new to the firm, but cooperation predicts market novelties and patent applications. In general, the effect of cooperation with universities on more novel product innovations and patent applications is consistent with some prior empirical studies (Belderbos *et al.*, 2004; Lööf and Broström, 2008; Aschoff and Schmidt, 2008; Eom and Lee, 2010) and supports the view of the university as an important source of complementary knowledge when exploring novel domains of technology. In contrast, the result from

[63] See e.g. Angrist and Pischke (2009) and Laursen and Salter (2006) regarding the procedure to compare coefficient size across models.

R&D contracting partially differs from those in Vega-Jurado *et al.*, (2009), Tsai and Wang (2009) and Fey and Birkinshaw (2005) on the effectiveness of R&D outsourcing as an innovation strategy. Although neither of these studies specifically analyses the contracting of R&D services to universities, all of them find that R&D outsourcing does not have a positive effect on innovative performance and in some cases even suggest a negative net effect. These results have been explained by firms' reluctance to share relevant knowledge because of the threat of unexpected transfer of knowledge to competitors. To be effective, contracting typically requires a bi-directional flow of knowledge insofar as the firm has to give the external provider access to its own knowledge base in order to achieve enhanced performance. In this sense, problems related to knowledge leakage and the opportunistic behaviour of the R&D provider may arise during the task and may compromise the effectiveness of this strategy. In the light of our results, these problems seem to be less sensitive in the case of universities possibly because these agents are not potential competitors and the social norms in academia favor sharing knowledge rather than monopolizing it (Fey and Birkinshaw, 2005). In terms of implications, this result highlights the distinctive nature of universities as providers of R&D services and points out the importance of choosing the external knowledge source when firms face the acquisition of technology on a market basis. In fact, our analysis also shows that contracting R&D services with commercial partners does not favor product innovation of any degree of novelty.

Another important implication arising from our results is that governance mode matters when considering relationships with universities. Thus different strategies to access university knowledge may lead to different innovative outcomes. So far, most empirical research about university-industry links has addressed these linkages in a generic way while seldom linking the differences between the specific types of relationships with the nature of innovative outcome. Perhaps as a result, previous research has uncovered multiple and even contradictory findings regarding the role of universities in industrial innovation. In this sense, the results of this research bring clarity to the ways through which university links influence firms' innovative performance and the nature of returns derived from them.

The interesting question at this point is why cooperation leads to more novel innovation outcomes than contracting. There are general differences between these strategies that may shed light on our findings. R&D contracting often takes the form of arms-length, iterative exchanges of explicit knowledge largely codified, for example, in the form of blueprints, contracts, results, or technological packages (Lucena, 2011). Since both parties are responding to specific information, R&D contracting limits the scope to clearly defined problems and solutions. Furthermore, the firm often determines unilaterally the expertise required from the university, such that the relationship is asymmetric in nature (Perkmann and Walsh, 2007). In this way the R&D contract initiated and defined by a firm is less explorative in nature and does not fully access the broad knowledge held in a university. Thus although universities are recognized as having a broad base of easily accessible knowledge (Un, Cuervo-Cazurra and Asakawa, 2010), R&D contracting is limited in scope and possibilities for feedback such that firms are not able to take advantage of the full breadth of knowledge in a university to generate market novelties.

On the other hand, R&D cooperation, due to its interactive nature and sharing of resources, promotes the exchange and development of tacit knowledge and exposure to spillovers and heterogeneous knowledge (Lucena, 2011). This may lead the collaboration down a different, explorative path than both parties were able to envision at the outset. Furthermore, cooperation increases the potential for mutual learning because the firm is concerned not only with the knowledge output per se (as in the case of contracting) but also with the process of developing that knowledge. Through cooperation with universities, firms may enhance their knowledge base and create new combinations, making new technological breakthroughs more likely (Fey and Birkinshaw, 2005). The development of innovations with a high degree of novelty is full of uncertainty and often follows an unforeseeable development path. In this sense, cooperation can allow for ambiguity and adjustment during the development of an R&D project.

On balance, the results of this study highlight that the ability of the firm to achieve a higher innovative performance from its relationships with external agents is a function of both the nature of external knowledge sources and the nature of the relationships forged with these sources. Exploring jointly the effect of these factors therefore appears as a prominent line of inquiry in order to go a step further in the analysis of the effectiveness of external knowledge sourcing as innovation strategy. Along these lines, future studies on organizational boundaries and innovative performance should consider that firms may not only forge relationships with several agents (universities, clients, suppliers, and even competitors) but also organize these relationships in different ways, and the way that these relationships are organized has an important effect on the firm's capacity to gain access to external knowledge and develop new competencies from it. In this paper, we focus on the case of universities, and although we have considered the role of other agents as control variables (commercial sources), there is need for more research linking firm strategies to access different external knowledge sources and the nature of the innovative outcome.

This study also offers a methodological contribution in two areas. First, accounting for individual heterogeneity is essential in innovation studies (Blundell, Griffith and Reenen, 1995). Through using each firm as its own counterfactual over time, panel data provides one method of controlling for multitude unobservable yet important characteristics. By including time dummies, two-way fixed-effects models control for period-specific effects such as policy changes or economic conditions that may bias the results a cross-sectional study, for instance by virtue of which period the sample happens to be drawn from. This allows for greater generalizations over time.

Second, the share of sales from new products has been used as a dependent variable in many outstanding empirical studies on innovation (e.g. Faems, Van Looy and Debackere, 2005; Laursen and Salter, 2006; Mairesse and Mohnen, 2002). Unfortunately, this continuous and censored variable presents methodological difficulties in accounting for fixed effects. We apply three models (CFE OLS, FE Tobit, and CFE Poisson) as feasible approaches to account for fixed effects. Although this didn't lead to substantial differences in terms of the statistical significance and sign of coefficients since we have a large sample with robust findings, censoring in smaller samples with more complex sets of variables could lead to misleading conclusions if censoring is not properly dealt with.

6.5.1 Relevance for practitioners

These findings not only are important at a theoretical level but also have important implications for management practice. Managers look increasingly outside firm boundaries for sources of technological innovation, and the general message that arises from this study is that the effectiveness of such processes is to some degree a matter of strategic choice, not only in terms of the type of external knowledge source but also in terms of the way in which the external relationships are structured. Thus diverse relationships with various agents may lead to different innovative outcomes. In particular, the results of this study can help shape managerial decision making and expectations regarding the use of universities as partners in the product development process. Firms may contract to universities for any number of reasons, including cost savings or accessing specialized diagnostic equipment. However, contracting seems to result in less novel product innovations that merely exploit existing know-how, possibly as a result of limiting access to a narrow range of the university's broad knowledge base. Conversely, the returns to cooperation are higher for market novelties.

6.5.2 Limitations and future research

Large datasets permit broader generalizability but necessarily omit many idiosyncrasies, such as how the observed relationship may differ according to industrial factors. Future research could seek to understand under what conditions our general results do or do not hold. Further, we have made a number of assumptions based on the literature regarding the nature of the differences in university R&D contracting and cooperation, such as communication patterns and the type of agreements. More detailed research could seek to break down and operationalize differences in contracting and cooperation with universities in order to see how these factors contribute to the innovative performance and novelty of product innovations.

Our research examined an important innovation outcome: sales from innovative products. There may be other tangible and intangible organizational consequences that differ between contracting and cooperation with universities, such as process innovation, appropriability of results, profitability and project costs, time to market, etc. Given that these two modes of formal interaction seem to have fundamental differences in terms of knowledge creation and transfer, future research could explore broader implications for firm performance.

This study takes the case of Spain. Prior empirical literature has often focused on highly technologically intensive environments, characterised by a large number of R&D intensive firms and a long history of relationships between scientific agents and industrial organizations. Spain, in contrast, is a technology follower country with a manufacturing structure based on small firms with weak links between private and public actors (Eurostat, 2007)[64]. Thus, a structured comparison of the results with those from leading economies would be informative.

Finally, future research could explore the impact of R&D contracting and cooperation on university behaviour and scientific output. Universities are, after all, the other party in the relationship, and it would do little for the public good if firms were poisoning their own wells. A discussion on this is out of the scope of this article, but understanding the effects of these relationships on university output is still an important concern for policy makers.

[64] According to the fourth Community Innovation Survey (CIS-4), cooperation between firms and research centres in Spain is lower than the European average.

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CHAPTER 7

STUDY 3:

MODES OF OPEN INNOVATION IN SERVICE INDUSTRIES AND PROCESS INNOVATION: A COMPARATIVE ANALYSIS[65]

Abstract

This broad study empirically compares the returns to different open innovation approaches, namely forms of pecuniary acquisition and non-pecuniary sourcing, on both product and process innovation in low-tech service and manufacturing firms. A fixed-effects analysis reveals differing patterns of the effectiveness of open innovation strategies across sectors and type of innovation outcome, along with decreasing returns from being "too open". In general, the purchase of intangible intellectual property and broad search breadth have greater effects on product innovation, whereas the returns to knowledge

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[65] Kask, Sean (2011). "Modes of Open Innovation in Service Industries and Process Innovation: A Comparative Analysis." In Open Innovation at Firms and Public Administrations: Technologies for Value Creation. Ed. C. de Pablos Heredero and D. López. Hershey, PA: IGI Global, 15-36.

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embodied in physical artefacts and to drawing deeply from external sources are greater for process innovation. Overall, external sources of knowledge more strongly predict innovation in low-tech service firms than in the manufacturing sector. The final section considers implications for managers and policy makers.

7.1 Introduction

Open innovation, which posits that firms should use external knowledge in their internal innovation process, is an approach which is increasingly embraced by firms. In the short time since the term open innovation has been coined (Chesbrough, 2003b), numerous academic research projects, conferences, and specialized service providers quickly sprung up dedicated to the topic (Fredberg, Elmquist, & Ollila, 2008; Lichtenthaler, 2011). Many corporations have recently started to formalize open innovation into designated departments and roles; consider, for example, Hewlett-Packard's "Open Innovation Office" or the employees with the job title "Director of Open Innovation" walking the halls of General Mills, Nokia, and Unilever. A number of leading firms have introduced open innovation competitions and initiatives, such as Sarah Lee's Open Innovation Portal or Cisco's I-Prize competition (Drakos, 2008). Indeed, authors have observed a bandwagon effect as open innovation gains momentum, with many senior executives "under increasing pressure to justify their refusal to cooperate with the outside world and exploit the open innovation wave" (Gassmann, Enkel, & Chesbrough, 2010: 215). Supported by numerous case studies that corroborate the positive results of open strategies (Chesbrough & Garman, 2009; Huston & Sakkab, 2006; Rohrbeck, Hölzle, & Gemünden, 2009), open innovation has become an imperative for firms over a relatively brief period of time.

However, despite all the excitement as policy makers and firms race to embrace open innovation, most of the research is drawn from case studies on product development in large, multinational high-tech firms or niche business models and open source (Chesbrough & Crowther, 2006). This means that, as a young, emerging theory, it lacks empirical support and generalizability across diverse conditions and businesses (Van de Vrande, Vanhaverbeke, & Gassmann, 2010; West, Vanhaverbeke, & Chesbrough, 2006: 302).

This chapter looks at some of these under-studied circumstances by addressing different sectors, modes of open innovation, and objectives. In particular, it (1) compares the effectiveness of various inbound open innovation activities between low-tech manufacturing and service sectors; (2) evaluates the returns to several strategies for conducting open innovation, including different forms of pecuniary (monetary) and non-pecuniary external sourcing; (3) and examines objectives beyond products to include a firm's process innovation. The chapter also includes a discussion and analysis of the potentially adverse consequences of being "too open". The analysis links these factors to firm innovation performance by comparing the "returns" or "effect sizes" across innovation type and sectors. Thus the general aim is to bring these important yet understudied topics into the open innovation discussion. A panel survey of innovation activities in 3,800 Spanish low-tech manufacturing and service firms over a four year period provides the sample for the analysis.

The remainder of the chapter is organized as follows: (1) the first section reviews the literature and generates several hypotheses. This includes a review of process innovation, the nature of innovation in the service industries, the relationship of different modes of inbound open innovation with these factors, and decreasing returns from over-searching. (2) The empirical section presents the data and variables used in the analysis. It explains the methodology and advantages of fixed-effects estimation. (3) The next section discusses the results of the empirical estimations in relation to the hypotheses and the significance of the uncovered patterns. (4) The concluding section proposes implications for managers and policy makers and identifies directions for future research.

7.2 Theory development and hypotheses

7.2.1 Product and process innovation

To date, the open innovation literature has focused on the generation of commercial products. Unfortunately, this concentration on product development neglects an important avenue of firm competitiveness and profitability: process innovation (Niehaves, 2010). Process innovation is defined as "new elements introduced into an organization's production or service operations—input materials, task specifications, work and information flow mechanisms, and equipment used to produce a product or render a service—with the aim of achieving lower costs and/or higher product quality" (Reichstein & Salter, 2006). Process innovation is an important source of firm performance and productivity growth (Vivero, 2002), and new processes used to produce and deliver goods and services are often central to a firm's ability to compete in terms of costs, quality, and flexibility (Pisano, 1997). The following section links differences in product and process innovation to particular open innovation activities.

Further to simply including process innovation, the structure of the analysis enables a distinction between process innovation in service and manufacturing sectors. Process innovation in service industries can differ substantially from that in manufacturing since, often by nature, the delivery of the service is tied to the locus of its production (Berry, Venkatesh, Parish, Cadwallader, & Dotzel, 2006). Competitive advantage comes not merely from *what* a service firm does for a customer, but *how* it is delivered. Since some authors argue that services are commoditized at an even faster rate than most goods (Pine & Gilmore, 1999), even low-tech service firms must continuously innovate in order to remain competitive. Therefore, returns to sourcing strategies on process innovation are considered and compared between industries in the analysis.

7.2.2 Modes of inbound open innovation

Innovative search describes the adaptive process by which organizations learn, develop and explore new technologies and new ways of doing things (Levinthal & March, 1981). Search efforts can be inwardly (e.g. R&D, operations analysis) or externally (e.g. imitation, external sourcing) focused (Nelson & Winter, 1973), can vary in depth and scope of information sources accessed (Katila & Ahuja, 2002), and can be directed towards sources both within and external to a firm's industry (Katila, 2002). Each search strategy can thus vary along many dimensions such as locus, timing, knowledge source, and the degree to which limited resources are directed towards exploring new ideas or exploiting existing knowledge (March, 1991). Chesbrough's argument for the shift towards an open innovation paradigm predicts search strategies that are more externally oriented. As such, there is variety in potential external search strategies available to firms. More generally, firms differ in the level and nature of "openness", defined as "the degree to which the firm seeks to draw in new knowledge and to re-use existing knowledge from external sources" (Laursen & Salter, 2004). Accordingly, different search strategies result in differing degrees of innovative performance depending on the nature of the innovation in question.

Although much of the original rationale for open innovation revolves around inadvertent spillovers and missed opportunities to commercialize technologies developed in-house, or "inside-out" open innovation (Chesbrough, 2003b; Chesbrough & Rosenbloom, 2002), the research and practitioner interest to date has focused on the benefits of "outside-in" open innovation. This "inbound" open innovation involves identifying and appropriating external knowledge for commercialization or implementation. Two meaningful dimensions of inbound open innovation are sourcing (non-pecuniary) and acquiring (pecuniary) (Dahlander & Gann, 2010).

Acquiring involves the procurement and purchase of intellectual property (IP) or artefacts developed outside the firm. Firms may buy external technology for any number of reasons, such as insufficient internal R&D resources, diversification into new competencies, or simply to access cutting-edge, specialized technologies developed by other organizations (Lowe & Taylor, 1998). Since some pecuniary, commercial transaction takes place, acquiring infers that the firm foresees some immediate application for the externally-sourced knowledge artefact. In other words, since it is unlikely that a firm would expend financial resources simply for the purposes of exploration, acquiring occurs with exploitation and direct application or commercialization in mind. I further consider two forms of pecuniary open innovation: the acquisition of *intangible* (or disembodied) knowledge in the form of patents, licences, or other IP, and the purchase of tangible knowledge *embodied* in physical artefacts such as machinery, equipment, and software (Baetjer, 2000; Vega-Jurado, Gutierrez-Gracia, & Fernandez-de-Lucio, 2009).

The open innovation literature advises firms to seek out opportunities to licence in technologies, namely in the form of patents and IP, which can be commercialized as products in the firm's current business model (Chesbrough, 2006). Previous research, for example from the Finnish manufacturing sector, indicates that use of intangible knowledge is more often applied to product innovations whereas process innovation results from the incorporation of knowledge embodied in artefacts (Rouvinen, 2002). When a firm incorporates a new piece of machinery or software (embodied knowledge) into the production process, one firm's product becomes an input into another firm's processes. The incorporation of knowledge embodied in equipment into internal infrastructure allows firms to "know less than they buy" while still achieving improvement in processes (Flowers, 2007). Regarding intangible technological IP, since the internal processes of most firms remain secretive and proprietary, there is less of an incentive or market for firms to purchase intangible IP inputs into processes. Thus there is a distinction between purchasing components for a production process (buy to build) and purchasing capital goods for operational infrastructure and processes (buy to use). I draw the following hypotheses from this distinction between intangible and embodied knowledge:

H1a: The effect of pecuniary acquisition of intangible technological IP is greater for product innovation than for process innovation.

H1b: The effect of pecuniary acquisition of embodied knowledge is greater for process innovation than for product innovation.

In contrast to acquiring, *sourcing* entails scanning the environment for information related to new technologies and new opportunities, which the firm may then decide to act on, whether through instigating internal R&D or acquiring external technologies (Chesbrough, Vanhaverbeke, & West, 2006). The constructs *breadth* and *depth* (Laursen and Salter, 2006) are roughly analogous to external search scope and depth (Katila & Ahuja, 2002) but more precisely describe the variety and intensity of external sources from which organizations draw knowledge. These constructs thus represent variations in external sourcing strategy. An interesting aside from Laursen and Salter (2006) is that depth is a stronger predictor of sales from radical product innovations, whereas the effect of breadth is greater for sales from incremental product innovations. That is, the form of sourcing strategy impacts product innovation differently.

Some authors differentiate two forms of process innovation: *technological process innovation,* which results from the incorporation of new goods and embodied knowledge into production or service delivery, and *organizational process innovation*, which involves learning and more intangible changes in the coordination of human resources, such as new management practices or ways of doing things (Edquist, Hommen, & McKelvey, 2001: 14-17). The prediction in Hypothesis 1 (that the incorporation of embodied knowledge has a greater effect on process innovation than product innovation) follows from technological rather than organizational process innovation. Learning from external, non-pecuniary sourcing, such as through best-practice sharing at conferences, management training from universities, or working closely with clients to better serve their needs, can also influence organizational process innovation; external sourcing, and not just pecuniary inbound innovation, should influence process innovation, and different sourcing strategies, namely breadth and depth, can affect process innovation in different ways. For starters, the organizational changes required for process innovation are not easy to come by, with an emerging literature on the difficulties of organizational process change management (Kettinger & Grover, 1995). Organizational processes are intangible and often tacit in nature, requiring a fair amount of effort to understand and explicate, develop or imitate, and implement. Therefore, deeper, more intense relationships with external sources are needed to adequately develop, transfer, or implement organizational process innovations. Conversely, breadth of search provides firms with a wider yet shallower scope of available knowledge and opportunities which the firms may decide to further develop into products (Laursen & Salter, 2006). These differences in the nature of sourcing related to product and process development lead to the following hypotheses:

H2a: The effect of non-pecuniary search breadth is greater on product innovation than on process innovation.

H2b: The effect of non-pecuniary search depth is greater on process innovation than on product innovation.

7.2.3 Open innovation in service industries

Despite making up significant portions of the economy, there is a relative paucity of research on innovation in service industries, not to mention in an emerging theme such as open innovation. Many leading firms currently have very different ways of defining service innovation and the processes which enable it (Anderson-Macdonald & Kask, 2010). However, despite the "manufacturing bias" in innovation studies (Drejer, 2004), there is good reason for the growing interest in the antecedents and outcomes of service innovation: developed countries are predominantly moving towards service economies, with the sector comprising well over 70% of the share of economic activity (Anderson, Howells, Hull, Miles, & Roberts, 2000; Boden & Miles, 2000; Gallouj & Djellal, 2010; OECD, 2000; Rubalcaba, 2007). The analysis of the consequences of growth in services – and corresponding reduction in the proportion of the labour force engaged in manufacturing – has a long history of theoretical and political debate, with views of the service sector ranging from a passive adopter of technology and “innovation laggard” (Baumol, 1967) to “the core engine of the new knowledge-based economy” (Gallouj & Savona, 2009). Whatever the impact of services on the economy as a whole, services represent a significant area of activity which has largely been left out of the open innovation discussion.

How might innovation in services differ from the innovation traditionally studied in manufacturing? Some authors propose a radically different model of innovation in services, suggesting a “reverse product cycle” whereby incremental improvements first increase the efficiency of delivery of existing services, only later to lead to improved service quality through process innovations and finally to the generation of new service products (Barras, 1986, 1990; Gallouj, 1998). Non-technological and tacit knowledge play an important role in service innovation (Tether et al., 2007), and informational activities within service firms, largely facilitated by ICTs and the network of actors and interactions between them, lead to knowledge creation that is not bound within specific domains in traditional R&D labs (De Bandt and Dibiaggio, 2002). This suggests that, although service industries share as many similarities as differences with manufacturing when it comes to innovation, interaction with the external environment is crucial for service innovation.

In light of this, the model compares the returns to open innovation activities between service and manufacturing sectors. Although some research has shown that service and manufacturing firms often exhibit comparable patterns of the use of knowledge sources for technological innovation (Sirilli & Evangelista, 1998), the relative returns to these sources may differ substantially between industries. If service firms benefit from interactions with external suppliers due to the nature of service innovation and are indeed more passive adopters of technological innovation, then inbound open innovation will more strongly predict innovative performance in service firms than in the manufacturing sector. This leads to the following hypothesis:

H3: Overall, the effect of inbound open innovation activities are greater in low-tech service firms than in low-tech manufacturing firms.

7.2.4 Decreasing returns to openness

Finally, although the hypotheses in this chapter and evidence from previous studies predict a positive effect of external knowledge on both process and product innovation, one highly-cited contribution proposes an inverted-u shaped relationship between the number of kinds of external sources and innovative performance of products (Laursen & Salter, 2006). Using a cross-sectional survey of British manufacturing firms, these authors find that firms drawing from external knowledge sources will have a better innovative performance than firms relying solely on themselves – up to a point. After a certain level, firms experience decreasing returns to external sourcing. Graphically, the relationship between innovative performance, in this case measured as the percentage of sales from new products, and breadth or depth takes on an inverted u-shape. A more recent, similar study using a slightly different econometric methodology looks at Finnish manufacturing firms, again finding strong support for the benefits of external search breadth but with some evidence for decreasing returns (Leiponen & Helfat, 2010). How is it that firms can be “too open”? Laursen and Salter posit that decreasing returns set in because of (1) natural constraints on absorptive capacity, (2) Not Invented Here (NIH) syndrome, (3) timing, and (4) limited allocation of managerial attention.

First, absorptive capacity is the ability to recognize, internalize, and exploit external knowledge to commercial ends (Cohen & Levinthal, 1990). Building absorptive capacity is seen as a prerequisite for firms to successfully engage in inbound open innovation (Spithoven, Clarysse, & Knockaert, 2010). Conceptualized as a *capacity*, it has limits. When a wide array of diverse external knowledge is accessed, much of that knowledge may or may not be appropriate or relevant to the firm. Sorting out which knowledge is relevant requires resources and great effort. Simply put, there may be too many ideas to comprehend and utilize at one point in time, leading to “information overload.” Similarly to the absorptive capacity problem, attention-based theory of the firm places limits on the attention of managers (Simon, 1997). According to this theory, managerial attention is the most valuable resource in a firm, and the behaviour of the firm results from how decision makers focus and distribute their limited attention (Ocasio, 1997).

The allocation of attention, especially from senior management, during the innovation search process is important for performance (Koput, 1997; Yadav, Prabhu, & Chandy, 2007). Managers who are bombarded by information have little time to contemplate it all and may direct their attention to “safe” projects.

“Not Invented Here” (NIH) syndrome, which the open innovation literature mentions often, is the rejection of knowledge and technologies originating externally to the firm, which can be detrimental to firm performance (Katz & Allen, 1982). Some level of scepticism stemming from the uncertainty of externally acquired knowledge can be healthy, but too much can be a major barrier to open innovation (Chesbrough, 2003b: 182). As the amount of external knowledge being accessed increases, the effects of NIH syndrome can become more apparent. Although not typically addressed in open innovation studies, the case also exists where firms overvalue external knowledge, which may lead to detrimental effects and poorer innovative performance (Lichtenthaler & Ernst, 2006). The “Not Invented There” (NIT) syndrome is defined as occurring when “people in management show more interest in what is going on elsewhere than in their own laboratories” (Laden, 1996). For NIT syndrome, “the other person’s dessert always looks better”, which causes management to spend more time evaluating external sources because they may already be technically feasible or on the market. Menon and Pfeffer demonstrate empirically the prevalence of some firms having a preference for external knowledge over their own internal knowledge (2003). This is due to (1) status associated with gaining knowledge from external sources and (2) the fact that external knowledge is rarer which makes it appear special and unique. Firms at a higher degree of external search breadth may be over-zealous and overly positive about drawing from external knowledge sources, resulting in inadequate focus on internal capabilities and mistaken selection of inappropriate knowledge. Thus the poorer innovation performance relative to the extremes of external sourcing may reflect both sides of the NIH-NIT coin.

Regarding the “timing” problem, too many ideas may come at the wrong time to be fully exploited. With a lot of potentially good ideas coming at once, the ratio of good ideas passed over is higher. Chesbrough touches upon a similar reason regarding timing, where accelerated cycle times for projects allows firms to assess only so many ideas or technologies at a time, leading them to eventually pass over some (Chesbrough, et al., 2006: 17). Some innovations take years before a use is discovered for them. For example, one of the inventors of the laser, Gordon Gould, said that for the first five years after its discovery, the laser was "a solution in search of a problem" (Brown, 1988: 310). When companies are inundated with ideas, some may get buried when the appropriate time finally emerges.

Research by Chandy et. al. similarly finds this inverted u-shaped relationship between a firm's ability to convert ideas into innovations: "a strong focus on speed and on generating many ideas may actually hurt firms by lowering their conversion ability" (2006). They hypothesize that problem solving ability is influenced by four factors, namely (1) workload, (2) time pressure, (3) expertise, and (4) task importance. At high levels of external search breadth and depth, firms may be hurting their conversion ability, resulting in decreased performance. This paradox of allotting the right level of pressure in the open innovation process has also been noted in practitioner case studies (Mesaglio & Hunter, 2008).

Therefore, consistent with Laursen and Salter (2006), the following hypothesis predicts an inverted-u relationship between external sourcing and the performance of both product and process innovation:

H4: non-pecuniary breadth and depth are positive predictors of both product and process innovation up until a point, after which firms experience decreasing returns to external sourcing.

7.3 Data and empirical estimation

7.3.1 Data source

The analysis in this chapter is carried out using the PITEC (*Panel de la Innovación Tecnológica*), which is based the OECD's Oslo Manual. The survey is administered by a joint effort of the Spanish National Statistics Institute (INE), the Spanish Foundation for Science and Technology (FECYT), and the Foundation for Technical Innovation (COTEC). The unit of analysis is the single enterprise, whether part of a group or independent. The PITEC differs from most other OECD-based innovation surveys in two important and favourable aspects. First, firm participation is mandated by law (*Leyes* 4/1990, 13/1996, and article 10.1 of the LFEP), which limits problems associated with respondent selection bias; since many of the national innovation surveys in other countries are voluntary, this opens the door to respondent selection bias with only eager, innovative firms responding. Second, as the "P" in the acronym indicates, it is structured as a panel dataset, with observations repeated on the same firms over time. As discussed below, there are several advantages to panel data.

The dataset contains observations on more than 2,200 low-tech manufacturing and 1,600 low-tech service firms over four periods, with the most recent ending in 2007. Firms are assigned to 31 sectors according to the Spanish National Classification of Economic Activities (CNAE-93 - *Clasificación Nacional de Actividades Económicas*), roughly equivalent to the NACE system. The sectors are divided into high-tech/low-tech manufacturing and services along this classification system by the INE. The specific industries are included in Table 7.1.

Table 7.1 Manufacturing and service industries included in analysis

Low-Tech Manufacturing	Low-Tech Services
Food and Beverages	Electricity, Gas and Water Utilities
Tobacco	Construction
Textiles, Tailoring and Furs	Sales and Repair of Automobiles
Leather and Footwear	Wholesale
Lumber and Cork, Paper	Retail
Editing, Arts, Graphics, and Copying	Hotel
Petroleum Refinement	Transport
Rubber and Plastic Materials	Transport, Travel Agencies
Glazed and Tile Ceramics	Financial Intermediation
Non-Metallic Mineral Products	Real Estate
Ferrous Metallic Products	Architectural services
Non-Ferrous Metallic Products	Testing and Analysis
Metallic Products (excluding Machinery)	Other Business Services
Shipbuilding	Education
Furniture	Film and Video Activities
Toys and Games	Radio and Television
Recycling	Other Sanitary, Social and Collective Services

7.3.2 Exploiting panel data: accounting for unobserved firm heterogeneity

Undoubtedly, there are many idiosyncratic and contextual factors which influence a firm's behaviour and ability to innovate, not all of which can be measured and included as variables in the analysis. Some obvious examples are star managers, proximity to resources such as clusters, organizational structure, etc. These are collectively termed "unobserved heterogeneity" in the management literature, and failing to account for it can result in bias due to omitted variables. Fortunately, the properties of panel data – repeated observations on the same firm over time – allow one to account for much of this heterogeneity via *fixed-effects models*. Fixed effects are factors at the level of the individual firm which remain more-or-less constant over time. In essence, each individual firm acts as its own counterfactual before and after some "treatment" of interest, in this case the use of various sources of knowledge. Because fixed effects models estimate variation in a firm over time, it is also called the *within* estimator. The inclusion of time and controlling for unobserved, omitted variables gets us closer to determining causal effects (Angrist & Pischke, 2009: 115-117). Although fixed-effect models are less efficient (i.e. it is difficult to achieve statistical significance), the estimates are consistent (i.e. the estimated coefficients are close to the "true" value). For these reasons, I employ a fixed-effects model described in the following description of the estimation procedure.

7.3.3 Dependent variables: measures for effect of product and process innovation

The dependent variables evaluate the effect of innovation on each firm's products and processes. The survey measures the *effect of product innovation* along three dimensions: (1) improved range of products or services; (2) penetration into new markets or increased market share; and (3) improved quality of product or services. The dependent variable, PROD_EFF, counts the number of effects rated as "high impact" and, therefore, ranges from 0-3. Firms rate the *effect of process innovation* along three dimensions which are relevant to both product and service firms: (1) improved flexibility of production or service provision; (2) improved capacity of production or services; (3) reduced labour costs. The variable PROC_EFF ranges from 0-3 where firms rated the impact of innovation on processes as "high".

7.3.4 Covariates

Two dummy variables measure pecuniary inbound open innovation: TECIP and EMBK. TECIP indicates whether the firm purchased external technological IP, such as patents or licences, during the period. EMBK indicates the purchase of external knowledge embodied in physical artefacts, such as in machinery, equipment, or software, used for product or process innovation. Finally, the log of R&D intensity, LRDIN, accounts for the internal resources used for innovation, measured as the spending on internal R&D as a percentage of total firm revenue.

NPBREADTH measures the number of kinds of external knowledge sources used for innovation which are considered *non-pecuniary*. This is similar to the *breadth* construct used by Laursen and Salter (2006), but excludes *suppliers* and *knowledge-intensive business services* as categories because of the potential to confound free or low-cost external public knowledge sources with pecuniary open innovation – firms handsomely pay suppliers and consultants, whereas fees for things like conferences or access to publications, if any, are negligible. The eight remaining types of external source include: clients, competitors, universities, public research organizations, technological centers, conferences and fairs, journals/publications, and professional associations. Likewise, NPDEPTH is the number of types of non-pecuniary external sources from which the firm has drawn intensely for innovation. Note that in order to test for decreasing returns and the inverted-u shape relationship predicted in Hypothesis 4, the regression models include the squared terms NPBREADTH_2 and NPDEPTH_2.

The within-regression accounts for variables that are subject to change in an individual firm over time, with constant variables accounted for with the fixed effects. This parsimonious approach thus excludes many unchanging characteristics that differ between firms and are normally included as controls in cross-sectional analyses. I do however include three variables as controls for changes in firm strategy or circumstances. First, LOGEMP, the log number of employees, controls for changes in firm size due to things such as growth, acquisitions, mergers, divestitures, etc. Second, since firms operating in international markets often face more diversified competition and have a higher propensity to innovate (Frenz, Girardone, & Ietto-Gillies, 2005), GEOMARKET indicates the geographical market in which the firm sells its products or services, taking on the values 1 (local market only), 2 (national, within Spain), 3 (inside the European Union), or 4 (international, outside the EU). Finally, dummies for each year in the panel control for cross-industry, macroeconomic fixed effects. Table 7.2 lists the descriptive statistics by industry for the variables before log transformation. With the exception of surprisingly higher R&D intensity and larger size of service firms, the dependent and key sourcing variables show no significant differences between industries.

Table 7.2 Descriptive statistics by industry for innovation-active firms, prior to log transformation

Variable	Range	Average (standard deviation)	
		Manufacturing	Services
Product Innovation	0-3	1.06 (0.616)	0.858 (0.545)
Process Innovation	0-3	0.575 (0.575)	0.491 (0.512)
Non-Pec. Breadth	0-8	4.37 (1.62)	4.09 (1.57)
Non-Pec. Depth	0-8	0.765 (0.683)	0.735 (0.672)
Internal R&D	0-100	1.75 (2.98)	3.71 (4.28)
Technological IP	0/1	0.052 (0.165)	0.085 (0.199)
Embodied Knowledge	0/1	0.337 (0.375)	0.334 (0.356)
Size: # employees	10-41,509	169 (79.6)	637 (473)
Geographical Market	1-4	3.36 (0.348)	2.43 (0.363)
Year dummies	-	-	-

7.3.5 Estimation procedure

The dependent variables are discrete integers in panel data format, making a conditional fixed-effects (CFE) Poisson model appropriate (Hausman, Hall, & Griliches, 1984). The Poisson is attractive because it allows for a large number of zero values in the dependent variable and performs well in the presence of unknown forms of heteroskedasticity. Although normally used for discrete data counting the occurrence of some event, the estimator is consistent as long as the conditional mean is correctly specified, meaning that the dependent variable doesn't even need to be an integer (Santos Silva & Tenreyro, 2006). As per the usual convention, the variables are log transformed in order to provide a better fit with the distribution of the Poisson, which stipulates that the mean be equal to the variance lest the distribution is over-dispersed (Gourieroux, Montfort, & Trognon, 1984). Furthermore, these log-transformed variables are dimensionless and in the same range, enabling the comparison of effect sizes between product and process innovation. The CFE Poisson model drops those observations with either all-zero outcomes or unchanging sets of independent variables over time, which could introduce a systematic selection bias (Reitzig & Wagner, 2010). However, in the models run in this study, there is sufficient variability in the independent variables such that all innovative firms are kept in the analysis. In any case, fixed-effects models are robust against most kinds of selection bias since the selection characteristics are largely controlled for in the fixed effects (Kennedy, 2003: 312), such that the analysis estimates the variables within the firms of interest. Stata 11 executes the CFE Poisson regressions with the robust standard errors, which produces standard errors in line with more complex repeated-sampling procedures (Cameron & Trivedi, 2010).

The magnitude and significance levels of the coefficients tell an interesting story if one makes the comparison between industry, source of knowledge, and product or process innovation. Since the fixed effects controls for many idiosyncratic factors between low-tech manufacturing and service firms, we can compare the different estimated coefficients. A Chow test is normally the appropriate method in linear regression for determining if the coefficients of subsegments within a population, in this case low-tech manufacturing and service firms, differ statistically from one another due to some underlying structural break (Chow, 1960). However, a Chow test is not appropriate in the case of a non-linear maximum likelihood model such as the Poisson; instead, the better option is to run separate models on each group and compare the resulting estimated coefficients (Hoetker, 2007). Because of these "nonstandard standard error issues", I employ a non-parametric bootstrapping procedure on the difference in the estimated coefficients by accounting for the resulting residual variation matrix (Angrist & Pischke, 2009: 155-164). Bootstrapping means simply repeatedly running the model on randomly drawn samples from the dataset (with replacement) so that the resulting standard error is the standard deviation of an estimator from these many draws. Although computationally burdensome, the advantage is that one does not make any assumptions about the underlying error distribution. The resulting p-values of the differences in coefficients tells us the magnitude and whether the coefficients for each variable are significantly different for the two industrial sectors. Using this procedure, Table 7.4 and Table 7.5 in the next section present the results of the comparison of coefficients across groups and type of innovation.

7.4 Discussion of results

Table 7.3 lists the results of the four CFE Poisson regressions. The same set of covariates is regressed on the variables for the effect of product innovation and process innovation in separate regressions for each of the service and manufacturing subsamples. With the exception of technological IP and the control variables, the covariates are all significant and positive in magnitude. The interpretation of individual coefficients in a Poisson model is as follows: the expected change in the (log) count of the effect of product or process innovation for a one-unit increase in the variable is equal to the magnitude of the individual coefficient.

Table 7.3 Conditional fixed-effects Poisson regression results, by industry and type of innovation

	Product Innovation		Process Innovation	
	Manufacturing	Services	Manufacturing	Services
	Coeff. (s.e.)	Coeff. (s.e.)	Coeff. (s.e.)	Coeff. (s.e.)
Non-Pec. Breadth	0.355*** (0.024)	0.463*** (0.032)	0.219*** (0.036)	0.331*** (0.041)
(Non-Pec. Breadth)^2	-0.032*** (0.002)	-0.042*** (0.003)	-0.016*** (0.004)	-0.030*** (0.009)
Non-Pec. Depth	0.157*** (0.025)	0.251*** (0.035)	0.240*** (0.041)	0.283*** (0.050)
(Non-Pec. Depth)^2	-0.017*** (0.005)	-0.027*** (0.006)	-0.026*** (0.008)	-0.029*** (0.009)
Internal R&D	0.081*** (0.019)	0.047* (0.025)	0.101*** (0.032)	0.079* (0.042)
Technological IP	0.010 (NS) (0.041)	0.125** (0.045)	0.043 (NS) (0.072)	0.030 (NS) (0.076)
Embodied Knowledge	0.078*** (0.017)	0.096*** (0.025)	0.191*** (0.032)	0.274*** (0.044)
Firm Size	0.121** (0.062)	0.016 (0.069)	-0.080 (0.091)	-0.011 (NS) (0.089)
Geographical Market	0.105*** (0.022)	0.013 (0.026)	0.075** (0.035)	-0.017 (NS) (0.038)
year dummies	included	included	included	included
# observations	8266	5790	5543	4259
# firms	2274	1625	1509	1180
Wald chi^2	493.68	458.74	257.26	281.37
prob> chi^2	0.0000	0.0000	0.0000	0.0000
LL	-4005.55	-2543.29	-2510.76	-1739.48

Significance levels: * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$ (NS) Not Significant
Robust standard errors used.

7.4.1 Pecuniary acquisition and type of innovation

Although a quick look at Table 7.3 reveals some interesting patterns in the returns to sourcing strategies across sectors and type of innovation, evaluation of Hypotheses 1-3 requires a statistical test to determine whether these differences are significant. To this end, Table 7.4 reports the results of the bootstrapped standard error procedure described above in Estimation Procedure. The estimated coefficients for each variable's regression on product innovation are subtracted from the estimates for process innovation, by industry, in order to indicate the magnitude of the difference. The p-value tells us whether this difference in estimated coefficients is statistically significant.

Table 7. 4 Statistical significance of difference between estimated coefficients: product and process innovation

	Coeff. Product Innovation – Coeff. Process Innovation			
	Manufacturing Sector		Service Sector	
	Δ coeff. (s.e.)	p-value	Δ coeff. (s.e.)	p-value
Non-Pec. Breadth	0.137*** (0.041)	0.001	0.131*** (0.045)	0.003
Non-Pec. Depth	-0.084** (0.043)	0.038	-0.032 (NS) (0.058)	0.580
Internal R&D	-0.020 (NS) (0.036)	0.566	-0.032 (NS) (0.048)	0.508
Technological IP	-0.033 (NS) (0.080)	0.678	0.094 (NS) (0.079)	0.235
Embodied Knowledge	-0.113*** (0.038)	0.002	-0.178*** (0.051)	0.000

Significance levels: * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$ (NS) Not Significant, Wald Chi² test Bootstrap method with 400 repetitions.

Table 7.3 provides some support for Hypothesis 1a, whereby pecuniary acquisition of technological IP has a positive and significant effect on product innovation, however only for the low-tech service industry. Since technological IP is not significant in the case of process innovation or for product innovation in low-tech manufacturing firms, any comparison between industries is moot. The results in Table 7.4 strongly support Hypothesis 1b, indicating that returns to pecuniary acquisition of embodied knowledge are greater for process innovation than product innovation in both the services and manufacturing industries.

The finding that acquiring technological IP has no impact on process innovation nor on product innovation in low-tech manufacturing firms has intriguing implications for open innovation, especially considering the importance the open innovation literature places on inbound IP (Chesbrough, 2003a). These results echo findings from Tsai and Wang's study of the low-tech manufacturing sector, whereby technological IP sourcing had no predictive effect on more radical product innovation (2009). Similar results have been shown at the project level (Kessler, Bierly, & Gopalakrishnan, 2000). Other findings, however, indicate that sourcing technological IP becomes effective in high-tech industries as a firm's internal R&D capacities increase (K.-H. Tsai & Wang, 2007), suggesting that the impact of acquiring IP is a function of the technological intensity of the sector. Interestingly, in contrast to findings from the manufacturing sector, external IP sourcing seems to have a significant relationship with product development in low-tech *service* firms.

7.4.2 Non-pecuniary sourcing and type of innovation

Relatively strong support for Hypotheses 2a and 2b is evident in Table 7.4: the effect of non-pecuniary search breadth (2a) is greater for product innovation in both the service and manufacturing industries. On the other hand, returns to non-pecuniary search depth (2b) are significantly larger for process innovation, but only for manufacturing firms. This indicates that, at least in low-tech sectors, firms casting a wide yet shallow net (non-pecuniary breadth) are more likely to discover avenues for product innovation. This more superficial level of external sourcing may not be as appropriate for finding and implementing innovative processes. The comparable magnitude of the effect of non-pecuniary search depth on product and process innovation in service industries is intriguing. Although the effect of depth is slightly higher for process innovation in service firms, this difference is not enough to be statistically significant. This finding serves as evidence for dissimilar kinds of innovation processes between these two broad sectors.

7.4.3 Open innovation in manufacturing and service industries

In order to test Hypothesis 3, which predicts higher overall relative effect of inbound open innovation activities in service firms, Table 7.5 lists the results of the bootstrapping procedure on the difference in the estimated coefficients between industries.

Table 7.5 Statistical significance of difference between estimated coefficients: services and manufacturing

	Coeff. Service Sector – Coeff. Manufacturing Sector			
	Product Innovation		**Process Innovation**	
	Δ coeff. (s.e.)	p-value	Δ coeff. (s.e.)	p-value
Non-Pec. Breadth	0.107*** (0.039)	0.006	0.112** (0.057)	0.048
Non-Pec. Depth	0.094** (0.045)	0.027	0.043 (NS) (0.076)	0.542
Internal R&D	-0.034 (NS) (0.036)	0.339	-0.228 (NS) (0.058)	0.696
Technological IP	0.115* (0.062)	0.065	-0.012 (NS) (0.120)	0.917
Embodied Knowledge	0.018 (NS) (0.034)	0.588	0.083 (NS) (0.062)	0.183

Significance levels: * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$ (NS) Not Significant, Wald Chi^2 test
Bootstrap method with 400 repetitions.

Taken as a whole, the significant and positive results in Table 7.5 largely support the hypothesis of greater returns to inbound open innovation for service firms as compared to the manufacturing sector. For product innovation, the effects for the purchase of technological IP and non-pecuniary sourcing are significantly higher for service firms. The same trend is evident for process innovation in service firms. From Table 7.3 and Table 7.5 there is weak evidence that internal R&D is more important for manufacturing firms since the difference is not statistically significant. This is likely partly due to the markedly lower level of significance of the internal R&D coefficient for service firms, which in itself further supports evidence for lower returns to internal R&D in low-tech service firms. Despite the higher average R&D intensity in service firms evident in Table 7.2, the returns from internal R&D are lower than for manufacturing firms. The service firms seem to live up to their reputation as adopters of externally developed technology, although ultimately services get higher innovation returns to external sourcing than their low-tech manufacturing cousins.

7.4.4 Decreasing returns from being "too open"

Finally, Hypothesis 4 predicts decreasing returns to breadth and depth of non-pecuniary external sourcing. The significant and negative coefficients on the squared terms in Table 7.3 strongly support this. That is, an inverted-u shaped relationship exists between both product and process innovative performance and the breadth and depth of external sourcing. The relationship holds equally for service and manufacturing industries.

It is possible to roughly calculate the inflection point at which decreasing returns occur by setting the first derivative of the estimated coefficients equal to zero and solving. Given the scale for breadth and depth, which ranges from 0-8, on average decreasing returns set in for non-pecuniary breadth after about 5.5 external sources and for non-pecuniary depth at 4.5. Stated in a more meaningful way that is comparable and consistent with results from Laursen and Salter (2006), firms sourcing from more than two-thirds of the available external knowledge sources and using more than half of those sources intensely experience decreasing or even negative returns. Unsurprisingly, these results also indicate that decreasing returns set in much sooner for depth than breadth: depth requires higher involvement and quickly strains internal resources.

The recent enthusiasm surrounding open innovation and the detrimental effects of over-searching indicated in this analysis suggest that firms' external search strategies can be "too open". The presence of decreasing returns to external sourcing highlights the importance of neither being too open nor too closed to the external innovation ecosystem. That is, focused and targeted open innovation efforts lead to optimal returns.

7.5 Conclusions and implications

This chapter addresses the following questions: How effective are various open innovation strategies (pecuniary and non-pecuniary) across sectors (manufacturing and services) and objectives (product and process innovation)? And how open should a firm be?

First, the literature and empirical analysis suggest that forms of pecuniary and non-pecuniary external sourcing are differentially effective according to innovation objective, namely product and process innovation. Predictably, external knowledge embodied in artefacts, such as equipment, components or even software, is effectively integrated into firms' processes but is a weaker predictor of product innovation. Although the open innovation literature places an emphasis on the acquisition of intellectual property, in this sample from low-tech industries, the acquisition of patents and other intangible IP did not predict process innovation and predicted product innovation only in service firms. This could be significant for low-tech firms in general; physical artefacts (and software systems) are "pre-packaged" knowledge that can be more easily exploited, whereas low-technology firms may face greater knowledge barriers to valuing and exploiting intangible intellectual property. Different approaches to drawing from non-pecuniary external sources of knowledge also impact a firm's propensity for product and process innovation. In general, greater "depth" of interaction is needed for process innovation, whereas "breadth" – drawing from a broad range of external actors – seems to be more pertinent for the effect of product innovations.

This chapter contributes empirical evidence for the effectiveness of knowledge sourcing in low-tech sectors. Similarly to the lack of research on service innovation, low-tech industries face a paradox, with these "traditional" industries making up the bulk of economic activity in many countries but still being largely left out of innovation studies (Hirsch-Kreinsen, 2008). Although any comparative analysis between high- and low-tech firms would be out of the scope of this chapter and no specific hypotheses are given regarding low-tech industries, it aims to serve as a starting point to bring these important sectors into the open innovation discussion. In general, the analysis reveals that external sources of knowledge have a greater impact on service-sector firm innovation in comparison with their low-tech manufacturing counterparts, who seem to benefit more from investments in internal R&D.

The arguments and evidence brought forth in this chapter are intended to draw attention to the fact that practitioners must carefully consider what kind of open innovation strategy is right for their business and intended objective. Not all modes of inbound open innovation provide the same returns depending on the nature of innovation in question, and overzealous external sourcing can actually lead to inferior returns and performance. Instead, focused efforts are likely to bring optimal results. The documented benefits of openness aside, history provides us with no shortage of *management fads* (or the more politically correct term of *management fashions*) whereby firms rush to adopt the latest and greatest management practices in hopes of gaining competitive advantage or even for fear of not being viewed as progressive (Phillips Carson, Lanier, Carson, & Guidry, 2000). Open innovation's rapid growth shares many characteristics of a management fashion, and there is danger that it will be unsustainable if the open innovation process is not properly managed and approached with realistic expectations (Gassmann, et al., 2010: 213). Often the expectations on managers to adopt the latest "big thing" in management, in this case open innovation, result in pressure to implement a process which may or may not be the most rational, effective course of action. One study found that firms employing popular management techniques did not have higher economic performance – although they were perceived as more admired and competent (Straw & Epstein, 2000). Clearly firms should engage in open innovation practices. However, as with any emerging management practice, there is danger of managers jumping in with both feet first, and after the realities of the difficulty of implementing any new process set in, abandoning it. The implication for firms is to embrace an open innovation strategy with selective external sources and particular objectives in mind while maintaining investments in internal capabilities.

In addition to implications for management, policy makers are now increasingly considering open innovation (OECD, 2008: 113-127). Some of the means in which policy is directed towards fostering open innovation include (1) technology and knowledge transfer policies; (2) the organization of the public sector research base such as universities and science parks; (3) establishment of public innovation intermediaries (Lee, Park, Yoon, & Park, 2010); (4) public funding for open innovation research and projects with a strong collaborative nature; and (5) policies directed towards the fair and tradable use of IP, i.e. the appropriation regime. The implications of this research for policy makers are twofold. First, open innovation clearly creates value but brings with it yet unknown difficulties. Knowledge is often "sticky" and difficult to transfer or value (von Hippel, 1988), especially for firms with few internal capabilities (Cohen & Levinthal, 1989). That is, investment in resources and capabilities internal to the firm still matter, both for the creation of new knowledge, whether tradable or destined for internal use, and for the generation of the absorptive capacity required to recognize and commercialize existing external knowledge. Open innovation is not a panacea, so policy makers must carefully consider policies which divert public funding away from the development of internal firm R&D to schemes simply supporting open innovation. Second, there is likely not a viable "one-policy-fits-all" approach to facilitating open innovation practices among firms. As argued in this chapter, firms are very heterogeneous in how they source and apply external knowledge, and furthermore the relevance of inbound open innovation may vary according to any number of factors such as a firm's industry and whether product or process innovation is the intended outcome. Policies directed at fostering open innovation will likely need to consider how the intended outcome may be contingent upon the idiosyncrasies of various industries and types of innovation.

7.6 Future research directions

Thanks to much attention from the academic research community, a fair amount of progress has been made in our understanding of open innovation over a relatively short period of time. However, as an emerging theory there are still many questions to explore. First and foremost, an objective of this chapter is to bring low-tech service industries and process innovation into the open innovation discussion. As such, this comparative analysis provides some initial clues about how open innovation differs across these subjects, but much further research is needed.

Innovation survey data is only able to capture the breadth and depth of different *categories* of external sources used for innovation. Although this is a good proxy for a firm's external sourcing strategy and level of openness, access to more granular data on the actual nature and number of actors and interactions with external sources of knowledge would provide a much richer understanding of the optimal external orientation of the firm. This kind of data could well be supplemented with a better understanding of the relationship between organizational forms and internal practices which influence a firm's ability to benefit from various open innovation strategies.

Although the analysis in this chapter focuses on search strategy regarding external sources of innovation, it does not address the myriad tools currently being proposed and used by firms generally included under the umbrella of open innovation. These include crowdsourcing competitions, the use of open source strategies, lead user methodologies, co-creation and mass customization. Although there is a growing volume of research into these specialized tools, many questions remain regarding their effectiveness and appropriateness across diverse contexts, such as various types of intended innovation outcomes, innovation of commercial services versus goods, or how these tools and techniques can be combined.

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CHAPTER 8

GENERAL CONCLUSIONS

The question of how firms organize their innovation processes with respect to the external environment remains at the forefront of research interests. Given that the environment contains diverse sources of technological and scientific knowledge, it naturally leads to questions related to (1) the conditions under which firms use certain strategies to access external sources of knowledge and (2) what the innovative performance implications of these externally-oriented innovation activities are. The three studies in this dissertation address several open questions and contribute empirical evidence along these two broad streams of inquiry. This final chapter complements the introduction in Chapter 1 by summarizing the findings in the dissertation[66] and, based partly on the results and the limitations of analyses, provides general suggestions for future research additional to those given in each study's respective conclusions.

8.1 Study 1

Study 1 addresses the first stream of literature by examining the determinants of externally-oriented product development behaviour. With the exception of several studies, the literature has traditionally approached this question by investigating the sourcing decisions of firms, such as the propensity to engage in R&D contracting or

[66] This chapter spares the reader from the works referenced in previous chapters of the dissertation.

enter into technology alliances, without addressing whether these are the main ways through which firms actually bring new products to market. Study 1 defines *new product development mode* according to whether products are developed internally, through collaboration with external agents, or primarily by external agents. In this way, the analysis examines directly the boundaries of the firm and the origins of new products rather than channel-specific sourcing decisions which may or may not result in new products.

Study 1 draws from the three main theoretical approaches to understanding firm make-buy-ally behaviour: transaction cost economics (TCE), resource-based view (RBV), and industrial organization theory (IOT) (Hagedoorn, Link and Vonortas, 2000). Still, it should be noted that Study 1 ultimately falls short of integrating the three together (see e.g. Silverman, 1999, for a work that integrates RBV with TCE on a theoretical and empirical level). Rather, Study 1 aims to disentangle some of the particulars of environmental uncertainty and internal resources and, further, contribute empirical evidence to these three theories. By including specific aspects of TCE, RBV, and IOT separately, Study 1 also controls for important variables proposed by these theories in the econometric analysis. A true integration of these perspectives is an avenue for future research.

Since its roots in the theory of the firm, TCE has found widespread application across a number of disciplines in the social sciences and increasingly in explaining innovation governance behaviour (Macher and Richman, 2008). In strategic management understanding the sources of different transaction costs is important because transaction costs lead to inefficiencies, destroy value, and undermine appropriability (Foss, 2003). Generally, when transaction costs are high, firms prefer internalization, a result that has been systematically supported in the literature on vertical integration decisions of manufacturing firms. However, the picture is less clear regarding collaboration and innovation. As a hybrid form of governance, collaboration offers the chance to spread risk and uncertainty while aligning development goals, but also raises concerns about dealing with unforeseen contingencies. The pursuit of innovation, by its very definition, is an uncertain endeavour, making an understanding of the effects of uncertainty key in an analysis of innovation governance behaviour.

Study1 considers environmental (market and technological) uncertainty as sources of transaction costs. It finds that technological uncertainty promotes collaborative development, possibly due to the need to access external expertise in order to solve technological problems[67]. On the other hand, market uncertainty predicts collaborative development but has a negative effect on the propensity to acquire external innovations. This could be due to the desire to spread the risk of market uncertainty with a collaborative partner; equally, acquisition might not make sense if the firm doesn't perceive a ready market for its product since the firm is taking on all of the investment and risk.

It could be argued that the technological (and to some extent market) uncertainty measured in our variables stems from a lack of technical knowledge on the part of the firm rather than more objective measures like the complexity of a certain technology. This is to be expected and does not undermine the predictive value of the constructs. As several studies point out, the *perception of the managers* is what provides predictive power. Furthermore, by including the R&D capacity of the firm in the model, we also indirectly control for investments in technological knowledge. Nevertheless, the relationship between internal knowledge and the perception of technological uncertainty is an interesting area of future research. For example, it could be argued that firms with low levels of investment in R&D 'don't know what they don't know' and, therefore, perceive low technological uncertainty[68]; on the other hand these technologically weak firms might experience high levels of uncertainty because they have under-invested in R&D and cannot make sense of complex technologies. Getting at the underlying psychological foundations of managerial perception is a promising emerging line of research.

Study 1 considered only environmental uncertainty (and cost) as TCE factors and, due to the construction of the PITEC dataset, is unable to include TCE's other main source of uncertainty in the analysis: behavioural uncertainty. This would be interesting to

[67] Technological uncertainty also seems to have a positive effect on the likelihood of acquisition, although this was not statistically significant.

[68] This is called the *Dunning-Kruger effect* in the psychology literature. For example, an armchair athlete is more likely to underestimate the skill needed to play a professional sport than a college athlete with more experience and knowledge (Kruger and Dunning, 1999).

evaluate using the framework and approach in Study 1. Market and technological uncertainty are closely tied to the nature of innovation, whereas behaviour uncertainty is seen to stem from a lack of trust or the inability to measure and control the partner's accordance with contractual agreements. The effect of behavioural uncertainty in cases where firms strive towards highly novel innovations would be interesting to study because of the difficulty in measuring such outcomes in the first place. Similarly, contracts seeking to constrain behavioural uncertainty may also constrain the chance of developing radical innovation due to the inability to experiment.

Perhaps the most interesting finding in Study 1 is the relationship between internal R&D capacity and the mode of new product development. Drawing from resource-based view and resource-dependency theory, Study 1 essentially pits the effect of the 'need' for external knowledge (or lack thereof) against the effect of the search for 'complementary' knowledge. In doing so, we find evidence for a weak inverted-u relationship between internal R&D capacity and the propensity to develop products collaboratively (in relation to internal development). Likewise, we find a negative relationship between the likelihood of external acquisition (versus internal development) as a function of internal R&D capacity. Basically, as firms have greater internal R&D capacity, they are able to identify and attract partners for collaborative product development, although at some point their internal resources are so great that they don't need external partners or wish to expose their valuable knowledge to competitors. This tension is reflected in the model. Conversely and perhaps in contrast to what the open innovation literature might predict, firms with higher internal R&D capacity are simply less likely to release new products onto the market that were developed externally since they can do it and appropriate all the value themselves. On the other hand, firms with low internal capacity, should they be able to innovate at all, do so through acquisition.

In contrast to the constructs from transaction cost and resource-based theories, the IOT variables have little predictive power for the mode of new product development. The importance of industry spillovers is not significant, and in contrast to our prediction, the average use of industry appropriability mechanisms has a negative effect on the propensity of firms to engage in collaborative development. Part of these unexpected findings may be due to the difficulty in operationalizing a construct like industry appropriability. Many industries do not rely on legal protection mechanisms like patents or trademarks (Laursen and Salter, 2005), and unfortunately the Spanish innovation survey does not ask about strategic appropriability mechanisms such as secrecy. Future research could look at how various approaches to appropriability at the firm and industry level predict innovation governance behaviour and performance. For example, the literature generally considers spillovers and protection mechanisms under IOT approaches at the industry level. However, similar to how the perception of uncertainty by managers is a better predictor of behaviour than 'actual' uncertainty, perhaps the perception of the importance of spillovers and appropriability strategy by individual firms is a better and more meaningful predictor of behaviour than industry level variables. This research question obviously breaks away from IOT but may provide insight into the nature of the firm and the innovation process.

One natural follow-on question to Study 1 might be the consideration of performance implications from products developed through the three modes rather than the comparable mechanisms of university interaction explored in Study 2. For example, a starting point for a model could estimate the sales performance and novelty of product innovation as a function of whether a new product was developed internally, in collaboration, or externally. However, this research topic has already been exploited using the same variables from the PITEC (Barge-Gil, 2011). Although he defines the variables slightly differently, Barge-Gil finds that 'open' strategies perform better than 'closed' ones when it comes to generating sales from highly novel products. The results in Study 1 indicate that cooperative (but not external) development seem to be positively correlated with new products which are highly novel. Evidence from Study 2 discussed below also supports cooperation as a mechanism for developing more novel products compared to acquisition. Study 2 and Study 3 take on more specific open research questions.

8.2 Study 2

The exploration of interaction with universities in Study 2 can be considered a contribution to the call for '2nd generation' studies that aim to better understand the various channels of interaction and complex heterogeneity of university-firm relations (Gulbrandsen, Mowery and Feldman, 2011). The study examines this heterogeneity by analyzing R&D cooperation and R&D contracting as activities and by differentiating between the novelty of innovative performance outcomes. By studying the novelty of the outcomes, we can learn about the explorative and exploitative nature of the mechanisms and interaction with the external agent. Investigating collaboration and outsourcing with universities thus fills a current and important gap in the literature while keeping in line with the aims of the dissertation. Study 2 also contributes to the general literature on strategic management and new product development because, surprisingly, few studies have considered how the characteristics of R&D contracting, and R&D contracting partners in particular, influence innovative outcomes (Stanko and Calantone, 2011).

The finding that both interaction mechanisms with universities predict sales from new products is new in itself. Although the literature finds generally that collaboration often leads to product innovation, there are also reasons why such collaborations will not be successful, such as the misalignment of goals and communication problems between agents. As Study 2 points out, many previous studies find an insignificant or even negative relationship between R&D contracting and innovative performance. The lack of findings could be due to the generic way in which R&D contracting is often defined in the literature since the characteristics of the type of partner are often not accounted for.

However, while both contracting and cooperation support the introduction of new products, Study 2 finds a difference in how these interaction mechanisms predict the novelty of these product innovations. R&D cooperation predicts innovative products that are new to the market (and therefore more novel), whereas R&D contracting predicts innovative products that are new to the firm (and therefore less novel). Cooperative development provides flexibility to adjust to unexpected contingencies and also facilitates feedback, communication, and iterative problem solving between parties, making it more likely to be an explorative process that can result in novelties. On the other hand, contracting implies that the firm has requested some knowledge output in advance. Thus whatever the firm has put into the contract likely reflects the firm's existing knowledge base and outlook and is therefore more exploitative in nature, regardless of the broad knowledge base of the university partner.

Nevertheless, these arguments regarding the nature of cooperation versus contracting are based on assumptions drawn from the literature. Future research could attempt to measure and operationalize the differences between these two interaction mechanisms. For example, could the possibility for greater interaction and open-ended results be built into R&D contracts to facilitate better communication and overcome these shortcomings? Are there differences between these two channels in terms of knowledge leakage from the firm? This research would be informed by interviews and a more qualitative approach. Likewise, examples and case studies of new products resulting from these kinds of high-relational interactions with universities could provide a richer context for the findings.

8.3 Study 3

The last study (Chapter 7) continues the theme of disentangling returns to knowledge sourcing activities from the type of innovative outcome. Study 3 makes a broad empirical comparison of the relative effectiveness of different open innovation activities on both process and product innovation and, furthermore, how returns to these innovation strategies differ across manufacturing and service industries.

Study 3 classifies open innovation activities according to pecuniary and non-pecuniary modes of inbound open innovation; this broad categorization is based on a review of the 'different types of openness' identified in the literature by Dahlander and Gann (2010). Pecuniary inbound innovation is the acquisition of external knowledge from the marketplace. Pecuniary modes include the acquisition of knowledge embodied in artefacts (e.g. machinery, software) and intangible knowledge (e.g. patents or licences). Non-pecuniary inbound innovation involves scanning the environment for ideas and technologies which the firm can then decide to use or not. The constructs for measuring non-pecuniary sourcing include the *breadth* of external sources from which a firm draws information and the *depth* of sources which the firm uses intensely. This finer comparison proves to be meaningful since the effects of each mode are shown to differ according to industry and innovation outcome.

Study 3 finds that the acquisition of intangible knowledge has a positive effect only on product innovation in service firms. Since the open innovation literature places much emphasis on buying in such IP (in manufacturing firms), it is an intriguing finding that it is more important for services than manufacturing. On the other hand, the acquisition of embodied knowledge predicts both product and process innovation; however, as hypothesized, the returns to acquisition of embodied knowledge are higher for process innovation. Future research could explore the returns to pecuniary acquisition across industries since it is conceivable that high-tech firms rely more on the combination of complex knowledge inputs. Regarding non-pecuniary sourcing in the effect of new products and processes, Study 3 finds that returns to a wide breadth of external sources are higher for product innovation, whereas returns to depth of sourcing are higher for process innovation. This may reflect that, although firms can get ideas and inputs for product innovation from a shallow scanning of external sources, process innovation requires deeper interactions and effort to develop and implement.

Next, the findings indicate that, on average, low-tech service firms have higher returns to external innovation activities than their low-tech manufacturing counterparts for both product and process innovation. Also, although the difference is not statistically significant, there is some evidence from the magnitude of the estimated coefficients that low-tech manufacturing firms receive higher returns to internal R&D than service firms. These results support the notion of low-tech service firms as more passive adopters of innovation. Still, an interesting question that is out of the scope of Study 3 is how these innovation activities differ across high- and low-tech manufacturing and services sectors. In contrast to low-tech services, high-tech services – such as information technology firms, telecommunications, and technical knowledge-intensive business services (KIBS) – typically have high levels of R&D investment and provide complex knowledge outputs and inputs into other firms (Anderson *et al.*, 2000; Barras, 1990). Simply including low-tech sectors and providing econometric evidence on them in Study 3 may help bring them into the open innovation discussion but still falls short of making a meaningful comparison with high- or medium-tech sectors. Future research could contribute this kind of open innovation analysis and would shed further light on the nature of firm innovation processes.

Study 3 makes a final contribution by re-evaluating the findings of Laursen and Salter (2006), who find an inverted-u relationship between the breadth and depth of external sourcing and the share of sales from innovative products. These authors hypothesize that, although firms benefit from accessing external knowledge, firms can ultimately only absorb and utilize so much before they are overloaded. Using a different measure for product innovation and including process innovation in the analysis, along with a fixed-effects analysis, Study 3 reveals that the decreasing returns to being 'too open' are very robust and seemingly generalizable across several dimensions of innovative output. Future research could explore the degree of openness using different constructs, such as the number of technologies or ideas evaluated at any one time. Another interesting line of research could open up the firm and pull apart the types of external knowledge to better understand the moderators of these decreasing returns. For example, how do IT or formal knowledge management systems help firms evaluate and organize diverse external knowledge? How do organization design or communication routines influence this relationship? Can the engagement of professional services and experts, such as knowledge-intensive business service firms, add expertise and mental capacity to help firms benefit from a broad range of external knowledge sources? In other words, are there moderators that shift over the inflection point or mitigate the decreasing returns to external sourcing, thereby helping firms to absorb and combine complex knowledge from external sources?

One potential shortcoming of Study 3 is that the analysis did not include cooperation as a strategy. Although analyzing cooperation would have fit better into the line of the other two studies in the dissertation and provided an interesting result in its own right, including one more dimension would have stretched the article and drawn attention away from its main contributions. I note that controlling for collaboration in the models, although statistically significant, does not change the results of the other variables. All the same, understanding whether and why returns to collaboration differ between services and manufacturing could be a future line of research.

8.4 Further questions

The studies share several limitations and suggest avenues for future research. First, there is room for future research in line with the path followed by this dissertation: the split in the literature between the antecedents and consequences of various innovation activities. The literature on the predictors of firm sourcing behaviour certainly provides much insight into why firms make certain decisions, but this says little about whether these are the right decisions under those circumstances or how these decisions effect other outcomes, such as appropriability and profitability. For example, while Study 1 finds that perceptions of environmental uncertainty lead firms to collaborate for product development and Study 2 shows that collaboration predicts more novel and more commercially successful products, but these conclusions say nothing about the interplay between these two dimensions. This could be analyzed by including other performance measures in the analysis, such as productivity, time to market, etc. Although some studies have considered both the determinants and performance implications of external sourcing activities in the same article, a comprehensive empirical framework tying the two together is underdeveloped.

Second, although the PITEC dataset used in the studies provides a rich source of innovation-specific data in a panel format, some limitations stem from the restriction placed on supplementing the PITEC with data from external sources. Other studies have matched CIS data with other rich data sources, such as Dun and Bradstreet (e.g. Frenz and Ietto-Gillies, 2009). These kinds of matching exercises allow researchers to supplement innovation survey data with other sources specific to their research questions. Data matching techniques also mitigate common method bias. Unfortunately, the use of the PITEC has a stipulation that no attempts can be made to match or otherwise identify the firms. Still, this restriction does not exist on all CIS or similar innovation surveys, so future research could apply the robust panel techniques with matched datasets to investigate specific research questions.

Finally, although Study 3 theorizes on some of the differences between manufacturing and service firms, Study 1 and 2, like many others, do not take service firms into consideration. The applicability and generalizations that one can make to service firms from the general literature (and from the findings in Study 1 and Study 2) may be limited due to the manufacturing bias in innovation studies. Do the findings from Study 1 and Study 2 also apply to service firms? Or is there something fundamentally different in the innovation governance behaviour and innovation processes of service firms and their outputs? Is it even meaningful in this day and age to differentiate service from manufacturing firms?

Research often generates more questions than it addresses. Although the discussions of each study and Chapter 8 try to raise some questions and highlight limitations, with luck the studies in this dissertation will provide fruitful starting points for future research and contribute to our understanding of the innovation puzzle.

8.5 References

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