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Contents

German Summary / Deutsche Zusammenfassung

Ziel dieser Arbeit ist es zu untersuchen, ob offene Innovationsprozesse Unternehmen positiv oder negativ beeinflussen. Der von Chesbrough (2003) geprägte Begriff "offene Innovation" (*open innovation*) konnte seither große Bedeutung in Wissenschaft und Wirtschaft gewinnen. Chesbrough vermutet, dass die Art und Weise, wie Unternehmen ihre Entwicklungen und Erfindungen vermarkten und weiterentwickeln, sich grundlegend verändert hat. Unternehmen haben sich von internen Forschungs- und Entwicklungs-Aktivitäten (F&E) abgewendet und offenen Innovationsprozessen zugewandt (Chesbrough, 2003, 2006). Der Ansatz offener Innovationsprozesse betrachtet Forschung und Entwicklung als ein offenes System, in welchem internen und externen Wissensquellen dieselbe Bedeutung beigemessen wird (Chesbrough et al., 2006). Im Falle offener Innovationsprozesse sind betriebliche Strukturen durchlässig und Unternehmen suchen aktiv die Interaktion mit externen Akteuren (Chesbrough, 2003).

Diese Veränderungen im Innovationsmanagement werden mit erhöhtem globalen Wettbewerb und schnellen Änderungen im Marktumfeld assoziiert (Chesbrough, 2003). Da heutzutage technologische Veränderungen sehr ressourcenintensiv sind und sich der Lebenszyklus vieler Produkte extrem verkürzt hat, müssen Unternehmen damit umgehen, nicht mehr alle F&E-Aktivitäten intern bewältigen zu können (Chesbrough, 2003; Keupp und Gassmann, 2009). Aus diesem Grund erhöhen Unternehmen den Grad ihrer F&E-Offenheit und teilen dadurch Kosten und Risiken von F&E-Projekten mit externen Akteuren. Damit erhalten sie nicht nur Zugriff auf die nötigen Ressourcen, sondern beschleunigen auch den Innovationsprozess (Chesbrough, 2003; Keupp und Gassmann, 2009).

Der wachsende Trend hin zu offenen Innovationsprozessen wird weiter durch aktuelle Entwicklungen in Informations- und Telekommunikationstechnologien erleichtert (Dodgson et al., 2006), welche es Unternehmen erlauben, sich untereinander zu vernetzten und mit hoch-qualifizierten Wissenschaftlern und Ingenieuren aus aller Welt zu sehr geringen Kosten zusammenzuarbeiten. Da Wissen mit Hilfe moderner Informations- und Kommunikationstechnologien augenblicklich und kostengünstig mit vielen Menschen an vielen verschiedenen Orten geteilt werden kann, ist der Wert der rein internen F&E-Aktivitäten erheblich geschwunden (Malone und Laubacher, 1998; Chesbrough, 2003). Daher sind Innovationsprozesse offener geworden.

Die Literatur zum Thema offener Innovationen unterscheidet zwei allgemeine Strategien der externen Wissensbeschaffung durch formale Verträge: i) Outsourcing von F&E-Aufgaben und ii) gemeinsame Entwicklung von Innovationen. Die externen Akteure sind dann entweder F&E Anbieter oder Innovations-Kooperationspartner. Die erste Strategie impliziert die Akquise einen Entwicklungsergebnisses von externen Akteuren, während bei der zweiten Strategie die Kooperationspartner zusammen die Entwicklung wertvoller Wissensgüter anstreben. Um mit den schnellen Veränderungen im Marktumfeld umgehen zu können, müssen Unternehmen F&E-Aufgaben an spezialisierte Forschungsinstitutionen auslagern oder Innovationen gemeinsam mit diesen entwickeln. Diese Vorgehensweisen können Unternehmen dabei helfen, Innovationen relativ schnell und kostengünstig zu entwickeln und sich dadurch rasch auf neue Marktentwicklungen, Bedrohungen und Möglichkeiten einzustellen (Chesbrough, 2003; Keupp und Gassmann, 2009). Nichtsdestotrotz kann ein Wechsel von internen F&E Bemühungen zu offenen und dezentralisierten Innovationsprozessen auch Risiken beherbergen. Unternehmen können unter Umständen die Fähigkeit verlieren, intern Innovationen hervorzubringen und somit ihre eigene Innovationsleistung negativ beeinflussen. Diese Arbeit soll, motiviert von diesen gegensätzlichen Argumenten, Risiken und Chancen offener Innovationsprozesse näher analysieren.

Bevor die Leistungsauswirkungen dieses Ansatzes näher untersucht werden, wird in Kapitel 2 diskutiert, wie Unternehmen bei offenen Innovationsprozessen Grenzen setzen. Frühere Untersuchungen offener Innovationsprozesse bieten keinen systematischen Einblick, ob Unternehmen mit internen Innovationsbeschränkungen mehr F&E Outsourcing betreiben oder die Anzahl ihrer Innovationskooperationen erhöhen. Infolgedessen beschäftigt sich Kapitel 2 mit dieser Forschungslücke und analysiert, ob es sich um kosten- oder ressourcenorientierte Determinanten handelt, welche Unternehmen dazu ermutigen, verschiedene Arten von offenen Innovationsstrategien zu verfolgen. Die Auswertung eines Paneldatensatzes deutscher Unternehmen des produzierenden Gewerbes, welcher aus dem Mannheimer Innovationspanel stammt, zeigt, dass wissensbezogene Hindernisse zu einer Erweiterung des F&E Outsourcings und zu mehr Innovationskooperationen mit einer Vielzahl an externen Akteuren führen. Im Gegensatz dazu, wird eine insignifikante Beziehung zwischen Innovationshindernissen ökonomischen Ursprungs und F&E-Offenheit festgestellt. Die Studie zeigt insbesondere, dass

Kosten- und Risikominimierung weder eine signifikante Rolle für den erhöhten Umfang an F&E Outsourcing noch für den Eingang von Innovationskooperationen spielt. Demzufolge kann gezeigt werden, dass die offene Innovationsübernahme ein wertsteigerndes Ziel verfolgt und nicht zur Kostenminimierung genutzt wird. Sprich, das Wachstumsziel (im Bezug auf externe Wissensbeschaffung) ist der Hauptfaktor, welcher Unternehmen dazu anregt, Outsourcing von F&E-Aktivitäten zu betreiben und Innovationskooperationen einzugehen, während das Ziel der Kosten- und Risikominimierung keine signifikante Rolle spielt. Aus diesem Grund sollten Unternehmen größeren Wert auf strategische Überlegungen legen, wenn sie den Grad der Offenheit ihrer Innovationsprozesse erhöhen; und sie sollten versuchen, Wachstum durch die Anwendung von offenen Innovationsstrategien zu erreichen. Es ist dennoch überraschend, dass der vorrangige Grund fürgroß angelegtes F&E Outsourcing darin liegt, mit wissensbezogenen Innovationsbeschränkungen zurecht zu kommen. F&E Outsourcing Strategien helfen Unternehmen möglicherweise dabei, relevantes und intern nicht verfügbares Wissen zu erlangen. Anderseits ist es jedoch möglich, dass der externe Zugriff auf Wissen durch entfernte vertragliche Beziehungen keine effektive Strategie darstellt, um implizites technologisches Wissen richtig zu nutzen. Des Weiteren kann diese Strategie eigene Innovationsaktivitäten des outsourcenden Unternehmens verdrängen und somit dazu führen, dass die Innovationsleistung des Unternehmens abnimmt.

In Kapitel 3 wird dieses Problem erläutert und es wird untersucht, ob F&E Outsourcing[1], oder externe F&E, andere Innovationsstrategien komplementiert oder substituiert (z.B. interne F&E und Innovationskooperationen). Obwohl frühere Untersuchungen dieses Problem diskutieren (Cassiman und Veugelers, 2006; Schmiedeberg, 2008; Lokshin et al., 2008; Grimpe und Kaiser, 2010), wurde die geographische Dimension externer F&E bis zu diesem Zeitpunkt noch nicht näher untersucht. Anders ausgedrückt, Unternehmen, welche internationales F&E Outsourcing betreiben, tendieren eher dazu, in interne F&E Projekte zu investieren und Innovationskooperationen einzugehen als Unternehmen die nationales F&E Outsourcing betreiben. Ein möglicher Grund dafür ist, dass die Nutzung extern erlangten Wissens aus internationalen Quellen eines höheren internen Leistungsvermögens bedarf (von Zedtwitz und

[1] Der Begriff F&E Outsourcing und externe F&E werden im Verlauf dieser Arbeit synonym verwendet.

Gassmann, 2002; Bertrand und Mol, 2013). Daher werden weitere Untersuchungen benötigt, um festzustellen, ob nationales und internationales F&E Outsourcing interne F&E Aktivitäten und Innovationskooperationen komplementiert oder substituiert. Im Laufe dieses Kapitels wird weiterhin untersucht, welche Leistungsimplikationen nationale und internationale externe F&E haben. Dieser Sachverhalt wird mit Hilfe eines Querschnittsdatensatzes dänischer Unternehmen des produzierenden Gewerbes analysiert, welcher dem Community Innovation Survey entnommen wurde. Diese Umfrage enthält Informationen zu Ausgaben für F&E, welche durch nationale oder internationale externe Akteure durchgeführt wurden und daraufhin in internen Innovationsaktivitäten genutzt wurden. Um die Existenz einer komplementäre Beziehung zwischen den Innovationsstrategien zu überprüfen, wurden der anwendungsorientierte - (*adoption approach*) und der leistungsorientierte Ansatz (*performance approach*) genutzt. Der anwendungsorientierte Ansatz zeigt, dass internationale externe F&E interne F&E und Innovationskooperationen komplementiert. Im Gegensatz dazu finden sich bei Verwendung des leistungsorientierten Ansatzes ein signifikant negativer Effekt der gemeinsamen Nutzung dieser Strategien auf Produktinnovationen. Dieser Gegensatz zeigt die Schwierigkeiten auf, welche beim Versuch einer erfolgreichen Verbindung von internationaler externer F&E mit interner F&E sowie bei der Verbindung von internationaler externer F&E mit Innovationskooperationen auftreten. Dies hängt möglicherweise damit zusammen, dass ein hoher Grad an Innovationsoffenheit das Problem absorptiver Kapazitäten (*absorptive capacity problem*) verursachen könnte. Aus diesem Grund müssen Unternehmen ihre internen F&E Aktivitäten und den Grad an Innovationsoffenheit ins Gleichgewicht bringen, um das Oversearching Problem zu vermeiden und vom offenen Innovationsmodell zu profitieren. Des Weiteren kann keine signifikant komplementäre oder substituierende Beziehung zwischen einheimischem externen F&E und internen F&E, sowie zwischen einheimischem externen F&E und Innovationskooperationen festgestellt werden.

Kapitel 3 zeigt, dass Unternehmen, welche F&E Inputs von internationalen statt von einheimischen externen Akteuren beziehen, mit höherer Wahrscheinlichkeit Produkte mit einem höheren Neuheitsgrad einführen. Im Gegensatz dazu ist einheimische externe F&E signifikant und positiv mit Produktimitation korreliert, hat aber auch einen signifikant negativen Effekt auf Produktinnovation. Diese Ergebnisse zeigen, dass der Bezug von F&E Inputs von einheimischen externen Akteuren eine riskante Strategie zur Erlangung radikaler Produktinnovationen darstellt.

An Stelle dessen sollten Unternehmen versuchen, Wissen auf internationalen Märkten zu akquirieren. Wissensbasierte Güter, die von internationalen Märkten bezogen werden, sind aufgrund von verschiedenen Institutionen und Innovationsprozessen möglicherweise heterogener als solche Güter, die aus dem Inland bezogen wurden. Daher ist es wahrscheinlicher, dass Firmen, die internationale externe F&E beziehen, Produktinnovationen mit einem höheren Neuheitsgrad einführen. Firmen, welche ihre F&E Inputs vom internationalen Marktplatz beziehen, haben mehr Gelegenheit zur Neukombination von Wissen und erreichen von daher eine bessere Innovationsleistung als Wettbewerber, welche ausschließlich auf inländische Dienstleister zurückgreifen. Um Zugang zu Ressourcen, die im Inland unverfügbar sind, zu erlangen, müssen Unternehmen internationale Kontakte knüpfen und sich verlinken, um damit ihre Innovationsleistung zu verbessern. Politische Entscheidungsträger sollten Unternehmen zu internationalen Kollaborationen ermutigen und Wachstum durch die Akquise von externem F&E zu fördern. Im Einzelnen sollten Regierungen Restriktionen für das Outsourcing von F&E-Aktivitäten im Ausland mindern und Unternehmen dabei helfen, passende Partner für F&E-Kooperationen zu identifizieren. Besonders würde dies kleinen und mittelständischen Unternehmen helfen, welche Kollaborationen mit internationalen F&E-Anbietern wünschen und somit Zugang zum internationalen Wissenspool erlangen können.

Kapitel 4 diskutiert zusätzlich die Leistungsimplikationen von F&E Outsourcing und bietet neue Erkenntnisse über die Beziehung zwischen dieser Strategie und der Erfindungsleistung. Obwohl Kapitel 3 signifikant zum Verständnis der Leistungsimplikationen von externer F&E beiträgt, kann es sein, dass das Messen von F&E Output durch Produktinnovationen nicht die Gesamtqualität der Forschungsleistung des Unternehmens wiederspiegelt. Eine Produktinnovation kann zum Beispiel das Resultat der Kombination verschiedener externer Wissensinputs sein und ist somit eventuell kein guter Indikator für die Qualität von internen F&E-Aktivitäten. Sprich, Wissens- und Produktionsmöglichkeiten von Unternehmen können sich unterscheiden. Aus diesem Grund wird in Kapitel 4 näher untersucht, wie F&E Outsourcing mit dem Wert des Forschungsoutouts eines Unternehmens zusammenhängt (in Bezug auf Qualität sowie Quantität der hervorgebrachten Erfindungen und Innovationen). Um diesen Sachverhalt zu untersuchen, kombinieren wir Daten des Mannheimer Innovationspanels mit Patentdaten des Europäischen Patentamtes. Die zuerst genannte Quelle bietet detaillierte Informationen zu Innovationsaktivitäten deutscher Unternehmen, während letztere Daten zu Patentanmeldungen in der EU beinhaltet.

Die Ergebnisse der Datenanalyse lassen vermuten, dass jene Firmen, welche ihre F&E Aufgaben an spezialisierte Forschungsorganisationen auslagern, mehr Erfindungen generieren als Wettbewerber, die auf diese Auslagerung verzichten. Gegebenenfalls, da F&E Outsourcing in den Gebieten stattfindet, in denen das Unternehmen selbst keine hochgradige Expertise besitzt, kann dies dazu führen, dass die Effizienz und Effektivität der Innovationsleistung des Unternehmens gesteigert wird, da dieses sich so auf seine Kernkompetenzen fokussieren kann. Nichtsdestotrotz scheint diese positive Leistungsimplikation von F&E Outsourcing nicht für die Qualität der Erfindungen zu gelten. Genauer gesagt kann eine insignifikante Beziehung zwischen F&E Outsourcing und Qualität der Erfindungen festgestellt werden. Des Weiteren deuten die empirischen Untersuchungen daraufhin, dass großskalierte F&E Auslagerungen weder mit signifikanter Quantität an neuen Erfindungen, noch mit einer besonders hohen Qualität dieser Erfindungen korreliert ist. Aufgrund der limitierten Daten war es nicht möglich zu untersuchen, was die Beziehung zwischen F&E Outsourcing und Qualität der Erfindung antreibt oder wie die Intensität dieser Strategie und die Erfindungsleistung (Qualität und Quantität) zusammenhängt. Um die Erfindungsleistungsimplikationen von F&E Outsourcing genau zu verstehen, ist es notwendig in Betracht zu ziehen, ob F&E an Anbieter, Beratungen oder Forschungsinstitute ausgelagert wird. Das letzte Kapitel diskutiert diese und andere Anwendungsgrenzen, die in dieser Arbeit identifiziert wurden und zeigt Möglichkeiten für zukünftige Forschungsvorhaben auf.

1 Introduction

1.1 Motivation

Innovation[2] is considered to be a key element of a firm's competitive advantage (Schumpeter, 1934). This induces firm managers to invest in research and development (R&D) activities, but to create and commercialize inventions[3] they need to apply an appropriate R&D management practice (Chesbrough, 2003). For this reason, the discussion about how to set R&D boundaries is attracting substantial attention from scholars and practitioners (Powell, 1990; Powell et al., 1996; Chesbrough, 2003, 2006; Cassiman and Veugelers, 2006; Schmiedeberg, 2008; Enkel et al., 2009; Grimpe and Kaiser, 2010; Berchicci, 2013). In particular, whether it is more advantageous to organize R&D activities internally or externally is subject to intensive discussion (Chesbrough, 2003, 2006; Langlois, 2003, 2004; Cassiman and Veugelers, 2006; Schmiedeberg, 2008), but the conclusions are far from being straight forward.

Rather generally, historical accounts suggest that the choice between different economic organizational forms depends on the costs of the coordination technologies and the extent of the market (Smith, 1776/1976; Leijonhufvud, 1986; Langlois, 2003, 2004). Specifically, the literature proposes that when the transportation and communication costs are high and the extent of the market is small, it might be more advantageous to organize economic activities internally to ensure the quality and quantity of certain inputs and, at the same time, to reduce the transaction costs related to an external governance mode (Langlois, 2003, 2004). In other words, as the number of specialized suppliers in a small-sized market can be low and, hence, certain goods and services may not be available on a competitive basis, the internal organizational form may be more beneficial due to the advantages associated with economies of scale. In contrast, once the costs of the coordination technologies diminish and the extent of the market grows, the economic organizational structure might be shifted from the internal to the external governance mode to acquire cheap inputs from cost-effective suppliers as well as to source valuable resources from a wide set of external actors dispersed across various geographical locations (Langlois, 2003, 2004). Indeed, in the early period, when the communication costs were high and the extent of the market was relatively small, the internal-R&D-oriented approach was more

[2]Innovation is defined as the act of introducing a novel method, good or service to a market (Nelson, 1993).
[3]Invention is a process of generating a novel device.

prevalent, because it allowed companies to decrease their transaction costs and also to benefit from the scale effect (Chandler, 1977, 1990; Langlois, 2003). A large research effort exhibits greater productivity not only because the fixed cost of R&D is spread over multiple projects, but also because it permits firms to capture knowledge spillovers through investing in different R&D projects internally (Chandler, 1990). Consequently, this approach allows companies to achieve efficiency and effectiveness in their R&D activities. However, the advantages of the internal-R&D-oriented framework may be less significant when the costs of coordination technologies diminish and valuable resources are accessible from a large number of specialized suppliers (Langlois, 2003). In fact, as the development of the Internet and related technologies allows firms to work with external actors around the world at a very low cost, the value of the internal-R&D-oriented approach has eroded (Chesbrough, 2003). Instead, firms have increased their degree of R&D openness to source external resources and to develop innovation relatively quickly and inexpensively (Chesbrough, 2003; O'Conner, 2006; Keupp and Gassmann, 2009). This trend towards more R&D openness is referred to as open innovation, a process in which organizational boundaries are *porous* and a firm strongly engages in interaction with external actors (Chesbrough, 2003, 2006).

In open innovation, firms develop innovation jointly with external actors or acquire ready R&D results from them. This allows companies to accelerate and improve their innovation activities and to respond swiftly to new market threats and opportunities (Chesbrough, 2003; Keupp and Gassmann, 2009). However, shifting attention from the internal-R&D-oriented approach towards the open innovation framework can also be a risky business in terms of eroding firms' internal innovation capabilities and, as a result, undermining their innovation performance. Motivated by these contradictory arguments, the thesis aims to study the antecedents and performance implications of the open innovation approach. In particular, this PhD dissertation intends to explore whether it is a cost- or a resource-oriented logic that encourages firms to adopt the open innovation framework. It also aims to study when and how companies combine different open innovation strategies to achieve the best possible outcome. Moreover, the thesis examines how the open and distributed R&D approach is associated with product imitation and innovation as well as invention quantity and quality.

To achieve these objectives, three empirical studies are presented in Chapter 2 to Chapter 4, which examine various inter-related research questions. Furthermore, the remainder of this chapter provides theoretical arguments to precede the empirical analyses. For this purpose, Section 1.2 presents the definition and novelty of open innovation and discusses the antecedents to R&D openness. Section 1.3 studies the boundary conditions in open innovation. Section 1.3 examines the inter-relationship between absorptive capacity and R&D openness and, subsequently, Section1.5 reviews the three main chapters of the dissertation.

1.2 The notion of open innovation

1.2.1 The definition and novelty of open innovation

The notion of open innovation, introduced by Chesbrough (2003), has gained considerable attention within academia and the business community. Chesbrough suggests that there has been a fundamental transformation in the way in which firms develop and commercialize inventions. In particular, companies have shifted their innovation activities from a closed to an open model (Chesbrough, 2003, 2006). The closed innovation framework refers to an internal-R&D-oriented approach in which innovation takes place within the formal boundaries of the firm. On the contrary, the open innovation approach considers *research and development as an open system* in which knowledge purposefully inflows and outflows across organizational boundaries to accelerate and improve the internal innovation activities of the firm (Chesbrough, 2003, 2006). To put it another way, the open innovation concept refers to a process in which the organizational boundaries are *porous* and the firm collaborates with a wide set of external actors on innovation (Laursen and Salter, 2006).

However, neither R&D openness in general nor external collaboration in particular is a new phenomenon. As Grönlund et al. (2010: 10) suggest, 'external collaboration is as old as the first invention', implying that research and development activities have always been open (at some level) to external ideas and technologies. For this reason, some scholars argue that the idea of open innovation is not new (Christensen, 2006; Trott and Hartmann, 2009). Before Chesbrough (2003) coined the open innovation concept, a number of scholars had already proposed that innovation practice spans organizational boundaries (Christensen, 2006; West et al., 2006). In particular, two streams of literature can be differentiated that study external sources of innovation. The first stream of literature focuses on user-driven innovation (von Hippel, 1988; Lundvall, 1992; von Hippel and Katz, 2002). As the literature suggests, collaboration with customers or users helps a producer to understand the market needs better, to decrease the errors in an early new product development process and to improve the quality of a product innovation (Lundvall, 1992).

The second stream of literature developed from the observation that collective action, interaction and knowledge sharing are the source of innovation (Allen, 1983). Hence, among the different locations where innovation takes place, such as non-profit organizations (i.e. universities, research institutions, etc.), profit-seeking firms and the mind of individual inventors (Nelson, 1959, 1962), the interaction between actors is an additional institution that drives innovation and this institution is labelled collective invention (Allen, 1983). The notion of collective invention refers to a setting in which technical knowledge is freely exchanged between individuals or economic organizations (Cowan and Jonard, 2003). One of the best examples of the collective invention approach is open-source software, which is publicly available and developed by a group of individuals based on the principle of open and free knowledge exchange (von Hippel and von Krogh, 2003). Nowadays, it is common practice between computer programmers to share algorithms via the Internet and to help each other in solving programming-related problems. By doing so, the development process of new hardware and software programs is greatly improved and accelerated in the computer industry. Motivated by these advantages associated with knowledge sharing and collective invention, firms collaborate with a wide set of external actors and form networks for the purpose of accelerating and improving their R&D activities as well as minimizing the costs and risks of internal R&D projects (Powell, 1990; Powell et al., 1996). Networked innovation implies that independent economic actors and organizations devote their resources to common R&D projects to cope with the increased complexity of product and technology development (Powell et al., 1996).

Given that the open innovation model shares a common perspective with user and collective innovation as well as with inter-organizational or networked innovation studies, a question arises concerning the extent to which this new concept contributes to the literature. First of all, one should note that the open innovation approach incorporates many already existing techniques or strategies into one term (Huizingh, 2011). Accordingly, the open innovation concept has induced the academic and business community to rethink the R&D organizational structure (Huizingh, 2011). In particular, the open innovation literature focuses on boundary conditions in R&D activities and studies how firms can gain competitive advantages through pursuing and combining different forms of R&D openness. As the open innovation framework refers to 'a paradigm that assumes that firms can and should use external ideas, and internal and external paths to market, as the firms look to advance their technology' (Chesbrough, 2006: 2), a number of opportunities are available for firms to develop and commercialize innovation within this framework. For instance, Enkel et al. (2009) differentiate outside-in and inside-out organizational processes in open innovation. The former process allows firms to utilize knowledge from a wide set of external actors and, in this way, to accelerate and improve their innovation activities. The latter process, by contrast, enables companies to open up their knowledge-based resources to external exploitation and, in this way, to enlarge the marketplace for internally generated inventions. Firms also 'combine the outside-in process (to gain external knowledge) with the inside-out process (to bring ideas to market) and, in doing so, firms jointly develop and commercialize innovation' (Enkel et al., 2009: 313). In this context, the open innovation framework refers to a business model that can help firms to improve and accelerate their innovation activities through exploring internally and externally available ideas and technologies.

More importantly, the open innovation concept suggests that internal R&D has lost its strategic significance (Chesbrough, 2003, 2006). Instead, internal and external knowledge sources are given equal importance in innovation (Chesbrough, 2006). For instance, Procter & Gamble (P&G) has adopted the *connect and develop* (C&D) framework in innovation to involve a wide set of external actors from around the world in internal problem-solving activities (Chesbrough, 2003; Dodgson et al., 2006). The C&D approach implies that P&G sources half of its ideas and technologies for internal innovation activities from outside the company. The management team of the company realized that there are more scientists and engineers outside the organizational boundaries working in the same areas of technologies as P&G and they may possess superior skills or competencies to its internal R&D staff (Dodgson et al., 2006). For this reason, P&G

increased its degree of openness in innovation to work with high-quality scientists and engineers inside and outside the company. This approach also allows P&G to share the costs and risks of R&D with external actors and to accelerate its innovation activities. Given these advantages associated with external knowledge sourcing, innovation activities have become more open and market-oriented. As a result, the role of internal R&D has shifted 'from discovery generation as the primary activity to system design and integration as the key function' (West et al., 2006: 10), implying that the internal R&D team (in most large corporations) performs the integration and system assembly task – combining internally and externally developed technologies (Prencipe et al., 2003; Allio, 2005).

1.2.2 Antecedents to open innovation

1.2.2.1 Information and communication technologies

This increased trend towards the open innovation framework is greatly facilitated by the recent progress of information and communication technologies (ICTs) (Chesbrough, 2003; Dodgson et al., 2006). As modern ICTs allow firms to source knowledge from a wide set of external actors at very low costs, the value of the internal-R&D-oriented approach has diminished (Dodgson et al., 2006). Instead, firms have increased their degree of openness in innovation and shifted their attention from internal to external knowledge sources.

In the open innovation strategy, various ICT tools can be used to access and utilize globally dispersed valuable ideas and technologies. For instance, ICTs enable companies to create a virtual team to work simultaneously with highly talented individuals around the world inexpensively (Ebrahim et al., 2009). The virtual team is defined as a geographically dispersed group of individuals working on a common project and interacting via ICTs (Gassmann and Von Zedtwitz, 2003; Powell et al., 2004; Ebrahim et al., 2009). As a result, it allows firms to work efficiently with external actors across national boundaries and, in this way, to improve their innovation activities as well as to reduce the time and cost of new product development.

In addition, ICTs give firms the possibility to post innovation-related problems in an open marketplace via the Internet and then to induce individuals to provide solutions to the problem by rewarding the winning participants financially (von Hippel and Katz, 2002; Füller et al., 2004; Bretschneider et al., 2008; Poetz and Schreier, 2012). This approach is often used to involve users in product innovation-related problem-solving activities (Sawhney and Prandelli, 2000; von Hippel and Katz, 2002), which can be attained through displaying the product's virtual prototype on the Internet and then inviting users to express their opinions and to suggest various options for improving the new product concept. For example, P&G induces customers to participate in the elaboration of a new product design; then, those with the best ideas are given the status of R&D advisors and invited to work with the firm's R&D team (Füller et al., 2004). Similarly, LEGO and Dell conduct idea competitions to improve their existing and new product models via the Internet, and the winning participants are then financially rewarded (Bretschneider et al., 2008; Poetz and Schreier, 2012). This approach helps firms to upgrade a new product design before introducing it to the market (Füller and Matzler, 2007). As a consequence, with the help of ICTs, firms can substantially increase the efficiency and effectiveness of their innovation activities.

1.2.2.2 The globalization of markets

The development of ICTs has also had an indirect effect on increasing the popularity of open innovation among practitioners. In particular, with the enormous cost reduction of coordination technologies, the integration process of domestic markets has increased, which in turn has induced firms to reshape their organizational structure and to adopt to the more open or distributed R&D model. In other words, the globalization of markets stimulates firms to collaborate with a wide set of external actors across different geographical locations (von Zedtwitz and Gassmann, 2002; von Zedtwitz et al., 2004). This can be explained by several factors. First, firms internationalize their R&D activities to explore the requirements of foreign markets (von Zedtwitz and Gassmann, 2002; von Zedtwitz et al., 2004; Cantwell and Mudambi, 2005). As the needs and preferences of customers differ across countries, firms collaborate with international entities with the purpose of adapting their products to the tastes and needs of customers abroad (von Zedtwitz and Gassmann, 2002). Second, there is a cost-based logic implying that the internationalization of R&D activities allows companies to purchase cheap inputs from low-cost countries (von Zedtwitz and Gassmann, 2002; von Zedtwitz et al., 2004).

Hence, acquiring some R&D inputs from international marketplaces may help firms to improve the efficiency of their innovation activities. Third, companies collaborate with international actors to access ideas and technologies that are unavailable internally (von Zedtwitz and Gassmann, 2002; von Zedtwitz et al., 2004; Lewin et al., 2009; Nieto and Rodriguez, 2011). Given that knowledge-based resources vary across countries due to the different innovation systems (Cantwell, 1989), R&D internationalization enables firms to tap into the global knowledge pool and to keep abreast of the technologies developed by foreign companies. To put it another way, companies organize R&D on a global scale to diversify their external knowledge sources and to access resources that are unavailable within their home country (von Zedtwitz and Gassmann, 2002; von Zedtwitz et al., 2004; Lewin et al., 2009; Nieto and Rodriguez, 2011).

Furthermore, the globalization of markets increases the competitive pressure and accelerates the pace of technological changes, forcing firms to distribute their R&D activities and to search for resources globally to accelerate and improve their innovation activities (Chesbrough, 2003; Gassmann et al., 2010). In addition, rapid technological changes induce firms to increase their organizational flexibility to respond effectively to market threats and opportunities (Chesbrough, 2003). However, to gain from R&D openness and to avoid the drawbacks related to open innovation, the way in which firms should set boundaries in open innovation requires careful consideration.

1.3 Open innovation and boundary conditions

1.3.1 Integrated and disintegrated R&D models

According to Chesbrough (2006: 2), open innovation is defined 'as the antithesis of the traditional vertical integration model'. The term vertical integration refers to an organizational structure in which a single firm owns its suppliers and users. This structure enables companies to control their value chain and to carry out all the economic activities within their formal boundaries. As a consequence, the vertically integrated research organization may allow firms to attain economies of scale and scope in R&D activities (Chandler, 1977, 1990; Langlois, 1999). The former implies increasing returns to scale, which arise from reusing knowledge and spreading the fixed R&D costs over a large number of identical R&D activities, whereas the latter refers to increasing returns to scope arising when common tangible and intangible resources are shared over different R&D projects (Langlois, 1999). In this context, vertical integration may permit firms to increase the efficiency and effectiveness of their R&D activities. However, vertical integration can also be a risky business model under rapid technological changes. In particular, given that a technological change is often 'competence-destroying to firms and their suppliers' (Afuah, 2001: 1), integrating vertically with or acquiring other companies to access their capabilities and competencies may restrain firms' strategic flexibility. An alternative option is to disintegrate vertically and to use a market mechanism to acquire the resources needed. This may allow firms to switch suppliers relatively easily when a new competence-destroying technology emerges on a market (Gilley and Rasheed, 2000; Chesbrough, 2003). In other words, the cost of disintegrating from the vertical organization and selling an acquired firm might be higher than the cost of withdrawing from a contract relationship. Afuah (2001: 1) suggests that when a new competence-destroying technology emerges on the market, 'firms that are integrated vertically into the new technology will perform better than those that are not. At the same time, firms that had been vertically integrated into the old technology will perform worse than those that had not been'. Given that, nowadays, it is a challenging task to forecast the technological requirements for long-term success, the advantages of the vertical integration business model are significantly reduced (Harrigan, 1984, 1985; Balakrishnan and Wernerfelt, 1986; Chesbrough, 2003). For this reason, a number of firms have shifted their economic organizational structure from the integrated to the disintegrated business model to increase their strategic flexibility and to react quickly to market threats and opportunities (Ulset, 1996; Chesbrough, 2003; Calantone and Stanko, 2007). However, an alternative line of reasoning suggests that when firms face rapid changes in markets and technologies, they integrate vertically to generate their own inputs and to avoid dependency on external suppliers (Monteverde and Teece, 1982; Williamson, 1985; Monteverde, 1995).

These contradictory arguments about the advantages of the integrated and disintegrated business models in dealing with rapid technological changes cause ambiguity regarding how firms should set boundaries to improve their R&D activities. Historical accounts suggest that firms often reshape their organizational structure in response to changes in the external environment (Langlois, 2003, 2007). To survive in a dynamic market environment, firms need to adjust their organizational structures to the market conditions. 'Like a biological organism, an organization confronts an environment that is changing, variable and uncertain. To survive and prosper, the organization must perceive and interpret a variety of signals from the environment and adjust its conduct in light of those signals' (Langlois, 2007: 66). For this reason, the economic organizational structure greatly depends on the market environment and the problems that firms need to solve. Hence, explaining the underlying factors that induce firms to integrate or disintegrate vertically (to use the intra- and inter-organizational division of labour) requires a historical look at the market and industry evolution to understand the reasons behind the systemic changes in boundary conditions (Langlois, 2003; Jacobides, 2005).

1.3.2 A brief historical look at market and industry evolution

Since Adam Smith, there have been many debates about the advantages associated with the division of labour. In Smith's view, the division of labour leads to higher productivity, because specialization in one particular task enables workers to improve their efficiency through performing the same task repetitively (Smith, 1776/1976). As an illustrative example, he contrasts craft and factory production in pin-making (Smith, 1776/1976; Leijonhufvud, 1986). The former refers to *individual* production in which each craftsman specializes in a wide range of tasks to carry out the entire operation necessary to make a pin. The latter stands for *team* production in which the pinproduction process is decomposed into separate operations and these operations are completed by distinct workers (Leijonhufvud, 1986). By task division, the organizational form of factory production allows workers to concentrate on a narrow range of specialization and, as a result, to improve their productivity (Smith, 1776/1976; Leijonhufvud, 1986). For this reason, factory production is seen as more efficient than craft production, but the choice between these two productionforms depends on the extent of the market (Smith, 1776/1976); 'when the extent of the market is small, clearly production will be local, small in scale and oriented to markets' (Langlois, 2004: 370). On the contrary, once the extent of the market increases, the economic organizational structure will shift from craft to factory production and the division of labour will increase in the production system (Smith, 1776/1976; Leijonhufvud, 1986). Indeed, in the early period, when the transportation and communication costs were high and consequently the extent of the market was small, production was mainly fragmented and decentralized to serve *isolated* local markets (Langlois, 2003, 2004). As production was small in scale in this period, labour was undivided and local producers specialized in a wide range of activities. This situation changed substantially in the late nineteenth and early twentieth centuries when the progress of coordination technologies, such as train and telegraph, reduced the transportation and communication costs (Langlois, 2003). The development of coordination technologies in turn facilitated the integration of regional markets and, as a result, the distributed and local market-oriented production system was replaced by the centralized or vertically integrated organizational structure (Chandler, 1977; Leijonhufvud, 1986; Langlois, 2003). This happened at least for two reasons. First, the reduced costs of transportation and communication allowed firms to serve large markets at relatively low costs (Langlois, 2003, 2004). This enabled producers to organize their economic activities in a specific location and to ship goods to remote markets (Langlois, 2003). Second, as the increased extent of the market allowed producers to attain economies of scale, the organizational form of the production system was changed to serve mass markets (Chandler, 1977). In particular, a complex production system was decomposed into simpler tasks, which were then assigned to distinct workers, implying that the division of labour increased among production operations (Chandler, 1977; Leijonhufvud, 1986). The production process was also standardized with the help of machinery technologies, which allowed producers to accelerate the working process and also to minimize qualitative variation and human errors in operations by assigning workers to manage machinery tools (Langlois, 2004). At the same time, such an economic organizational form enabled firms to reduce their average production costs. In other words, 'larger markets allowed a shift to higher-fixed-cost methods, which were capable of lowering unit costs – often dramatically – at high levels of output' (Langlois, 2007: 72). Thus, the development of coordination technologies and, as a result, the enlarged extent of the market played a major role in shifting the economic organizational structure from the fragmented and localized production system towards the integrated business model in the late nineteenth and early twentieth centuries.

In contrast, the further progress of coordination technologies had a substantially different effect on the economic organizational form in the late twentieth century. More specifically, the development of the Internet and personal computers promoted the globalization of domestic markets (von Zedtwitz and Gassmann, 2002; von Zedtwitz et al., 2004), which in turn allowed firms not only to increase their product sales abroad, but also to acquire cheap inputs from low-cost countries and to tap into the global knowledge pool. As valuable knowledge became distributed worldwide, firms increased their international collaboration to keep track of various fields of technological development and to access resources that were unavailable within their home market (von Zedtwitz and Gassmann, 2002; von Zedtwitz et al., 2004; Lewin et al., 2009; Nieto and Rodriguez, 2011). For these reasons, the trends towards the disintegration of product development functions increased, implying that the new product development process is decomposed so that some activities are executed internally while others are purchased from domestic and international suppliers.

One may ask why the progress of coordination technologies and the growth extent of the market had a substantially different effect on the economic organizational structure in the early and the late twentieth century. It might be due to the fact that 'in the early stages of an industry's evolution when certain inputs are not available in competitive supply, vertical integration may be necessary to assure the quality or quantity of supply' (Teece, 2010: 307). On the contrary, when an industry grows and goods/services are accessible from a large number of specialized suppliers, the needs for vertical integration may diminish (Langlois, 2003). In this sense, as industries were in the early stage of development in the early twentieth century, vertical integration was essential to develop the required resources in common ownership. This situation changed in the later period, when economic globalization allowed firms to acquire cheap and high-quality inputs from domestic and international suppliers, which in turn induced firms to disintegrate their production development functions and to outsource some of their operations to external actors (Langlois, 2003). Moreover, 'because information can be shared instantly and inexpensively among many people in many locations, the value of centralized decision making and expensive bureaucracies decreases' (Malone and Laubacher, 1998: 147). However, to understand how the boundaries are set between the firm and the market, a closer look at transaction cost theory (TCT) and the resource-based view (RBV) of the firm is required.

1.3.3 Transaction cost theory

TCT considers internal and external governance modes based on their relative costs; when the market offers a certain good or service at a lower price than organizing the same activities internally then a *buy* strategy is considered to be optimal (Coase, 1937; Williamson, 1975). TCT assumes that 'transactions within integrated companies may be insulated from competitive pressure and subject to bureaucratic phenomena' (Geyskens et al., 2006: 520). In this context, the market mechanism might be superior to the internal organization form, because the market competition forces suppliers to improve their efficiency and to lower their prices. However, the transaction or coordination costs might increase when firms use the market mechanism instead of the internal governance mode, because monitoring and enforcing a contract performance is often problematic due to bounded rationality, opportunism and asset specificity (Williamson, 1975). According to Simon (1957), humans have limited cognitive ability in spite of the assumption of their rationality. Hence, limited cognitive ability prevents firm managers from foreseeing all the possible opportunistic actions of their contractors. Opportunism is defined as the disregard of the contract partners or the *defeat* strategy that may also reduce the total welfare. To avoid such situations, firm managers attempt to write a complete contract; this, however, is only accomplishable when the contracted quantity and quality of specific assets are readily observable and measurable, which certainly is not the case with the outcome of product and process innovation activities. Usually, those activities are characterized by high levels of uncertainty with regard to outcomes (Mudambi and Tallman, 2010). Related to that, it is difficult to estimate the period of time and the resources required to fulfil certain research and development tasks. Hence, contracting those activities out will lead to high transaction costs (for monitoring the processes and results). To avoid excessive transaction costs, internal, rather than external, organizational forms for innovation activities appear to be more appropriate.

However, the transaction costs related to the market mechanism will be substantially lowered if a firm manages to modularize its innovation activities. Modularity implies that a complex engineering system is decomposed into discrete components, which are developed separately and then interconnected with a standardized interface to assemble the final product (Langlois, 2002; Mikkola, 2003). This makes the inter-organizational division of labour possible at very low transaction costs through minimizing the interdependence between sub-components or modules (Mikkola, 2003). Hence, the modularization of product development functions enables firms to acquire some parts of R&D activities in the open marketplace. However, TCT alone does not explain why firms organize certain R&D activities internally and certain ones externally. As TCT is considered to be a cost-based approach, it neglects the learning processes embodied within internal and external governance modes. In other words, TCT focuses on minimizing transaction costs when considering which activities should be retained internally and which should be contracted out, but it ignores the ideas and technologies available inside and outside the firm (Barney, 1999). Therefore, to provide a complete picture of how firms set R&D boundaries, I present insights from the RBV of the firm in the next section.

1.3.4 The resource-based view of the firm

The RBV of the firm further discusses the resource allocation issue and shifts the attention from a cost-based approach towards a resource-oriented framework (Penrose, 1959; Barney, 1991; Peteraf, 1993; Barney et al., 2001). In particular, the RBV of the firm suggests understanding the performance of a firm via its combination of specific resources. Resources can be tangible and intangible assets, such as physical assets, financial capital, human capital, organizational knowledge, information, managerial capabilities, etc. (Grant, 1991). According to the RBV, firms should possess valuable, rare, inimitable and non-substitutable (VRIN) resources to attain above-normal profits (Barney, 1991; Peteraf, 1993). Valuable and rare resources enable firms to satisfy consumer requirements better than their competitors (Peteraf, 1993). Resources should also be inimitable and non-substitutable, because competitors should not be able to duplicate the valuable resources of the firm or to attain a comparable performance based on other resources. To develop VRIN resources, firms should define their organizational strengths and weaknesses relative to their rivals so that they can focus on the economic activities that they can perform best (Barney, 1991). As the internal governance mode is also considered to be one of the most powerful isolating mechanisms, organizing strategically important economic activities internally enables firms not only to build up valuable and rare resources but also to protect these resources from imitation (Wang et al., 2009; Grimpe and Kaiser, 2010). This is especially true in the case of R&D activities because protecting strategically important knowledge-based resources from imitation can be difficult once they have been revealed or contracted out to external actors (Grimpe and Kaiser, 2010). For this reason, the RBV suggests that firms should concentrate on R&D functions in their core competency areas and use the market mechanism for rather peripheral or non-core activities (Prahalad and Hamel, 1990; Grimpe and Kaiser, 2010). The term core competency refers to a firm's unique capabilities that determine its competitive advantages from the long-term perspective (Prahalad and Hamel, 1990). This core competency approach has become more relevant in the current fast-changing market environment, because rapid technological changes and a shorter product life cycle deplete firms' valuable resources and put pressure on them to pursue innovation (Chesbrough, 2003).

As technological and product innovation also spans different scientific disciplines, many firms face a cognitive limitation in carrying out all the R&D tasks internally (Keupp and Gassmann, 2009). The internal impediments to innovation are more critical under rapid technological changes, because undertaking radical transformation and developing new competitive capabilities internally, in the short run, can hardly be achieved without external collaboration (Powell et al., 1996; Chesbrough, 2003; Keupp and Gassmann, 2009). Therefore, firms increase their degree of R&D openness to collaborate with a wide set of external entities and to gain timely access to required resources that are otherwise unavailable (Powell et al., 1996). To reduce the transaction costs related to the external governance mode, complex innovation systems are decomposed into a small number of R&D subcomponents or tasks, which then are developed by distinct external actors (Mikkola, 2003). As a result, the modularization of innovation activities permits firms to benefit from several advantages. First, it allows firms to focus on their key research activities and to contract out those modules in which they have little or no competence. Such inter-firm division of labour enables companies to devote their financial and human resources to their core innovation activities and to acquire rather peripheral R&D functions from a specialized research organization to which these are the key activities (Prahalad and Hamel, 1990; Grimpe and Kaiser, 2010; Mudambi and Tallman, 2010). As a result, the modularization of R&D functions may help firms to improve the efficiency and effectiveness of their innovation activities. Second, as modules are developed separately, R&D activities shift from a serial to a parallel working process (Howells et al., 2003). Consequently, this approach allows firms to accelerate their innovation processes. Third, a modular product is more adaptive to changes in markets and technologies than a complete system (Langlois, 2002). In other words, a modular system enables companies to change internal parts of modules without altering the functionality of the entire system (Langlois, 2002; Mikkola, 2003). Hence, the modularization of product development functions increases a firm's strategic flexibility.

However, the core competency approach also has its negative side. In particular, firms that focus on a narrow set of core functions may fall into a competence trap (Leonard-Barton, 1992). To put it another way, core competency may turn into core rigidity (Leonard-Barton, 1992). This might be due to the fact that organizational routines, which are developed over time through learning-by-doing processes, often become a source of resistance to organizational changes and may lock firms into specific production activities (Nelson and Winter, 1982; Henderson and Clark, 1990). A routine is interpreted as 'a functionally similar pattern of behavior in a given stimulus situation without explicitly selecting it over alternative ways of behaving' (Gersick and Hackman, 1990: 69). In this sense, concentrating on a narrow set of R&D activities (specializing in a certain technological domain) may cause structural inertia and, as a result, generate obstacles to adopting technological changes, because past learning is stored in the organizational memory and the further learning process is greatly affected by the previously accumulated knowledge stock (Nelson and Winter, 1982; Huber, 1991; Cyert and March, 1992), implying that 'firms may be expected to behave in the future according to the routines they have employed in the past' (Nelson and Winter, 1982: 134). Hence, the core competency framework may lead firms towards a competence trap and, as a result, undermine their performance (Leonard-Barton, 1992). To prevent such a situation, firms not only focus on the product development functions in their core competence areas, but also contain knowledge in the models that are contracted out to specialized research organizations. For example, Brusoni et al. (2001) suggest that firms know more than they make. Indeed, a number of empirical studies (based on patent data analysis) reveal that large technologically intensive firms decrease their product diversification, but broaden their technological knowledge base (Granstrand et al., 1997; Patel and Pavitt, 1997; Prencipe, 1997, 2000; Brusoni et al., 2001). In doing so, firms coordinate the acquisition of externally developed R&D modules more effectively and, at the same time, keep track of various fields of technological development that in turn may help them to avoid a competence trap in innovation activities. This approach suggests that firms assemble a final product internally but develop only a small part of the sub-technologies themselves (Prencipe et al., 2003), implying that companies emerge as system integrators (Christensen, 2006). This integrative competency framework is closely associated with the open innovation concept (Christensen, 2006), in which a firm strongly engages in interaction with external actors and the internal R&D team specializes in integrative competence to manage externally developed technologies (Chesbrough, 2003; Allio, 2005). The central argument in favour of open innovation is that a firm should increase its R&D openness to work with skilled labour inside and outside the company (Chesbrough, 2003).

As the number of specialized suppliers has increased during recent decades due to the growth extent of the market, firms are increasingly turning their attention towards external knowledge sources to acquire the resources they need and to develop innovation relatively quickly and inexpensively (Chesbrough, 2003; O'Connor, 2006). As a result, R&D activities have become more open and market-oriented.

1.3.5 External knowledge sourcing in open innovation

Drawing on the R&D management literature, scholars differentiate two generic strategies for sourcing external knowledge via formal contracts: i) outsourcing R&D functions and ii) developing innovation jointly (Narula, 2001; Nakamura and Odagiri, 2005; Grimpe and Kaiser, 2010); the external actors are then R&D suppliers and innovation cooperation partners, respectively. The former strategy implies the acquisition of a research outcome from external actors, whereas the latter strategy refers to a joint effort of the partner firms to develop valuable knowledge assets. Given that these two strategies imply different types of external collaboration (Grimpe and Kaiser, 2010), firms may adopt a portfolio approach to increase the efficiency and effectiveness of their external knowledge sourcing. In other words, the choice between these strategies may depend on the knowledge-based resources that companies seek to acquire from external actors.

1.3.5.1 Reasons for outsourcing R&D activities

The main advantage attributed to R&D outsourcing is that this strategy allows firms to purchase ready R&D results without substantial involvement in the innovation activities, which are contracted out to specialized research organizations (Grimpe and Kaiser, 2010). In this context, R&D outsourcing permits firms to concentrate on core R&D activities internally and to outsource rather peripheral R&D tasks to external suppliers (Quinn, 1999, 2000; Grimpe and Kaiser, 2010). As a consequence, firms may achieve several potential gains from R&D outsourcing. First, innovation costs can be considerably reduced through acquiring cheap R&D inputs from cost-effective suppliers (Calantone and Stanko, 2007; Howells et al., 2008; Grimpe and Kaiser, 2010). In general, competitive pressure forces external suppliers to increase their efficiency and to reduce their production costs; for this reason, the outsourcing strategy can help firms to source some R&D inputs from specialized suppliers at low prices (Grimpe and Kaiser, 2010). Usually, specialized suppliers attain cost effectiveness by selling the same inputs to multiple clients, which in turn allows them to attain economies of scale and, as a result, to reduce their unit costs. Second, R&D outsourcing allows firms to reduce the time period for new product and technology development. This is achieved through distributing R&D tasks among specialized suppliers, that is, shifting innovation activities from serial to sequential working processes (Howells et al., 2003). Third, 'an outsourcer is able to take advantage of emerging technology without investing significant amounts of capital in that technology' (Gilley and Rasheed, 2000: 766). In other words, R&D outsourcing may help firms to build up a flexible organizational structure and to switch suppliers when more cost-effective technologies emerge on the market (Gilley and Rasheed, 2000). As technological capabilities are developed over time through the learning-by-doing process, firms may not be able to develop new technological competencies (in the short run) without external collaboration. For this reason, R&D outsourcing can be an important instrument to acquire resources that are unavailable internally (Howells et al., 2008). Fourth, by the division of R&D labour, firms increase the organizational commitment to the R&D activities that they can perform best and use the R&D service of specialized research organizations for rather peripheral innovation activities in which they lack competency (Quinn, 1999, 2000; Grimpe and Kaiser, 2010). As a result, this R&D strategy may help firms to improve their innovation performance.

Furthermore, considering the composition of knowledge resources, a number of studies suggest that a complementary rather than a substitutive relationship is more likely to result in superior performance (Nelson and Winter, 1982; Rosenkopf and Nerkar, 2001). Complementary resources allow firms to reconfigure their competencies by generating new combinations of existing resources to respond timely and effectively to new market opportunities and external threats. In this context, R&D activities can be seen as recombination activities, because an innovation is considered to be a new combination of the existing knowledge (Schumpeter, 1934). In this sense, a firm that possesses a heterogeneous stock of knowledge and competencies has more opportunities for knowledge recombination and performs better in innovation than others that apply a rather homogeneous knowledge base (Nelson and Winter, 1982; Rosenkopf and Nerkar, 2001; Cantner and Plotnikova, 2009). Taking into account that firms are heterogeneous in terms of their resources due to their different routines and operation systems, which cause the formation and accumulation of diverse capabilities and competencies (Nelson and Winter, 1982), R&D outsourcing can help firms to access miscellaneous knowledge inputs and, as a result, to improve their innovation performance.

Although R&D outsourcing promises the above-mentioned advantages, this governance mode is considered to be inappropriate when the knowledge-based resources that a client firm seeks to acquire from a specialized supplier are tacit in nature (e.g. skill, know-how), because the effective utilization of such knowledge requires intensive interaction with the knowledge holder (Narula, 2001; Mudambi and Tallman, 2010). For this reason, accessing tacit knowledge resources through R&D outsourcing may not be sufficient to learn and enrich the internal stock of knowledge.

1.3.5.2 Reasons for engaging in innovation cooperation

In contrast to R&D outsourcing, innovation cooperation implies joint R&D development whereby collaborative firms interact intensively to learn and generate new valuable knowledge assets (Hagedoorn, 1993; Tether, 2002). This intensive interaction process itself facilitates tacit knowledge exchange through building up trust-based relationships between employees coming from partner firms (Holste and Fields, 2010). For this reason, innovation cooperation is seen as a superior governance mode over R&D outsourcing in terms of utilizing the skills and know-how of external partners (Hamel, 1991; Sakakibara, 1997). Moreover, taking into account that product and technology innovation activities are often a complex and uncertain process, outsourcing such activities to an external provider may be an inefficient strategy due to the high level of information asymmetry between contract parties. In this case, it will be more appropriate to use innovation cooperation, because it is an intermediated governance mode between internal organization and market mechanism, which allows firms to keep a certain degree of control over transactions (Williamson, 1991). Therefore, innovation cooperation rather than R&D outsourcing can be a more viable option to deal with the contractual complexity of innovation activities.

Furthermore, there are several other advantages associated with innovation cooperation. In particular, this strategy permits partner firms to improve their innovation activities through pooling and combining heterogeneous knowledge inputs (Hagedoorn, 1993; Tether, 2002). The joint R&D effort allows collaborative parties not only to improve their innovation performance, but also to attain economies of scale in R&D and, hence, to diminish their costs and to increase the efficiency of their innovation processes (Sakakibara, 1997). In addition, combining the complementary skills and competencies embodied in partner organizations enables the contract parties to accelerate their innovation activities and, at the same time, to share the risks related to new product and technology development (Hagedoorn, 1993; Tether, 2002).

1.3.5.3 International knowledge sourcing

With the help of modern ICTs, R&D outsourcing and innovation cooperation strategies are also applied on the global scale. In other words, as there is substantial cost cutting in coordination technologies, firms intensively collaborate with domestic and international specialized R&D organizations to source valuable resources from excellent research laboratories spread across various geographical locations (von Zedtwitz et al., 2004). The primary motive in internationalizing R&D activities is to source resources that are unavailable within the domestic market (Lewin et al., 2009). Rather generally, resources may vary across countries due to the different institutional settings (Freeman, 1995). Taking into consideration that 'national innovation systems help to shape firm capabilities and resources, […] knowledge resources are more homogeneous within a country and more heterogeneous across countries' (Bertrand and Mol, 2013: 753). In this context, collaboration with international actors allows firms to diversify their external knowledge sources and to access complementary resources abroad (Lewin et al., 2009; Bertrand and Mol, 2013). Hence, firms that source knowledge from international marketplaces are more likely to improve their innovation performance than their counterparts that rely only on domestic resources (Nieto and Rodriguez, 2011; Bertrand and Mol, 2013). However, as companies may differ across countries in terms of their knowledge bases, the level of understanding between them can be limited, which in turn can be a substantial obstacle to gaining from international collaboration (Bertrand and Mol, 2013). To safeguard against such a situation, firms need to possess large absorptive capacity to learn and utilize knowledge from diverse external actors.

1.4 Absorptive capacity and R&D openness

Absorptive capacity refers to 'the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends' (Cohen and Levinthal, 1990: 128). In particular, it stands for the pre-existing knowledge stock that allows a firm to identify and exploit external knowledge (Cohen and Levinthal, 1989, 1990). As the authors suggest, the prior knowledge structure within a firm determines its ability to learn and add new knowledge to its memory. In this sense, companies with a rich internal knowledge stock are more likely to gain from R&D openness in terms of absorbing knowledge from a wide set of external actors than their counterparts that lack the required level of competencies. However, learning performance depends not only on the amount of accumulated knowledge, but also on the prior related knowledge (Cohen and Levinthal, 1990). In other words, a firm is more likely to learn and acquire new knowledge in a particular area of the technological domain in which it has already accumulated some level of expertise. In contrast, learning in new and unfamiliar technological areas can be limited due to the lack of associated linkages between the firm's knowledge basis and the new technological domain. For this reason, increasing the degree of R&D openness can hamper innovation performance. For instance, previous studies provide empirical evidence that over-searching affects innovation performance negatively (Katila and Ahuja, 2002; Laursen and Salter, 2006). More specifically, Katila and Ahuja (2002) study the search behaviour of manufacturing firms in the robotic industry, and they focus on two dimensions of knowledge search: 'search depth, or how frequently the firm reuses its existing knowledge, and search scope, or how widely the firm explores new knowledge' (1). The results of the study show that the search scope and depth have decreasing returns in innovation activities. Laursen and Salter (2006) further study this issue and provide similar results. In particular, they study UK manufacturing firms, grouping them based on their search strategy defined as breadth and depth. The breadth search strategy refers to diverse external knowledge sources, and the depth strategy is defined as how intensively firms use external knowledge sources in innovation. They also find out that searching for external knowledge too widely and deeply decreases the returns in product innovation. Hence, the studies show that increasing R&D openness may undermine firms' innovation performance. To gain from R&D openness and avoid the associated risks, companies need to invest deliberately in internal R&D to develop the required level of expertise and to utilize knowledge from a wide set of external actors effectively.

1.5 Thesis structure and research questions

In the previous sections, I presented theoretical arguments for why R&D activities have shifted from the closed to the open model and provided a general discussion of how firms set boundaries in open innovation. The primary purpose of this dissertation is to analyse empirically the conditions under which firms engage in one or other open innovation strategy and to identify the potential gains from different forms of R&D openness. In particular, this dissertation presents empirical studies that attempt to address the following research questions. First, do economic- and knowledge-related impediments induce firms to increase the scale of R&D outsourcing or the number of innovation cooperation partnerships? Second, (i) do domestic and international external R&D[4] complement or substitute internal R&D and innovation cooperation and (ii) how do domestic and international external R&D relate to innovation performance? Third, how is the R&D outsourcing strategy associated with the value of the firm's research output (in terms of invention quantity as well as quality)?

To address these questions, the PhD dissertation presents three interconnected studies. The theoretical foundations of the studies are built upon transaction cost theory (TCT), the resource-based view of the firm (RBV), the knowledge-based view (KBV) of the firm and evolutionary economics. Based on these, theoretical arguments are provided and appropriate hypotheses are developed. To validate the hypotheses empirically, the Community Innovation Survey (CIS) is used in the empirical analyses. In particular, the empirical part of the first and third studies is based on the German part of the CIS, whereas the Danish part of the CIS is used in the empirical analysis of the second study. The former refers to the Mannheim Innovation Panel (MIP) database, which is collected annually by the Centre for European Economic Research (ZEW). The main objective of the MIP is to explore the innovation behaviour of German firms. For this purpose, the survey provides a broad variety of information on innovation activities that gives the authors possibilities to examine empirically the driving factors of open innovation and to study the performance implication of R&D openness in the first and third papers, respectively. In contrast to the first and third studies, the second paper focuses on the international dimension of open innovation. For this reason, the Danish part of the CIS is used in the empirical analysis. The

[4]The terms external R&D and R&D outsourcing are used interchangeably in the thesis.

survey, which is collected by the Danish Statistical Office, provides information about Danish firms' innovation activities at the national and international levels.

The first two studies provided in Chapter 2 and Chapter 3 are based on co-authored work, to which each author made an equal contribution. The third study is a single-author paper and it is presented in Chapter 4. A summary of the three papers is offered in Chapter 5. In addition, I briefly review these three papers in the next part of this chapter.

1.5.1 The journey towards open innovation: why do firms choose different routes?

Chapter 2 contributes to the current debate about the driving factors of open innovation adoption. Recent studies discuss this theme intensively and conclude that 'for explaining open innovation adoption the internal environment in firms is more important than the external environment' (Huizingh, 2011: 5). In particular, Keupp and Gassmann (2009) provide empirical evidence that internal innovation impediments (i.e. *finance-, risk- and information and skill-related*) are one of the major factors that induce firms to source knowledge from a wide set of external actors. However, little is known about whether external knowledge sourcing is undertaken through innovation cooperation or R&D outsourcing under such innovation constraints. This differentiation is important because R&D outsourcing implies the acquisition of a research outcome from external entities, whereas innovation cooperation refers to joint R&D development. Thereby, these two strategies involve different types of learning, and firms may adopt a portfolio approach to deal adequately with the economic- and knowledge-related constraints.

Furthermore, taking into account that R&D outsourcing implies the acquisition of ready R&D results without involvement in the related R&D problem-solving activities, it is less clear whether the primary purpose of using this strategy in innovation processes is cost–risk minimization or the knowledge-seeking objective. Although firms may attempt to achieve both of the objectives simultaneously through outsourcing their R&D activities, there is much suspicion regarding whether this strategy can be effective in realizing growth objectives (in terms of acquiring knowledge-based resources) (Mudambi and Tallman, 2010). Several factors can be differentiated that make R&D outsourcing less effective for this purpose. First, learning certain skills and know-how is considered to be a function of involvement in related problem-solving activities (Arrow, 1962). Second, utilizing tacit knowledge from an R&D provider requires intensive interaction with the knowledge holder (Weigelt, 2009; Mudambi and Tallman, 2010). As neither of these is delivered by R&D outsourcing, scholars are concerned that relying greatly on this R&D strategy may hamper a firm's innovation performance.

Motivated by this issue, the study explores the effect of cost–risk- and knowledge-related innovation constraints on R&D outsourcing. Furthermore, to provide a holistic picture, R&D outsourcing is studied in comparison with innovation cooperation. Hence, this chapter examines whether economic- and knowledge-related constraints induce firms to increase the scale of R&D outsourcing or a number of innovation cooperation partnerships.

1.5.2 The inter-relationship between external R&D, innovation cooperation and product innovation

Chapter 3 focuses on the international dimension of open innovation and examines why and when firms combine different strategies in product innovation. More specifically, this study explores whether domestic and international external R&D complement or substitute other innovation strategies (i.e. domestic/international innovation cooperation and internal R&D). The debate about the inter-relationship between external and internal R&D has attracted considerable attention within academia (Cassiman and Veugelers, 2006; Lokshin et al., 2008; Schmiedeberg, 2008), because R&D management scholars are concerned that sourcing knowledge-based resources from external actors via external R&D or innovation cooperation may displace a firm's internal innovation activities. This concern is related more to external R&D than to innovation cooperation, because the former strategy allows firms to acquire a research output from an R&D supplier without devoting time and resources to the related problem-solving activities. This, on the one hand, enables firms to reduce the costs and risks of R&D projects, to diminish the time of new product development and to access valuable external resources (Calantone and Stanko, 2007; Howells et al., 2008). However, on the other hand, these may substitute internal learning processes and, as a result, hamper the firms' innovation performance (Weigelt, 2009). Therefore, to understand whether firms *gain* or *lose* from R&D outsourcing, scholars study whether this strategy complements or substitutes internal innovation activities. A complementary relationship between R&D strategies is considered to exist when 'the implementation of one activity pays off more if the complementary activity is present, too. Thus, internal and external R&D being complements means that the performance of externally sourced R&D is higher if the firm conducts internal R&D at the same time and vice versa' (Schmiedeberg, 2008: 1493).

Rather generally, the theoretical arguments are in favour of the complementary relationship between external and internal R&D. In particular, the absorptive capacity concept suggests that firms need to invest in internal R&D to utilize external knowledge (Cohen and Levinthal, 1990). Hence, those firms acquiring external R&D may improve their innovation performance if they simultaneously invest in internal R&D. This issue is also empirically examined by a number of studies, but the conclusions are rather ambiguous (Cassiman and Veugelers, 2006; Schmiedeberg, 2008). For example, while some studies provide evidence of complementarities between external and internal R&D (Cassiman and Veugelers, 2006), others find a non-significant relationship between them (Schmiedeberg, 2008). This ambiguous relationship between external and internal R&D might be driven by the fact that the geographical dimension of external R&D is largely neglected in these studies. In other words, as the utilization of external knowledge sourced from international, rather than from domestic, marketplaces may require an advanced level of internal capability (von Zedtwitz and Gassmann, 2002; Bertrand and Mol, 2013), firms that acquire international external R&D may have a greater tendency to invest in internal R&D than those sourcing knowledge-based resources from domestic suppliers. This consideration of complementarity can also be extended to innovation cooperation. In other words, not only internal R&D, but also innovation cooperation can help firms to learn and develop internal capabilities. Hence, further research is required to understand whether firms sourcing external R&D from domestic or international marketplaces simultaneously pursue other innovation strategies.

Besides that, this chapter explores the performance implication of domestic and international external R&D. Prior studies show that there is an increased tendency towards R&D internationalization (von Zedtwitz and Gassmann, 2002; von Zedtwitz et al., 2004). The recent substantial progress of ICTs has eased cross-country collaboration, which in turn has stimulated firms to source valuable resources from different geographical locations, to acquire cheap R&D inputs from low-wage countries and to gain access to foreign markets (von Zedtwitz et al., 2004). Although the importance of R&D internationalization is very well recognized by prior studies, we lack an understanding of whether firms that acquire international, rather than domestic, external R&D are more likely to introduce product innovation with a higher degree of novelty. Furthermore, this research explores how firms combine different innovation strategies in product imitation and innovation.

1.5.3 The innovative performance of R&D outsourcing

Chapter 4 studies the performance implication of R&D outsourcing. This topic has attracted substantial attention among scholars, practitioners and policy makers. Given that firms have increasingly turned their attention from the internal-R&D-oriented framework towards the open or distributed R&D approach (Chesbrough, 2003, 2006), a question arises concerning the consequence of outsourcing R&D functions. Prior studies discuss this issue intensively, but the conclusions are rather mixed and controversial. For instance, some studies suggest that R&D outsourcing is an important instrument for firms to survive in a fast-changing market environment (Gilley and Rasheed, 2000). It allows companies to gain strategic flexibility, to reduce the costs and risks of R&D projects, to speed up new product development and to improve their innovation performance (Quinn, 1999, 2000; Gilley and Rasheed, 2000; Howells et al., 2008). Such advantages of R&D outsourcing are derived by an inter-firm division of R&D labour that allows companies to specialize in a limited number of key activities that they can perform best and to contract out rather peripheral R&D functions in which they lack the required level of expertise. By doing so, firms aim to acquire cheap R&D inputs from cost-effective suppliers and to access valuable resources that are unavailable internally (Grimpe and Kaiser, 2010). As a result, R&D outsourcing may help firms to improve the efficiency and effectiveness of their innovation activities. Furthermore, this distributed R&D framework supports firms in shifting their innovation activities from serial to parallel working processes and, consequently, to accelerate their new product development (Howells et al., 2003).

However, a number of other studies highlight the drawbacks of R&D outsourcing, suggesting that this strategy may undermine firms' innovation performance (Bettis et al., 1992; Weigelt, 2009). In particular, as R&D outsourcing implies the acquisition of ready R&D results, it may substitute internal learning-by-doing and innovation-related problem-solving activities (Bettis et al., 1992; Weigelt, 2009), which are seen as essential to learning new skills and to developing firm-specific competencies. Moreover, as technological knowledge is often tacit in nature, acquiring knowledge-based resources through R&D outsourcing may not be sufficient to learn and enrich the internal stock of knowledge (Weigelt, 2009). Hence, R&D outsourcing may erode a firm's internal innovation competencies and shift knowledge-creation capabilities from the company to an R&D supplier (Bettis et al., 1992). These mixed potential outcomes of R&D outsourcing in turn raise the question of whether firms *gain* or *lose* from outsourcing R&D activities. Some of the prior studies examine this issue empirically, but the value of R&D output in these studies is most commonly measured as the number of patents applied for (Beneito, 2006) and new product sales (Grimpe and Kaiser, 2010; Berchicci, 2013), which may not reflect the overall quality of an outsourcer firm's internal research processes. In other words, patents may differ with regard to their quality and innovation content (Trajtenberg, 1990; Griliches, 1990). As for product innovation, it can be a result of combining externally available resources (Brusoni et al., 2001). Hence, additional research is required to understand the innovative performance of R&D outsourcing. This chapter takes up this issue to examine how R&D outsourcing is associated with invention quantity and quality, which are measured as patent counts and patent forward citations, respectively. For this purpose, the MIP dataset is supplemented by patent data obtained from the European Patent Office (EPO) to examine the relationship between R&D outsourcing and invention performance.

2 The journey towards open innovation: why do firms choose different routes?

2.1 Introduction

Innovation processes have become more open and market-oriented during recent decades (Chesbrough, 2003; Chesbrough et al., 2006; Laursen and Salter, 2006; Dahlander and Gann, 2010; Grönlund et al., 2010). Chesbrough (2003) suggests that companies have shifted their attention from an internal-R&D-oriented approach towards an open innovation framework to accelerate and improve their innovation activities. The open innovation framework implies that the boundaries between firms and the market are open and permeable, allowing firms to collaborate intensively with a wide set of external actors (Chesbrough, 2003; Laursen and Salter, 2006). In other words, open innovation refers to a process in which firms balance their internal R&D activities and their degree of openness (Grönlund et al., 2010). Such changes in innovation management are associated with increased global competition and fast changes in the market environment (Chesbrough, 2003). As in modern days technological change is intensive and product life cycles are considerably shortened, many firms face internal economic- and knowledge-related constraints to accomplishing all their R&D activities internally (Chesbrough, 2003; Keupp and Gassmann, 2009). In particular, the fast pace of technological and product changes implies considerable risks regarding the economic success of innovation activities. Furthermore, keeping track of various fields of technological development requires substantial financial, physical and human resources from a firm to conduct research across a broad spectrum. Accordingly, many companies lack adequate internal resources to cope with the increased complexity of product and technological innovation. For this reason, firms open up their innovation processes to share the costs and risks of R&D projects with external actors and to source the necessary resources from them (Chesbrough, 2003; Keupp and Gassmann, 2009).

Once a firm has decided to open up its innovation processes, it should identify anappropriate governance mode for external collaboration to deal efficiently and effectively with internal innovation obstacles. The literature on R&D management identifies two forms of formal openness in innovation, innovation cooperation on the one hand and R&D outsourcing on the other (Narula, 2001; Nakamura and Odagiri, 2005; Grimpe and Kaiser, 2010). The former strategy refers to a joint effort of contract partners in developing certain innovations, whereas the latter strategy stands for the acquisition of ready R&D results from external actors. The main advantage of external R&D compared with innovation cooperation is that it reduces a firm's involvement in innovation activities; once R&D tasks have been accomplished by an external actor, the results are consequently transferred back and used in internal innovation processes. In this sense, R&D outsourcing allows firms to contract out rather peripheral R&D activities to external actors and to concentrate internally on the key activities that determine their competitive advantages (Quinn, 1999, 2000). In this way, this innovation strategy helps firms (i) to reduce the costs and risks of innovation processes and (ii) to acquire knowledge that is unavailable internally.

In this context, an interesting question arises regarding which of these two aims the opening up of innovation processes is targeting. There has been much debate about this topic (Narula, 2001; Nakamura and Odagiri, 2005; Calantone and Stanko, 2007; Howells et al., 2008; Stanko and Calantone, 2011), but the conclusions are far from being straightforward. Concerning R&D outsourcing, although a firm may pursue cost–risk minimization and knowledge-seeking motives simultaneously and these motives do not exclude each other, there is doubt regarding whether this strategy can help firms to fulfil their growth objectives (Bettis et al., 1992; Weigelt, 2009; Mudambi and Tallman, 2010). Several factors make R&D outsourcing less effective for this purpose. First of all, learning new skills or competencies is considered to be a function of involvement in a problem-solving process (Arrow, 1962), which is not implied in R&D outsourcing. Secondly, transferring technological knowledge (which is often tacit in nature) across firms requires intensive interaction between them (Dhanaraj et al., 2004), which is more likely to be facilitated by innovation cooperation than R&D outsourcing (Narula, 2001; Mudambi and Tallman, 2010). Third, the resources acquired through R&D outsourcing may not be unique, because the R&D supplier may sell the same assets to multiple client firms or strategically important knowledge may spillover unintentionally from the R&D supplier to multiple client firms while working with them (Grimpe and Kaiser, 2010). For these reasons, R&D outsourcing may not be a relevant governance mode to acquire skills and know-how from external actors. Increasing the scale of R&D outsourcing may even reduce the tacit knowledge application and learning-by-doing processes in internal research and, as a result, it may hamper the innovation performance of the firm (Bettis et al., 1992; Weigelt, 2009).

Therefore, further research is required to identify the motives for using the R&D outsourcing strategy in innovation activities. In contrast to prior research, we study this issue from the open innovation perspective and undertake an empirical analysis to understand whether economic- or knowledge-related innovation impediments induce firms to increase the scale of their R&D outsourcing. We additionally study R&D outsourcing in comparison with innovation cooperation to understand under which internal innovation constraints firms engage in the one or the other.

To study this issue, we analyse a three-year panel dataset of German manufacturing firms. The findings from the empirical analysis suggest that economic-related barriers do not play a significant role in the organizational decision to increase the degree of R&D openness (including both R&D outsourcing and innovation cooperation). This non-significant relationship might be related to the fact that R&D openness is itself a risky and costly process (Cohen and Levinthal, 1990; Katila and Ahuja, 2002; Laursen and Salter, 2006). A high degree of openness in innovation may involve considerable transaction costs associated with enforcing a contract performance and integrating external knowledge into internal R&D. Another result of the empirical analysis shows that knowledge-related impediments to innovation are the major internal factor that drives a high degree of openness with regard to R&D outsourcing and innovation cooperation. It is surprising that knowledge-related obstacles to innovation are the primary motive for increasing the scale of R&D outsourcing, because this innovation strategy may not be an effective governance mode to enhance internal learning as well as to acquire tacit knowledge from external actors; therefore relying greatly on the R&D outsourcing strategy in innovation activities may deteriorate firms' innovation performance (Weigelt, 2009; Grimpe and Kaiser, 2010). However, companies may complement R&D outsourcing with other innovation strategies (e.g. internal R&D, innovation cooperation) to facilitate knowledge utilization from R&D suppliers (Cassiman and Veugelers, 2006; Lokshin et al., 2008; Schmiedeberg, 2008; Grimpe and Kaiser, 2010).

The remainder of this chapter is organized in the following way. Section 2.2 discusses the related literature and develops hypotheses. Section 2.3 provides the dataset and variables used in the empirical analysis. Section 2.4 presents the econometric methods. Section 2.5 discusses the findings from the empirical analysis, and Section 2.6 concludes.

2.2 Theoretical framework

In this section, we discuss the role of internal innovation constraints in designing the boundaries of the firm. More concretely, we study the effect of economic- and knowledge-related innovation impediments to openness with regard to R&D outsourcing and innovation cooperation. These innovation strategies can be important instruments for firms to cope with internal weaknesses in innovation (Narula, 2001; Chesbrough, 2003). As technological innovation is a complex process and often involves different scientific disciplines, many companies lack adequate internal resources to afford to undertake the entire innovation processes themselves (Chesbrough, 2003; Keupp and Gassmann, 2009). In this context, R&D openness can be a promising strategy for firms to deal with internal innovation barriers through acquiring the necessary resources from external actors or developing innovation jointly with them. However, R&D openness can also be a risky and costly process (Laursen and Salter, 2006). Shifting the focus from an internal-R&D-oriented approach towards a more open or market-oriented innovation framework may increase the costs of integrating external knowledge into internal R&D (Cohen and Levinthal, 1990), exhaust firm-specific resources (Weigelt, 2009) and, as a result, deteriorate the innovation performance of the firm (Laursen and Salter, 2006). Therefore, the pros and cons of different forms of R&D openness should be discussed to identify anappropriate external governance mode for dealing with internal innovation constraints efficiently and effectively. In this process, insights from transaction cost theory (TCT) and the resource-based view (RBV) of the firm can be helpful.

Transaction cost theory

The primary objective of TCT is to explain whether it is more efficient to organize economic activities inside or outside a company (Coase, 1937; Williamson, 1975). In particular, TCT discusses internal and external governance modes based on their efficiency in minimizing production and transaction costs (Coase, 1937; Williamson, 1975). Production costs refer to the costs of making goods or services, whereas transaction costs stands for the expenses incurred by gathering all the required information to coordinate an economic exchange between different units of a firm or with an external partner when the goods or services are acquired in a market (Williamson, 1975). Stated differently, the transaction costs associated with an internal governance mode can also be defined as administrative or bureaucratic costs, whereas in the case of an external governance mode, transaction costs are related to searching for appropriate contractors for certain economic activities, negotiating and bargaining with them to reach an acceptable agreement and then monitoring and enforcing the contract performance. Given that some external contractors may act unscrupulously or opportunistically to maximize their self-interests (Williamson, 1975), firm managers attempt to write a complete contract to avoid unscrupulous behaviour from contractors. However, it might be a challenging task, because humans are considered to have bounded rationality (Simon, 1957). In other words, firm managers often face limited cognitive ability (despite their rationality) to foresee all the possible opportunistic actions of a contract partner and, therefore, to write a complete contract. This issue is more critical when the goods or services that firms aim to acquire in a market involve high levels of asset specificity, because it is difficult to measure the quantity and quality of such resources. In this situation, a contract is more likely to be incomplete and contractor parties will have more chances to engage in opportunism.

A high level of asset specificity often characterizes innovation activities, because technological knowledge is partly of a tacit nature (e.g. skill, know-how), which is difficult to articulate or to define clearly (Polanyi, 1967; Kogut and Zander, 1992). Such knowledge is accumulated through learning by doing and it is embodied in individuals (Polanyi, 1967). For this reason, it is often problematic to transfer tacit knowledge across organizational boundaries, requiring a transaction-specific investment and multiple interactions between organizations to facilitate such knowledge transfer across firm boundaries (Narula, 2001; Dhanaraj et al., 2004; Mudambi and Tallman, 2010). In this sense, the effective utilization of knowledge-based resources obtained through R&D outsourcing may require high transaction costs and, as a result, this strategy might be a less attractive alternative to internalization. From the TCT perspective, R&D outsourcing is economically optimal only when it is possible to codify and standardize R&D tasks, allowing firms to purchase such types of goods or services from external actors without intensive interaction with them, because codified knowledge can be fairly easily transferred between companies through verbal communication or in written forms.

The resource-based view of the firm

An alternative approach to explaining a 'make' or 'buy' decision is offered by the resource-based view (RBV) of the firm (Barney, 1991; Peteraf, 1993; Barney et al., 2001). In contrast to TCT, in which the attention is devoted to cost-based analysis, the RBV of the firm focuses on a value-enhancing dimension to identify a proper governance mode for certain economic activities. In other words, the RBV of the firm discusses resources allocated between internal and external governance modes based on their effectiveness in improving the sustainable competitive advantage of the firm (Barney, 1991; Peteraf, 1993). The term sustainable competitive advantage refers to an above-normal rent that a firm attains on a long-term basis. According to the RBV of the firm, a sustainable competitive advantage or superior performance is attained through generating valuable, rare, inimitable and non-substitutable resources (VRIN) (Barney, 1991). Valuable and rare resources allow firms to satisfy customers' requirements better (Peteraf, 1993). These valuable and rare resources should also be inimitable and non-substitutable, because competitors should not be able to replicate the firm's competitive strategy or attain a similar performance based on other resources (Peteraf, 1993). Therefore, the RBV of the firm suggests that companies should use an isolating mechanism (an internal governance mode) for economic activities that determine their competitive advantages and to outsource those activities that are strategically less important to them (Wang et al., 2009; Grimpe and Kaiser, 2010). This is particularly true in the case of R&D activities, because protecting strategically important knowledge from imitation can be difficult when it is revealed to or generated by external actors (Grimpe and Kaiser, 2010; Mudambi and Tallman, 2010).

There are several reasons that make outsourcing strategically important R&D activities a risky business. First, knowledge acquired from an R&D supplier may not be unique, because competitors may have access to the expertise of the same R&D supplier (Grimpe and Kaiser, 2010). For this reason, increasing the scale of R&D outsourcing may reduce the firm-specific resources and, as a result, deteriorate the competitive advantages of the firm. Second, given that technological knowledge is partly tacit in nature, acquiring such knowledge from a partner firm without direct involvement in problem-solving activities or intensive interaction with the knowledge holder can be difficult or impossible (Narula, 2001). Therefore, firms should keep internally the R&D activities that determine their competitive advantages and outsource those R&D tasks that are strategically less important to them (Quinn, 2000). By doing so, firms can improve their innovation processes through concentrating on the R&D activities in which they possess superior capabilities or competencies.

Additionally, R&D outsourcing may help firms to minimize the costs and risks of peripheral innovation activities (Quinn, 1999, 2000; Grimpe and Kaiser, 2010). As firms are considered to be heterogeneous in terms of their resources and they may carry out the same economic activities with different costs (Barney, 1991), R&D outsourcing may allow firms to acquire rather peripheral R&D services from specialized suppliers relatively more cheaply than they can perform the same activities internally. Given that in modern days technological change is intensive and product life cycles are considerably shortened, many firms face internal economic- and knowledge-related constraints to accomplishing all their R&D activities internally (Chesbrough, 2003; Keupp and Gassmann, 2009). Prior research suggests that the lack of adequate internal resources limits firms' capability to execute an R&D project effectively and, hence, undermines their innovation performance (Blanchard et al., 2013). Internal innovation constraints may even discourage a firm from undertaking innovation activities (Hottenrott and Peters, 2012), because it is less likely that the firm will accomplish an R&D project successfully when the gap between its existing resources and those needed for the project implementation is large. Hence, R&D openness and collaboration with external entities can be required to complement the internal innovation activities with external resources and, as a result, to overcome the internal impediments to innovation. In fact, Keupp and Gassmann (2009) show that firms open up their R&D boundaries in response to internal barriers to innovation. To deal with internal innovation constraints effectively, firms may employ different forms of R&D openness depending on whether they face economic- or knowledge-related obstacles. Regarding R&D outsourcing, this strategy can be a promising instrument to minimize the costs and risks of innovation activities, but it might be inferior to acquiring skills and know-how from external actors because such knowledge transfer across organizations requires mutual learning and intensive interaction between firms, which is less likely to be delivered by R&D outsourcing. As an external collaboration driven by cost- rather than skill-sharing objectives may involve fewer asset specificity problems and, in this sense, require less interaction between contractors, R&D outsourcing can be a more appropriate strategy for dealing with economic- rather than knowledge-related innovation constraints. Therefore, we consider economic-related innovation impediments to be the primary driving force for R&D outsourcing, whereas knowledge- and capability-seeking motives can be a secondary issue. Hence, we propose the following hypothesis:

> *H1: Economic- rather than knowledge-related innovation constraints are more likely to induce firms to increase the scale of their R&D outsourcing.*

An alternative governance mode to organize R&D activities outside a company is innovation cooperation, which is defined as an intermediate or hybrid organizational form between internal and market governance modes (Williamson, 1991). In contrast to R&D outsourcing, innovation cooperation allows firms to retain some degree of control over transactions (Williamson, 1991; Mudambi and Tallman, 2010). In particular, innovation cooperation implies a joint effort of contract partners to implement certain R&D activities (Hagedoorn, 1993; Tether, 2002). For this reason, innovation cooperation compared with R&D outsourcing may allow firms to create more efficient transactions, to lower the uncertainty over monitoring knowledge transfer and to mitigate partners' opportunistic behaviour through a reciprocal and repeated relationship with them (Mudambi and Tallman, 2010). The frequent interaction between employees coming from cooperative parties is likely to build a trust-based relationship and a mutual understanding practice between them that can help the firms to exchange tacit knowledge. In this sense, innovation cooperation can be a better option than R&D outsourcingto utilize the skills and know-how of external partners (Hamel, 1991; Narula, 2001; Mudambi and Tallman, 2010). This innovation strategy can also be an important instrument for firms to reduce the costs and risks of R&D projects (Hagedoorn, 1993; Sakakibara, 1997; Narula, 2001). As R&D activities often involve many components of fixed costs, innovation cooperation can help firms to share the costs and to prevent the duplication of unnecessary R&D efforts (Sakakibara, 1997).

Despite numerous advantages associated with innovation cooperation, this strategy may also turn out to be a risky and costly process. In particular, inter-firm intensive interaction, resource sharing and mutual learning can be risky in relation to the leakage of strategically important tacit knowledge and, as a result, the loss of technological competitiveness. Moreover, considerable managerial resources are required to coordinate innovation cooperation with external actors, which can also be a costly process. Therefore, firms may adopt a portfolio approach to cope with internal innovation impediments and to mitigate the negative side of R&D openness. In particular, firms may favour the use of the R&D outsourcing strategy to deal with economic-related obstacles and to engage in innovation cooperation partnerships with the purpose of coping with knowledge-related constraints. Although a firm may pursue economic- and knowledge-related objectives simultaneously in innovation cooperation and these objectives do not exclude each other, knowledge-acquisition rather than cost-minimization motives are more likely to be given the attention when firms engage in innovation cooperation partnerships. Based on these arguments, we suggest the following hypothesis:

> *H2: Knowledge- rather than economic-related innovation impediments induce firms to engage more broadly in innovation cooperation.*

2.3 Data description

2.3.1 Sample

The empirical analysis is based on the Mannheim Innovation Panel (MIP)5 database. The MIP is the German part of the Community Innovation Survey, which is financed by the German Federal Ministry of Education and Research. The Centre for European Economic Research (ZEW) has conducted the survey annually since 1993 and gathers data on German innovative firms. The data are collected by sending questionnaires by email, and the target respondents of the MIP are innovative firms with at least five employees. The survey methodology is mainly constructed

[5] The paper acknowledges access to the Mannheim Innovation Panel data from the Centre for European Economic Research (ZEW).

based on the OECD/Eurostat Oslo Manual on innovation statistics. The main objective of the survey is to explore the innovation activities of German firms. For this purpose, in each wave of the survey, firm managers are asked about the process of generating innovation. As a result, the database provides a broad variety of information on innovation activities, such as innovation cooperation, R&D outsourcing, product and process innovations, etc. The MIP also contains information on firms' internal innovation impediments, the specific factors that companies consider to be an obstacle to innovation activities.

Although MIP data have been collected every year since 1993, the questionnaires sent to the respondents differ each year. As we are interested in studying the effect of internal innovation impediments on the degree of R&D openness and the required information for this study is available in the 1997, 2001 and 2005 surveys of the MIP, we build a 3-year panel dataset. The sample is also restricted to firms representing manufacturing industries, which gives us 3-year balanced panel data with 996 observations.

2.3.2 Dependent variable

The first dependent variable of interest is the proportion of R&D carried out by external actors (R&D_OUT), which is measured as the expenses for outsourced R&D over the spending for total R&D (the sum of internal and outsourced R&D expenditures). This measure enables us to study the extent to which firms invest in R&D outsourcing instead of internal R&D. The second dependent variable (INNO_COOP) is the number of innovation cooperation partnerships. The survey lists six possible such partners: suppliers, customers, competitors, consulting firms, universities and research institutes. The respondents were asked to indicate whether they have cooperative agreements with the above-listed organizations. To measure R&D openness with regard to innovation cooperation, the variables are added up so that a firm receives zero when it has no innovation cooperation and six when it has collaboration agreements with all of the listed entities. Thus, firms with a high number of innovation cooperation partnerships are considered to be more open than those with low numbers (Laursen and Salter, 2006).

2.3.3 Explanatory variables

The explanatory variables used in the econometric analysis are the firms' internal innovation constraints. The respondents were asked to indicate whether they experience difficulties in innovation activities and, in the case of a positive answer, to identify the possible factors responsible for a problem. The survey lists several possible internal impediments that firms might face during innovation activities, such as high costs and risks of innovation activities, a lack of skilled personnel, a lack of market information, a lack of technical information and organizational rigidity. The variables are scaled between 0 (not relevant) and 3 (highly relevant). To identify groups of innovation constraints with similar information content, each of the variables is coded as binary values, 0 for 0–1 scales and 1 for 2–3 scales; then, we conduct a component factor analysis (see Table I). The component factor analysis suggests two main groups of innovation constraints. In the first group, economic risks and costs of innovation go handinhand, and we name the group ECONOMIC IMPEDIMENTS. Innovation obstacles such as organizational rigidity, a lack of suitable qualified personnel, a lack of technical information and a lack of market information are joined in the second group, and we consequently refer to it as KNOWLEDGE IMPEDIMENTS.

Table I – Component factor analysis

INNOVATION IMPEDIMENTS	KNOWLEDGE IMPEDIMENTS	ECONOMIC IMPEDIMENTS	UNIQUENESS
Risks of innovation		0.9041	0.1419
Costs of innovation		0.9105	0.1269
Organizational rigidity	0.5929		0.5498
Lack of technical information	0.8667		0.2469
Lack of market information	0.7395		0.4203
Lack of suitable qualified personnel	0.6155		0.4398

Blanks represent abs(loading) < 0.45.

2.3.4 Control variables

Several control variables are introduced into the econometric analysis to account for other specific factors that may induce firms to increase their openness in innovation. First of all, we control for R&D intensity[6] (R&D_INTENSITY) measured as the expenditures on innovation-

[6]The variable is expressed in percentages.

related activities divided by the firm's sales[7]. As R&D-intensive firms may have a greater tendency to conduct exploratory research or to develop breakthrough innovations, these firms are more likely to be open to external collaborations (including both innovation cooperation and R&D outsourcing) to access knowledge outside their expertise. Investing intensively in R&D activities may also allow firms to develop internal expertise required for an effective external collaboration (Cohen and Levinthal, 1989, 1990; Cassiman and Veugelers, 2006; Grimpe and Kaiser, 2010). Therefore, we expect a positive relationship between R&D intensity and openness in innovation. Second, to account for whether a firm faces international competition, we introduce export intensity into the econometric analysis (Cassiman and Veugelers, 2006; Grimpe and Kaiser, 2010). The variable is measured as the share of sales from exports (EXPORT_INTENSITY). As firms competing in global markets may often face rapid changes in technology and consumer preferences, they may engage in open innovation to cope with the increased risks and costs of R&D projects and to acquire the needed resources from external actors.

Table II – Industry breakdown

Technology class	Classification of manufacturing industries	NACE
Low-technology manufacturing industries	Food and beverages, tobacco	15, 16
	Textiles, leather, footwear	17–19
	Wood, paper, paper products	20, 21
	Furniture	22
Medium-low-technology manufacturing industries	Non-metallic mineral products	26
	Metal products	27, 28
Medium-high-technology manufacturing industries	Rubber and plastic products	25
	Machinery and equipment	29
	Motor vehicles, aircraft and spacecraft	34, 35
High-technology manufacturing industries	Coke, refined petroleum, chemical industry	23, 24
	Electrical apparatus, computing machines, communication equipment	30–32
	Medical, precision and optical instruments	33

Industries are classified according to the OECD (2003) manual. Manufacturing sectors related to natural resources such as mining and construction are excluded.

Besides, to control for unobservable firm and industry characteristics that may influence the organizational decision to adopt open innovation principles, we include firm size and industry dummies in the econometric models. Firm size (LOG_SIZE) is measured as the number of

[7]Total innovation expenditures are scaled by sales to avoid the firm size effect in R&D spending.

employees in logarithmic values. Given that large-sized firms often act as an assembler rather than a producer, they may outsource more R&D activities than small-sized firms (Mol, 2005). A positive relationship is also expected between firm size and innovation cooperation partnerships, because smaller firms may lack adequate resources to collaborate with a wide set of external actors. With regard to industry dummies, four manufacturing industry groups are introduced based on the OECD classification – low-technology manufacturing industries, medium-low-technology manufacturing industries, medium-high-technology manufacturing industries, and high-technology manufacturing industries (see Table II) – for which the benchmark variable is low-technology manufacturing industries.

2.4 Econometric methods

The first dependent variable used in the empirical analysis is R&D_OUT, which has zero and one values as well as intermediate outcomes. The variable is also right-skewed, containing a high number of zeros. One way to handle these specific features of the data is to use the generalized estimating equation (GEE) model, which enables us to estimate the parameters of a generalized linear model in panel data (Liang and Zeger, 1986). In particular, GEE allows us to relate a response variable that follows a non-normal distribution to a predictor variable in a linear term via a proper family distribution and link function. Given that the dependent variable of interest is the share of R&D outsourcing in the total R&D expenditures (the sum of internal and outsourced R&D spending), we use a binomial family distribution and a logit link function, which are usually employed to model a dependent variable with proportional or fractional values (Papke and Wooldridge, 1996; Baum, 2008). The GEE also allows us to control for the possible serial correlation in the model (Liang and Zeger, 1986; Katila and Ahuja, 2002). For diagnostic purposes, we also estimate a right-censored random-effect tobit model, which adequately accounts for these specific features of our data by treating firms with and without R&D outsourcing differently (Grimpe and Kaiser, 2010). An alternative fixed-effect tobit model is inconsistent with short panel data (Grimpe and Kaiser, 2010).

The second dependent variable of interest (INNO_COOP) has non-negative count outcomes, ranging from zero to six. Usually, the starting point of a count data analysis is a Poisson model (Cameron and Trivedi, 2005, 2009), which is used to model count data when an equal-dispersion property is satisfied, implying that the variance and mean are equal in a dependent variable. In our case, a regression-based over-dispersion test provides a significant coefficient, rejecting the equal-dispersion assumption (see model 3 in Table V). Over-dispersion is problematic, because it 'leads to grossly deflated standard errors and grossly inflated *t* statistics' (Cameron and Trivedi, 2005: 670). The standard method for dealing with the over-dispersion problem is a negative binomial model (Cameron and Trivedi, 2005, 2009). Accordingly, we use the random-effect negative binomial model to model adequately the count data with the over-dispersion problem and repeated observations. To ensure that the results obtained from the random-effect negative binomial model are reliable, we also employ other econometric models. Taking into consideration that INNO_COOP has count outcomes and it is also right-skewed, we estimate the GEE model with the negative binomial family distribution[8] and log link function. For diagnostic purposes, we also estimate the right-censored random-effect tobit model (Keupp and Gassmann, 2009).

Table III – Descriptive statistics

Variable names	Type	Obs.	Mean	Std. dev.	Min	Max
R&D_OUT	Share	996	0.0460	0.1480	0	1
INNO_COOP	Count	996	0.4919	1.1652	0	6
ECONOMIC IMPEDIMENTS	Count	996	0.8242	0.9276	0	2
KNOWLEDGE IMPEDIMENTS	Count	996	0.7479	1.1543	0	4
R&D_INTENSITY	continuous	996	1.1451	4.2939	0	55.803
EXPORT_INTENSITY	Share	996	0.0518	0.1437	0	0.9333
LOG_SIZE	continuous	996	4.4728	1.6143	0.6931	11.173
MEDIUM-LOW-TECH INDUSTRY	Binary	996	0.3433	0.4750	0	1
MEDIUM-HIGH-TECH INDUSTRY	Binary	996	0.2730	0.4457	0	1
HIGH-TECH INDUSTRY	Binary	996	0.1475	0.3548	0	1

2.5 Estimation results

Table V contains the estimates from the empirical analysis. Models 1 and 2 are devoted to R&D outsourcing and models 3 to 5 to innovation cooperation. Regarding the core explanatory

[8] We compare the GEE models with negative binomial and Poisson family distributions with each other. The former model presents a lower value of the Akaike Information Criterion. Therefore, the GEE model with negative binomial family distribution is considered to be a better fitted model for the data than the one with Poisson family distribution.

variables, ECONOMIC IMPEDIMENTS and KNOWLEDGE IMPEDIMENTS, the econometric models present similar outcomes for R&D_OUT as for INNO_COOP.

Table IV – Correlation table

	Variable names	1	2	3	4	5	6	7	8	9	10
1	R&D_OUT	1.000									
2	INNO_COOP	0.257***	1.000								
3	ECONOMIC IMPEDIMENTS	0.065**	0.094***	1.000							
4	KNOWLEDGE IMPEDIMENTS	0.116***	0.133***	0.504***	1.000						
5	R&D_INTENSITY	0.043***	0.139***	-0.080**	-0.030	1.000					
6	EXPORT_INTENSITY	0.046	0.112***	-0.157***	-0.103***	0.312***	1.000				
7	LOG_SIZE	0.106***	0.397***	0.009	0.085***	-0.001	0.157***	1.000			
8	MEDIUM-LOW-TECH INDUSTRY	-0.022	-0.114***	0.048	-0.005	-0.034	-0.045	-0.091***	1.000		
9	MEDIUM-HIGH-TECH INDUSTRY	0.086***	0.130***	-0.039	-0.001	0.003	0.111***	0.093***	-0.443***	1.000	
10	HIGH-TECH INDUSTRY	0.014**	0.103***	0.054	0.012	0.111***	0.010	0.019	-0.301***	-0.255***	1.000

*Note: ** and *** denote significance at the 5% and 1% level respectively.*

Looking first at the control variables, the econometric analysis identifies a significant positive relationship between R&D intensity (R&D_INTENSITY) and R&D openness (including both R&D_OUT and INNO_COOP). Given that firms' R&D activities significantly and positively contribute to their absorptive capacity (Cohen and Levinthal, 1989, 1990), those companies that invest intensively in R&D processes develop a large absorptive capacity and, in this sense, they are more likely to manage R&D collaboration with a wide set of external entities than others with fewer R&D competencies.

Moreover, we find a significant positive relationship between LOG_SIZE and R&D_OUT as well as between LOG_SIZE and INNO_COOP. Compared with small-sized firms, large companies usually own better internal research capabilities (i.e. financial, physical and human resources) that enable them to adopt the open innovation framework. Furthermore, as large firms often act as an assembler rather than a producer, they intensively outsource their R&D activities and cooperate with a wide set of external actors in innovation to acquire the needed R&D inputs. In other words, large companies often carry out a system integrator task, combining externally available technological knowledge but developing only a small part of the sub-technologies internally (Prencipe et al., 2003).

Table V – Estimation results for R&D outsourcing and innovation cooperation

	R&D_OUT	R&D_OUT	INNO_COOP	INNO_COOP	INNO_COOP
	GEE Population Averaged Model	Random-Effects Tobit Model	Random-Effects Negative Binomial Model	GEE Population Averaged Model	Random-Effects Tobit Model
	1	2	3	4	5
ECONOMIC IMPEDIMENTS	0.0846	0.0404	0.1457	0.0165	0.2742
	(0.1355)	(0.0288)	(0.0872)	(0.0758)	(0.1813)
KNOWLEDGE IMPEDIMENTS	0.2489***	0.0465**	0.1613***	0.1961***	0.3407**
	(0.0908)	(0.0214)	(0.0614)	(0.0565)	(0.1346)
R&D_INTENSITY	0.0285**	0.0101**	0.0403***	0.0472***	0.1028***
	(0.0119)	(0.0047)	(0.0125)	(0.0111)	(0.0272)
EXPORT_INTENSITY	0.4061	0.0926	-0.0041	0.1305	0.4255
	(0.5684)	(0.1429)	(0.3483)	(0.3952)	(0.8531)
LOG_SIZE	0.1701***	0.0961***	0.4857***	0.4365***	1.0161***
	(0.0526)	(0.0181)	(0.0650)	(0.0438)	(0.1269)
MEDIUM-LOW-TECH INDUSTRY	0.2906	0.1234	0.2045	0.1187	0.4037
	(0.5004)	(0.0829)	(0.2943)	(0.3371)	(0.5537)
MEDIUM-HIGH-TECH INDUSTRY	0.8831**	0.2483***	0.9427***	0.6889**	1.9214***
	(0.4351)	(0.0831)	(0.2889)	(0.3182)	(0.5564)
HIGH-TECH INDUSTRY	0.2871**	0.2771***	0.8144**	0.8451**	1.6758***
	(0.1402)	(0.0954)	(0.3352)	(0.4201)	(0.6431)
INTERCEPT	-4.5629***	-1.1980***	-3.0833***	-3.6411***	-9.3849***
	(0.4552)	(0.1361)	(0.5491)	(0.3432)	(0.9151)
Obs.	996	996	996	996	996
Wald >chi2	48.14	54.84	108.23	150.19	101.12
Prob>chi2	0.0000	0.0000	0.0000	0.0000	0.0000
Test for over-dispersion			1.327***		

*Note: ** and *** denote significance at the 5% and 1% level, respectively. Standard errors are in parentheses.*

The data analysis also suggests that those firms belonging to medium-high- and high-technology manufacturing industries are more likely to outsource their R&D activities and also to engage in innovation cooperation partnerships than their counterparts operating in low- and medium-low-technology manufacturing sectors. This inter-industry difference with regard to open innovation adoption might be related to the fact that medium-high- and high-technology sectors are on average more technology-intensive comparing with low- and medium-low-technology industries. Therefore, medium-high- and high-technology manufacturing firms engage in open innovation practices to accelerate innovation processes and to cope with rapid changes in the external environment.

Besides, export intensity (EXPORT_INTENSITY) provides a significant coefficient neither for R&D_OUT nor for INNO_COOP. It is surprising that export-oriented firms show no inclination towards the open innovation approach, because these firms are subject to global competitive pressure and R&D openness might be relevant to them to accelerate their innovation activities, to share the risks-costs of R&D projects with external actors and to acquire needed resources from them to perform successfully in international markets. However, an alternative line of reasoning may suggest that increased global competition can also be an obstacle to a high degree of R&D openness in terms of driving the unpredictability of the market demand and increasing the pace of technological changes. Under such conditions, renegotiation or cancellation of R&D contracts might be required and, as a result, it can be costly to organize R&D activities outside the company. Hence, the non-significant correlation between export intensity and formal R&D openness might be driven by the ambiguous relationship between the international competition and the boundaries of the firm.

Looking now at hypothesis H1, we find no support for economic related impediments being more relevant to R&D outsourcing than knowledge-related obstacles. In models 1 and 2 of Table V, the respective coefficients for ECONOMIC IMPEDIMENTS are statistically not significant. In addition, the data show a non-significant relationship between ECONOMIC IMPEDIMENTS and the breadth of innovation cooperation (INNO_COOP). In view of our hypothesis H2, we expected economic-related impediments to be not or less relevant than knowledge-related constraints to innovation cooperation. This general insignificance of economic-related barriers might be partly due to the fact that increasing openness with regard to R&D outsourcing and innovation cooperation may involve considerable risks and costs in terms of coordinating external collaborations and utilizing knowledge from a wide set of external actors. For these reasons, firms with cost-risk minimization objectives may avoid increasing their degree of openness in innovation.

Regarding knowledge-related obstacles (KNOWLEDGE IMPEDIMENT), the variable has a significant and positive sign in all the regression models for innovation cooperation (INNO_COOP) and for R&D outsourcing (R&D_OUT). The econometric analysis suggests that firms lacking internal expertise to innovate increase the breadth of their innovation cooperation partnerships as well as the scale of their R&D outsourcing. This firstly supports our prediction in hypothesis H2; we find evidence that knowledge- rather than economic-related innovation impediments induce firms to engage more broadly in innovation cooperation. Secondly, it turns our hypothesis H1 on R&D outsourcing upside down; it is quite surprising that knowledge-related innovation constraints are the primary driving force for outsourcing R&D activities. However, prior research also suggests that firms have shifted their attention from a cost-oriented framework towards a value-enhancing consideration in the decision to outsource R&D activities (Hätönen and Eriksson, 2009).

2.6 Conclusion

During the last few decades, increased global competition and fast changes in the market environment have forced firms to alter the way in which they organize their innovation activities (Chesbrough, 2003). In particular, companies have shifted their innovation activities from an internal-R&D-oriented approach towards an open innovation framework to accelerate and improve their innovation activities. Given that the fast pace of technological changes and shortened product life cycles increase the risks and costs of innovation activities, many firms lack adequate internal resources to carry out all their R&D activities internally (Chesbrough, 2003; Keupp and Gassmann, 2009). Valuable knowledge is also spread across different specialized research organizations and external collaboration can be required to supplement internal innovation activities with relevant external resources. For these reasons, companies adopt the open innovation approach to overcome internal innovation obstacles (Keupp and Gassmann, 2009). Based on that, an interesting question arises about how firms design their R&D boundaries in response to internal innovation constraints. More concretely, little is known about whether firms with economic- and knowledge-related obstacles increase their degree of openness towards R&D outsourcing or innovation cooperation. To study this issue, we analyse a three-year panel dataset of German manufacturing firms obtained from the MIP database. The results obtained from the econometric analysis suggest that cost–risk minimization objectives do not significantly affect the organizational decision to increase the openness in innovation. This may be because open innovation itself entails considerable costs and risks in terms of searching for and utilizing knowledge from a wide set of external actors. In other words, a high degree of R&D openness puts an additional burden on a firm in terms of dynamically increasing the costs of integrating new external knowledge into the internal R&D.

Another result of the empirical analysis shows that knowledge-related obstacles induce firms to increase the scale of R&D outsourcing as well as to engage more broadly in innovation cooperation. It is surprising that knowledge- rather than economic-related impediments are the primary reason behind R&D outsourcing. This strategy can assist firms to acquire external knowledge-based resources, but there is no guarantee that increasing the degree of openness with regard to R&D outsourcing can help firms to improve their innovation performance. On the contrary, prior research highlights the potential drawbacks of large-scale R&D outsourcing, because sourcing knowledge-based resources from external actors via an arm's length contract may reduce the tacit knowledge application and learning-by-doing processes in internal research; as a result, it may hamper the innovation performance of the firm (Bettis et al., 1992; Weigelt, 2009). However, companies may combine different forms of openness in innovation to facilitate knowledge utilization from external entities and to boost their innovation activities.

In summary, our findings suggest that firms devote more attention to *growth objectives* (in terms of accessing external knowledge) than to *defensive motives* (in terms of minimizing the costs and risks of innovation activities) in the decision to adopt the open innovation framework. In this context, R&D openness may complement rather than substitute internal innovation activities. Given that effective knowledge utilization from external entities requires substantial internal expertise, firms need strong internal research capabilities to benefit from the open innovation approach. Hence, the degree of openness in innovation should be in balance with the internal R&D activities, which can help firms to gain from open innovation and to enhance their innovation performance.

3 The inter-relationships between external R&D, innovation cooperation and product innovation

3.1 Introduction

In a world of abundant access to external knowledge, the question of how firms should organize their R&D and innovation activities, taking into account the potential benefits of opening up the innovation processes, once again becomes high on the managerial agenda. In particular, the opportunities to utilize inter-organizational relationships, alliances, external R&D contractors and consultants open up a wide array of organizing opportunities for a firm's innovation activities, but also questions whether these activities are complementary (Schmiedeberg, 2008) and hence beneficial. The open innovation concept coined by Chesbrough (2003) has been studied intensely in recent years (for reviews see e.g. Enkel et al., 2009; Dahlander and Gann, 2010; Gassman et al., 2010) and especially research on the structural aspects focusing on the use and performance implications of alliances and partnerships has been conducted heavily (Fey and Birkinshaw, 2005; Laursen and Salter, 2006; Henttonen et al., 2011; Inauen and Schenker-Wicki, 2011; Knudsen and Mortensen, 2011; Henttonen and Ritala, 2013). Thus far, however, only a little attention has been paid to the challenges of identifying the best organization of these processes for the firm when taking into account both internal and external opportunities for innovation.

Enkel et al. (2009: 312–313) coins three organizing processes: outside-in, inside-out and the coupled process. The outside-in processes are typically associated with the utilization of external partnerships like alliances, whereas the coupled processes 'combine the outside-in process (to gain external knowledge) with the inside-out process (to bring ideas to market) and, in doing so, jointly develop and commercialize innovation' (Enkel et al., 2009: 313). Within the outside-in processes, a number of opportunities are available as sources of knowledge for the innovation process. The literature differentiates between two general outside-in strategies: the acquisition of external R&D through licenses or contracts with R&D suppliers and the joint development of innovation with cooperation partners. The former strategy implies the acquisition of a research outcome from external contracting partners, whereas the latter strategy refers to a joint effort of the partner firms to develop valuable (knowledge) assets that they may not have been able or willing to develop alone through internal R&D. However, these organizing processes neglect the linkage between the ongoing activities within the firm, that is, internal R&D and the external organizational opportunities. Recent research focuses on the potential complementarities between internal R&D and external organizing processes like the utilization of partnerships in cooperation or the acquisition of R&D from contractors (Cassiman and Veugelers, 2006; Schmiedeberg, 2008). Complementarities exist when 'the implementation of one activity pays off more if the complementary activity is present, too. Thus, internal and external R&D being complements means that the performance of externally sourced R&D is higher if the firm conducts internal R&D at the same time and vice versa' (Schmiedeberg, 2008: 1493). Hence, when firms organize their activities, they simultaneously consider the advantages of utilizing internal sources of R&D compared with external sources and how these may be combined to achieve the best possible outcome. Schmiedeberg (2008) highlights the difficulties in establishing unambiguous empirical results, although the literature clearly argues in favour of complementarities. This paper therefore follows up on the research on complementarities to analyse the organization of innovation decisions of manufacturing firms by examining the following research questions:

Do domestic and international external R&D complement or substitute internal R&D and innovation cooperation?

How do domestic and international external R&D relate to innovation performance?

By analysing these questions, this paper contributes to the literature on innovation management and to the literature on the organization of innovation activities in three ways. First, although previous studies discuss a complementary relationship between external R&D and other innovation strategies (i.e. internal R&D and innovation cooperation) (Cassiman and Veugelers, 2006; Lokshin et al., 2008; Schmiedeberg, 2008; Grimpe and Kaiser, 2010), the geographical dimension of external R&D has thus far not been studied. In other words, firms that acquire international, rather than domestic, external R&D may have a greater tendency to invest in internal R&D as well as to engage in innovation cooperation partnerships, because the utilization of external knowledge stemming from international R&D suppliers may require an advanced level of internal capability (von Zedtwitz and Gassmann, 2002; Bertrand and Mol, 2013) and absorptive capacity.

Secondly, it is not clear whether firms that acquire international external R&D are more likely to generate product innovations with a higher degree of novelty than others that purchase external R&D from the domestic market. This paper therefore contributes to the literature by introducing the geographic dimension of the location of the external contractors into the understanding of complementarities in the organization of innovation activities. In particular, the differentiation between domestic and international R&D seems promising as it may be expected that the adoption of knowledge from external sources with larger geographical and cultural distance is more difficult than domestic and close-by relationships.

The third contribution concerns the empirical methodology. Rather than using standard yes or no questions to identify the use of such strategies, this paper uses the amount of money invested in these activities as a proxy. This allows us to investigate the inter-relationships between different innovation strategies and product innovation in detail.

The empirical results from the analyses in this paper are ambiguous as those firms acquiring external R&D from international marketplaces invest simultaneously in internal R&D and engage in a high number of innovation cooperation partnerships, but joint representation of these instruments shows a significant negative relationship with product innovation. Furthermore, the results show no significant complementary or substitutive relationship between domestic external R&D and internal R&D as well as between domestic external R&D and innovation cooperation. Moreover, the analysis indicates that those firms acquiring international, rather than domestic, external R&D are more likely to develop product innovation with a higher degree of novelty, implying that those firms sourcing knowledge from international R&D suppliers tap into the global knowledge pool and, in this way, improve their innovation performance compared with others that rely only on domestic external R&D. These results are discussed and the implications are outlined at the end of the paper.

3.2 Literature review and hypothesis development

The organization of external knowledge sourcing in the form of external R&D on the one hand and innovation cooperation on the other and the combination with internal R&D have come to be important managerial decisions, especially in the light of the focus on the increased opening of innovation processes (Chesbrough, 2003; Grimpe and Kaiser, 2010; Berchicci, 2013; Clausen, 2013). Hence, firms may organize their activities with increasing degrees of openness by establishing innovation cooperation and buy external R&D to source relevant external knowledge resources and to increase the speed or quality of innovation activities faster and at a lower cost (Chesbrough, 2003; Grimpe and Kaiser, 2010; Berchicci, 2013).

3.2.1 Organization of R&D activities

Chesbrough (2003) argues that the increased global competition and the fast pace of technological change have eroded the effectiveness of vertically integrated R&D organization. A vertically integrated research function implies that a firm has full control over its value chain (it owns its suppliers and customers) and all of the economic activities are organized within the formal boundaries of the firm. This, on the one hand, allows firms to reduce their transaction costs and to coordinate their economic activities efficiently (Williamson, 1975), but on the other hand, vertical integration can be risky under market and technological uncertainties (Chesbrough, 2003), because technological changes may be competence-destroying for incumbent firms and their suppliers (Afuah, 2001). As an alternative, a firm may reorganize its activities by sourcing the required resources and knowledge to increase the firm’s strategic flexibility and to switch knowledge suppliers adaptively when new competence-destroying technologies emerge on the market (Gilley and Rasheed, 2000; Chesbrough, 2003). Hence, the open innovation framework offers an alternative strategic direction for firms to cope with the rapidly changing market environment as the organizing opportunities enable the company to accelerate innovation through exploring combinations of internal and external knowledge sources (Chesbrough, 2003; Laursen and Salter, 2006).

External R&D implies that firms enhance and fertilize their innovation activities by acquiring knowledge and technologies from R&D service firms. Ideally, knowledge-based activities that give firms competitive advantages over their competitors should be organized internally and R&D activities that are less important for long-term competitiveness should be contracted out to external specialized suppliers (Quinn, 1999, 2000). In this way, companies can reduce the costs and risks of non-core R&D activities in which they lack competencies. Moreover, this division of R&D tasks enables firms to improve their efficiency and effectiveness in innovation through concentrating on the activities in which they have already accumulated competencies and experience.

Several reasons why the use of external R&D improves firms' innovation performance (Quinn, 1999, 2000; Gilley and Rasheed, 2000; Cassiman and Veugelers, 2006; Grimpe and Kaiser, 2010) can be put forward. First, it enables companies to overcome internal innovation constraints, such as a lack of suitable qualified personnel, a lack of technical expertise and the high costs and risks of R&D projects (Quinn, 1999, 2000; Grimpe and Kaiser, 2010). Second, external R&D may allow firms to access better-quality resources than they can generate internally (Grimpe and Kaiser, 2010). This is the case when a firm lacks expertise in certain innovation activities whereas an R&D supplier is specialized in just these activities. Third, external R&D may help firms to access complementary or heterogeneous knowledge assets (Cassiman and Veugelers, 2006; Grimpe and Kaiser, 2010), which are considered to be the primary source of innovation (Nelson and Winter, 1982; Rosenkopf and Nerkar, 2001). For this reason, firms diversify their external knowledge sources and search for complementary resources within their home country as well as beyond the national borders (von Zedtwitz and Gassmann, 2002; von Zedtwitz et al., 2004; Lewin et al., 2009; Bertrand and Mol, 2013).

An external R&D strategy may also involve certain risks, because protecting strategic knowledge from imitation can be difficult when it is generated by external actors. Knowledge that is non-excludable could spill over from an R&D supplier to multiple client firms (Grimpe and Kaiser, 2010). Additional reasons that increase the risk of using external R&D in innovation activities may be listed. First, knowledge acquired from an R&D supplier may not be unique, because competitors may have access to the expertise of the same R&D supplier. Second, external R&D may reduce firm-specific competencies, because this strategy implies the acquisition of a research outcome from external suppliers without participating in problem-solving activities. For this reason, external R&D can hamper a client firm's innovation capabilities. Complete reliance on external R&D in innovation activities is not likely, because the utilization of knowledge sourced from R&D suppliers requires substantial expertise and competencies in the client firm.

An alternative external governance mode for R&D activities is *innovation cooperation*. In contrast to external R&D, innovation cooperation allows firms to keep some degree of control over business processes performed jointly by the contract partners in general (Williamson, 1991) and over the knowledge-generating processes in particular. The literature defines cooperation as a hybrid organizational form (between market and internal governance) whereby firms commit their resources to a common project and interact intensively to induce and benefit from learning processes (Mudambi and Tallman, 2010). The frequent interaction between the employees coming from the partner firms is likely to build the trust-based relationships between them (Powell, 1990) that are required to share unwritten knowledge such as skills and know-how (Holste and Fields, 2010). For these reasons, innovation cooperation may enable firms to create more efficient transactions for monitoring the behaviour of the contract partners and transferring as well as exchanging knowledge (Mudambi and Tallman, 2010). Furthermore, innovation cooperation allows firms to reduce the costs and risks of R&D projects as well as to speed up new product development through pooling complementary resources (Hagedoorn, 1993).

The main advantage of external R&D compared with innovation cooperation is that it allows firms to acquire ready R&D results; once the activities have been performed, the outcome is subsequently transferred back and used in internal R&D. In this context, external R&D allows firms to contract out rather peripheral innovation activities to external actors and to concentrate internally on the core innovation activities that determine their competitive advantages (Quinn, 1999, 2000). In doing so, companies move their innovation activities from sequential to parallel working processes (Howells et al., 2003; Langlois, 2003). In other words, a firm distributes its R&D tasks among different external actors in which separated R&D activities are implemented independently and simultaneously. The benefit of this approach is that external R&D enables companies to speed up the new product development as well as to reduce the costs and risks of peripheral innovation activities in which they lack competencies (Quinn, 1999, 2000). However, openness in innovation in the form of external R&D may also turn out to be costly (Cohen and

Levinthal, 1990); ‘costly’ means not only in terms of coordinating and enforcing external contracts, but also in terms of interpreting and utilizing external knowledge. As Cohen and Levinthal (1990) suggest, a firm needs absorptive capacity to be able to identify, assimilate and transform external knowledge for internal purposes. Absorptive capacity, which refers to a firm’s prior related knowledge, enables the company to acquire new knowledge in the particular field in which it has already accumulated a certain level of expertise. Building up absorptive capacity requires direct involvement in innovation and problem-solving activities, practice and experience-based learning. For these reasons, shifting the attention from internal innovation activities towards the exploitation of external knowledge can hamper firms’ absorptive capacity and, as a result, their innovation performance. This issue is more critical in the case of external R&D than in the case of innovation cooperation (Mudambi and Tallman, 2010), because in the case of external R&D the client firm is not involved in problem-solving activities. This, on the one hand, allows the firm to specialize in a narrow set of core innovation activities and to contract out rather peripheral R&D tasks to external actors. However, on the other hand, to use the externally provided results requires substantial expertise from the firm to evaluate and utilize the external R&D (Cohen and Levinthal, 1990). For this reason, this innovation strategy may not be independent from internal R&D. In other words, internal R&D is considered to be a prerequisite for developing absorptive capacity and, hence, utilizing knowledge sourced from R&D service firms. Indeed, Cassiman and Veugelers (2006) find a complementary relationship between external and internal R&D in product innovation. In other words, the authors provide empirical evidence that the marginal returns of external R&D in product innovation increase if firms simultaneously invest in internal R&D.

These considerations of complementarity can also be extended to innovation cooperation. For instance, Grimpe and Kaiser (2010) provide empirical evidence that not only internal R&D but also a high number of innovation cooperation partnerships positively moderate the effect of external R&D on product innovation. There are two reasons for the complementary relationship between external R&D and innovation cooperation. First, implementing innovation activities together with external actors allows firms to enlarge their internal expertise and knowledge stock. By knowing more, firms can manage the utilization of external R&D effectively (Brusoni et al., 2001). Second, coordinating a high number of innovation cooperation partnerships enables firms to develop external collaboration skills and capabilities, which can be essential to avoid errors in selecting specialized research organizations for certain innovation activities and then to transfer knowledge from them effectively (Grimpe and Kaiser, 2010). In other words, as innovation cooperation with a wide set of external actors allows firms to enrich their internal stock of knowledge and also to specialize in the management of external partnerships, firms that engage in innovation cooperation partnerships are more likely to manage the knowledge transfer from R&D suppliers effectively than others that are less experienced in innovation cooperation. Hence, prior research suggests that firms adopt different R&D strategies in open innovation to improve the efficiency and effectiveness of their innovation activities.

3.2.2 International external knowledge sourcing as part of innovation activities

Open innovation does not stop at national borders, although the issue has only been addressed very briefly (Gassmann et al., 2010). Due to the cost reductions in communication technologies, increased internationalization of R&D activities has developed, which enables companies to access cheap R&D inputs from low-cost countries and to access valuable knowledge abroad (von Zedtwitz and Gassmann, 2002; von Zedtwitz et al., 2004; Lewin et al., 2009). If a firm does not manage to identify appropriate knowledge partners in its own country, it may organize R&D on a global scale to diversify its external knowledge sources and to access resources that are unavailable within its home country (von Zedtwitz and Gassmann, 2002; von Zedtwitz et al., 2004; Lewin et al., 2009; Nieto and Rodriguez, 2011). Given that scientific expertise is distributed worldwide, innovation cooperation with international actors or the acquisition of external R&D from them can be essential to keep pace in various fields of technological development (von Zedtwitz and Gassmann, 2002; von Zedtwitz et al., 2004; Lewin et al., 2009). In other words, firms outsource some R&D tasks outside their home country because international R&D suppliers may possess superior technological expertise to domestic providers (Lewin et al., 2009; Nieto and Rodriguez, 2011). For example, Lewin et al. (2009) find that the limited resources and shortages of highly skilled workers within the home market induce firms to outsource some R&D activities outside the national borders. Other motives for the internationalization of R&D activities include acquiring cheap R&D inputs from low-cost countries and exploring the requirements of foreign markets (von Zedtwitz and Gassmann, 2002;

von Zedtwitz et al., 2004). The internationalization of R&D activities allows firms to have direct access to customers abroad, to align their needs with new product development and to meet the requirements of various foreign markets. In this way, companies seek to exploit their resources in an international market.

Distinguishing external R&D based on a geographical dimension, knowledge transfer from international, rather than from domestic, R&D suppliers might be more problematic (von Zedtwitz and Gassmann, 2002; Bertrand and Mol, 2013). Even though the development of information technologies has decreased the obstacles to long-distance communication, tacit knowledge is considered to be geographically bounded (von Zedtwitz and Gassmann, 2002; Morgan, 2004). Learning tacit knowledge requires intensive informal and face-to-face communications, which are often problematic to perform between remote locations. Besides, different national innovation systems, cultures and institutions across countries create a heterogeneous learning environment for local and foreign firms (Freeman, 1995). As a result, the levels of understanding between them can be limited due to their diverse routines and knowledge bases.

Firms that have a large absorptive capacity and prior related knowledge may safeguard against these problems of limited understanding and tacitness of knowledge. According to Prencipe (1997, 2000), the technological knowledge overlap between client and supplier firms facilitates the effective utilization of external R&D. In this sense, increasing the common understanding in technological knowledge between partner firms may help them to overcome the geographical distance in knowledge exchange. Based on that, firms need to engage in internal R&D activities to build up appropriate absorptive capacities and to ease knowledge sourcing from international marketplaces. Hence, firms that are more intensely engaged in international, rather than domestic, external R&D may invest more in internal R&D.

Another way to bridge geographical distance is to engage in international innovation cooperation, which generally increases the common understanding and overcomes frictions due to different innovation cultures; as a consequence, the utilization of external R&D from remote locations will be ameliorated. Hence, the following hypotheses are proposed:

H1a: Firms that acquire international, rather than domestic, external R&D are more likely to invest in internal R&D.

H1b: Firms that acquire international, rather than domestic, external R&D are more likely to engage in international innovation cooperation partnerships.

3.2.3 International knowledge sourcing and innovation performance

Previous studies have shown that internal R&D as well as innovation cooperation are important drivers of product innovation (Deeds and Hill, 1996; Becker and Dietz, 2004; Nieto and Santamaria, 2007; Vega-Jurado et al., 2008), whereas the contribution from external R&D is not clear. Firms organize strategically important R&D activities internally to generate valuable and competitive resources and to protect these resources from imitation by competitors. In other words, internal R&D allows companies to develop and accumulate firm-specific competencies, which determine their innovation capabilities. To cope with the increased complexity of innovation, firms also collaborate with external actors to access resources that cannot be generated internally (Powell et al., 1996). This allows companies to develop valuable (knowledge) assets through a joint effort of the partner firms (Hagedoorn, 1993). This strategy is characterized by intensive interaction, resource sharing and mutual learning, which help firms to enhance their innovation activities (Hagedoorn, 1993; Powell et al., 1996; Becker and Dietz, 2004; Belderbos et al., 2004; Nieto and Santamaria, 2007).

On the contrary, external R&D does not imply mutual learning or intensive interaction in a knowledge-creation process. Instead, a client firm purchases research results from R&D suppliers without being involved in the knowledge generation of external R&D. The uniqueness of research results acquired from an R&D supplier is also questionable, because competitors may have access to the expertise of the same R&D supplier (Grimpe and Kaiser, 2010). In the long run, relying heavily on external R&D may even exhaust firms' innovation potential through reducing skilled employees and problem-solving activities in internal R&D (Bettis et al., 1992; Weigelt, 2009). Based on that, the question arises of how and to what extent external R&D contributes to a firm's product innovation performance.

Drawing on our discussion above, given that the utilization of external knowledge requires absorptive capacity, it is unlikely that firms rely entirely on external R&D for their innovation activities. They complement it with internal innovation activities whereby the gains to be reaped from external R&D depend on the effective integration of external knowledge into internal innovation activities (Grimpe and Kaiser, 2010).

Prior studies provide empirical evidence that the marginal returns of external R&D in product innovation increase if firms simultaneously invest in internal R&D and vice versa, external R&D enhances internal innovation activities (Cassiman and Veugelers, 2006; Grimpe and Kaiser, 2010).

In view of the internationalization of knowledge sourcing, one may ask whether there is a difference in domestic external R&D and international external R&D. Despite the fact that the coordination of international R&D relates to high transaction costs, firms organize R&D on a global scale to access resources that are unavailable within the domestic market. In this sense, companies outsource some R&D activities outside the national borders to cope with the limited resources and shortages of highly skilled workers within their home market (Lewin et al., 2009). Moreover, the knowledge-based assets sourced from international marketplaces might be more heterogeneous than those within the home country due to the different institutions and national innovation systems (Freeman, 1995). In this sense, international, rather than domestic, external R&D can help firms to access more diverse knowledge inputs. Hence, the higher transaction costs appear to go hand in hand with a higher value of the externally addressed knowledge accessed. Looking at the empirical evidence, firms with external R&D from international marketplaces can have more opportunities for knowledge recombination and perform better in innovation than others relying only on domestic resources (Bertrand and Mol, 2013). Based on that, we want to check the first hypothesis on international external R&D:

H2a: Firms that acquire international, rather than domestic, external R&D are more likely to introduce product innovations with a higher degree of novelty.

Connecting this to our discussion of the complementarity of different innovation-oriented governance modes above, we emphasize even more that firms should also possess strong integrative or absorptive capacity to gain from international external R&D. Therefore, firms that purchase international, rather than domestic, external R&D are more likely to introduce product innovation with a higher degree of novelty if they simultaneously invest in internal R&D and engage in international innovation cooperation for the purpose of developing knowledge-integrative capabilities. Hence, we propose the following two additional hypotheses on international external R&D:

H2b: Firms that acquire international, rather than domestic, external R&D are more likely to introduce product innovations with a higher degree of novelty if they simultaneously invest in internal R&D.

H2c: Firms that acquire international, rather than domestic, external R&D are more likely to introduce product innovations with a higher degree of novelty if they simultaneously engage in international innovation cooperation partnerships.

3.3 Data description

The empirical analysis of the paper is based on the Danish part of the Community Innovation Survey (CIS).[9] The CIS is conducted at the enterprise level, and it gives a broad variety of information on innovation activities such as internal R&D, domestic and international external R&D, innovation cooperation and different types of product innovations. To avoid cross-sectional data-related problems in the empirical analysis, we impose a timelag between innovation input and output variables. As the literature suggests (Griliches and Mairesse, 1984; Pakes and Schankerman, 1984), time is required to finalize an R&D project, to introduce a new product to a market and then to obtain revenues from the new product sales. Although the timelag may vary across firms and depend on the type of R&D projects that they run, an average lag between innovation input and innovation output is about two years (Griliches and Mairesse, 1984; Pakes and Schankerman, 1984). Therefore, we combine the 2008 and 2010 CIS datasets, implying that innovation strategies and other control variables come from the 2008 CIS, whereas

[9]The paper acknowledges the access to the Danish CIS data from the Danish Statistical Office.

the innovation output (i.e. turnovers from product innovation) is taken from the 2010 CIS (see Table VI). In the original 2008 and 2010 CIS datasets, there were 939 and 1111 firms, respectively. After combining these two datasets and restricting the sample to manufacturing firms in line with prior studies (Cassiman and Veugelers, 2006; Schmiedeberg, 2008), we obtain 491 observations.

Table VI – Variable definitions

Variable	Definition	Step	CIS survey – year
INTERNAL R&D	The expenses for own R&D divided by the number of employees	1,2	2008
DOMESTIC EXTERNAL R&D	The expenses for R&D performed by external actors located in Denmark divided by the number of employees	1,2	2008
INTERNATIONAL EXTERNAL R&D	The expenses for R&D performed by external actors located abroad divided by the number of employees	1,2	2008
INNO COOPERATION	The number of innovation cooperation partners with external actors located in Denmark and abroad	1,2	2008
DOMESTIC INNO COOPERATION	The number of innovation cooperation partners with external actors located in Denmark	1,2	2008
INTERNATIONAL INNO COOPERATION	The number of innovation cooperation partners with external actors located abroad	1,2	2008
PATENT	Binary: 1 if a firm applied for a patent	1	2008
ABANDONED PROJECT	Binary: 1 if a firm abandoned an innovation project without results	1	2008
TRAINING	Binary: 1 if a firm organized training as part of the innovation activity	1	2008
MEDIUM-SIZED FIRMS	250–500 employees	1,2	2008
LARGE-SIZED FIRMS	More than 500 employees	1,2	2008
INDUSTRY	Industry dummies (2-digit classification)	1,2	2008
INNFIRM	The turnover from product innovation that is new to the firm but known on the market	2	2010
INNMARKET	The turnover from product innovation that is new to the firm's own market	2	2010
INNWORLD	The turnover from product innovation that is new to the world	2	2010

To test the complementary relationship between innovation strategies, we use a two-step approach: adoption and performance. In the adoption approach, we examine whether firms adopt different innovation strategies. In the performance approach, we check whether the implementation of one strategy pays off more once complementary activities are present

(Cassiman and Veugelers, 2006; Schmiedeberg, 2008). Therefore, innovation strategies are used as dependent variables in the first step and as explanatory variables in the second step. The CIS allows us to distinguish the following different innovation strategies: INTERNAL R&D, DOMESTIC EXTERNAL R&D, INTERNATIONAL EXTERNAL R&D, DOMESTIC INNO COOPERATION, INTERNATIONAL INNO COOPERATION and INNO COOPERATION. The first variable, INTERNAL R&D, represents the expenses for own R&D. The second and third strategies concern external R&D and refer to the expenditures for R&D performed by external actors, such as other parts of the business group, other companies, approved technological service institutes, universities and colleges, and other public research institutions. We distinguish here DOMESTIC EXTERNAL R&D and INTERNATIONAL EXTERNAL R&D, in which the external actors are located in Denmark and abroad, respectively. To control for the firm size effect in R&D spending, we divide the expenses for internal R&D, domestic external R&D and international external R&D by the total number of employees (Grimpe and Kaiser, 2010).

Table VII – Industry breakdown

Technology class	Classification of manufacturing industry	NACE
Low-technology manufacturing industries	Food and beverages, tobacco	15, 16
	Textiles, leather, footwear	17–19
	Wood, paper, paper products	20, 21
	Furniture	22
Medium-technology manufacturing industries	Non-metallic mineral products	26
	Metal products	27, 28
	Rubber and plastic products	25
	Machinery and equipment	29
High-technology manufacturing industries	Chemical industry	24
	Electrical apparatus, computing machines, communication equipment	30–32
	Medical, precision and optical instruments	30–32

Source: OECD (2003)

Another set of dependent variables (i.e. DOMESTIC INNO COOPERATION, INTERNATIONAL INNO COOPERATION, INNO COOPERATION) refers to a firm's innovation cooperation strategy. The CIS lists different types of innovation cooperation partners (i.e. suppliers, customers, competitors, approved technological service institutes, consulting organizations, companies from other industries (excluding customers and suppliers), universities, public research institutions, public services and other public institutions), and the respondents were asked to indicate whether they collaborate with the above-listed partners in Denmark, Europe, the USA, China and/or other locations. The variable DOMESTIC INNO COOPERATION refers to a number of innovation collaboration partners in Denmark, whereas INTERNATIONAL INNO COOPERATION stands for a number of innovation collaboration partners abroad.[10] The variable INNO COOPERATION represents the total number of collaboration arrangements with local and international actors.

Table VIII – Descriptive statistics

Variable names	Obs.	Mean	Std dev.	Min.	Max.
INTERNAL R&D	491	49.921	110.81	0	1024.0
DOMESTIC EXTERNAL R&D	491	2.5512	13.428	0	163.18
INTERNATIONAL EXTERNAL R&D	491	5.8986	36.376	0	475.57
INNO COOPERATION	491	3.1018	5.1908	0	32
DOMESTIC INNO COOPERATION	491	0.9124	1.6886	0	10
INTERNATIONAL INNO COOPERATION	491	1.1771	2.7787	0	24
PATENT	491	0.2362	0.4252	0	1
ABANDONED PROJECT	491	0.1608	0.3678	0	1
TRAINING	491	0.4155	0.4934	0	1
MEDIUM-SIZED FIRMS	491	0.1812	0.3856	0	1
LARGE-SIZED FIRMS	491	0.1527	0.3601	0	1
MEDIUM-TECH INDUSTRY	491	0.4582	0.4987	0	1
HIGH-TECH INDUSTRY	491	0.2647	0.4416	0	1
INNFIRM	491	0.2723	0.2965	0	1
INNMARKET	491	0.15559	0.2675	0	1
INNWORLD	491	0.08204	0.2210	0	1

To explain a firm's innovation behaviour, we consider several explanatory variables in the econometric analysis. First, we control for whether a firm is innovative or not. For this purpose, we use the PATENT variable, which indicates whether a company applied for a patent during the 2006–2008 period. Second, we account for whether a firm has terminated an innovation project without a result (ABANDONED PROJECT). Firms often fail to complete an innovation project due to the gap between their existing resources and those needed to execute the innovation project successfully (Cooper and Kleinschmidt, 1990). To cope with this issue, companies

[10]The number of cooperation cases in the USA, China and other locations is very small; therefore, we combine these three categories into one, implying that international innovation cooperation counts the number of collaboration partners in Europe and in other countries (the USA, China and others).The variable receives a positive count if a firm has at least one innovation partner in one of the countries – the USA, China and others.

collaborate with external actors to acquire the necessary resources and to improve their innovation processes (Keupp and Gassmann, 2009). In this sense, we expect a positive relationship between ABANDONED PROJECT and R&D openness. In addition, we introduce a TRAINING variable into the econometric model. The variable indicates whether a firm conducts training as part of its innovation activities. As training improves employees' formal and/or specific qualifications and, hence, enhances the firm's absorptive capacity (Cohen and Levinthal, 1990), we presume that those companies that provide their employees with training as part of their innovation activities are more likely to increase their degree of openness in innovation than others that undertake no such activities, because substantial internal expertise is required to utilize external knowledge effectively.

Table IX– Correlation table

	Variable names	1	2	3	4	5	6	7	8	9	10	11	12	13
1	INTERNAL R&D	1.000												
2	DOMESTIC EXTERNAL R&D	0.234***	1.000											
3	INTERNATIONAL EXTERNAL R&D	0.307***	0.227***	1.000										
4	INNO COOPERATION	0.355***	0.147***	0.327***	1.000									
5	DOMESTIC INNO COOPERATION	0.177***	0.110**	0.115**	0.501***	1.000								
6	INTERNATIONAL INNO COOPERATION	0.336***	0.117***	0.210***	0.617***	0.666***	1.000							
7	PATENT	0.321***	0.092**	0.210***	0.346***	0.261***	0.328***	1.000						
8	ABANDONED PROJECT	0.143***	0.020	0.040	0.411***	0.282***	0.249***	0.252***	1.000					
9	TRAINING	0.159***	0.047	0.111***	0.313***	0.253***	0.207***	0.177***	0.206***	1.000				
10	MEDIUM-SIZED FIRMS	-0.001	-0.040	0.002	0.063	0.090***	0.086*	0.037	0.053	0.047	1.000			
11	LARGE-SIZED FIRMS	0.113**	0.112**	0.111**	0.376***	0.230***	0.287***	0.203***	0.168***	0.045	-0.199***	1.000		
12	MEDIUM-TECH INDUSTRY	-0.211***	-0.046	-0.125***	-0.121***	-0.044	-0.141***	0.085*	0.008	0.073	-0.040	-0.106**	1.000	
13	HIGH-TECH INDUSTRY	0.379***	0.094**	0.231***	0.261***	0.137***	0.247***	0.133***	0.076*	0.076	-0.078*	0.027	-0.551***	1.000

*Note: *, ** and *** denote significance at the 10%, 5% and 1% level, respectively.*

In the second step, the dependent variables are the turnovers from different types of product innovation. To measure the novelty of new products, the CIS asked the respondents to indicate whether a company introduced a product that was new to the firm but known on a market (1), new to the firm's own market (2) or new to the world (3). The first question relates to product imitation rather than to product innovation. The second question describes whether firms introduced a product that was new to their own market, but might already have been introduced to other markets in which the firms do not perform. In the final question, firms were asked to indicate whether they had introduced a completely new product to the world. Therefore, we consider a product that is new to the world to be characterized by a higher degree of novelty than others. Taking into account that the success of a new product depends on its market acceptance, we use the turnovers from product innovations as dependent variables in the analysis (Cassiman and Veugelers, 2006; Laursen and Salter, 2006; Grimpe and Kaiser, 2010). Thus, we use three measures of product innovation. First, we take the share of turnover from the product that is new to the firm but known in the market (INNFIRM). The second dependent variable is the share of the turnover from the product that is new to the firm's own market (INNMARKET), and the third one is the share of the turnover from the product that is new to the world (INNWORLD) (see Table VI).

Table X–Distribution of firms across industries, size classes and trends in innovation activities

Variable names	Frequency	Percentages
FIRM SIZE		
Fewer than 249 employees	327	66.60
250–500 employees	89	18.13
More than 500 employees	75	15.27
INDUSTRY		
Low-tech manufacturing industries	136	27.70
Medium-tech manufacturing industries	225	45.82
High-tech manufacturing industries	130	26.48
INTERNAL R&D		
Yes	323	65.78
DOMESTIC EXTERNAL R&D		
Yes	131	26.68
INTERNATIONAL EXTERNAL R&D		
Yes	80	16.29
DOMESTIC INNO COOPERATION		
Yes	157	31.98
INTERNATIONAL INNO COOPERATION		
Yes	75	15.70
INNFIRM		
Yes	168	34.22
INNMARKET		
Yes	126	25.66
INNWORLD		
Yes	82	16.70

To explain a firm's product innovation performance, we use innovation strategies (i.e. INTERNAL R&D, DOMESTIC EXTERNAL R&D, INTERNATIONAL EXTERNAL R&D, DOMESTIC INNO COOPERATION, INTERNATIONAL INNO COOPERATION, INNO COOPERATION) as explanatory variables in the second-step analysis. To control for other factors that may influence the estimation results of the first- and second-step analyses, we introduce firm size and industry dummies into the econometric models. Firm size is measured by the number of employees. Specifically, we create three size groups: fewer than 250employees,[11] between 250 and 499 employees, and more than 500 employees. As regards the industry dummies, we break down industries into three groups (OECD, 2003): low-technology manufacturing industries,[12] medium-technology manufacturing industries[13] and high-technology manufacturing industries. An overview of the industry technology classes is provided in Table VII.

Looking at the sample distribution of the variables, Table X shows that a large share (45%) of firms operate in medium-technology manufacturing industries, whereas 28% and 26% of companies come from low- and high-technology manufacturing industries, respectively. Regarding the firm size distribution in the sample, those firms that have fewer than 249 employees account for 66%. Companies with 250–499 employees and more than 500 employees represent 18% and 15%, respectively.

Furthermore, Table X shows that the firms in our sample differ substantially in terms of their innovation activities. As the data indicate, 65% of firms invest in internal R&D. Compared with internal R&D, external R&D is less intensive among Danish companies: 26% of firms report domestic external R&D and 16% international external R&D. With regard to innovation cooperation strategies, 31% of companies cooperate with domestic actors, whereas 15% of enterprises engage in innovation cooperation with international entities. Considering the trends in product innovation, 34% of firms introduce products that are new to their company, but known

[11] Firms with fewer than 250 employees are taken as the reference category in the econometric analysis.
[12] The group of low-technology manufacturing industries is taken as the reference category in the econometric analysis.
[13] Medium-low and medium-high technology manufacturing industries are grouped into one category, because the number of observations in medium-low technology manufacturing industries is low.

on a market. Companies that develop products that are new to their own market and new to the world account for 25% and 16%, respectively.

3.4 Econometric models

As described in the previous section, we employ the adoption and the performance approach to check whether there is a complementary or a substitutive relationship between innovation strategies (Cassiman and Veugelers, 2006; Schmiedeberg, 2008). To confirm a complementary effect in the adoption approach, a positive and significant correlation must be present between the adopted activities. However, the pair-wise correlation between innovation activities does not allow us to prove the existence of complementarities, because positive and significant signs can be driven by other exogenous factors that influence the organizational decision to adopt different innovation strategies (Cassiman and Veugelers, 2006; Schmiedeberg, 2008). To control for the possible exogenous factors, we first conduct a regression analysis for each innovation strategy, then we extract the residuals from the estimations and check for correlations between them, which are called conditional correlations. To identify the complementary condition in the performance approach, the coefficients of the interaction term between innovation strategies have to be significantly larger than zero.

The first set of dependent variables (i.e. INTERNAL R&D, DOMESTIC EXTERNAL R&D and INTERNATIONAL EXTERNAL R&D) used in the adoption approach has continuous outcomes, whereas the second set of dependent variables (i.e. INNO COOPERATION, DOMESTIC INNO COOPERATION and INTERNATIONAL INNO COOPERATION) has count outcomes. All of these variables are skewed to the right, containing a high number of zeros; there are numbers of firms that do not perform the above-mentioned R&D activities. To account for the specific features of the data, we use the generalized linear model (GLM) introduced by Nelder and Wedderburn (1972). The GLM is flexible and allows us to use dependent variables with non-normal distribution by introducing a proper family distribution and link function. We use the Akaike Information Criterion (AIC) to compare models with different family distributions and link functions (a model with a low value of the AIC is considered the model that best fits the data). The comparative analysis suggests a gamma distribution with a log link function for INTERNAL R&D, DOMESTIC EXTERNAL R&D and INTERNATIONAL EXTERNAL R&D and a negative binomial distribution with a log link function for INNO COOPERATION, DOMESTIC INNO COOPERATION and INTERNATIONAL INNO COOPERATION. A robust option is also included in the econometric models to obtain robust standard errors if the family distribution is incorrectly specified.

In the second step, the performance approach, the dependent variables are the turnovers from different types of product innovation: INNFIRM, INNMARKET and INNWORLD. The variables have continuous outcomes that fall between zero and one. As many firms do not engage in product innovation and hence report no turnover from product innovation, the dependent variables contain a high number of zeros. For this reason, the right-censored tobit model is used to account adequately for this specific feature of our data by treating firms with and without product innovation differently (Schmiedeberg, 2008; Grimpe and Kaiser, 2010).

3.5 Estimation results

3.5.1 Adoption approach

For the analysis of complementarity, the adoption approach is applied first. Table XI shows the conditional correlations for the complementarity analysis. Table XII presents the results regarding whether and to which degree firms take up certain innovation strategies.

For the conditional correlations among the various innovation strategies in Table XI, we find far fewer significant correlations than in Table IX stating the unconditional correlations; the latter are all significantly positive. Turning to the conditional correlations, we find that our empirical model contains quite a number of variables that account for unconditional correlations.

More specifically, we find the following conditional relations. For the internal–external R&D relationship, a significant correlation exists between INTERNAL R&D and INTERNATIONAL EXTERNAL R&D, which suggests that these innovation strategies are additive. Contrariwise, DOMESTIC EXTERNAL R&D is not related to either of them. As discussed in section 2.2, this may have to do with the fact that the effective utilization of external R&D sourced from international, rather than from domestic, marketplaces may require a more advanced level of internal absorptive capacity. For this reason, those firms acquiring international, rather than domestic, external R&D invest more intensely in internal R&D. The result is in line with our H1a hypothesis.

Looking at cooperation strategies, we find that the INTERNATIONAL INNO COOPERATION and DOMESTIC INNO COOPERATION are significantly and highly correlated with each other. Via construction both are related to INNO COOPERATION. As evidenced by the insignificant conditional correlations, INTERNAL R&D does not show a significant connection with any of the innovation cooperation variables. Considering external R&D activities and innovation cooperation, complementarity can only be detected between INNO COOPERATION and INTERNATIONAL EXTERNAL R&D. All the other conditional correlations between the specific versions of innovation cooperation and DOMESTIC EXTERNAL R&D are not significant. Hence, the conditional correlation analysis partially confirms our H1b hypothesis in which we suggest that those firms acquiring international, rather than domestic, external R&D are more likely to engage in international innovation cooperation partnerships. In other words, the data analysis suggests that it is innovation cooperation in general and not the international dimension that correlates significantly and positively with international external R&D.

Table XI –Conditional correlation table

	Variables	1	2	3	4	5	6
1	INTERNAL R&D	1.0000					
2	DOMESTIC EXTERNAL R&D	0.0660	1.0000				
3	INTERNATIONAL EXTERNAL R&D	**0.1102****	0.0257	1.0000			
4	INNO COOPERATION	0.0824	0.0502	**0.1801*****	1.0000		
5	DOMESTIC INNO COOPERATION	0.0065	0.0844	0.0652	**0.3005*****	1.0000	
6	INTERNATIONAL INNO COOPERATION	0.0936	0.1352	0.0514	**0.3450*****	**0.5769*****	1.0000

*Note: ** and *** denote significance at the 5% and 1% level, respectively.*

As for the control variables used in the first-step analysis, the results show that innovativeness proxied by the PATENT variable is significantly and positively associated with internal R&D (INTERNAL R&D) as well as with all the innovation cooperation variables (i.e. INNO COOPERATION, DOMESTIC INNO COOPERATION and INTERNATIONAL INNO COOPERATION); however, it shows no significant relationship with DOMESTIC EXTERNAL R&D and INTERNATIONAL EXTERNAL R&D. The data suggest that innovative firms invest in internal R&D and also engage in a high number of innovation cooperation partnerships. The relationship with external R&D remains unclear; here it would be interesting to know whether the purchased R&D results are used for the buying firm's own patented innovations or contribute to not-patented innovations, such as process innovations that are often used immediately in the production process. It may equivalently hold that relying heavily on external R&D in innovation may cause shifting knowledge creation capabilities from the client firm towards an R&D provider (Bettis et al., 1992; Weigelt, 2009).

Table XII – Estimation results for innovation strategies

	GLM MODELS					
	1	2	3	4	5	6
	INTERNAL R&D	DOMESTIC EXTERNAL R&D	INTERNATIONAL EXTERNAL R&D	INNO COOPERATION	DOMESTIC INNO COOPERATION	INTERNATIONAL INNO COOPERATION
PATENT	0.6330***	0.4770	0.8544	0.2995***	0.3727**	0.7675***
	(0.1519)	(0.3591)	(0.6296)	(0.1147)	(0.1734)	(0.1856)
ABANDONED PROJECT	0.2298	-0.2542	1.3740	0.5081***	0.4455**	0.3466
	(0.1838)	(0.3550)	(0.8303)	(0.1279)	(0.1798)	(0.2190)
TRAINING	0.3754**	-0.0172	-0.5359	0.5229***	0.5582***	0.4353**
	(0.1863)	(0.4067)	(0.6302)	(0.1149)	(0.1680)	(0.1865)
MEDIUM-SIZED FIRMS				0.4083***	0.4190**	0.7706***
				(0.1507)	(0.2018)	(0.2147)
LARGE-SIZED FIRMS				0.8558***	0.5796***	1.0089***
				(0.1205)	(0.1836)	(0.2061)
MEDIUM-TECH INDUSTRY	-0.3861	0.0337	1.0697	0.0867	0.1786	-0.2294
	(0.2985)	(0.8864)	(0.9687)	(0.1480)	(0.2130)	(0.2404)
HIGH-TECH INDUSTRY	1.0179***	0.6728	3.6470***	0.5713***	0.3206	0.6139**
	(0.2919)	(0.4716)	(0.9959)	(0.1530)	(0.2075)	(0.2374)
INTERCEPT	3.2965***	0.8181	-0.9899	-0.7246***	-0.8626***	-0.8977***
	(0.2952)	(0.7828)	(0.7930)	(0.1500)	(0.2060)	(0.2275)
LINK	Log	Log	Log	Log	Log	Log
FAMILY	Gamma	Gamma	Gamma	Negative Binomial	Negative Binomial	Negative Binomial
LOG PSEUDO-LIKELIHOOD	-1744.8	-762.94	-686.35	-1145.0	-577.05	-698.65
AIC	9.7002	4.2601	3.8356	6.3878	3.2413	3.9149
BIC	-1613.5	-1531.9	-1452.8	-577.11	-1318.6	-1076.0
OBS.	491	491	491	491	491	491

*Note: *, ** and *** denote significance at the 10%, 5% and 1% level, respectively; S.E. in parentheses.*

Regarding the other independent variables, ABANDONED PROJECT is significantly and positively associated with INNO COOPERATION and also with DOMESTIC INNO COOPERATION, but it shows no significant relationship with INTERNAL R&D. Here, firms that failed to complete an innovation project show a higher inclination towards an open innovation framework. Our data do not allow a causal interpretation here; it might be that firms with abandoned projects hope to improve on them with the help of cooperation partners;

however, it might also hold that in research cooperation projects are much more easily abandoned. Moreover, ABANDONED PROJECT is associated significantly with neither DOMESTIC EXTERNAL R&D nor INTERNATIONAL EXTERNAL R&D.

Regarding TRAINING, this variable is significantly and positively related to INTERNAL R&D and all the innovation cooperation variables (i.e. INNO COOPERATION, DOMESTIC INNO COOPERATION and INTERNATIONAL INNO COOPERATION); it shows no significant relationship with DOMESTIC EXTERNAL R&D and INTERNATIONAL EXTERNAL R&D. This might be due to the fact that executing innovation projects internally and in cooperation is connected to training activities and therefore a high level of internal expertise; drawing on external R&D, however, does not show a systematic relationship with training activities, suggesting that firms without a higher level of internal expertise may also purchase R&D results from specialized external providers.

Turning to the firm size variables, MEDIUM-SIZED FIRMS and LARGE-SIZED FIRMS have a significant and positive correlation with INNO COOPERATION (including DOMESTIC INNO COOPERATION and INTERNATIONAL INNO COOPERATION). As large-sized firms possess strong research capabilities in terms of financial, physical and human resources, they are more likely to cooperate with a wide set of external actors in innovation than their small counterparts.

Last but not least, the estimation results indicate a non-significant relationship between the industry dummies (i.e. MEDIUM-TECH INDUSTRY, HIGH-TECH INDUSTRY) and R&D openness with regard to domestic partnerships (i.e. DOMESTIC INNO COOPERATION, DOMESTIC EXTERNAL R&D). In line with previous studies, the data analysis shows that there are not many inter-industry differences in terms of adopting open innovation principles (Chesbrough and Crowther, 2006; Huizingh, 2011). However, regarding international knowledge sourcing, HIGH-TECH INDUSTRY shows significant positive signs for INTERNATIONAL INNO COOPERATION and INTERNATIONAL EXTERNAL R&D. This industry group is also significant and positive for INTERNAL R&D, whereas MEDIUM-TECH INDUSTRY is neither significant for international partnerships (i.e. INTERNATIONAL INNO COOPERATION, INTERNATIONAL EXTERNAL R&D) nor significant for internal R&D (INTERNAL R&D). It is not surprising that high-technology manufacturing firms have higher internal R&D spending than their counterparts from low- and medium-technology manufacturing sectors, 'because the definition of low technology and high technology firms is itself based on the firms' share of expenditures on R&D' (Kirner et al., 2009: 450). As for the positive correlation between HIGH-TECH INDUSTRY and international partnerships (i.e. INTERNATIONAL INNO COOPERATION and INTERNATIONAL EXTERNAL R&D), this might be explained by the small market size of Denmark. More concretely, Danish firms operating in high-technology manufacturing industries may engage in international R&D partnerships to increase their product sales on the global market and, as a result, to cover the high costs of their R&D activities and to cope with the small domestic market size (von Zedtwitz and Gassmann, 2002).

3.5.2 Performance approach

Having discussed the results from the adoption approach, we turn our attention towards the performance approach. In relation to the innovation performance of firms, we distinguish between new to the firm (INNFIRM), new to the market (INNMARKET) and new to the world (INNWORLD) innovations, which allows us to examine whether different forms of R&D openness are complementary or substitutive in product imitation and innovation. Complementarity between innovation strategies is given when the respective interaction terms show a significantly positive coefficient. It indicates that the two innovation strategies together are related to a higher innovation output. Since we measure the implementation of the strategies and the innovation output in different years, we can carefully assume a causal relationship here.

Table XIII shows that domestic external R&D (DOMESTIC EXTERNAL R&D) as well as innovation cooperation (INNO COOPERATION) in general and domestic innovation cooperation (DOMESTIC INNO COOPERATION) in particular are significantly and positively associated with product imitation (INNFIRM). Other innovation strategies, such as internal R&D (INTERNAL R&D) and international partnerships (i.e. INTERNATIONAL INNO COOPERATION and INTERNATIONAL EXTERNAL R&D), provide no significant signs for INNFIRM. Similarly, these innovation strategies are non-significant for INNMARKET (see Table XIV), which is somewhere between imitation and innovation. As the data analysis suggests, only INNO COOPERATION and DOMESTIC INNO COOPERATION are related significantly and positively to INNMARKET. Surprisingly, none of the external R&D variables (i.e. DOMESTIC EXTERNAL R&D and INTERNATIONAL EXTERNAL R&D) provides a significant sign for this type of innovation output.

Table XIII – Estimation results for innovation performance (INNFIRM)

	TOBIT MODEL					
	INNFIRM	INNFIRM	INNFIRM	INNFIRM	INNFIRM	INNFIRM
	1	2	3	4	5	6
INTERNAL R&D	-0.0001	0.0001	-0.0001	-0.0001	-0.0001	-0.0000
	(0.0001)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
DOMESTIC EXTERNAL R&D	**0.0039*****	**0.0038*****	**0.0045*****	**0.0044*****	**0.0057*****	**0.0039*****
	(0.0013)	(0.0014)	(0.0016)	(0.0014)	(0.0017)	(0.0013)
INTERNATIONAL EXTERNAL R&D	-0.0004	-0.0001	-0.0003	0.0001	-0.0001	-0.0009
	(0.0006)	(0.0005)	(0.0006)	(0.0008)	(0.0006)	(0.0010)
INNO COOPERATION	**0.0141*****		**0.0139*****	**0.0142*****	**0.0151*****	**0.0134*****
	(0.0044)		(0.0044)	(0.0044)	(0.0044)	(0.0046)
MEDIUM-SIZED FIRMS	0.0581	0.0778	0.0582	0.0588	0.0590	0.0586
	(0.0567)	(0.0573)	(0.0566)	(0.0566)	(0.0562)	(0.0565)
LARGE-SIZED FIRMS	**0.1123***	**0.1664*****	**0.1128***	**0.1150***	**0.1136***	**0.1110***
	(0.0616)	(0.0599)	(0.0615)	(0.0616)	(0.0611)	(0.0615)
MEDIUM-TECH INDUSTRY	0.0674	0.0796	0.0679	0.0674	0.0695	0.0677
	(0.0534)	(0.0542)	(0.0534)	(0.0534)	(0.0531)	(0.0533)
HIGH-TECH INDUSTRY	**0.1654*****	**0.1926*****	**0.1646*****	**0.1612****	**0.1615****	**0.1670*****
	(0.0627)	(0.0633)	(0.0626)	(0.0628)	(0.0623)	(0.0626)
DOMESTIC INNO COOPERATION		**0.0283***				
		(0.0151)				
INTERNATIONAL INNO COOPERATION		-0.0023				
		(0.0097)				
DOMESTIC EXTERNAL R&D*INTERNAL R&D			-0.0001			
			(0.0001)			
INTERNATIONAL EXTERNAL R&D* INTERNAL R&D				-0.0001		
				(0.0001)		
DOMESTIC EXTERNAL R&D*INNO COOP					**-0.0003***	
					(0.0002)	
INTERNATIONAL EXTERNAL R&D*INNO COOP						0.0000
						(0.0000)
INTERCEPT	-0.3413***	-0.3565***	-0.3425***	-0.3444***	-0.3463***	-0.3381***
	(0.0543)	(0.0560)	(0.0543)	(0.0544)	(0.0542)	(0.0543)
OBS.	491	491	491	491	491	491
PROB > CHI2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
PSEUDO R2	0.0969	0.0861	0.0975	0.0987	0.1024	0.0975

*Note: *, ** and *** denote significance at the 10%, 5% and 1% level, respectively; S.E. in parentheses.*

In contrast, the empirical analysis shows that when firms attempt to obtain breakthrough innovations (INNWOLRD), they invest more intensively in internal R&D and opt for international knowledge sourcing than others that try to imitate. In particular, the results indicate that INTERNAL R&D and INTERNATIONAL EXTERNAL R&D are significantly and positively correlated with INNWOLRD (see Table XV). The data analysis also shows that innovation cooperation in general and international innovation cooperation in particular are significant and positive for product innovation that is new to the world; domestic innovation cooperation provides a non-significant sign for INNWOLRD, whereas domestic external R&D is significantly and negatively related to this specific type of product innovation. As one can see from the empirical analysis, domestic knowledge sourcing is positively related to a low degree of product innovation (i.e. INNFIRM and INNMARKET), whereas internal R&D activities and international knowledge sourcing are positively associated with a high degree of product innovation (i.e. INNWORLD).

Table XIV– Estimation results for innovation performance (INNMARKET)

	TOBIT MODEL					
	INNMARKET	INNMARKET	INNMARKET	INNMARKET	INNMARKET	INNMARKET
	1	2	3	4	5	6
INTERNAL R&D	0.0003 (0.0002)	0.0003 (0.0002)	0.0003 (0.0002)	0.0003 (0.0002)	0.0003 (0.0002)	0.0003* (0.0002)
DOMESTIC EXTERNAL R&D	0.0015 (0.0015)	0.0012 (0.0015)	0.0021 (0.0018)	0.0019 (0.0016)	0.0019 (0.0019)	0.0020 (0.0015)
INTERNATIONAL EXTERNAL R&D	-0.0012 (0.0007)	-0.0008 (0.0007)	-0.0009 (0.0008)	-0.0005 (0.0011)	-0.0010 (0.0008)	0.0007 (0.0011)
INNO COOPERATION	**0.0113**** (0.0048)		**0.0110**** (0.0048)	**0.0112**** (0.0048)	**0.0115**** (0.0049)	**0.0141***** (0.0051)
MEDIUM-SIZED FIRMS	0.0785 (0.0624)	0.0557 (0.0625)	0.0783 (0.0624)	0.0786 (0.0624)	0.0785 (0.0624)	0.0788 (0.0622)
LARGE-SIZED FIRMS	0.1021 (0.0683)	0.1050 (0.0645)	0.1029 (0.0683)	0.1042 (0.0683)	0.1024 (0.0683)	0.1037 (0.0681)
MEDIUM-TECH INDUSTRY	**0.1082*** (0.0596)	0.0950 (0.0591)	**0.1091*** (0.0596)	**0.1085*** (0.0596)	**0.1089*** (0.0597)	**0.1065*** (0.0595)
HIGH-TECH INDUSTRY	0.1108 (0.0704)	0.1044 (0.0695)	0.1100 (0.0705)	0.1075 (0.0706)	0.1104 (0.0705)	0.1029 (0.0704)
DOMESTIC INNO COOPERATION		**0.0549***** (0.0159)				
INTERNATIONAL INNO COOPERATION		-0.0020 (0.0101)				
DOMESTIC EXTERNAL R&D*INTERNAL R&D			-0.0001 (0.0001)			
INTERNATIONAL EXTERNAL R&D* INTERNAL R&D				-0.0001 (0.0001)		
DOMESTIC EXTERNAL R&D*INNO COOP					-0.0001 (0.0002)	
INTERNATIONAL EXTERNAL R&D*INNO COOP						**-0.0001*** (0.0000)
INTERCEPT	-0.4472*** (0.0652)	-0.4525*** (0.0651)	-0.4489*** (0.0654)	-0.4495*** (0.0654)	-0.4487*** (0.0655)	-0.4569*** (0.0658)
OBS.	491	491	491	491	491	491
PROB > CHI2	0.0007	0.0000	0.0012	0.0012	0.0013	0.0003
PSEUDO R2	0.0634	0.0941	0.0641	0.0645	0.0636	0.0726

*Note: *, ** and *** denote significance at the 10%, 5% and 1% level, respectively; S.E. in parentheses.*

The results obtained from the performance analysis are in line with our H2a hypothesis, in which we suggest that those firms acquiring international, rather than domestic, external R&D are more likely to introduce product innovation with a higher degree of novelty. This might be related to the fact that international partnerships may allow firms to work with world-class suppliers and to access resources that are unavailable within the domestic market. As a consequence, companies sourcing knowledge from international markets perform better in product innovation than their counterparts that rely only on domestic resources.

Regarding the complementarity between the innovation strategies, the data analysis provides contradictory results. More specifically, while the adoption analysis identifies an additive relationship between INTERNATIONAL EXTERNAL R&D and INTERNAL R&D as well as between INTERNATIONAL EXTERNAL R&D and INNO COOPERATION, the performance analysis suggests that combining these innovation strategies relates negatively to product innovation; the interaction terms between INTERNATIONAL EXTERNAL R&D and INTERNAL R&D as well as between INTERNATIONAL EXTERNAL R&D and INNO COOPERATION are significantly and negatively associated with INNWORLD (see Table XV), but the coefficients of these interaction terms are very low. The latter interaction term (INTERNATIONAL EXTERNAL R&D*INNO COOPERATION) also has negative signs for INNMARKET. In addition, pursuing simultaneously DOMESTIC EXTERNAL R&D and INNO COOPERATION strategies is negatively related to INNFIRM and INNWORLD. Hence, the relevant significant coefficients are all negative, which indicates no complementarity between the innovation strategies.[14] This might be linked to the fact that a high degree of openness in innovation may cause the absorptive capacity problem. In other words, to integrate external knowledge into the internal R&D, a common interface has to be established that requires absorptive capacity to identify and transform external knowledge for internal purposes (Cohen and Levinthal, 1990). As firms engage in different forms of R&D openness, they may lack adequate internal expertise to manage external partnerships effectively. Moreover, when there are many ideas for a firm to choose between, only a few of them will be given the required level of attention and effort to be implemented (Koput, 1997; Katila and Ahuja, 2002). For these

[14] The interaction terms between other innovation strategies (i.e. internal R&D*international innovation cooperation, internal R&D*domestic innovation cooperation, domestic external R&D*international innovation cooperation, domestic external R&D*domestic innovation cooperation, international external R&D*international innovation cooperation, international external R&D*domestic innovation cooperation) provide non-significant signs in the performance analysis. Therefore, we do not present the results in Tables XIII, XIV and XV.

reasons, a high degree of R&D openness is expected to have negative effects on firms' innovation performance (Laursen and Salter, 2006).

Table XV– Estimation results for innovation performance (INNWORLD)

	TOBIT MODEL					
	INNWORLD	INNWORLD	INNWORLD	INNWORLD	INNWORLD	INNWORLD
	1	2	3	4	5	6
INTERNAL R&D	**0.0009*****	**0.0009*****	**0.0010*****	**0.0010*****	**0.0009*****	**0.0010*****
	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
DOMESTIC EXTERNAL R&D	**-0.0070****	**-0.0065****	0.0008	-0.0032	0.0027	**-0.0052***
	(0.0031)	(0.0031)	(0.0033)	(0.0034)	(0.0029)	(0.0031)
INTERNATIONAL EXTERNAL R&D	**0.0016*****	**0.0018*****	**0.0018*****	**0.0027*****	**0.0020*****	**0.0034*****
	(0.0006)	(0.0005)	(0.0006)	(0.0007)	(0.0006)	(0.0008)
INNO COOPERATION	**0.0136****		**0.0124****	**0.0150*****	**0.0198*****	**0.0196*****
	(0.0055)		(0.0055)	(0.0056)	(0.0064)	(0.0059)
MEDIUM-SIZED FIRMS	0.0509	0.0474	0.0555	0.0558	0.0582	0.0464
	(0.0784)	(0.0783)	(0.0778)	(0.0779)	(0.0769)	(0.0773)
LARGE-SIZED FIRMS	0.0997	0.1185	0.1092	0.1065	0.0998	0.1018
	(0.0837)	(0.0789)	(0.0830)	(0.0832)	(0.0823)	(0.0820)
MEDIUM-TECH INDUSTRY	**0.3082*****	**0.3178*****	**0.3057*****	**0.3053*****	**0.3097*****	**0.3036*****
	(0.0876)	(0.0884)	(0.0870)	(0.0872)	(0.0869)	(0.0868)
HIGH-TECH INDUSTRY	**0.2552*****	**0.2547*****	**0.2447****	**0.2361****	**0.2393****	**0.2371****
	(0.0965)	(0.0974)	(0.0959)	(0.0962)	(0.0954)	(0.0954)
DOMESTIC INNO COOPERATION		0.0155				
		(0.0199)				
INTERNATIONAL INNO COOPERATION		**0.0193***				
		(0.0115)				
DOMESTIC EXTERNAL R&D*INTERNAL R&D			-0.0001			
			(0.0001)			
INTERNATIONAL EXTERNAL R&D* INTERNAL R&D				**-0.0003****		
				(0.0001)		
DOMESTIC EXTERNAL R&D*INNO COOP					**-0.0015****	
					(0.0006)	
INTERNATIONAL EXTERNAL R&D*INNO COOP						**-0.0001*****
						(0.0000)
INTERCEPT	-0.7752***	-0.7820***	-0.7783***	-0.7855***	-0.7896***	-0.7872***
	(0.1056)	(0.1073)	(0.1055)	(0.1061)	(0.1062)	(0.1059)
OBS.	491	491	491	491	491	491
PROB > CHI2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
PSEUDO R2	0.2085	0.2162	0.2192	0.2233	0.2339	0.2358

*Note: *, ** and *** denote significance at the 10%, 5% and 1% level, respectively; S.E. in parentheses.*

Furthermore, the data analysis indicates that firm size is slightly significant and positive for INNFIRM, but it shows a non-significant relationship with INNMARKET and INNWORLD. This result is in line with other studies suggesting that firm size does not matter for a substantial product innovation (Laursen and Salter, 2006; Grimpe and Kaiser, 2010). Regarding the industry dummies, MEDIUM-TECH INDUSTRY is significantly and positively associated with INNMARKET, whereas HIGH-TECH INDUSTRY is significantly and positively related to

INNFIRM. Both of the industry groups show a significant positive correlation with INNWORLD. In agreement with prior research, the estimation results suggest that firms operating in low-technology manufacturing industries lag behind companies belonging to medium- and high-technology manufacturing industries in terms of product innovation performance (Kirner et al., 2009).

3.6 Conclusion

The paper contributes to the current debate on complementarities between different types of innovation strategies. Rather than using standard yes or no answers to identify the use of such instruments, the paper uses the amount of money invested in those activities. This allows us to study the inter-relationship between external R&D, internal R&D, innovation cooperation and product innovation in more detail. Our data also allow us to differentiate external R&D based on a geographical location, that is, whether it comes from domestic or international marketplaces.

To study the complementary relationship between the innovation strategies, we present a two-step approach: adoption and performance. In the adoption approach, first, we conduct a regression analysis for each of the innovation activities. After that, we extract the residuals from each of the regressions and check the correlations between them. In the performance approach, we use the interaction term to check the complementary relationship between the innovation strategies. The two-step analysis suggests that those firms acquiring international external R&D simultaneously invest in internal R&D as well as engaging in a high number of innovation cooperation partnerships, but the joint representation of these instruments shows a significant negative relationship with product innovation. This might be due to the fact that engaging in different forms of R&D openness may cause the over-searching problem and, hence, deteriorate firms' product innovation performance. Furthermore, no significant complementary or substitutive relationship is found between domestic external R&D and internal R&D as well as between domestic external R&D and innovation cooperation. Regarding the relationship between external R&D and product innovation, we find that firms acquiring international, rather than domestic, external R&D are more likely to generate product innovation with a higher degree of novelty, because sourcing knowledge from international marketplaces allows companies to tap into the global knowledge pool and, as a result, to improve their innovation performance.

While the paper contributes to the current literature on complementarities between different innovation activities and their links with product novelty, it also has several limitations. First of all, our dataset is cross-sectional and does not allow us to examine changes in variables over time. Moreover, for future research, it is vital for the inter-relationship between external R&D and product innovation to be studied more concretely. In particular, one should examine whether external R&D comes from research institutions, competitors, suppliers or consulting companies.

4 The innovative performance of R&D outsourcing

4.1 Introduction

Nowadays, firms are under great pressure to reduce the costs of their R&D activities and to speed up their new technology and product development to respond efficiently and effectively to the increased global competition, the fast pace of technological changes and shortened product life cycles (Chesbrough, 2003; Chesbrough et al., 2006; Holcomb and Hitt, 2007; Keupp and Gassmann, 2009). All these requirements lead firms to specialize in a limited number of key areas and to outsource rather peripheral R&D activities to independent research organizations (Quinn, 1999, 2000). R&D outsourcing, which implies the acquisition of knowledge-based resources from external actors via contracts, enables companies to concentrate on the narrow sets of research functions that they can perform best and to use the R&D services of specialized research organizations for the activities in which they lack high-class expertise. Consequently, R&D outsourcing may allow firms to acquire high-quality knowledge inputs from specialized research organizations and to share the costs and risks of R&D projects with them (Mowery, 1983; Dess et al., 1995; Gilley and Rasheed, 2000). Furthermore, by distributing R&D tasks among different external actors, firms shift their R&D activities from serial to synchronous actions so that these activities are implemented independently and simultaneously, resulting in an increased speed of R&D processes (Howells et al., 2003; Langlois, 2003; Ebrahim et al., 2009).

However, R&D outsourcing also has its drawbacks. First, distributing R&D activities among external providers may induce a firm to specialize in combining externally available technologies rather than to develop its own (West et al., 2006). For instance, Prencipe et al. (2003) suggest that nowadays large companies organize whole projects, but develop only a small part of the sub-technologies internally. In this sense, those firms that increasingly outsource their R&D activities may shift their knowledge creation capabilities to supplier organizations (Bettis et al., 1992; Gilley and Rasheed, 2000; West et al., 2006). As a result, R&D outsourcing may deplete a client firm's research competencies and deteriorate its R&D performance (Bettis et al., 1992). The second issue is that the knowledge-based resources acquired from external actors via contracts may not be unique, because competitors may have access to the expertise of the same supplier

(Grimpe and Kaiser, 2010). In other words, knowledge may unintentionally spillover from a supplier to multiple clients firms while working with them. Moreover, the effective utilization of external knowledge sourced through R&D outsourcing requires substantial expertise from the client firm (Cohen and Levinthal, 1990). As R&D outsourcing may replace learning-by-doing activities in internal R&D and, hence, deteriorate a client firm's integrative competencies, this strategy may hamper the overall innovative performance of the firm (Bettis et al., 1992; Weigelt, 2009). Given these mixed potential value-creating outcomes of R&D outsourcing, the question arises of whether those firms that outsource R&D tasks generate a higher-quality research output from their R&D processes than their counterparts that do not invest in this strategy.

Motivated by this question, a number of studies examine the relationship between R&D outsourcing and R&D output, in which the quality of the R&D output is most commonly measured as sales from product innovations (Grimpe and Kaiser, 2010; Berchicci, 2013) and patent counts (Beneito, 2006). These papers contribute significantly to our understanding of the performance implication of R&D outsourcing, but the indicators of R&D output (e.g. sales from product innovation, patent counts) used in the studies may not reflect the overall quality of outsourcer firms' research processes. For example, a product innovation might be a result of combining externally available knowledge inputs, and it may not be a good indicator of the quality of the internal research process. In other words, the knowledge and production boundaries of a firm may differ (Brusoni et al., 2001). An alternative measure of R&D output, such as patent counts, shows firms' property rights upon their inventions, but patents may vary significantly in terms of their quality and innovative contents (Griliches, 1990). Therefore, further research is required to understand *how R&D outsourcing is associated with the quality of a firm's research process*.

To study this issue, I analyse the data obtained from the Mannheim Innovation Panel (MIP) and the European Patent Office (EPO). The former provides detailed information about the innovation activities of German firms (e.g. expenditures on internal and outsourced R&D, innovation impediments, product and process innovation, R&D cooperation partners, etc.), whereas the latter provides data about the patents applied for by German firms at the EPO. To capture the value of firms' R&D effort, I use the average forward citations that firms' patents obtain in subsequent time periods weighted by their patent counts to measure the quality of the firms' inventive activities (Trajtenberg, 1990). In other words, to evaluate the value of a firm's inventive activities, I check how many times its inventions (patents) are cited by subsequent patents of other firms to account for the effect of the firm's research output on subsequent technological development (Trajtenberg, 1990). Accordingly, I take the average forward patent citations as a dependent variable in the econometric analysis. The second dependent variable used in the analysis is patent counts, which are used to evaluate the relationship between R&D outsourcing and invention quantity.

Looking at the econometric analysis, the results show that R&D outsourcing is significantly and positively associated with invention quantity. As inter- rather than intra-firm knowledge-based resources are more likely to vary, those companies acquiring R&D from an external provider may have more chance of accessing diverse knowledge inputs and, as a result, performing better in invention activities than their counterparts that experiment only with internal knowledge. In other words, this strategy may help firms to access complementary knowledge inputs and, in this way, to improve their invention performance. However, this positive performance implication of R&D outsourcing does not appear to hold for invention quality. Furthermore, the empirical analysis indicates that the intensity of R&D outsourcing is significantly related neither to invention quantity nor to invention quality.

The rest of this chapter is organized in the following way. Section 4.2 discusses the theoretical arguments for the hypotheses' development. Section 4.3 reviews the database and variables used in the econometric analysis. Section 4.4 presents the econometric methods. After that, Section 4.5 provides the estimation results and Section 4.6 concludes.

4.2 Theoretical framework

In this section, the relationship between R&D outsourcing and the inventive performance of a firm is examined. R&D outsourcing is considered to be an important instrument for acquiring the necessary resources from external actors, reducing the costs and risks of R&D projects and accelerating new technology and product development (Quinn, 1999, 2000; Howells et al., 2003;

Calantone and Stanko, 2007; Howells et al., 2008). However, this strategy may also involve considerable risks in terms of declining internal R&D activities, depleting firms' research or knowledge-creation competencies and, as a result, deteriorating the overall performance of their R&D processes (Bettis et al., 1992; Kotabe, 1992; Weigelt, 2009). To understand the conditions under which firms experience 'gain' or 'pain' from R&D outsourcing, I use insights from transaction cost theory (TCT) and the resource-based view (RBV) of the firm. The two theories attempt to explain the boundaries of the firm, but from different perspectives. While TCT is considered to be a cost-based approach, the RBV of the firm is seen as a resource-oriented framework.

Transaction cost theory

From the TCT perspective, an outsourcing decision is considered to be an economically optimal choice if it is cheaper to buy certain goods or services in a market than to make them within a firm (Williamson, 1975, 1985). TCT assumes the dominance of the market mechanism over the hierarchical organization or internal governance mode, because the market competition among outside suppliers forces them to eliminate inefficient practices and, hence, to reduce their prices; the same level of competition is less likely to occur between the business units of a firm (Vining and Globerman, 1999; Geyskens et al., 2006; Mudambi and Tallman, 2010). However, a market governance mode may also increase the transaction costs when the goods or services that a firm aims to acquire from independent contractors are characterized by high levels of asset specificity (Williamson, 1975, 1985; Geyskens et al., 2006; Mudambi and Tallman, 2010). Resources with a high degree of asset specificity are designed to serve a single purpose or transaction and may not have an alternative function. Acquiring such resources from external entities may cause dependency of one party on another and give rise to a 'hold-up' problem (Ulset, 1996; Vining and Globerman, 1999). The term 'hold-up problem' refers to the situation in which one party makes a transaction-specific investment and another transacting partner has the opportunity to take advantage of that commitment in terms of maximizing its value and reducing the rents of the former party (Vining and Globerman, 1999). For instance, when a client firms builds up its production line so that it depends on specific resources acquired from a particular supplier, the latter may have the opportunity to increase the prices of the resources unscrupulously and maximize its profit, because the transaction-specific investment has already been made by the client firm. To safeguard against such a situation in transactions, a well-negotiated or complete contract is required. However, given that firm managers have bounded rationality and limited cognitive abilities (Simon, 1957), they may face difficulties in considering all the possible contingencies and specifying all the contract terms precisely to avoid opportunism or unscrupulously behaviour from their transaction partners (Vining and Globerman, 1999; Calantone and Stanko, 2007). As highly specific assets are also considered to be firm-specific, the quality of such resources may not be readily observable and measurable by an external actor. Accordingly, acquiring resources with high levels of asset specificity may increase the transaction costs in terms of negotiating for contractual terms and then monitoring and enforcing the contract performance. As a result, the market mechanism may become inefficient herein. Hence, a degree of asset specificity determines whether economic activities are internalized or outsourced.

R&D activities are frequently characterized by high levels of asset specificity, because they are partially tacit in nature and firm-specific. Tacit knowledge, which refers to know-how and skills, is accumulated over time through learning by doing, and it is embodied in individuals and organizational routines (Nelson and Winter, 1982). As the quality of such knowledge is not readily measurable, it can be difficult to evaluate a contractor's expertise and the effort it will devote to a task (Pisano, 1990). Moreover, transferring tacit knowledge across organizations requires intensive interaction between firms that may increase the transaction costs. Therefore, R&D tasks that are specialized and firm-specific in character should be organized internally and those activities that are generic in nature should be outsourced. However, as the primary purpose of R&D activities is to enhance organizational learning and generate valuable resources, a cost-based analysis may not be enough to explain completely the make-or-buy decision in R&D activities (Foss and Klein, 2010). In other words, a strategic or resource-oriented analysis is also required to identify an appropriate governance mode for certain innovation activities.

The resource-based view of the firm

The RBV of the firm takes up this issue by examining the role of internal and external governance modes in generating superior resources (Barney, 1991; Peteraf, 1993; Grimp and Kaiser, 2010; Mudambi and Tallman, 2010). According to this theory, resources with valuable, rare, inimitable and non-substitutable (VRIN) attributes determine the competitive advantage of a firm (Barney, 1991). These attributes of resources allow companies to pursue a value-creating strategy, to serve the market requirements better and, as a result, to outperform their competitors (Barney, 1991; Peteraf, 1993; Wang et al., 2009; Grimp and Kaiser, 2010). To sustain a competitive advantage on a long-term basis, the firm's resources should be valuable and rare as well as having inimitable and non-substitutable features, because rivals should not be able to replicate the firm's competitive assets or to attain a similar performance based on other resources. For this reason, firms often use an isolating mechanism to protect valuable and rare resources from imitation (Rumelt, 1984). One of the most powerful isolating mechanisms is considered to be the firm specificity of resources (Wang et al., 2009; Grimp and Kaiser, 2010), because such resources are not easily tradable across organization boundaries and they may also have less applicability outside the firm (Peteraf, 1993). Therefore, strategically important economic activities should be carried out internally to develop valuable and rare resources and to protect these resources from imitation. In this sense, R&D activities that determine the competitive advantage of a firm should be organized in-house and relatively peripheral knowledge-based activities should be contracted out to specialized R&D suppliers. By doing so, firms can devote their financial and human resources to the narrow sets of core activities that they can perform best and use an R&D service of an independent research organization for activities in which they have little or no expertise (Quinn, 1999, 2000; Calantone and Stanko, 2007; Howells et al., 2008; McIvor, 2008). Given that a technological development is a complex process and it often involves different scientific areas, most companies lack adequate internal resources to be able to afford to carry out entire R&D processes internally (Chesbrough, 2003; Keupp and Gassmann, 2009). In this context, R&D outsourcing may serve a complementary purpose, helping firms to acquire resources that are unavailable internally. In fact, prior studies find that the marginal returns of internal R&D activities increase if a firm simultaneously outsources some parts of its R&D activities to specialized research organizations (Cassiman and Veugelers, 2006; Lokshin et al., 2008).

The performance implication of R&D outsourcing

Several potential benefits can be realized as a result of R&D outsourcing. First, firms may reduce the costs of R&D projects through outsourcing rather peripheral knowledge-based activities to a cost-efficient specialized supplier. As the supplier may offer economies of scale by spreading the production costs over more units of output and selling products to multiple client firms, it might be cheaper for firms to use the services of specialized R&D suppliers for their peripheral R&D activities than to perform the same activities internally. Second, R&D outsourcing can help firms to spread the risks of R&D projects over independent research organizations (Quinn, 1992). In other words, it might be less risky to acquire certain technological knowledge from these organizations than to develop a new technology in areas in which the firm has little or no expertise. Third, the division of R&D tasks among firms enables them to shift their innovation activities from serial to parallel working processes and, hence, to accelerate new product and technology development (Howells et al., 2003; Ebrahim et al., 2009). Moreover, this strategy may allow firms to improve the quality of their R&D activities through outsourcing rather peripheral R&D tasks to a specialized R&D organization to which these are key activities (Mudambi and Tallman, 2010). Accordingly, the specialized R&D organization may possess superior knowledge-based resources as well as a more appropriate research infrastructure and, therefore, it may carry out these R&D tasks better than they can be implemented by the client firm (Quinn, 1992; Gilley and Rasheed, 2000). R&D outsourcing may also promote creativity within internal research activities, because new knowledge is brought in from an external actor. Evolutionary economists suggest that conducting R&D close to prior knowledge or specialized areas reduces the likelihood of errors and makes searches more reliable, but it may have a negative effect on the R&D output through decreasing intensity of new idea production (Cyert and March, 1963; Levinthal and March, 1982; Nelson and Winter, 1982; Dosi, 1988; Pisano, 1990). As innovation is considered to be a new combination of existing knowledge, firms may increase the opportunities for knowledge recombination and, hence, for innovation when they access resources that are unavailable internally. Since knowledge heterogeneity is more likely to be found between firms rather than within a firm, R&D outsourcing may help firms to enrich their internal stock of knowledge and to improve the quality and intensity of their R&D activities. Although knowledge-based resources sourced from R&D suppliers may not be unique and they might also be accessible by competitors, these external resources may enable firms to pursue a unique combination of external and internal knowledge, resulting in firm-specific resources (Grimp and Kaiser, 2010). Based on the above-developed arguments, I expect a positive relationship between R&D outsourcing and the invention performance of a firm. Hence, the following hypothesis is proposed:

H1: R&D outsourcing is positively associated with invention quantity as well as quality.

The drawbacks of R&D outsourcing

Although a firm obtains a number of benefits from outsourcing its R&D activities to specialized research organizations, a large scale of R&D outsourcing may deteriorate the overall invention performance of the firm for several reasons. First, this R&D strategy may reduce the internal learning-by-doing and problem-solving activities (Bettis et al., 1992; Weigelt, 2009; Grimpe and Kaiser, 2010), which are considered to be the primary source of new skills and know-how. In this sense, R&D outsourcing may deplete a firm's research capabilities and shift knowledge creation competencies from the firm to an R&D supplier (Bettis et al., 1992). The second issue is that a company may not be able to internalize the tacit knowledge component of outsourced R&D activities via arm's length transactions, because transferring such knowledge across organizational boundaries requires intensive interaction between transaction partners, which is not implied in the R&D outsourcing strategy. Accordingly, large-scale R&D outsourcing may hollow out tacit knowledge applications in internal R&D and limit the firm's insights into codified knowledge components of innovation activities (Weigelt, 2009). Given that codified knowledge is relatively easy to imitate, relying greatly on R&D suppliers in innovation activities undermines the competitive advantages of a client firm. Moreover, as the knowledge-based resources acquired from an external supplier may not be unique (Grimpe and Kaiser, 2010), large-scale R&D outsourcing may deplete a firm's ability to develop valuable and rare resources. Based on the above-developed arguments, I expect a negative relationship between large-scale R&D outsourcing and the invention performance of the firm. Thus, I propose the following hypothesis:

H2: Large-scale R&D outsourcing is negatively associated with invention quantity as well as quality.

4.3 Data description
4.3.1 Sample

The dataset used in this study comes from the Mannheim Innovation Panel (MIP)[15] database. The MIP, which is the German part of the Community Innovation Survey, has been collected annually since 1993 by the Centre for European Economic Research (ZEW). The target population of the MIP is German innovative firms with at least five employees. The survey gathers detailed information on the innovation activities of the firms, such as the type of innovation partner, expenditures on internal and outsourced R&D, product and process innovation, etc. This dataset is supplemented by patent data obtained from the European Patent Office (EPO) to study the relationship between R&D outsourcing and invention performance. The EPO provides information about the patents applied for by German firms at the EPO from 1978 until the end of the data (2011). In particular, I obtain information about the number of patents that German firms applied for at the EPO and the number of forward citations that these patents obtained in subsequent time periods. To have enough time windows to count the patent forward citations, which are used to measure the quality of a patent, the empirical analysis covers two waves (1997, 2001) of the MIP. In other words, two-year cross-sectional data are used in the analysis obtained from the 1997 and 2001 surveys of the MIP. I also restrict the sample to manufacturing firms and, as a result, I obtain 1568 observations and 784 firms that are each observed twice.

4.3.2 Dependent variables

Two types of dependent variables are considered in the empirical analysis. The first one (INV_N) is the number of patents filed by firm *i* in period *t+3*. Stated differently, INV_N refers to the number of patents that firms are granted in the periods 1998–2000 and 2002–2004, respectively to the 1997 and 2001 surveys. Given that patents vary significantly in terms of their quality and innovative contents (Narin and Olivastro, 1988; Griliches, 1990; Trajtenberg, 1990), as the second dependent variable, I use the average forward citations that the patents obtain in subsequent seven-year windows after the filing year, and this variable is expressed as INV_Q.

[15] The paper acknowledges access to the Mannheim Innovation Panel and patent databases from the Centre for European Economic Research (ZEW).

4.3.3 Explanatory variables

An explanatory variable used in the econometric analysis is EXT_R&D, which is a binary variable and indicates whether a firm outsources R&D activities to specialized research organizations. In addition to the standard yes or no answers to identify the use of this R&D strategy, I consider the ratio of expenditures on R&D outsourcing over the firm's sales as an indicator of R&D outsourcing intensity (EXT_R&D_INTENSITY). The expenditures on R&D outsourcing are scaled by the firm's sales to avoid the firm size effect on R&D spending (Grimpe and Kaiser, 2010).

Table XVI– Descriptive statistics

Variable names	Variable definition	Obs.	Mean	Std dev.	Min.	Max.
INV_N	Patent counts in the periods 1998–2000 and 2002–2004, respectively to the 1997 and 2001 surveys	1568	1.067	5.852	0	84
INV_Q	The average forward citations that the firm's patents obtain in subsequent seven-years windows after the filing year	1568	0.103	0.497	0	10
EXT_R&D	Binary: 1 if a firm outsources R&D activities	1568	0.312	0.463	0	1
EXT_R&D_INTENSITY	The expenditures for R&D outsourcing divided by the firm's sales	1568	0.001	0.003	0	0.075
INT_R&D	Binary: 1 if a firm invests in internal R&D	1568	0.4536	0.498	0	1
INT_R&D_INTENSITY	The expenditures for internal R&D divided by the firm's sales	1568	0.005	0.019	0	0.2291
R&D_COOP	Binary: 1 if a firm has R&D cooperation with an external actor	1568	0.192	0.394	0	1
R&D_INTENSITY	The expenditures for entire R&D divided by the firm's sales	1568	0.016	0.038	0	0.5580
EXPORT_INTENSITY	The share of sales from exports	1568	0.174	0.226	0	0.9333
LOCATION_EAST	Binary: 1 if a firm is located in East Germany	1568	0.328	0.469	0	1
PRE_INV_N	Pre-sample patents in the period 1989–1993	1568	1.187	10.836	0	264
PRE_INV_Q	Average forward patent citations obtained for the pre-sample patents in the seven years after the filing year	1568	0.174	0.731	0	8
LOG_SIZE	Firm employees in logarithmic values	1568	5.398	1.559	1.609	12.213
MEDIUM-LOW-TECH INDUSTRY	Industry dummy: 1 if a firm belongs to the medium-low-tech industry	1568	0.324	0.468	0	1
MEDIUM-HIGH-TECH INDUSTRY	Industry dummy: 1 if a firm belongs to the medium-high-tech industry	1568	0.288	0.453	0	1
HIGH-TECH INDUSTRY	Industry dummy: 1 if a firm belongs to the high-tech industry	1568	0.166	0.372	0	1

4.3.4 Control variables

I consider several control variables that might be relevant in the econometric model for invention performance. First, I control whether a firm conducts R&D activities internally. For this purpose, I use a binary variable to identify whether a firm invests in R&D undertaken inside its laboratory establishment (INT_R&D), and I also control the internal R&D intensity calculated as the expenditures on internal R&D divided by the firm's sales (INT_R&D_INTENSITY). A number of previous studies consider internal R&D as a key source for leveraging firm learning processes and developing firm-specific competencies (Cohen and Levinthal, 1989, 1990). Internal R&D is also considered to be a requirement for the effective utilization of knowledge acquired from external actors (Cohen and Levinthal, 1990; Cassiman and Veugelers, 2006). Based on these arguments, there should be a positive relationship between internal R&D and invention performance. Second, I account for whether a firm has formal R&D cooperation with an external actor; the variable has a binary outcome and it is expressed as R&D_COOP. Cooperation in R&D is seen as an important instrument to acquire skills and specialized know-how from external entities, to minimize the costs and risks of R&D projects and, as a result, to improve the performance of R&D activities (Hagedoorn, 1993; Powell et al., 1996).

Moreover, I include the size of the entire R&D activities of the firm measured as the ratio of expenditures on the entire R&D over the firm's sales (R&D_INTENSITY). In line with prior research (Bound et al., 1984; Pakes and Griliches, 1984; Jensen, 1987; Cardinal and Hatfield, 2000; Ahuja and Katila, 2001), I expect a positive relationship between the size of R&D spending and the invention performance.

In addition, I introduce the variable export intensity (EXPORT_INTENSITY), which is calculated as the share of sales from exports, to control for the international competition that firms face (Cassiman and Veugelers, 2006; Grimpe and Kaiser, 2010). In the econometric analysis, I also control for firm location, specifically whether it is in East or West Germany (LOCATION_EAST). Given that there are regional differences between East and West Germany with regard to the infrastructure and economic growth, firms located in East Germany might be lagging behind those located in West Germany in terms of invention performance (Grimpe and Kaiser, 2010).

Furthermore, I account for firms' prior accumulated knowledge in the econometric analysis. It can be expected that those firms that accumulated a high stock of knowledge in time *t-1* are more likely to be innovative in period *t*. In other words, there can be pass dependency in invention activities (Nelson and Winter, 1982; Cyert and March, 1992). Therefore, I introduce the PRE_INV_N and PRE_INV_Q variables into the regression models to control for pass dependency in the invention performance. PRE_INV_N refers to the pre-sample patent counts in the five-year period. Given that the sample includes the 1997 and 2001 surveys and each survey contains information about the innovation activities of the firms during the past three years (for instance, the 1997 survey provides information about the firms' innovation activities in the period 1994–1996), PRE_INV_N represents patent counts in the period 1989–1993. To account for the quality of these pre-sample patents, I take the average number of forward citations per patent in seven-year windows after a patent was filed (PRE_INV_Q). In the econometric models, the variables PRE_INV_N and PRE_INV_Q are introduced in logarithmic values. Given that some firms do not have any patent or forward patent citations, the logarithmic transformation of these variables results in missing values. To deal with this issue, I set the value to zero for the missing values (LOG (PRE_INV_N) = 0 if PRE_INV_N = 0) and introduce an additional dummy variable (zero for patent values and one for non-patent values; the same applies to average forward patent citations) (Beneito, 2006; Grimp and Kaiser, 2010).

Table XVII– Industry breakdown

Technology class	Classification of manufacturing industry	NACE
Low-technology manufacturing industries	Food and beverages, tobacco Textiles, leather, footwear Wood, paper, paper products Furniture	15, 16 17–19 20, 21 22
Medium-low-technology manufacturing industries	Non-metallic mineral products Metal products	26 27, 28
Medium-high-technology manufacturing industries	Rubber and plastic products Machinery and equipment Motor vehicles, aircraft and spacecraft	25 29 34, 35
High-technology manufacturing industries	Coke, refined petroleum, chemical industry Electrical apparatus, computing machines, communication equipment, Medical, precision and optical instruments	23, 24 30–32 33

Industries are classified according to the OECD (2003) manual. Manufacturing sectors related to natural resources such as mining and construction are excluded.

Moreover, to account for firm unobserved characteristics (Cohen, 1995) and inter-industry differences in terms of investing in invention activities (Malerba, 2005), firm size and industry dummy variables are introduced into the econometric models. Firm size is measured as the number of employees transformed into logarithmic values (LOG_SIZE). With regard to the industry dummy variable, four industry groups are introduced (based on the OECD industry classification): low-technology manufacturing industries, medium-low-technology manufacturing industries, medium-high-technology manufacturing industries and high-technology manufacturing industries (see Table XVII). The low-technology manufacturing industry is taken as a benchmark variable.

4.4 Econometric methods

As the first dependent variable (INV_N) used in the empirical analysis has non-negative count outcomes (denoted by y, y ={0,1,2,….}), I use count data methods to analyse the sample. The starting point of count data analysis is a Poisson model (Cameron and Trivedi, 2005, 2009), which gives me the possibility to estimate a dependent variable with non-negative integers. The Poisson model is considered to be an appropriate econometric method for count data when the variance and the mean of the dependent variable have equal values (referred to as an equal-dispersion property), which is often violated in an applied work due to the over-dispersion problem (Cameron and Trivedi, 2009). The standard method to cope with the over-dispersion problem is to use a negative binomial model, which preserves the mean and increases the variance.

Another problem may also arise in count data analysis, such as a high number of zeros in the dependent variable. In my case, zeros may arise from different data-generation processes when a firm does not invest in R&D/invention activities and when a firm invests in R&D but achieves no invention results. These two responses have quite different meanings, because firms with no invention activities can only have a zero count. To cope with this issue, I use a hurdle method, which is a two-part model. In the first part, a logit regression is used to estimate the zero-versus-positive outcome (Cameron and Trivedi, 2009). In the second part, the Poisson or negative binomial model is employed to model the non-negative positive counts without zero values.

Table XVIII – Correlation table

	Variable names	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	INV_N	1.000															
2	INV_Q	0.308***	1.000														
3	EXT_R&D	0.174***	0.171***	1.000													
4	EXT_R&D_INTENSITY	0.052**	0.054**	0.301***	1.000												
5	INT_R&D	0.119***	0.168***	0.359***	0.153***	1.000											
6	INT_R&D_INTENSITY	0.098**	0.082***	0.137***	0.252***	0.341***	1.000										
7	R&D_COOP	0.198***	0.121***	0.351***	0.181***	0.411***	0.166***	1.000									
8	R&D_INTENSITY	0.051**	0.049**	0.126***	0.299***	0.293***	0.639***	0.189***	1.000								
9	EXPORT_INTENSITY	0.177***	0.136***	0.198***	0.072***	0.261***	0.119***	0.208***	0.075***	1.000							
10	LOCATION_EAST	-0.102***	-0.099***	-0.089***	0.029	-0.041	0.039	-0.003	0.104***	-0.242***	1.000						
11	PRE_INV_N	0.179***	0.159***	0.109***	0.002	0.101***	0.145***	0.083***	0.121***	0.074***	-0.068***	1.000					
12	PRE_INV_Q	0.266***	0.210***	0.111***	-0.006	0.121***	0.049**	0.075***	0.042*	0.239***	-0.127***	0.251***	1.000				
13	LOG_SIZE	0.281***	0.207***	0.276***	0.063**	0.326***	0.023	0.291***	0.022	0.401***	-0.241***	0.213***	0.261***	1.000			
14	MEDIUM-LOW-TECH INDUSTRY	-0.063**	-0.065***	-0.077***	-0.052**	-0.094***	-0.111***	-0.081***	-0.064**	-0.123***	0.061**	-0.038	-0.021	-0.062**	1.000		
15	MEDIUM-HIGH-TECH INDUSTRY	0.074***	0.081***	0.114***	0.045*	0.159***	0.084***	0.103***	0.069***	0.204***	-0.108***	0.018	0.083***	0.101***	-0.441***	1.000	
16	HIGH-TECH INDUSTRY	0.091***	0.092***	0.118***	0.103***	0.137***	0.182***	0.118***	0.114***	0.063**	-0.007	0.086***	0.012	0.013	-0.309***	-0.284	1.000

*Note: *, ** and *** denote significance at the 10%, 5% and 1% level, respectively. Standard errors are in parentheses.*

The second variable (INV_Q) used in the analysis is the ratio of forward patent citations to patent counts. Given that the dependent variable contains decimal numbers, the count data models are inappropriate in this case. To account for the specific feature of the data, a generalized linear model (GLM) is used in the econometric analysis (Nelder and Wedderburn, 1972). The GLM is flexible and has the power to model the data with ratio and non-normal distributions when a proper family distribution and link function are defined in the model. I use the GLM with a gamma family distribution and a log link, because the variance exceeds the mean in the dependent variable. I also introduce a robust option into the model to obtain robust standard errors if the family distribution is incorrectly specified. Furthermore, I control time dummies in the GLM as well as in the count models to account for the time effect and structural changes over time in the analysis.

4.5 Estimation results

Table XIX presents the results from the hurdle models. As expected, R&D outsourcing (EXT_R&D) is significantly and positively associated with invention quantity (INV_N). In particular, the results from the hurdle models show that EXT_R&D is significant and positive in the first part as well as in the second part of the estimations (see Table XIX, models 1 and 2), implying that those firms that outsource some parts of their R&D activities to external entities are more innovative than their counterparts that do not invest in this R&D strategy. Given that the R&D outsourcing strategy allows firms to focus on the activities that they can perform best and to use the services of independent research organizations for tasks in which they lack expertise, this strategy can help firms to improve their invention activities. However, a non-significant relationship is identified between large-scale R&D outsourcing (EXT_R&D_INTENSITY) and invention quantity (INV_N) (see Table XX). Furthermore, Table XXI indicates that neither EXT_R&D nor EXT_R&D_INTENSITY is significantly associated with invention quality (INV_Q). To sum up the findings from the empirical analysis, the results partially confirm the first hypothesis in which I suggest that a positive relationship exists between R&D outsourcing and invention performance. With regard to the second hypothesis, a non-significant relationship is identified between intensity of R&D outsourcing and research output (including invention quantity as well as quality). The data do not permit me to examine further the driving factors for this non-significant relationship. To understand clearly the invention performance of R&D outsourcing, it might be necessary to study the returns of this strategy more specifically in relation to whether R&D is sourced from suppliers, consulting companies or research institutions.

Table XIX –Innovative performance of R&D outsourcing (in terms of invention quantity)

	INV_N		INV_N	
	Hurdle Poisson Model		Hurdle Negative Binomial Model	
	Logit Model	Poisson Model	Logit Model	Negative Binomial Model
	1		2	
EXT_R&D	0.4518**	0.4380***	0.4518**	0.1834**
	(0.2068)	(0.0608)	(0.2068)	(0.0834)
INT_R&D	0.5715**	0.2145**	0.5715**	0.2795**
	(0.2362)	(0.1023)	(0.2362)	(0.1389)
R&D_COOP	0.4912*	0.4290	0.4412*	0.3551
	(0.2527)	(0.3413)	(0.2289)	(0.2965)
R&D_INTENSITY	0.5518	0.3204**	0.5518	0.1940**
	(2.7071)	0.1504	(2.7071)	(0.0967)
EXPORT_INTENSITY	0.5002	0.1935**	0.5002	0.5171**
	(0.4087)	(0.0882)	(0.4087)	(0.2487)
LOCATION_EAST	-0.5526**	-0.1485	-0.5526**	0.1480
	(0.2609)	(0.1103)	(0.2609)	(0.4473)
PRE_INV_N (logs)	0.4089*	0.0908***	0.4089*	0.6242***
	(0.2240)	(0.0174)	(0.2240)	(0.1396)
PRE_INV_N (d) (no pre-sample inventions)	-1.6720***	-1.2720***	-1.6720***	-0.2847
	(0.3572)	(0.0847)	(0.3572)	(0.4379)
LOG_SIZE	0.4096***	0.5973***	0.4096***	0.5778***
	(0.716)	(0.0157)	(0.716)	(0.0917)
MEDIUM-LOW-TECH INDUSTRY	0.5894	1.4226***	0.5894	1.1468**
	(0.3785)	(0.2588)	(0.3785)	(0.6352)
MEDIUM-HIGH-TECH INDUSTRY	1.5273***	1.3038***	1.5273***	1.5254**
	(0.3578)	(0.2564)	(0.3578)	(0.5933)
HIGH-TECH INDUSTRY	1.1959***	1.8906***	1.1959***	1.8789***
	(0.3884)	(0.2577)	(0.3884)	(0.6518)
INTERCEPT	0.9898	0.9630	0.9898	0.5030
	(0.6237)	(0.5754)	(0.6237)	(0.9541)
Year dummy	YES		YES	
Obs.	1568		1568	
Wald chi2 or LR chi2	270.19		270.19	
Prob>chi2	0.0000		0.0000	

*Note: *, ** and *** denote significance at the 10%, 5% and 1% level, respectively. Standard errors are in parentheses.*

Having discussed the relationship between R&D outsourcing and invention performance, I shift my attention to the control variables used in the econometric analysis. Table XIX shows the positive relationship between INT_R&D and INV_N, implying that those firms that carry out R&D internally (INT_R&D) are more likely to generate a high number of inventions than their

Table XX–Innovative performance of R&D outsourcing intensity (in terms of invention quantity)

	INV_N		INV_N	
	Hurdle Negative Binomial Model		Hurdle Negative Binomial Model	
	Logit Model	Negative Binomial Model	Logit Model	Negative Binomial Model
	1		2	
EXT_R&D_INTENSITY	0.8908	0.8908	0.7812	0.5644
	(0.7257)	(0.7257)	(0.1773)	(0.9533)
INT_R&D_INTENSITY	0.6792*	0.5892*	0.6928	0.5486
	(0.3467)	(0.2987)	(0.4253)	(0.4613)
R&D_COOP	0.5764*	0.4289	0.4087*	0.4387
	(0.2924)	(0.2732)	(0.2056)	(0.2776)
EXPORT_INTENSITY	0.8398	0.4725**	0.8076	0.4671**
	(0.4501)	(0.2301)	(0.4111)	(0.2267)
LOCATION_EAST	-0.4468**	0.1736	-0.4477*	0.1686
	(0.2145)	0.4479	(0.2608)	(0.4463)
PRE_INV_N (logs)	0.4359**	0.4478**	0.4359**	0.4527**
	(0.2215)	(0.2049)	(0.2215)	(0.2065)
PRE_INV_N (d) (no pre-sample inventions)	-1.6511***	-0.4335	-1.6508***	-0.4321
	(0.3516)	(0.4699)	(0.3516)	(0.4701)
LOG_SIZE	0.4718***	0.5153***	0.4711***	0.5152***
	(0.0728)	(0.0926)	(0.0733)	(0.0926)
MEDIUM-LOW-TECH INDUSTRY	0.6416*	1.0988*	0.6414*	1.0956*
	0.3807	(0.6190)	(0.3807)	(0.6194)
MEDIUM-HIGH-TECH INDUSTRY	1.7204***	1.5459***	1.7193***	1.5441***
	(0.3592)	(0.5801)	(0.3595)	(0.5804)
HIGH-TECH INDUSTRY	1.4224***	1.8837***	1.4204***	1.8919***
	0.3928	(0.6547)	(0.3936)	(0.6563)
INT_R&D_INTENSITY*EXT_R&D_ INTENSITY			-0.2993	0.6202
			(0.9238)	(0.4663)
INTERCEPT	0.6844	0.5863	0.4863	0.2684
	(0.5645)	(0.5665)	(0.4391)	(0.8957)
Year dummy	YES		YES	
Obs.	1568		1568	
Wald chi2 or LR chi2	268.21		268.21	
Prob>chi2	0.0000		0.0000	

*Note: *, ** and *** denote significance at the 10%, 5% and 1% level, respectively. Standard errors are in parentheses.*

counterparts that do not invest in in-house R&D. Generally speaking, internal R&D is considered to be a key source for enhancing the learning process within a firm and developing firm-specific resources and integrative competencies. However, internal R&D (INT_R&D) is slightly significant for invention quality (see Table XXI). This might be partly due to the fact that the expenditures for internal R&D are not differentiated among basic, applied or developing activities. The same applies to the variable internal R&D intensity (INT_R&D_INTENSITY), which is slightly significant for invention quantity but not significant for invention quality (see Tables XX and XXI). In the econometric models, I also introduce interaction terms between outsourced and internal R&D (i.e. INT_R&D_BINARY*EXT_R&D_BINARY and INT_R&D_INTENSITY*EXT_R&D_INTENSITY), but both interaction variables are significant neither for invention quantity nor for invention quality. Previous research on German manufacturing firms also provides no evidence of a complementary relationship between external (outsourced) and internal R&D (Schmiedeberg, 2008).

Additionally, the empirical analysis shows that R&D cooperation (R&D_COOP) is slightly significant and positive in the first part of the hurdle model but non-significant in the second part (see Tables XIX and XX). Moreover, Table XXI provides a non-significant relationship between R&D cooperation and invention quality. This could be explained by the fact that for invention quantity as well as for invention quality, not only cooperating with external actors in R&D, but also with whom this cooperation takes places, whether it is research institutions, suppliers, customers, etc. may be important. For invention performance, it may also matter whether the purpose of R&D cooperation is knowledge exchange or joint innovation development (Hottenrott and Lopes-Bento, 2012).

Turning to the other control variables, R&D intensity[16] (R&D_INTENSITY) is significantly and positively associated with invention quantity (see Table XIX), but the significance level of the coefficient is lower for invention quality (see Table XXI). In contrast, export intensity (EXPORT_INTENSITY) and firm size (LOG_SIZE) are significantly and positively related only

[16] The R&D intensity variable (R&D_INTENSITY) is excluded from the econometric analysis presented in Tables XX and XXI (models 3 and 4) due to the high correlation between R&D_INTENSITY and INT_R&D_INTENSITY (see Table XVIII).

to invention quantity (see Tables XIX and XX); both of the variables are non-significant in the econometric analysis for invention quality (see Table XXI). In a somewhat similar way, past innovation activities matter only for invention quantity and not for invention quality. This might be due to the fact that the number of forward citations, which is used as an indicator of patent

Table XXI – Innovative performance of R&D outsourcing (in terms of invention quality)

	INV_Q	INV_Q	INV_Q	INV_Q
	GLM Model	GLM Model	GLM Model	GLM Model
	1	2	3	4
EXT_R&D	0.3078 (0.2409)	0.3406 (0.5422)		
EXT_R&D_INTENSITY			0.6859 (0.5806)	0.5482 (0.5865)
INT_R&D	0.4715* (0.2456)	0.4921 (0.4296)		
INT_R&D_INTENSITY			0.7470 (0.8045)	0.9787 (0.6843)
R&D_COOP	0.1948 (0.2355)	0.1906 (0.2356)	0.0985 (0.2294)	0.1050 (0.2297)
R&D_INTENSITY	0.3393* (0.1704)	0.3203* (0.1688)		
EXPORT_INTENSITY	0.1787 (0.4446)	0.1755 (0.4471)	0.1787 (0.4412)	0.1779 (0.4421)
LOCATION_EAST	-0.2868 (0.3704)	-0.2859 (0.3706)	-0.4239 (0.3885)	-0.4231 (0.3884)
PRE_INV_Q (logs)	0.0665 (0.2403)	0.0674 (0.2407)	0.0938 (0.2381)	0.0961 (0.2385)
PRE_INV_Q (d) (no pre-sample citations)	-0.0191 0.2729	-0.0183 (0.2732)	-0.0043 (0.2717)	0.0227 (0.2742)
LOG_SIZE	0.0078 (0.0899)	0.0067 (0.0904)	0.0325 (0.0881)	0.0293 (0.0883)
MEDIUM-LOW-TECH INDUSTRY	0.6739 (0.6539)	0.6698 (0.6569)	0.5902 (0.6446)	0.5813 (0.6448)
MEDIUM-HIGH-TECH INDUSTRY	0.6589 (0.6187)	0.6537 (0.6237)	0.5744 (0.6092)	0.5639 (0.6095)
HIGH-TECH INDUSTRY	1.1034* (0.6301)	1.0969* (0.6359)	0.9328 (0.6286)	0.8930 (0.6306)
INT_R&D_BINARY*EXT_R&D_BINARY		-0.0402 (0.5973)		
INT_R&D_INTENSITY*EXT_R&D_ INTENSITY				-0.1670 (0.5832)
INTERCEPT	0.3065 (0.2178)	0.6029 0.3268	0.7282 (0.5011)	0.4256 (0.6292)
Year dummy	YES	YES	YES	YES
Obs.	202	202	202	202
Link function	LOG	LOG	LOG	LOG
Family distribution	Gamma	Gamma	Gamma	Gamma
Log pseudo-likelihood	-249.27	-249.26	-251.08	-250.72

*Note: *, ** and *** denote significance at the 10%, 5% and 1% level, respectively. Standard errors are in parentheses. The sample is restricted to those firms that have at least one patent.*

quality, depends on whether a firm's patent attributes technological knowledge of citing firms and their absorptive capacity (Hottenrott and Lopes-Bento, 2012). With regard to the variable LOCATION_EAST, it is significantly and negatively associated with invention quantity, which is line with other studies displaying that West German firms are more innovative than their counterparts located in East Germany. However, Table XXI shows that there is no significant difference between firms located in West Germany and firms located in East Germany in terms of generating substantial inventions.

4.6 Conclusion

The question of whether firms experience 'gains' or 'pains' from R&D outsourcing is a subject of ongoing research in the R&D management literature. A number of previous papers discuss this issue, yet little is known about how this strategy relates to the value of an outsourcer firm's research output. Motivated by this research gap in the literature, this study further discusses the prior research findings and provides new insights into the relationship between R&D outsourcing and invention performance (in terms of patent quantity as well as quality). In particular, this paper finds that those firms that outsource R&D functions to specialized research organizations generate more inventions than their counterparts that do not invest in this R&D strategy. Given that R&D outsourcing allows firms to contract out some R&D activities in which they do not possess high-class expertise and to concentrate on the activities that they can perform best, such inter-firm task division may help companies to devote their financial and human resources to their key research activities and, as a result, to improve the efficiency and effectiveness of their invention performance. However, this positive performance implication of R&D outsourcing does not appear to hold for invention quality. Moreover, the empirical analysis indicates that large-scale R&D outsourcing is associated significantly neither with invention quantity nor with invention quality.

Due to the data limitation, I could not explore what drives the ambiguous relationship between R&D outsourcing and invention quality as well as between the intensity of this strategy and invention performance (including invention quantity and quality). The dataset is also a two-year cross-sectional set, which does not allow a causal interpretation here. Moreover, to understand the performance implication of R&D outsourcing clearly, it might be required to take into account whether R&D functions are outsourced to a supplier, consulting firm or research institution.

5 Summary and conclusion

The main purpose of this thesis is to examine whether firms gain or lose from open innovation adaption. The recent progress of information and communication technologies has greatly induced firms to increase their degree of openness in innovation. In particular, as modern information and communication technologies allow firms to share knowledge instantly and inexpensively with high-quality scientists and engineers around the world, the value of the internal-R&D-oriented approach has eroded. Instead, firms have adopted the open innovation framework for the purpose of developing innovation jointly with external actors or acquiring ready R&D results from them. This, on the one hand, can help firms to develop innovations relatively quickly and inexpensively and to respond swiftly to new market threats and opportunities (Chesbrough, 2003; Keupp and Gassmann, 2009). However, on the other hand, the open and distributed innovation approach can also be a risky business in the context of hollowing out companies' internal innovation capabilities and, consequently, hampering their innovation performance. Motivated by these contradictory arguments, the thesis aims to examine the risks and benefits of the open innovation approach.

Before studying the performance implication of this approach, Chapter 2 explores how firms set boundaries in open innovation. Prior research on open innovation provides no systematic insight into whether firms with internal innovation constraints increase the scale of R&D outsourcing or the number of innovation cooperation partnerships. Hence, the chapter addresses this research gap in the literature and examines whether it is a cost- or resource-oriented logic that encourages firms to adopt different open innovation strategies. Analysing a three-year panel dataset of German manufacturing firms obtained from the Mannheim Innovation Panel database, we find that knowledge-related obstacles induce firms to increase their scale of R&D outsourcing as well as to engage in innovation cooperation with a wide set of external actors. In contrast, a non-significant relationship is detected between economic-related innovation impediments and R&D openness. In particular, the study shows that cost- and risk-minimization objectives do not play a significant role either in increasing the scale of R&D outsourcing or in engaging in innovation cooperation partnerships. Hence, the research shows that the primary purpose behind increasing the degree of openness with regard to R&D outsourcing and innovation cooperation is to access external skills and expertise. From the perspective of R&D outsourcing, it is surprising that the main purpose of large-scale R&D outsourcing is to deal with knowledge-related innovation impediments. The R&D outsourcing strategy may help firms to acquire valuable knowledge that is unavailable internally, but accessing external knowledge through an arm's length contractual relationship may not be an effective strategy to utilize the tacit component of technological knowledge. Furthermore, this strategy may displace the outsourcer firm's internal innovation activities and, in this way, hamper its innovation performance.

Chapter 3 takes up this issue and examines whether external R&D complements or substitutes other innovation strategies (i.e. internal R&D and innovation cooperation). Although previous studies discuss this issue (Cassiman and Veugelers, 2006; Lokshin et al., 2008; Schmiedeberg, 2008; Grimpe and Kaiser, 2010), the geographical dimension of external R&D has thus far not been studied. In other words, firms that acquire international, rather than domestic, external R&D may have a greater tendency to invest in internal R&D as well as to engage in innovation cooperation partnerships, because the utilization of external knowledge stemming from international R&D suppliers may require an advanced level of internal capability. Hence, Chapter 3 studies whether domestic and international external R&D complement or substitute internal R&D and innovation cooperation. Moreover, the performance implication of domestic and international external R&D is examined in this chapter. To study these issues, we analyse Danish manufacturing firms on the cross-sectional level using data obtained from the Community Innovation Survey. The survey contains information on the expenses for R&D performed by external actors, whether domestic or international, and then subsequently used in internal innovation activities. To confirm the complementary relationship between innovation strategies, we use the adoption and performance approaches. The adoption approach shows that international external R&D complements internal R&D and innovation cooperation, but the performance approach indicates that joint representation of these instruments has a significant negative sign for product innovation, implying that firms face difficulties in successfully combining international external R&D and internal R&D as well as international external R&D and innovation cooperation. Somewhat to the contrary, no significant complementary or substitutive relationship is found between domestic external R&D and internal R&D or between domestic external R&D and innovation cooperation.

More importantly, the research reveals that those companies sourcing R&D inputs from international rather than domestic external actors are more likely to introduce product innovations with a higher degree of novelty. In contrast, domestic external R&D is related significantly and positively to product imitation, but it has a significant and negative sign for the novelty of product innovation.

Chapter 4 further discusses the performance implication of R&D outsourcing and provides new insights into the relationship between this strategy and invention performance. Although Chapter 3 contributes significantly to our understanding of the performance implication of external R&D, measuring the R&D output by product innovation may not reflect the overall quality of an outsourcer firm's research processes. For example, a product innovation might be a result of combining externally available knowledge inputs, and it may not be a good indicator of the quality of internal invention activities. In other words, the knowledge and production boundaries of a firm may vary. Hence, Chapter 4 examines how R&D outsourcing is associated with the value of a firm's research output (in terms of invention quantity as well as quality). To study this issue, the Mannheim Innovation Panel dataset is combined with patent data obtained from the European Patent Office. The former gives detailed information about the innovation activities of German firms, whereas the latter provides data about the patents applied for by the firms at the European Patent Office.

The results obtained from the data analysis suggest that those firms that outsource some R&D functions are more likely to generate inventions than their counterparts that do not invest in this strategy. However, a non-significant relationship is identified between R&D outsourcing and invention quality. Furthermore, large-scale R&D outsourcing is associated significantly neither with invention quantity nor with invention quality.

From a managerial perspective, the above-presented findings have a number of implications. In particular, the thesis suggests that open innovation in general and R&D outsourcing in particular have a value-enhancing objective rather than a cost-minimization purpose. In other words, the growth objective (in terms of acquiring external knowledge) is the main factor that stimulates companies to outsource R&D activities, whereas the defensive objective (in terms of minimizing the costs and risks of R&D projects) does not play a significant role. Hence, companies should undertake more strategic consideration when outsourcing their R&D activities and they should seek to grow through employing this strategy. Nowadays, the question is not whether to acquire R&D inputs from external entities, but rather where to search for appropriate R&D suppliers and how to transfer knowledge effectively from them. Indeed, the study shows that there are significant differences in domestic external R&D and international external R&D. More specifically, the research reveals that sourcing R&D inputs from a domestic R&D provider can be a risky strategy when a firm aims to generate breakthrough product innovations. Instead, the firm should seek to acquire knowledge inputs from international marketplaces. As knowledge-based assets sourced from international marketplaces might be more heterogeneous than those within the home country due to the different institutions and national innovation systems, firms that acquire international, rather than domestic, external R&D are more likely to introduce product innovations with a higher degree of novelty. In other words, companies that source R&D inputs from international marketplaces can have more opportunities for knowledge recombination and perform better in innovation than others that rely purely on domestic resources. Therefore, firms need to establish international linkages to access valuable resources that are unavailable within their home markets and to improve their innovation performance. Policymakers should also encourage and reward firms to collaborate with international agencies and to grow through acquiring international external R&D. More specifically, governments should ease the restrictions on outsourcing R&D activities abroad and help companies to identify suitable R&D suppliers. This would be especially helpful for small and medium-sized firms wishing to collaborate with international R&D providers and to tap into the global knowledge pool.

Furthermore, outsourcing R&D activities abroad can stimulate other types of innovation activities, such as internal R&D and innovation cooperation. As the research suggests, firms that opt for international external R&D simultaneously invest in internal R&D and engage in innovation cooperation partnerships. This is due to the fact that knowledge transfer from international, rather than from domestic, R&D suppliers might be more problematic because of the different national innovation systems, cultures and institutions across countries. For this reason, firms that acquire international external R&D simultaneously engage in other innovation activities (i.e. internal R&D and innovation cooperation) to enlarge their absorptive capacity and to utilize knowledge from international entities effectively. However, the research also indicates that firms face problems in achieving a positive performance outcome through combining these innovation strategies. This might be due to the fact that a high degree of openness in innovation may cause not only the absorptive capacity problem but also the attention allocation problem. In particular, when there are many ideas for a firm to choose between, only a few of them will be given the required level of attention and effort to be implemented (Koput, 1997; Katila and Ahuja, 2002). Therefore, firms need to balance their internal R&D activities and their degree of openness to avoid the over-searching problem and to gain from the open innovation framework.

The research also shows that those firms that outsource R&D activities are more likely to generate inventions than their counterparts that do not invest in this R&D strategy. As the inter-firm division of R&D labour allows firms to concentrate on their key research activitiesand to acquire rather peripheral R&D functions from a specialized research organization, R&D outsourcing can help firms to improve the effectiveness of their research activities. However, this positive performance implication of R&D outsourcing does not appear to hold for invention quality. Due to the data limitation, I could not examine the drivers of the ambiguous relationship between R&D outsourcing and invention quality.

The thesis also suffers from other limitations that offer interesting avenues for future research. First, to understand the performance implication of R&D outsourcing in more detail, future research should examine the differences in R&D inputs sourced from suppliers, competitors, universities, consulting companies and other external actors. This differentiation could be important for a clear understanding about the performance implication of R&D outsourcing. Second, the thesis shows that firms engage in various open innovation strategies simultaneously, but they fail to combine these instruments successfully for product innovation. This might be due to the over-searching problem that reduces the returns from the open innovation framework, but future research should investigate the factors that prevent companies from capturing values from pursing different innovation strategies simultaneously. In particular, research should examine the challenges that R&D outsourcing brings to internal R&D activities. In this context, it could be interesting to study whether R&D outsourcing complements or substitutes internal basic and applied research activities and how it changes an outsourcing firm's skill composition. Third, further study is required of the geographical patterns of openness to understand the differences in the performance implication of R&D inputs sourced from various European countries, the USA, China and other geographical locations.

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Tbilisi, January 7, 2015

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December 15-26, 2012	Basics of Economic Innovations (intensive course), teaching assistant of Prof. Dr. Uwe Cantner, joint master program 'Managing International Enterprises' of Tbilisi State University (Georgia) and Friedrich Schiller University of Jena (Germany)

Summer Schools

July 24- August 7, 2011	Innovation and Uncertainty Summer School, jointly offered by Friedrich Schiller University of Jena and The Max Planck Institute of Economics, Jena, Germany

July 25- August 8, 2010	Innovation and Uncertainty Summer School, jointly offered by Friedrich Schiller University of Jena and The Max Planck Institute of Economics, Jena, Germany

Languages

Georgian (native), English (fluent), Russian (intermediate), German (basic).

Technical Skills

Programming languages: PHP, Python
Statistical software: Stata, R
Database: SQL Server, MySQL
Internet technologies: HTML

Research Grants and scholarships

02/2010 - 02/2013	DFG Doctoral Fellowship, Graduate College 'Economics of Innovative Change', Friedrich Schiller University of Jena, Germany.
10/2008 - 09/2009	Development and Reforms Foundation scholarship (public law legal entity under the president of Georgia) for an academic stay at Warsaw University, Georgia.
10/2007 - 09/2009	Bolnisi municipality scholarship for an academic stay at Warsaw University, Georgia.
10/2007 - 09/2009	A tuition waiver by Warsaw University, Poland.
09/2001 - 07/2005	A tuition waiver by Georgian Technical University, Georgia.

Levan Bzhalava

Tbilisi, January 7, 2015