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The Gains and Pains from R&D Outsourcing

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Balancing Internal and External Knowledge Acquisition: The Gains and Pains from R&D Outsourcing

Abstract

The outsourcing of research and development (R&D) activities has frequently been characterized as an important instrument to acquire external technological knowledge that is subsequently integrated into a firms' own knowledge base. However, in this paper we argue that these "gains" from R&D outsourcing need to be balanced against the "pains" that stem from a dilution of firm-specific resources, the deterioration of integrative capabilities and the high demands on management attention. Based on a panel dataset of innovating firms in Germany, we find evidence for an inverse U-shaped relationship between R&D outsourcing and innovation performance. This relationship is positively moderated by the extent to which firms engage in internal R&D and by the breadth of formal R&D collaborations: both serve as an instrument to increase the effectiveness of R&D outsourcing.

Keywords: Outsourcing, research and development, resource-based view of the firm.

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1 Introduction

Determining the research and development (R&D) boundaries of the firm has attracted considerable attention in the literature because of its central role in the management of innovative activities (e.g., Cassiman and Veugelers, 2002, 2006; Nagarajan and Mitchell, 1998; Pisano, 1990; White, 2000). As the institutional loci of new technological knowledge can be diverse, there is a high probability that at least from time to time firms need to acquire such resources externally (Teece, 1986, 1992). Even though R&D – just like production – has been characterized as a core "high-value function" of the firm (Leiblein et al., 2002; Leiblein and Miller, 2003), R&D activities have to an increasing extent become subject to outsourcing, offshoring or both (Arnold, 2000; Doh, 2005; Howells, 1999; Jahns et al., 2006; Weigelt, 2009). While offshoring refers to the relocation of R&D activities which could still be carried out by the focal firm (e.g., Kuemmerle, 1998; Lewin et al., 2009), outsourcing implies a move beyond a firm's boundaries to R&D contractors. In this sense, R&D outsourcing refers to the contractually agreed, non-gratuitous and temporary performance of R&D tasks for a client primarily by private contract research and technology organizations, but also by some private non-profit and related hybrid organizations (Howells, 1999). Research outcomes are transferred to the client with all specific exploitation rights upon completion of the task (Teece, 1988). Although a full reliance on such externally produced technological knowledge remains an unusual case (Tether and Tajar, 2008), R&D outsourcing – or external R&D [1] – has considerably increased in importance (Howells, 1999) and accounts for a substantial share of the total innovation expenditure in a large number of firms (Eurostat, 2004).

As the outsourcing of R&D becomes more common practice, the question arises whether such external knowledge acquisition is always conducive to higher innovation performance. Existing research has provided numerous arguments why R&D outsourcing benefits the innovative capabilities of a firm. Following the resource-based view (RBV) of the firm (e.g., Barney, 1991; Wernerfelt, 1984), external R&D serves as an instrument to access knowledge resources that may subsequently be redeployed with existing resources in a way superior to a competitor's deployment (Barthélemy and Quélin, 2006; DeSarbo et al., 2005; Kogut and Zander, 1992). In fact, Cassiman and Veugelers (2006) provide evidence that internal and external R&D are complementary activities, i.e. the marginal return to internal R&D increases with the intensity of R&D outsourcing. Although the downsides of R&D outsourcing are well documented (e.g., Howells, 2006; Howells et al., 2008), little is known about whether they do not only mitigate the positive effects but also have a negative effect on the firm's resource base as a whole, leading to a "tipping point" in the relationship between R&D outsourcing and innovation performance from which any additional investments in R&D outsourcing have a negative effect on innovation performance.

In this paper, we argue that "over-outsourcing" poses a serious threat to a firm's innovation performance. As a result, the "gains" from R&D outsourcing need to be balanced against the "pains" which we suspect to stem primarily from three sources. First, firm-specific resources are diluted if firms rely strongly on rather generic external knowledge to which competitors might have equally good access. Second, R&D outsourcing hurts the firm's integrative capabilities that are required to assimilate and build upon external knowledge (Helfat and Raubitschek, 2000; Weigelt, 2009). Third, managing external relationships with R&D contractors calls for heightened management attention (Ocasio, 1997) which is critical in the process of resource redeployment. Over-outsourcing might therefore offset the benefits expected from complementarities between internal and external R&D.

As a consequence, it is in the key interest of a firm's management to know if innovation expenditures are better spent elsewhere than on R&D outsourcing. Moreover, it is important for management to know how the negative effects from over-outsourcing can be reduced, i.e. how the tipping point can be influenced. For this purpose, we analyze the effect of two moderating variables which we assume to increase the effectiveness of R&D outsourcing, i.e. they push the tipping point towards a higher degree of R&D outsourcing: internal R&D and the breadth of formal R&D collaborations. While internal R&D is related to the importance of carefully balancing internal and external technology development, R&D collaboration is associated with the opportunities firms gain from external sources in the innovation process (Ahuja and Katila, 2002; Laursen and Salter, 2006). We hence aim at contributing to the literature by clarifying the complex role played by R&D outsourcing in achieving innovation performance. Our study is based on panel data of both manufacturing and service firms from Germany, covering a period of ten years from 1998 to 2008. In fact, most prior research on outsourcing focuses either on manufacturing industries (e.g., Leiblein et al., 2002) or services (e.g., Weigelt, 2009) while comprehensive evidence is scarce.

Our econometric analyses indeed provide evidence for a tipping point in R&D outsourcing since we find an inverse U-shaped relationship between the degree of R&D outsourcing and innovation performance. This implies that additional R&D outsourcing has positive but decreasing effects up to the tipping point from which extra spending on R&D outsourcing has negative effects. The tipping point may, however, be pushed further towards higher levels of R&D outsourcing (i) the more firms spend on internal

R&D and (ii) the more often firms collaborate externally in R&D. Internal R&D and R&D collaboration hence have moderating effects on the downsides of R&D outsourcing.

The remainder of this paper is organized as follows: Section 2 presents our conceptual considerations and the hypotheses. Section 3 describes our empirical strategy to test the hypotheses. Estimation results are presented in Section 4. We discuss our findings in Section 5. Section 6 concludes.

2 Theory and hypotheses

2.1 R&D outsourcing as a determinant of innovation performance

The idea to outsource R&D to contract research and technology organizations is not new. In fact, the consulting firm Arthur D. Little dates back to the year 1886 with the offering of "investigations for the improvement of processes and the perfection of products" (Kahn, 1986). In this sense, outsourcing R&D activities is directed at exploiting certain advantages associated with the nature and purpose of external R&D contractors. In the following, we will first outline how firms may realize these advantages before we turn to the downsides and delineate our first hypothesis regarding the relationship between R&D outsourcing and innovation performance.

The gains from R&D outsourcing

From an RBV perspective, R&D outsourcing may provide client firms with access to resources that are not available internally (Weigelt, 2009). Resources can be understood as the organizational knowledge, physical assets, human capital and other tangible and intangible factors that a business owns or controls (Amit and Schoemaker, 1993; Grant, 1991). Two main aspects have been put forward by the RBV. First, firms are heterogeneous with respect to their resource endowment which, as a consequence, drives firm performance (e.g., Wernerfelt, 1984). Second, in order to result in competitive advantage, resources need to be valuable, rare, as well as difficult to imitate and substitute (e.g., Barney, 1991; Dierickxs and Cool, 1989). Among the different types of resources, knowledge typically provides most opportunities to create competitive advantage (Grant, 1996; Kogut and Zander, 1992). Knowledge frequently results from the search for new solutions that are based on the firm's existing knowledge base (Cohen and Levinthal, 1989; Nelson and Winter, 1982; Teece, 1986). Dierickx and Cool (1989) point out that firms need to accumulate such knowledge over time, for example by investing into R&D, in order to eventually create innovative products and services.

A critical factor in the relationship between knowledge resources and performance is the strength of "isolating mechanisms" protecting the resources from imitation by competitors (Mahoney and Pandian, 1992). In this respect, the firm-specificity of resources has been characterized as one important isolating mechanism (Wang et al., 2009) since firm-specific resources may not be easily traded, redeployed outside the firm, or imitated by competitors (Dierickx and Cool, 1989). Another isolating mechanism may be the outcome of a deliberate resource deployment process within the firm (e.g., Barney and Mackey, 2005; Sirmon et al., 2007), leading to the creation of organizational capabilities (e.g., Kale and Singh, 2007; Slater et al., 2006). In fact, a firm's capacity to deploy resources through organizational capabilities may actually be more important for explaining performance than the absolute stock of resources available to the firm (e.g., DeSarbo et al., 2007; Vorhies et al., 2009). Because capabilities based on knowledge resources are hence partially path-dependent, firms, at least in the short run, are stuck with their endowment (Teece, 1986). Teece (2006) therefore asserts that firm performance critically depends on the management's ability to build capabilities from internal resources and/or to buy external resources which can then be combined with the firm's internal knowledge base. In other words, internal knowledge resources may become more valuable when they co-evolve with other resources (DeSarbo et al., 2005). To achieve competitive advantage, knowledge resources can therefore on the one hand be deployed in a way superior to a competitor's deployment (DeSarbo et al., 2005). On the other hand – and this is where R&D outsourcing becomes attractive – resources may be acquired externally and subsequently redeployed with the existing internal resources so that the combination results in firm-specific organizational capabilities.

As a result, the external acquisition of knowledge resources through R&D outsourcing may lead to several potential benefits. Cost advantages may be achieved by specialization of the contractor or by cost sharing in a joint commissioning of more than one client. Moreover, fixed costs may be reduced and R&D time and budgets better controlled (Tapon and Thong, 1999). Cost aspects should, however, only play a minor role as skilled – and thus well paid – R&D employees cannot be easily replaced by low-cost labor. Thus, quality advantages through R&D outsourcing may be more important since the contractor can employ specialized know-how, equipment and infrastructure. Using external sources may also foster creativity within internal R&D since new research methods and perspectives are brought in. Another advantage of R&D outsourcing relates to timing issues and the undivided attention that the project may receive by the contractor. This can be especially important if the contracting firm tries to catch up with competitors in an area of technology where no or little competence is available internally. Finally, firms may deliberately choose to establish external competition to stimulate internal R&D. Such forms of competition may also prove to be helpful in overcoming internal resistance to innovation projects (Tapon and Cadsby, 1994). Despite these arguments that suggest a positive relationship between R&D outsourcing and innovation performance, existing research also points to some downsides that might actually have detrimental effects on innovation performance (Weigelt, 2009).

The pains from R&D outsourcing

First of all, the downsides of R&D outsourcing refer to the outsourcing process. Intellectual property rights (IPR) as a result of R&D outsourcing might be difficult to allocate (Howells, 2006). Moreover, the contractual relationship involves informational asymmetries since potential contractors might lack the required expertise they declared to possess (Love and Roper, 2002). Client firms may also encounter considerable steering, controlling and confidentiality problems associated with the contracted research (Howells et al., 2008). Outsourced R&D might also trigger a “not invented here” syndrome which may lead to a reluctance of in-house R&D to adopt external technology (Katz and Allen, 1982; Veugelers and Cassiman, 1999). Outsourcing R&D projects that appear to be of high strategic relevance hence constitutes a risky strategy.

Additionally, the downsides of R&D outsourcing materialize because there are limits to the extent to which external knowledge resources can be integrated into a firm’s internal knowledge base (Weigelt, 2009). In this respect, firms might fail to assimilate and leverage acquired knowledge resources for at least three reasons that we shall review below.

First, knowledge produced externally is typically not a unique and firm-specific resource since potential competitors may benefit equally well from the contractor’s expertise. Knowledge is by its very nature a public good (Jaffe, 1986) that could “spill over” to competitors and allow them to free-ride on a firm’s investments in knowledge production (Arrow, 1962). We have, however, characterized firm-specific knowledge resources as one of the most important assets of the firm (Grant, 1996) in that they may effectively serve as isolating mechanisms (Wang et al., 2009). In fact, research on firm capabilities has recognized that a firm’s ability to deploy resources through organizational capabilities may actually be more important for achieving performance than absolute resource levels (e.g., DeSarbo et al., 2007). In this respect, an abundance of external knowledge resources does not per se increase innovation performance as a strong reliance on external knowledge may lead to a situation where the resource base of the firm suffers from dilution, making it less unique and easier for competitors to imitate. As dilution refers to the firm’s knowledge base as a whole, it is important to note that over-outsourcing not only mitigates the benefits of R&D outsourcing but also leads to a tipping point at which R&D outsourcing becomes negatively associated with innovation performance.

Second, R&D outsourcing might be detrimental to innovation performance because excessive external knowledge acquisition hurts a firm’s integrative capabilities required to actually deploy and build upon the acquired knowledge resources (Helfat and Raubitschek, 2000; Weigelt, 2009). Integrative capabilities evolve through learning by doing and investments into activities to create new knowledge (Nelson and Winter, 1982). They enable firms to tailor external knowledge resources to firm-specific needs and to redeploy them within the firm. As a result, the combination of internal and external knowledge resources will be firm-specific, unique and hence valuable. In this respect, an important distinction has to be made between the codified and the tacit components of knowledge (Grant, 1996; Kogut and Zander, 1992). Compared to codified knowledge that can be easily transferred between the client firm and the R&D contractor, tacit knowledge is "sticky" to its owner and the context (Polanyi, 1967). R&D activities, however, typically exhibit an abstract and demanding scientific base (Fichman and Kemerer, 1997) that is associated with a high degree of tacitness, for example with respect to the scientific personnel involved in these activities. If investments in knowledge creation activities are shifted from the client firm to the supplier, integrative capabilities are hurt because there is a high likelihood that firms fail to transfer the tacit knowledge (Weigelt, 2009). This limits firms' insights into the codified components and may even result in flawed assumptions about the external knowledge.

Third, R&D outsourcing requires a considerable amount of management attention which is a scarce resource itself (Ocasio, 1997). Managerial attention is needed to manage external relationships with R&D contractors. They have to be selected according to certain predefined criteria as well as to be constantly monitored and assessed. If R&D contractors fail to deliver a promised output, the client firm's management might even be required to step in and take tight control of the process. Further, management attention is required for redeploying internal and external knowledge resources. Management needs to recognize and implement promising combinations of internal and external knowledge resources. A failure to appropriately integrate acquired external knowledge may again increase the likelihood that the resource base of the firm suffers from dilution, making it less unique and easier for competitors to imitate. The demands on the client firm's management will rise considerably if a firm decides to engage heavily in R&D outsourcing, leading to a situation where firms neglect other relevant innovation activities. As a result, due to limited management attention, there is a tipping point at which R&D outsourcing becomes disadvantageous. The cost of managing external contractors as well as integrating and redeploying external knowledge then outweigh the benefits.

The above arguments suggest that R&D outsourcing is certainly beneficial to innovation performance in that firms may increase their efficiency, reduce costs, or foster innovation by getting access to valuable resources not available internally. However, we suspect that the dilution of the firm's resource base, the deterioration of integrative capabilities as well as the lack of management attention become particularly severe at a rather high degree of R&D outsourcing while the benefits should clearly excel the downsides at a rather low degree of R&D outsourcing. In other words, firms might "over-outsource" their R&D. This reasoning follows the arguments provided by Katila and Ahuja (2002) as well as Laursen and Salter (2006) who find that firms might "over-search" their environment for potential innovation impulses. As a result, we hypothesize that the effect of R&D outsourcing on innovation performance will initially be positive, that the returns to additional R&D outsourcing decrease with increasing R&D outsourcing and that the returns to additional R&D outsourcing become negative. This implies an inverse U-shaped relationship between R&D outsourcing and innovation performance. Our first hypothesis hence states:

Hypothesis 1 (H1): The relationship between R&D outsourcing and innovation performance is inverse U-shaped.

2.2 The moderating role of internal R&D

While the role of internal R&D activities as a source of innovation is undisputed, more recent research has stressed the importance of interactions between internally produced and externally acquired knowledge resources. In fact, there is considerable evidence that external knowledge acquisition increases the effectiveness of internal R&D in achieving innovation success (e.g., Cassiman and Veugelers, 2006; Lokshin et al., 2008). Based on the observation that firms often conduct internal and external knowledge acquisition activities simultaneously, Cassiman and Veugelers (2006) argue that these activities are complements, i.e. the marginal return to internal R&D increases with the intensity of R&D outsourcing. Conversely, internal R&D increases the effectiveness of external R&D for achieving innovation performance – a finding that relates to the importance of absorptive capacity of the firm (Cohen and Levinthal, 1989, 1990). A stock of prior knowledge is required to find and recognize relevant external knowledge so that it can be combined with existing knowledge resources (Todorova and Durisin, 2007). In other words, being a good "buyer" also requires being a good "maker" (Radnor, 1991; Veugelers and Cassiman, 1999). While Cohen and Levinthal (1989, 1990) have argued that absorptive capacity is closely linked to performing internal R&D activities, some authors have defined it more broadly as a dynamic capability that refocuses a firm's knowledge base through iterative learning processes (Szulanski, 1996; Zahra and George, 2002). From this it follows that the effectiveness of R&D outsourcing critically depends on the firm's in-house R&D capacities (Chatterji, 1996).

While the complementary relationship between internal and external R&D has been widely acknowledged, little is known about how internal R&D might also mitigate the negative effects from over-outsourcing on innovation performance. We have suggested that the negative effects from over-outsourcing materialize predominantly because of a lack of management attention in the process of resource redeployment, and because firms fail to transfer the tacit component of external knowledge, which is detrimental to their integrative capabilities. In this respect, performing R&D internally might be relevant in two ways. First, internal R&D creates firm-specific knowledge resources upon which the redeployment processes of external knowledge can be based (e.g., Barney and Mackey, 2005; Sirmon et al. 2007). This follows the logic that the firm-specificity of resources can been characterized as an isolating mechanism (Wang et al., 2009) in that they may not be easily traded, redeployed outside the firm, or imitated by competitors (Dierickx and Cool, 1989). The larger the internal stock of firm-specific knowledge resources, the higher the likelihood that combinations with acquired external knowledge will be unique, less generic and hence more valuable.

Second, similar to absorptive capacity that may be created through internal R&D activities, investments into internal R&D, and therefore learning by doing, create integrative capabilities (Weigelt, 2009). Integrative capabilities “sharpen” the firm management’s attention to recognize and deploy superior resource combinations. In this context, Kotabe (1990) finds that firms may lose relevant manufacturing process knowledge and innovative capabilities when they engage heavily in offshore sourcing of products and components. Performing internal R&D should prevent a loss of such knowledge and instead provide opportunities to learn as well as to build up skills and routines. Maintaining strong internal R&D activities also means that client firms retain the tacit knowledge necessary to discern and unfold the full potential of codified external knowledge (Weigelt, 2009). Assuming that there is competition for management attention among the different corporate functions, the management will presumably also stay focused on the effectiveness of the innovation process. As a result, higher management attention will be available in the process of resource redeployment, and the threat of a dilution of the firm’s resource base is reduced.

In conclusion, we expect the investments into internal R&D to positively moderate the inverse U-shaped relationship between R&D outsourcing and innovation performance. A positive moderation of an inverse U-shaped relationship results in a shift of the tipping point to the right. As a consequence, the tipping point is reached at higher levels of R&D outsourcing, allowing firms to benefit more from their investments into R&D outsourcing.[2] Our second hypothesis can hence be stated as:

Hypothesis 2 (H2): The relationship between R&D outsourcing and innovation performance is positively moderated by internal R&D expenditures, such that the tipping point from which additional R&D outsourcing has negative effects on innovation performance is reached at larger values of R&D outsourcing.

2.3 The moderating role of formal R&D collaboration

The effects from partnering in innovation projects, for example with customers, suppliers, competitors or universities and research institutes, have received considerable attention in the literature (e.g., Arora and Gambardella, 1990; Mowery et al., 1996). Such effects range from higher innovation success (Gemünden et al., 1992; Laursen and Salter, 2006; Love and Roper, 2004) to an increased novelty of innovations (Landry and Amara, 2002) as well as higher returns to R&D investments (Nadiri, 1993). In contrast to R&D outsourcing, where contractors deliver certain technological knowledge, collaborative R&D involves joint efforts of the partners and the co-creation of knowledge (Haagedorn et al., 2000). Apart from the direct effects of collaborative R&D, we also expect moderating effects of collaboration. Firms having collaborative agreements with a variety of external partners can be assumed to be more open to external knowledge (Chesbrough, 2003; Laursen and Salter, 2006). This openness may serve as a way to partially overcome the negative effects from over-outsourcing on innovation performance for at least two reasons: increased variety and increased experience.

First, more open firms will have a higher likelihood to be able to access a larger variety of knowledge resources from external partners. These collaboration partners have frequently been characterized as providing the firm with novel knowledge resources that may be redeployed within the firm. Customers, for example, are often considered to be especially valuable knowledge sources since their specific demands may be anticipatory for larger market segments in the future (von Hippel, 1988; Lukas and Ferrell, 2000). Although customer knowledge is oftentimes tacit, unarticulated and focused on the customer's own myopic needs (Frosch, 1996; von Zedtwitz and Gassmann, 2002), their contribution to product innovations might be substantial. Competitor knowledge, by contrast, is different with regard to its accessibility as competitors typically operate in a similar product and technology market (Dussauge et al., 2000). Their knowledge is frequently embodied in the products or services. This makes it easier to identify relevant aspects and to absorb them. At the same time, this reduces the novelty degree of competitor knowledge (Lukas and Ferrell, 2000).

Moreover, the importance of suppliers for the innovation process has been frequently acknowledged (e.g. Pavitt, 1984). By providing new materials, equipment and machinery, their knowledge enables the generation of novel products, services or processes. Critical parts of supplier knowledge are embodied in the products they deliver. Finally, universities and other public research institutes are primary producers of fundamentally new knowledge and technologies. The knowledge produced is frequently characterized by a high degree of novelty which provides important business opportunities (e.g. Cohen et al., 2002). In sum, given any degree of R&D outsourcing, higher variety in collaboration partners will be superior to less variety in achieving innovation performance as different partners will increase the likelihood of accessing novel and unique knowledge providing a better basis for valuable resource recombinations.

A second reason why collaborations might mitigate the negative effects from over-outsourcing is the experience that firms gain with a large variety of partnerships. Experience enables firms to build up routines and skills that facilitate activities in the "market for technology" (Arora et al., 2001). This will not only assist in the development of collaborative agreements when information is uncertain or incomplete. In fact, routines and skills that stem from collaborative experience can also help reducing the extent to which management attention is required in the process of resource redeployment. In this respect, firms will also be better able to manage R&D outsourcing relationships since they recognize superior resource deployments more easily. Moreover, collaborative experience might benefit the firm's ability to find suitable R&D contractors, to reduce informational asymmetries and to better manage and control the R&D outsourcing process. Experience might even substitute for the tacit knowledge component that is difficult to transfer from the R&D contractor to the client firm. It enables the firm to better understand cause-and-effect relationships surrounding externally acquired knowledge (Fichman and Kemerer, 1997). As a result, the negative effects of R&D outsourcing on integrative capabilities are reduced (Weigelt, 2009).

Given the above arguments, we expect the number of collaboration partners to positively moderate the inverse U-shaped relationship between R&D outsourcing and innovation performance. Hence, our third hypothesis reads:

Hypothesis 3 (H3): The relationship between R&D outsourcing and innovation performance is positively moderated by the firm's collaboration breadth, such that the *tipping point from which additional R&D outsourcing has negative effects on innovation performance is reached at larger values of R&D outsourcing.*

3 Methods

3.1 Data

We use longitudinal data from the German part of the European Union's Community Innovation Survey (CIS) to test our hypotheses. The survey is conducted annually by the Centre for European Economic Research (ZEW) on behalf of the German Federal Ministry of Education and Research. It is designed as a panel survey (Mannheim Innovation Panel, MIP) starting in 1993. The methodology and questionnaires used by the survey, which is targeted at enterprises with at least five employees, complies with the harmonized survey methodology prepared by Eurostat for CIS surveys. For our purpose, we construct a panel dataset by using the surveys conducted in the years 2001, 2005 and 2009, as our variables of interest are only available every four years.[3] The individual survey waves collect data on the innovation activities of enterprises during the three-year period before the survey year, e.g. the 2005 survey refers to the years 2002 to 2004. About 5,000 firms in manufacturing and services respond regularly to the German survey and provide information on their innovation activities. However, not all firms respond continuously to the survey which is why the resulting panel dataset is unbalanced.

CIS surveys are self-reported and largely qualitative which raises quality issues with regards to administration, non-response and response accuracy (for a discussion see Criscuolo et al., 2005). First, our CIS survey was administered via mail which prevents certain shortcomings and biases arising in telephone interviews (Bertrand and

Mullainathan, 2001). The multinational application of CIS surveys adds extra layers of quality management and assurance. CIS surveys are subject to extensive pre-testing and piloting in various countries, industries and firms with regards to interpretability, reliability and validity (Laursen and Salter, 2006; Tether and Tajar, 2008). Second, a comprehensive non-response analysis of the German survey for more than 4,200 firms did not indicate any systematic distortions between responding and non-responding firms with respect to their innovation activities (Rammer et al., 2005). In conclusion, the major advantages of CIS surveys are that they provide direct, importance-weighted measures. On the downside, this information is self-reported. Heads of R&D departments or innovation management are asked directly if and how their company was able to generate innovations. This immediate information on processes and outputs can complement traditional measures for innovation such as patents (Kaiser, 2002; Laursen and Salter, 2006; Tether and Tajar, 2008). We supplement the CIS data by patent data taken from the European Patent Office statistics (PATSTAT) and credit rating data taken from the VVC Creditreform business information service.

We restrict the sample to firms with product innovations because our dependent variable focuses on the market success of product innovations. Including firms that might have deliberately chosen not to innovate would otherwise be mixed up with firms whose product innovations had been unsuccessful.[4] In total, our panel data comprise 4,564 observations without missing values that refer to 3,966 different firms. Hence, on average every firm is observed 1.2 times which can be regarded as satisfactory given that we merge three survey years that span a time period of ten years.

3.2 Measures

Dependent variable

We use the share of sales with products new to the market as a dependent variable to measure innovation performance. The measure has frequently been used by related studies in the field (e.g., Cassiman and Veugelers, 2006; Laursen and Salter, 2006; Tether and Tajar, 2008). It provides direct information on the success of commercializing the firm's inventions and can thus be regarded as a success measure superior to patents since these constitute an intermediary output of R&D activities.

Main explanatory variables

We measure the extent to which firms outsource R&D by using the expenditures for external R&D divided by the firm's sales. Scaling a firm's external R&D expenditures by total sales is necessary in order to avoid estimating sheer firm size effects. Similarly, we use expenditures for internal R&D divided by sales. Both expenditure figures are part of the total innovation expenditures of the firm as defined by the Oslo Manual of the OECD (2005). Innovation expenditures that do not relate to either external or internal R&D constitute the reference category. This refers, for example, to the expenditure for innovation-related investments, i.e. machinery, equipment or software, plus other innovation related expenditure (marketing, testing, etc.).

We follow Laursen and Salter (2006) and measure the breadth of formal collaboration by using information on innovation-related collaboration partners. Respondents to the questionnaire were asked "Did your enterprise have any cooperation arrangements on innovation activities with other enterprises or institutions in the last three years?" A total of six different types of collaboration partners were listed from which respondents could choose (suppliers, clients/customers, competitors, consultants/commercial labs/private research institutes, universities/other higher education institutes, and government or public research organizations). These types of collaboration partners are mutually exclusive.[5] Innovation collaboration was defined as an "…active participation in joint innovation projects (including R&D) with other organizations." The variable for collaboration breadth is calculated so that a firm gets a value of zero if it did not collaborate with any type of partner and the value of six if it collaborated with all types of partners.

Control variables

We control for a number of other factors that might be relevant in the model for innovation performance. First of all, we account for the size of the innovation-related activities of the firm by including the total amount of innovation expenditures as defined by the OECD in logs. Some firms did not report any innovation expenditures which is why taking the log would lead to missing values. We therefore set the value of the variable for these firms to zero and include a dummy variable indicating that a firm reported to have made no innovation expenditures. This procedure corresponds with standard practices in econometrics (e.g., Greene, 1993). Moreover, we include the firm's patent stock in logs to account for a facet of the firm's absorptive capacity, i.e. the accumulated prior knowledge base of the firm. The patent stock is calculated using the perpetual inventory method with a discount factor of 0.15 as is standard in the literature (e.g., Hall, 1990).[6] As many firms do not have any patent at all, using the logarithm would again lead to missing values. For firms without patents, we therefore set the value to zero and include an additional dummy variable indicating whether firms have patents at all. The skills of the firm's employees are another facet of absorptive capacity which is why we include the share of employees with college education relative to the industry average.

Further, we include the share of sales that result from exports. This variable can be regarded as a proxy for the extent to which a firm faces international competition (Bhattacharya and Bloch, 2004; Cassiman and Veugelers, 2006). A firm's propensity to innovate can also be influenced by the availability of financial resources (Bond et al., 2006; O'Sullivan, 2005). We therefore include a measure of the firm's credit rating. It is calculated by VVC Creditreform, an independent business information service firm, based on a firm's asset, earnings, and liquidity situation, the business sector risk, as well as payment and debt service behavior. It is scaled from 100 (excellent credit standing) to 600 (hard negative features, cessation of payments). As the variable is skewed, we take its value in logs. Again, when no credit rating was provided by VVC Creditreform, we set the value of the variable to zero and included an additional dummy to control for this fact. Moreover, we include a dummy variable indicating whether the firm is part of a group. As younger firms tend to be more innovative than older firms in order to successfully enter a market (Bhattacharya and Bloch, 2004; Rammer et al., 2005), we include the firm age in logs.

Finally, we control for regional differences between East and West Germany, for firm size (number of employees in logs and in squared terms to allow for non-linearities) and for industry effects. A regional control is necessary as most parts of East Germany are still lagging behind West Germany in terms of infrastructure and economic growth. Although the effect of firm size on innovation has been found to be ambiguous, size is typically included in studies on innovation performance (Cohen, 1995). Sector differences in the propensity to invest into innovation activities (e.g., Cohen et al., 2000;

Malerba, 2005) are accounted for by 25 industry dummies based on the NACE industry classification system (for details see Table A-I in the Appendix). Because we are using data from three survey years, we also include year dummies.

3.3 Econometric model

Model choice

We use a random-effects panel tobit model to analyze innovation success. We choose a tobit model since our measure for innovation success is heavily left-censored – many firms do not have any market novelties and thus no sales from this type of innovation. Tobit models adequately account for this specific feature of our data by treating firms without market novelties differently from firms with market novelties. We choose a random effects model since the alternative fixed effects approach is not feasible with the data we have at hand as it requires at least three consecutive observations per firm.[7]

We estimate four model specifications to explain innovation performance: first, a baseline model (model 1) where we just include the linear terms for expenditures on external and internal R&D over sales as well as all control variables. In model 2, we augment our baseline specification by adding a squared term for external R&D expenditures over sales in order to test the over-outsourcing hypothesis (H1). A significant positive coefficient of the linear term and a significant negative (or at least jointly significant) coefficient of the squared term indicate that the relationship between R&D outsourcing and innovation performance is inverse U-shaped. In models 3 and 4, we test the hypotheses that internal R&D (H2) and collaboration breadth (H3) moderate this inverse U-shaped relationship. We test these hypotheses by interacting the linear term for external R&D expenditure over sales with the internal R&D expenditure over sales (H2) and the index variable on collaboration breadth (H3). A significant positive coefficient of the interaction terms will indicate that our hypotheses receive support – it also indicates that the moderating variables and external R&D are strategic complements. We will also show the results graphically and calculate the resulting tipping points.

Robustness check

The results presented may be subject to sample selection since they refer to innovating firms only. Hence, we re-estimate our regression and apply a parametric correction for sample selection (Heckman, 1979), i.e. the models include a correction term ("inverse Mill's ratio"). More precisely, Heckman (1979) proposes a two-step estimator, where a selection equation is estimated in a first step and the equation of interest is estimated in a second step, now including the inverse Mill's ratio which is calculated based upon the first stage regression results. In this respect, the first stage model is an equation for being innovative, i.e. having introduced a new product, which is estimated using a probit model. As the selection model is identified via the functional form (Greene, 1993), the regression includes the same set of previously mentioned control variables. We will discuss the results from the selection model in the following section while detailed results tables are available from the authors upon request.

4 Results

4.1 Descriptive statistics

Our results section starts with descriptive statistics of our dependent variables and our explanatory variables displayed in Table I. The table shows that roughly one third of the firms in our sample conduct R&D outsourcing. The table also reveals considerable differences between both groups of firms. Outsourcing firms have a better innovation performance as evidenced by the higher share of sales that results from products new to the market. Outsourcing firms spend two percent of their sales on R&D outsourcing and eight percent on internal R&D activities while non-outsourcing firms spend only six percent on internal R&D. Outsourcing firms have a higher collaboration breadth and substantially higher total innovation expenditures. Interestingly, the patent stock is higher for non-outsourcing firms which indicates that these firms rely more on internal technology development and its protection through patents despite the lower R&D intensity in comparison to outsourcing firms. Moreover, the share of employees with college education over industry average is higher in non-outsourcing firms, another indication that these firms rely more on internal resources. While both groups of firms have a similar credit rating, outsourcing firms are more often part of a company group. They are also slightly older and roughly double the size of non-outsourcing firms, thus reinforcing our decision to scale R&D expenditures by total sales. Finally, around 30 percent of the firms in both groups are located in East Germany.

Insert Table I about here

Table A-I in the Appendix shows the descriptive statistics for the industry dummies. Table A-II reports the pairwise correlations. It turns out that there is no indication for multicollinearity or even strong correlation between the explanatory variables in the model. The mean variance inflation factor (VIF) is 1.41 and the condition number

21.40, which is well below the respective critical values of 10 and 30 (Belsley et al., 1980).

4.2 Regression results

Table II displays the results from the random effects tobit regression models. The “rho” coefficient at the bottom of the table indicates the percentage contribution of the panel-level variance component to the total variance. The statistically significant coefficient, as shown for all four model specifications, indicates that using panel data estimation is superior to pooled estimation.

Model 1 presents our baseline model with the linear terms of our focus variables. It turns out that R&D outsourcing and collaboration breadth both positively and significantly affect innovation performance. There is no statistically significant effect of the share of internal R&D expenditures over total sales in any of our models. Note, however, that internal R&D expenditures are part of total innovation expenditures whose effect is statistically highly significant in all specifications.

Model 2 includes the squared term for R&D outsourcing. As hypothesized, the coefficient on the squared term is negative which, together with the positive coefficient on the linear term, suggests an inverse U-shaped relationship with innovation performance. Hence, over-outsourcing in fact occurs and Hypothesis 1 receives full statistical support.

Model 3 additionally includes the interaction term between R&D outsourcing and internal R&D. We find a significantly positive relationship of this term with innovation performance which indicates that the negative effects from over-outsourcing can indeed be mitigated by investing more into internal R&D. Hypothesis 2 therefore receives empirical support as well.

Model 4 includes the interaction term between R&D outsourcing and collaboration breadth. As before, we find a positive and significant relationship with innovation performance which provides support for Hypothesis 3: a higher engagement into formal R&D collaborations serves as an instrument to mitigate the negative consequences of over-outsourcing. We do not run specifications where we include all interactions due to the high correlation between the different interaction terms.

Insert Table II about here

The effect of the interaction terms on the inverse U-shaped relationship between R&D outsourcing and innovation performance can also be illustrated graphically. Figure 1 and Figure 2 show how increasing internal R&D and the breadth of collaborative activities influence the effect of R&D outsourcing.

Insert Figure 1 about here

Figure 1 displays the relationship between external R&D and innovation performance and the moderating effect internal R&D has on that relationship. The solid line shows the baseline case of no internal R&D expenditures (no moderating effects). The dashed line shows the relationship for the 95 percent percentile, i.e. the five percent most R&D intensive firms. The dotted line represents the relationship for the 99 percent percentile, i.e. the one percent most R&D intensive firms. Higher internal R&D expenditures shift the tipping point towards larger amounts of external R&D spending. The maximum total effect of external R&D on innovation success is reached at a ratio of external R&D to sales of 0.87 for firms without internal R&D spending. The effect of external R&D becomes negative for a spending ratio of 1.75. The tipping points, i.e. the maxima, are reached at a spending ratio of 0.90 for the five percent largest internal R&D spenders and at 0.96 for the one percent largest spenders. The "negativity points", where R&D outsourcing has an absolute negative effect, are reached at spending ratios of 1.75, 1.8 and 1.92 respectively for firms without any internal R&D, for the five percent and for the one percent largest spenders.

Insert Figure 2 about here

A similar picture arises in Figure 2. Higher collaboration breadth, as measured by the ten percent most collaboration active firms (i.e. more than three collaborations) moves the maximum from 0.64 to 0.95.[8]

Our estimates for the tipping points are to be related to an average ratio of R&D outsourcing to total sales for firms that engage in R&D outsourcing at all. The 90 percent percentile is 0.04, the 99 percent percentile is 0.38. The tipping points are hence rarely reached. This suggests that most firms act rationally and stop engaging in R&D outsourcing before the adverse effects materialize. It also suggests that most firms still realize comparatively large returns to additional external R&D spending since the concave relationship of external R&D and innovation performance implies decreasing returns to additional external R&D. However, our moderating variables are not only statistically highly significant but also economically important as both internal R&D and collaboration breadth improve the effectiveness of R&D outsourcing. Besides shifting the tipping points, R&D outsourcing also becomes more effective already at lower levels of R&D outsourcing because the slope is steeper. This provides additional support to Hypothesis 2 and Hypothesis 3.

Table II also shows interesting results for our control variables. Generally speaking, the results for the control variables remain very stable across the four model specifications. Our first control variable is the total innovation expenditure of the firm for which we find a positive and significant effect on innovation performance in accordance to our expectations. In contrast to this, we cannot substantiate a significant effect of the patent stock. Part of this might be due to the fact that the total innovation expenditures already represent an important facet of firms' investment into technology development. However, we find that the share of employees with college education relative to the industry average has a positive and significant effect on innovation performance which substantiates the importance of human capital. Moreover, Table II shows that a higher export share of sales propels innovation performance, which is what we expected. We do not find a significant effect of credit ratings and hence the firm's financial standing on innovation performance nor do we find that being part of a company group has an effect on innovation performance. In contrast to this, both firm age and firm size have a negative linear relationship with innovation performance. Apparently, younger and smaller firms succeed in being more innovative which is not surprising, particularly with respect to young firms, since they typically require innovations in order to successfully enter a market. Finally, our findings indicate that firms from East Germany are less successful than their West German counterparts.[9]

As indicated in Section 3.3, we perform a robustness check to control for a potential selection bias since we limit our analysis to innovating firms. We obtain a correction term (inverse Mill's ratio) that is subsequently added as a regressor to the random effects tobit models. We find that the correction term is statistically significant in all models, which suggests that a model without this term would suffer from sample selection. However, we find that all our results are robust to the inclusion of the selection term as the obtained coefficients only change marginally. Hence, our results can be regarded as unaffected by sample selection.

5 Discussion

This study provides new insights into the effects that R&D outsourcing has on a firm's innovation performance. Our findings suggest important implications both for research and management which will be delineated in the following sections.

5.1 Implications for research

We have argued that R&D outsourcing serves as an instrument to access external knowledge resources that can subsequently be redeployed with internal knowledge of the firm such that the combination will be firm-specific, unique and hence valuable for achieving innovation performance. This deliberate resource deployment process within the firm has been described as an isolating mechanism that protects the resources from imitation by competitors (Barney and Mackey, 2005; Sirmon, et al., 2007). At the same time, we have argued that relying heavily on R&D outsourcing might actually hurt innovation performance because it decreases the firm's integrative capabilities and leads to a dilution of the firm's resource base, making it less unique and thus more prone to imitation by competitors. Moreover, R&D outsourcing makes high demands on management attention. Our results in fact suggest that over-outsourcing of external R&D may occur: the relationship between the firm's investments into R&D outsourcing and innovation performance is inverse U-shaped. There hence exists a "tipping point" from which increasing R&D outsourcing further leads to negative additional returns to innovation performance.

In addition, we adopt a contingency perspective and search for moderating variables that move the tipping point towards higher levels of R&D outsourcing. The rationale for these moderating variables follows immediately from the discussion of valuable resource deployments. First, we suggest that internal R&D mitigates the negative effects from over-outsourcing. The complementary nature of internal and external R&D is in fact widely acknowledged in the literature (e.g., Cassiman and Veugelers, 2006). Internal and external R&D mutually reinforce their effectiveness for achieving innovation performance so that the resulting performance is superior compared to the case of spending all expenditures on either internal or external R&D. Little is known in the literature, however, about the moderating effect of internal R&D on the inverse U-shaped relationship between R&D outsourcing and innovative performance. We find that internal R&D is in fact capable of shifting the threshold from which R&D outsourcing becomes disadvantageous towards higher levels of external R&D. This result can be attributed to the fact that internal R&D serves on the one hand to generate firm-specific resources that can subsequently be deployed with external knowledge and on the other hand to build integrative capabilities. As a result, internal R&D enhances the effectiveness of R&D outsourcing and mitigates the negative effects from over-outsourcing. In this respect, our paper provides additional aspects to the tried and true argument on complementarity between internal and external R&D.

Second, we suggest that the breadth of formal R&D collaborations moderates the inverse U-shaped relationship between R&D outsourcing and innovation performance. Firms with a large number of collaborative agreements are more open to external knowledge (Laursen and Salter, 2006). This openness leads to a higher variety of external knowledge so that more novel knowledge resources are available for redeployment with outsourced R&D. Moreover, gaining experience from collaborative agreements also serves as an instrument to facilitate interactions with R&D contractors. The resulting skills and routines can subsequently be used to lower the required management attention in the resource deployment process, enabling a larger extent of deployment processes which increases the effectiveness of R&D outsourcing on innovation performance. Our research also confirms prior findings which have suggested that experience may compensate for a lack of tacit knowledge (Weigelt, 2009). In this regard, our research underlines the critical importance of collaboration in R&D as a way to increase the variety of external knowledge which may be translated into unique and firm-specific knowledge resources.

5.2 Implications for management

Our results are immediately relevant for the management of R&D outsourcing processes. First of all, managers should be aware that R&D outsourcing can become disadvantageous if firms rely heavily on external knowledge. The threshold from which R&D outsourcing becomes negative is firm-specific and largely depends on the internal knowledge base of the firm. The more a firm co-invests into internal resource creation and integrative capabilities, the higher the chances that over-outsourcing can be prevented. Besides the obstacles that are associated with the process of R&D outsourcing itself – i.e. allocation of Intellectual Property Rights, informational asymmetries, steering and control problems, potential “not invented here” syndromes – our findings call for a thorough examination of the firm’s internal resource base before R&D is contracted out. The management should not only identify knowledge gaps that are intended to be filled by the R&D contractor but also specify how internal and external knowledge resources can be redeployed in order to achieve a combination superior to that of competitors. Planning ahead should also improve the availability of management attention in the process of resource deployment which should eventually lead to more unique knowledge resources.

At the same time, our research has demonstrated that joint R&D projects with a variety of external partners can be used to complement R&D outsourcing in that diverse collaboration leads to a higher diversity of the accessed knowledge resources. Integrating these into the organizational knowledge base also benefits the effectiveness of R&D outsourcing in that more opportunities for firm-specific resource deployments arise. Firms should therefore not only rely on R&D outsourcing but complement it with collaborative R&D. These collaborations should not be too narrow but instead be used to get access to a variety of potential knowledge sources. Once established, collaborations should deliberately be used to build up experience on how to manage the process of external knowledge acquisition. Moreover, firms should consider the need for tacit knowledge for integrating the external knowledge and how a lack of it might be compensated. In this respect, Mayer and Argyres (2004) argue that contracts with external partners may serve as repositories for knowledge on how to collaborate. As a result, the more experience a firm acquires with collaborative R&D, the more R&D outsourcing will benefit in that routines can be created that facilitate resource redeployment and sharpen management attention.

Our results indicate, however, that the tipping points occur at rather high levels of R&D outsourcing relative to total sales. This suggests that most firms will typically not encounter the negative effects from over-outsourcing. Nevertheless, in order to improve their R&D outsourcing effectiveness, it makes sense for firms to constantly scrutinize the R&D outsourcing activities and use internal R&D and collaboration in order to benefit from the higher returns to R&D outsourcing arising from these moderating factors.

6 Conclusion and further research

Our research extends and contributes to the literature in three main ways. First, we extend the findings of Cassiman and Veugelers (2006) by accounting for the actual scale of R&D outsourcing versus internal R&D. We find that firms may over-outsource but that there is also a moderating effect between internal R&D and the inverse U-shaped relationship between R&D outsourcing and innovation performance. Second, we identify the breadth of formal collaborations as another central moderating variable. In this respect, we combine three major modes of knowledge generation and technology acquisition, i.e. internal, external and collaborative R&D. We show that these modes interact in the way they influence innovation performance and that this interaction is complex. Third, we apply a longitudinal framework to take account of firm-specific unobserved heterogeneity that would be left unaccounted for in a cross-sectional analysis. Our data span a period of ten years. Moreover, we account for a potential sample selection bias as we restrict our analysis to innovating firms.

Nevertheless, we leave ample opportunities for further research. We suggest that future research takes more explicitly account of the different knowledge acquisition modes, integrating not only internal, external and collaborative R&D but also firm acquisitions or the in-licensing of technology. It will, however, be challenging to find suitable measures especially if R&D cannot be easily disentangled from other activities as in the case of firm acquisitions. The challenges arising from R&D outsourcing at offshore locations are another aspect that we have neglected in our study. On the one hand, transaction costs can be expected to be higher as contractual relations become more complex. On the other hand, the production costs of knowledge might be lower due to differences in wages. In this respect, countries like India with a skilled workforce may succeed in attracting these high value functions. Moreover, the open innovation logic suggests that offshore locations provide more diverse knowledge which in turn may increase the value of a firm's resources.

Endnotes

[1] In the following, we will use the terms R&D outsourcing and external R&D interchangeably which is in line with the Oslo Manual of the OECD for measuring innovative activity (OECD, 2005).

[2] Conversely, a negative moderation would shift the tipping point to the left, making R&D outsourcing less beneficial to firms.

[3] In fact, CIS surveys are conducted in all 27 EU member states and some neighboring countries every four years only. Conducting innovation surveys in the remaining years is left to the discretion of the individual member states. For Germany, the number of questions is significantly reduced for surveys in non-CIS years in order to reduce the effort for participating firms.

[4] In a robustness check described in Section 3.3 we explicitly account for a potential sample selection bias.

[5] Max Planck institutes, for example, clearly belong to the category "government or public research organizations". They are no university but at the same time public and non-profit, as opposed to the collaboration partner "consultants/commercial labs/private research institutes", which are private and for-profit organizations.

[6] We use data on patent applications. Dating patents according to their application date as opposed to the granting date conforms to common practice (e.g. Griliches, 1981). The application date has the advantage of being closer to the actual completion of the invention.

[7] Moreover, the "within" variations of the dependent variable and the explanatory variables – the changes in these variables over time for a specific firm – is very low which makes it impossible to identify the parameters in any fixed effects model. Honoré (1992) suggests a fixed effects tobit estimator which has, however, rarely been used (despite its availability in standard econometric software) precisely because it requires a large "within" variation.

[8] Note that the maxima and the negativity points differ between the specifications. This is due to the fact that external R&D enters the specifications in different functional forms.

[9] Results concerning the industry dummies can be obtained from the authors upon request.

References

Amit, R. and P.J.H. Schoemaker (1993). 'Strategic Assets and Organizational Rent. *Strategic Management Journal* **14**, 33-46.

Arora, A. and A. Gambardella (1990). 'Complementarity and External Linkages: The Strategies of the Large Firms in Biotechnology'. *Journal of Industrial Economics* **38**, 361-379.

Arora, A., A. Fosfuri and A. Gambardella (2001). *Markets for Technology: Economics of Innovation and Corporate Strategy*, MIT Press, Cambridge MA.

Arnold, U. (2000). 'New Dimensions of Outsourcing: A Combination of Transaction Cost Economics and the Core Competencies Concept'. *European Journal of Purchasing and Supply Management* **6**, 23-29.

Arrow, K.J. (1962). 'Economic Welfare and the Allocation of Resources for Invention'. In R. R. Nelson (ed), *The Rate and Direction of Inventive Activity: Economic and Social Factors*, Princeton, NJ, 609-625.

Barney, J.B. (1991). 'Firm Resources and Sustained Competitive Advantage'. *Journal of Management* **17**, 99-120.

Barney, J.B. and T.B. Mackey (2005). 'Testing Resource-Based Theory'. In Ketchen, D.J. and D.D. Bergh (eds). *Research Methodology in Strategy and Management*, Elsevier: Greenwich, CT, 1-13.

Barthélemy, J. and B.V. Quélin (2006). 'Complexity of Outsourcing Contracts and Ex Post Transaction Costs: An Empirical Investigation'. *Journal of Management Studies* **43**, 1775-1797.

Bhattacharya, M. and H. Bloch (2004). 'Determinants of Innovation'. *Small Business Economics* **22**, 155-162.

Belsley, D.A., E. Kuh and R.E. Welsh (1980). *Regression Diagnostics: Identifying Influential Data and Sources of Collinearity*, New York.

Bertrand, M. and S. Mullainathan (2001). ‘Do People Mean What They Say? Implications for Subjective Survey Data’. *American Economic Review* **91**, 67-72.

Bond, S., D. Harhoff and J. Van Reenen (2006). ‘Investment, R&D and Financial Constraints in Britain and Germany’, forthcoming in *Annales d’Économie et de Statistique*.

Cassiman, B. and R. Veugelers (2002). ‘R&D Cooperation and Spillovers: Some Empirical Evidence from Belgium’. *American Economic Review* **44**, 1169-1184.

Cassiman, B. and R. Veugelers (2006). ‘In Search of Complementarity in the Innovation Strategy: Internal R&D and External Knowledge Acquisition’. *Management Science* **52**, 68-82.

Chatterji, D. (1996). ‘Accessing External Sources of Technology’. *Research Technology Management* **39**, 48-56.

Chesbrough, H.W. (2003). *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Boston.

Cohen, W.M. and D.A. Levinthal (1989). ‘Innovation and Learning: The Two Faces of R&D’. *The Economic Journal* **99**, 569-596.

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

Cohen W.M. (1995). ‘Empirical Studies of Innovative Activity’. In Stoneman, P. (ed), *Handbook of the economics of innovation and technological change,* Blackwell: Oxford, 342-365.

Cohen, W.M., R. R. Nelson and J. P. Walsh (2000). ‘Protecting their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or not)’. *NBER Working Paper*. Cambridge, MA.

Cohen, W.M., R.R. Nelson and J.P. Walsh (2002). ‘Links and Impacts: The Influence of Public Research on Industrial R&D’. *Management Science* **48**, 1-23.

Criscuolo, C., J.E. Haskel and M.J. Slaughter (2005). *Global Engagement and the Innovation Activities of Firms,* NBER Working Paper No. 11479, Cambridge, MA.

DeSarbo, W.S., C.A. di Benedetto, M. Song and I. Sinha (2005). ‘Revisiting the Miles and Snow Strategic Framework: Uncovering Interrelationships Between Strategic Types, Capabilities, Environmental Uncertainty, and Firm Performance’. *Strategic Management Journal* **26**, 47-74.

DeSarbo, W.S., C.A. di Benedetto and M. Song (2007). ‘A Heterogeneous Resource Based View for Exploring Relationships Between Firm Performance and Capabilities’. *Journal of Modeling in Management* **2,** 103-130.

Dierickx, I. and K. Cool (1989). ‘Asset Stock Accumulation and Sustainability of Competitive Advantage’. *Management Science* **35**, 1504-1511.

Doh, J.P. (2005). ‘Offshore Outsourcing: Implications for International Business and Strategic Management Theory and Practice’. *Journal of Management Studies* **42**, 695-704.

Dussauge, P., B. Garrette and W. Mitchell (2000). ‘Learning From Competing Partners: Outcomes and duration of Scale and Link Alliances in Europe, North America and Asia’. *Strategic Management Journal* **21**, 99-126.

Eurostat (2004). *Innovation in Europe. Results for the EU, Iceland and Norway.* Luxembourg.

Fichman, R. G. and C. F. Kemerer (1997). ‘The Assimilation of Software Process Innovations: An Organizational Learning Perspective’. *Management Science* **43**, 1345-1363.

Frosch, R.A. (1996). ‘The Customer for R&D is Always Wrong!’. *Research Technology Management* **39**, 22-25.

Gemünden, H., M. Heydebreck and R. Wijnberg (1992). ‘Technological Interweavement: A Means of Achieving Innovation Success’ *R&D Management* **22**, 359-376.

Grant, R.M. (1991). ‘The Resource-based Theory of Competitive Advantage: Implications for Strategy Formulation’. *California Management Review* **33**, 114-135.

Grant, R.M. (1996). ‘Toward a Knowledge-Based Theory of the Firm’. *Strategic Management Journal* **17**, 109-122.

Greene, W.H. (2003). *Econometric Analysis*. Upper Saddle River, NJ.

Griliches, Z. (1981). ‘Market Value, R&D and Patents. *Economics Letters* **7**, 183-187.

Hagedoorn, J., A.N. Link and N. Vonortas (2000). ‘Research Partnerships’. *Research Policy* **29**, 567-586.

Hall, B.H. (1990). ‘The Impact of Corporate Restructuring on Industrial Research and Development’. *Brookings Papers on Economic Activity*, 85-124.

Heckman, J.J. (1979). ‘Sample Selection Bias as a Specification Error’. *Econometrica* **47**, 153-161.

Helfat, C. E. and R. S. Raubitschek (2000). ‘Product Sequencing: Co-evolution of Knowledge, Capabilities and Products’. *Strategic Management Journal* **21**, 961-979.

Honoré, B. E. (1992). ‘Trimmed Lad and Least Squares Estimation of Truncated and Censored Regression Models with Fixed Effects’, *Econometrica* **60**, 533-565.

Howells, J. (1999). 'Research and Technology Outsourcing'. *Technology Analysis and Strategic Management* **11**, 17-29.

Howells, J. (2006). 'Outsourcing for Innovation: Systems of Innovation and the Role of Knowledge Intermediaries'. In Miozzo, M. and D. Grimshaw (eds.), *Knowledge Intensive Business Services: Organizational Forms and National Institutions*, Edward Elgar, Cheltenham, 61-81.

Howells, J., D. Gagliardi and K. Malik (2008). 'The Growth and Management of R&D Oursourcing: Evidence from UK Pharmaceuticals'. *R&D Management* **38**, 205-219.

Jaffe, A.B. (1986). 'Technological Opportunity and Spillovers of R&D: Evidence from Firms' Patents, Profits, and Market Values'. *American Economic Review* **76**, 984-1001.

Jahns, C., Hartmann, E. and L. Bals (2006). 'Offshoring: Dimensions and Diffusion of a New Business Concept'. *Journal of Purchasing and Supply Management* **12**, 218-231.

Kahn, E.J. (1986). *The Problem Solvers. A History of Arthur D. Little, Inc., Boston*. Toronto.

Kaiser, U. (2002). 'An Emprical Test of Models Explaining Research Expenditures and Research Cooperation: Evidence for the German Service Sector'. *International Journal of Industrial Organization* **20**, 747-774.

Kale P. and H. Singh (2007). 'Building Firm Capabilities Through Learning: The Role of the Alliance Learning Process in Alliance Capability and Firm-Level Alliance Success. *Strategic Management Journal* **28**, 981-1000.

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

Katz, R. and T.J. Allen (1982). 'Investigating the Not Invented Here (NIH) Syndrome. A Look at the Performance, Tenure, and Communication Patterns of 50 R&D Project Groups'. *R&D Management* **12**, 7-19.

Kogut, B. and U. Zander (1992). 'Knowledge of the Firm, Combinative Capabilities, and the Replication of Technology'. *Organization Science* **3**, 383-397.

Kotabe, M. (1990). 'The Relationship between Offshore Sourcing and Innovativeness of U.S. Multinational Firms: An Empirical Investigation'. *Journal of International Business Studies* **21**, 623-638.

Kuemmerle, W. (1998). 'Optimal Scale for Research and Development in Foreign Environments – An Investigation Into Size and Performance of Research and Development Laboratories Abroad'. *Research Policy* **27**, 111-126.

Landry, R. and N. Amara (2002). *Effects of Sources of Information on Novelty of Innovation in Canadian Manufacturing Firms: Evidence from the 1999 Statistics Canada Innovation Survey*, CHSFR/CIHR Working Paper, Department of Management, Laval University, Quebec.

Laursen, K. and A. Salter (2006). 'Open for Innovation: The Role of Openness in Explaining Innovation Performance among U.K. Manufacturing Firms'. *Strategic Management Journal* **27**, 131-150.

Leiblein, M.J. and D. Miller, J. (2003). 'An Empirical Examination of Transaction and Firm-Level Influences on the Vertical Boundaries of the Firm'. *Strategic Management Journal* **24**, 839-859.

Leiblein, M.J., J.J. Reuer and F. Dalsace (2002). 'Do Make or Buy Decisions Matter? The Influence of Organizational Governance on Technological Performance'. *Strategic Management Journal* **23**, 817-833.

Lewin, A.Y., S. Massini and C. Peeters (2009). 'Why are Companies Offshoring Innovation? The Emerging Global Race for Talent'. *Journal of International Business Studies* **40**, 901-925.

Lokshin, B., Belderbos, R. and M. Carree (2008): 'The Productivity Effects of Internal and External R&D: Evidence from a Dynamic Panel Data Model'. *Oxford Bulletin of Economics and Statistics* **70**, 399-413.

Love, J.H. and S. Roper (2002). 'Internal Versus External R&D: A Study of R&D Choice with Sample Selection'. *International Journal of the Economics of Business* **9**, 239-255.

Love, J.H. and S. Roper (2004). *Knowledge Sourcing, Innovation and Performance: A Preliminary Analysis of Irish Innovation Panel Data.* Aston Business School Working Paper, Birmingham.

Lukas, B. A. and O.C Ferrell (2000). 'The Effect of Market Orientation on Product Innovation'. *Journal of the Academy of Marketing Science* **28,** 239-247.

Mahoney, J.T. and J.R. Pandian (1992). 'The Resource-Based View Within the Conversation of Strategic Management'. *Strategic Management Journal* **13**, 363-380.

Malerba, F. (2005). 'Sectoral Systems: How and Why Innovation Differs Across Sectors'. In Fagerberg, J., D.C. Mowery and R.R. Nelson (eds), *The Oxford Handbook of Innovation*, Oxford University Press, 380-406.

Mayer, K.J. and N.S. Argyres (2004). 'Learning to Contract: Evidence from the Personal Computer Industry'. *Organization Science* **15**, 394-410.

Mowery, D.C., J.E. Oxley and B.S. Silverman (1996). 'Strategic Alliances and Interfirm Knowledge Transfer'. *Strategic Management Journal* **17**, 77-91.

Nadiri, I.M. (1993). *Innovations and Technological Spillovers,* NBER Working Paper No. 4423, Cambridge, MA.

Nagarajan, A. and W. Mitchell (1998). 'Evolutionary Diffusion: Internal and External Methods Used to Acquire Encompassing, Complementary, and Incremental Technological Changes in the Lithotripsy Industry'. *Strategic Management Journal* **19**, 1063-1077.

Nelson, R.R. and S.G. Winter (1982). *An Evolutionary Theory of Economic Change*. Cambridge, MA.

Ocasio, W. (1997). 'Towards an Attention-based View of the Firm'. *Strategic Management Journal* **18**, 187-206.

OECD (2005). *Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data* (3rd ed.). Paris: Organisation for Economic Co-operation and Development.

O'Sullivan, M. (2005). 'Finance and Innovation'. In Fagerberg, J., D.C. Mowery and R.R. Nelson (eds), *The Oxford Handbook of Innovation*, Oxford University Press, 240-265.

Pavitt, K. (1984). 'Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory. *Research Policy* **13**, 343-373.

Pisano, G.P. (1990). 'The R&D Boundaries of the Firm: An Empirical Analysis'. *Administrative Science Quarterly* **35**, 153-176.

Polanyi, M. (1967). *The tacit dimension*. Garden City, NY: Doubleday & Co.

Radnor, M. (1991). 'Technology Acquisition Strategies and Processes: A Reconsideration of the Make Versus Buy Decision'. *International Journal of Technology Management* **7**, 113-135.

Rammer, C., B. Peters, T. Schmidt, B. Aschhoff, T. Doherr and H. Niggemann (2005), *Innovationen in Deutschland. Ergebnisse Der Innovationserhebung 2003 in Der Deutschen Wirtschaft* **78**, Baden-Baden.

Sirmon, D.G., M.A. Hitt and R.D. Ireland (2007). 'Managing Firm Resources in Dynamic Environments to Create Value: Looking Inside the Black Box'. *Academy of Management Review* **32**, 273–292.

Slater S.F., E.M. Olson and G.T.M. Hult (2006). 'The Moderating Influence of Strategic Orientation on the Strategy Formation Capability-Performance Relationship'. *Strategic Management Journal* **27,** 1221-1231.

Szulanski, G. (1996). 'Exploring Internal Stickiness: Impediments to the Transfer of Best Practice within the Firm'. *Strategic Management Journal* **17**, 27-43.

Tapon, F. and C.B. Cadsby (1994). 'The Optimal Organization of Research: Evidence from Eight Case Studies of Pharmaceutical Firms'. *Journal of Economic Behavior & Organization* 31 (3), 389-399.

Tapon, F. and M. Thong (1999). 'Internal Versus External R&D: A Study of R&D Choice with Sample Selection'. *R&D Management* **29**, 219-231.

Teece, D.J. (1986). 'Profiting from Technological Innovation. Implications for Integration, Collaboration, Licensing and Public Policy'. *Research Policy* **15**, 285-305.

Teece, D.J. (1988). 'Technological Change and the Nature of the Firm'. In: Dosi, G., C. Freeman, R. R. Nelson, G. Silverberg and L. Soete (eds.). *Technical Change and Economic Theory*. London, New York, 256-281.

Teece, D.J. (1992). 'Competition, Cooperation, and Innovation: Organizational Arrangements for Regimes of Rapid Technological Progress'. *Journal of Economic Behavior and Organization* **18**, 1-25.

Teece, D.J. (2006). 'Reflections on "Profiting from Innovation"'. *Research Policy* **35**, 1131-1146.

Tether, B.S. and A. Tajar (2008). ‘Beyond Industry–University Links: Sourcing Knowledge for Innovation from Consultants, Private Research Organisations and the Public Science-base’. *Research Policy* **37**, 1079-1095.

Todorova, G. and B. Durisin (2007). ‘Absorptive Capacity: Valuing a Reconceptualization’. *Academy of Management Review* **32**, 774-786.

Veugelers, R. and B. Cassiman (1999). ‘Make and Buy in Innovation Strategies: Evidence from Belgian Manufacturing Firms’. *Research Policy* **28**, 63-80.

von Hippel, E. (1988). *The Sources of Innovation*, Oxford University Press.

von Zedtwitz, M. and O. Gassmann (2002). ‘Managing Customer Oriented Research’. *International Journal of Technology Management* **24**, 165-193.

Vorhies, D.W., R.E. Morgan and C.W. Autry (2009). ‘Product-Market Strategy and the Marketing Capabilities of the Firm: Impact on Market Effectiveness and Cash Flow Performance’. *Strategic Management Journal* **30**, 1310-1334.

Wang, H.C., J. He and J.T. Mahoney (2009). ‘Firm-Specific Knowledge Resources and Competitive Advantage: The Roles of Economic- and Relationship-Based Employee Governance Mechanisms’. *Strategic Management Journal* **30**, 1265-1285.

Weigelt, C. (2009). ‘The Impact of Outsourcing New Technologies on Integrative Capabilities and Performance’. *Strategic Management Journal* **30**, 595-616.

Wernerfelt, B. (1984). ‘A Resource-Based View of the Firm’. *Strategic Management Journal* **5**, 171-180.

White, S. (2000). ‘Competition, Capabilities, and the Make, Buy, or Ally Decision of Chinese State-Owned Firms’. *Academy of Management Journal* **43**, 324-341.

Zahra, S.A. and G. George (2002). ‘Absorptive Capacity: A Review, Reconceptualization, and Extension’. *Academy of Management Review* **27**, 185-203.

Figures and Tables (to be inserted into the text)

Figure 1: The effect of internal R&D on the relationship between R&D outsourcing and innovation performance

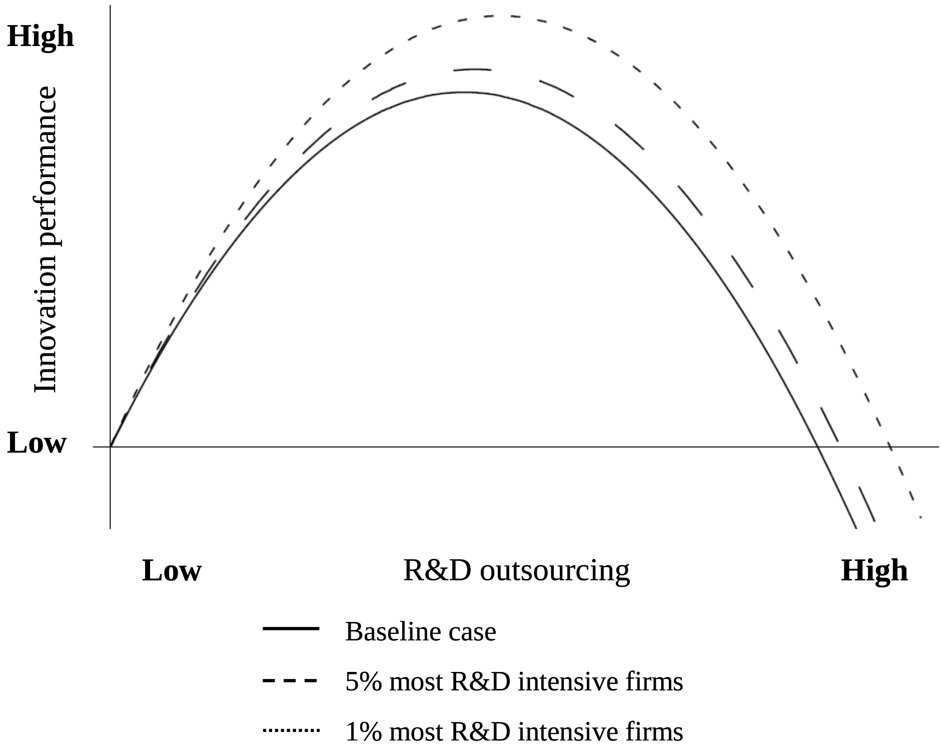

Figure 2: The effect of collaboration breadth on the relationship between R&D outsourcing and innovation performance

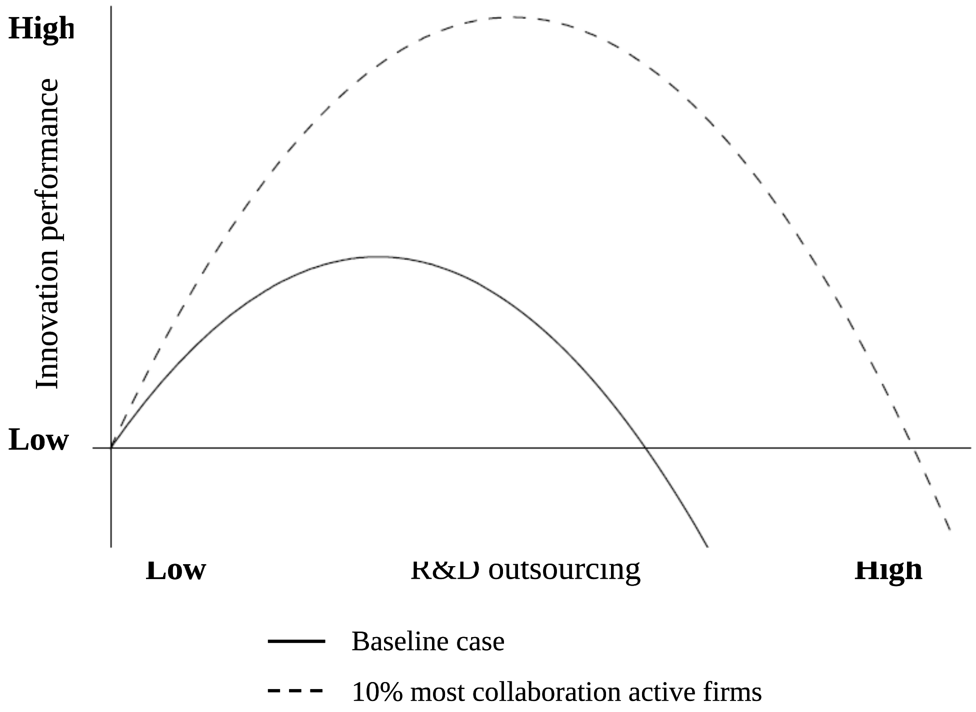

Table I: Descriptive statistics

Variable	All firms n = 4,564 Mean	S. D.	Engaged in R&D outsourcing n = 1,511 Mean	S. D.	Not engaged in R&D outsourcing n = 3,053 Mean	S. D.
Share of sales with products new to the market	0.085	0.170	0.106	0.183	0.075	0.162
Expenditures for R&D outsourcing as a share of sales	0.007	0.052	0.021	0.088	0.000	0.000
Expenditures for internal R&D as a share of sales	0.066	0.995	0.083	0.282	0.058	1.200
Collaboration breadth	0.844	1.407	1.650	1.710	0.446	1.015
Total innovation expenditure (kEUR)	3.011	11.431	6.045	16.329	1.538	7.622
Patent stock	1.945	80.754	1.594	9.792	2.119	98.500
Share of employees with college education relative to industry average	0.016	0.053	0.010	0.023	0.018	0.063
Sales from exports as a share of total sales	0.211	0.264	0.299	0.283	0.167	0.242
Credit rating (logs)	4.958	1.424	4.990	1.314	4.942	1.475
Part of a company group (d)	0.397	0.489	0.495	0.500	0.349	0.477
Firm age (years)	32.142	40.313	34.786	43.777	30.834	38.425
Firm size (number of employees)	250.580	579.217	378.655	729.420	187.192	475.617
Location in East Germany (d)	0.314	0.464	0.320	0.467	0.311	0.463

(d) dummy variable

Table II: Random effects tobit regression for innovation performance

Dependent Variable: Innovation performance	**Model 1 Coeff.**	**Model 2 Coeff.**	**Model 3 Coeff.**	**Model 4 Coeff.**
Focus variables				
Expenditures for R&D outsourcing as a share of sales	0.488***	1.090***	0.985***	0.945***
	(0.075)	(0.170)	(0.173)	(0.181)
Expenditures for R&D outsourcing as a share of sales squared		-0.471***	-0.567***	-0.728***
		(0.120)	(0.123)	(0.160)
Interaction (exp. for R&D outsourcing as a share of sales * exp. for internal R&D as a share of sales)			0.145***	
			(0.043)	
Interaction (exp. for R&D outsourcing as a share of sales * collaboration breadth)				0.146**
				(0.061)
Expenditures for internal R&D as a share of sales	0.003	0.003	0.001	0.003
	(0.004)	(0.004)	(0.004)	(0.004)
Collaboration breadth	0.017***	0.016***	0.016***	0.014***
	(0.003)	(0.003)	(0.003)	(0.003)
Control variables				
Total innovation expenditures (logs)	0.022***	0.020***	0.020***	0.020***
	(0.003)	(0.003)	(0.003)	(0.003)
Innovation expenditures > 0 (d)	0.089***	0.086***	0.085***	0.086***
	(0.012)	(0.012)	(0.012)	(0.012)
Patent stock (logs)	0.005	0.006	0.006	0.006
	(0.009)	(0.009)	(0.009)	(0.009)
Patent stock > 0 (d)	0.023	0.022	0.022	0.022
	(0.017)	(0.017)	(0.017)	(0.017)
Share of employees with college education relative to industry average	0.657***	0.662***	0.665***	0.663***
	(0.090)	(0.090)	(0.090)	(0.090)
Sales from exports as a share of total sales	0.121***	0.124***	0.121***	0.122***
	(0.019)	(0.019)	(0.019)	(0.019)
Credit rating (logs)	0.005	0.002	0.002	0.001
	(0.025)	(0.024)	(0.024)	(0.024)
Credit rating ≠ 0 (d)	-0.032	-0.015	-0.012	-0.009
	(0.135)	(0.135)	(0.134)	(0.135)
Firm age (years, logs)	-0.017***	-0.016***	-0.016***	-0.016***
	(0.006)	(0.006)	(0.006)	(0.006)
Part of a company group (d)	-0.010	-0.009	-0.009	-0.009
	(0.010)	(0.010)	(0.010)	(0.010)
Firm size (number of employees, logs)	-0.034**	-0.033**	-0.034**	-0.034**
	(0.016)	(0.016)	(0.016)	(0.016)
Firm size (number of employees, logs, squared)	0.001	0.001	0.001	0.001
	(0.002)	(0.002)	(0.002)	(0.002)
Location in East Germany (d)	-0.041***	-0.040***	-0.039***	-0.040***
	(0.010)	(0.010)	(0.010)	(0.010)
2 survey year dummies	Chi^2 (2)= 127.88	Chi^2 (2)= 127.60	Chi^2 (2)= 130.10	Chi^2 (2)= 129.49
24 industry dummies	Chi^2 (24)= 50.19***	Chi^2 (24)= 49.18***	Chi^2 (24)= 49.59***	Chi^2 (24)= 48.84***
Constant	0.036	0.023	0.022	0.020
	(0.042)	(0.042)	(0.042)	(0.042)
Observations	4564	4564	4564	4564
Wald Chi^2	715.58	733.70	747.42	741.00
Prob > Chi^2	0.000	0.000	0.000	0.000
Log (pseudo) likelihood	-1392.661	-1384.961	-1379.256	-1382.012
Rho	0.365***	0.358***	0.365***	0.364***
McFadden R^2	0.163	0.167	0.173	0.170

(d) dummy variable; standard errors in parentheses;
* significant at 10%; ** significant at 5%; ***significant at 1%

Appendix

Table A-I: Industry breakdown

		All firms		Engaged in R&D outsourcing		Not engaged in R&D outsourcing	
		n = 4,564		n = 1,511		n = 3,053	
NACE Code	**Industry**	**Mean**	**S. D.**	**Mean**	**S. D.**	**Mean**	**S. D.**
10 – 14	Mining and quarrying	0.006	0.077	0.005	0.073	0.006	0.079
15 – 16	Food and tobacco	0.036	0.187	0.023	0.150	0.043	0.203
17 – 19	Textiles and leather	0.025	0.155	0.021	0.144	0.027	0.161
20 – 22	Wood / paper / publishing	0.046	0.209	0.030	0.172	0.053	0.225
23 – 24	Chemicals / petroleum	0.059	0.236	0.076	0.265	0.051	0.220
25	Plastics / rubber	0.043	0.202	0.037	0.189	0.046	0.208
26	Glass / ceramics	0.025	0.157	0.031	0.174	0.023	0.149
27 – 28	Metal	0.070	0.256	0.074	0.262	0.068	0.253
29	Manufacture of machinery and equipment	0.103	0.303	0.146	0.353	0.081	0.273
30 – 32	Manufacture of electrical equipment and electronics	0.078	0.269	0.098	0.297	0.069	0.253
33	Medical, precision and optical instruments	0.074	0.263	0.117	0.322	0.053	0.225
34 – 35	Manufacture of motor vehicles	0.032	0.177	0.046	0.210	0.025	0.157
36 – 37	Manufacture of furniture, jewelry, sports equipment and toys	0.026	0.158	0.025	0.157	0.026	0.159
40 – 41	Electricity, gas and water supply	0.014	0.118	0.006	0.077	0.018	0.133
45	Construction	0.006	0.079	0.005	0.073	0.007	0.083
50, 52	Retail and motor trade	0.011	0.106	0.005	0.073	0.014	0.119
51	Wholesale trade	0.028	0.165	0.015	0.120	0.035	0.183
60 – 63, 64.1	Transportation and communication	0.035	0.183	0.023	0.148	0.041	0.197
65 – 67	Financial intermediation	0.035	0.185	0.017	0.128	0.045	0.207
70 – 71	Real estate activities and renting	0.011	0.105	0.007	0.081	0.013	0.115
72, 64.3	ICT services	0.067	0.249	0.061	0.239	0.069	0.254
74.1, 74.4	Consulting / advertising	0.031	0.174	0.011	0.102	0.042	0.200
74.5 – 74.8, 90	Other business-oriented services	0.037	0.189	0.020	0.140	0.046	0.209
92.1 – 92.2	Motion picture/broadcasting	0.008	0.088	0.004	0.063	0.010	0.099

Table A-II: Correlation matrix

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
1. Share R&D outsourcing	1.000														
2. Share internal R&D	0.083	1.000													
3. Collaboration breadth	0.149	0.030	1.000												
4. Total innovation exp. (logs)	0.089	0.047	0.261	1.000											
5. Total innov. exp. > 0 (d)	0.030	0.026	0.145	-0.155	1.000										
6. Patent stock (logs)	-0.007	-0.002	0.139	0.214	0.050	1.000									
7. Patent stock > 0 (d)	-0.005	0.001	0.151	0.210	0.055	0.455	1.000								
8. Share college graduates	0.031	0.038	0.024	-0.172	-0.021	-0.043	-0.065	1.000							
9. Share export sales	0.045	-0.004	0.199	0.320	0.131	0.210	0.271	-0.094	1.000						
10. Credit rating (logs)	-0.010	0.003	0.008	-0.003	0.007	0.005	0.026	-0.001	-0.040	1.000					
11. Credit rating ≠ 0 (d)	-0.017	-0.002	0.014	0.040	0.004	0.024	0.048	-0.027	-0.018	0.988	1.000				
12. Firm age (years, logs)	-0.063	-0.035	-0.034	0.111	-0.046	0.069	0.137	-0.161	0.119	0.184	0.252	1.000			
13. Part of group (d)	-0.027	-0.028	0.075	0.324	0.056	0.143	0.132	-0.144	0.197	-0.067	-0.031	0.068	1.000		
14. Firm size (employees, logs)	-0.041	-0.035	0.147	0.546	0.073	0.202	0.229	-0.388	0.276	0.005	0.077	0.298	0.499	1.000	
15. Location East Germany (d)	0.042	0.040	0.060	-0.139	0.042	-0.083	-0.076	0.081	-0.172	0.007	-0.033	-0.301	-0.146	-0.214	1.000

(d) dummy variable