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Gains and Pains from Contract Research: A Transaction and Firm-level Perspective

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Abstract

Determining the research and development (R&D) boundaries of the firm as the choice between internal, collaborative and external technology acquisition has since long been a major challenge for firms to secure a continuous stream of innovative products or processes. While research on R&D cooperation or strategic alliances is abundant, little is known about the outsourcing of R&D activities to contract research organizations and its implications for innovation performance. This paper investigates the driving forces of external technology sourcing through contract research based on arguments from transaction cost theory and the resource-based view of the firm. Using a large and comprehensive data set of innovating firms from Germany our findings suggest that technological uncertainty, contractual experience and openness to external knowledge sources motivate the choice for engaging in contract research activities. Moreover, we show that internal and external R&D sourcing are complements: the marginal contribution of internal (external) R&D is the larger the more firms spend on external (internal) R&D.

Keywords: Contract research, innovation, transaction cost theory, firm capabilities

JEL-Classification: O32, C24

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1 Introduction

Determining the boundaries of the firm has since long been a major topic of research from economic (e.g., Coase, 1937; Williamson, 1975; Klein et al., 1978) or organizational perspectives (e.g., Lawrence and Lorsch, 1967; Thompson, 1967; Galbraith, 1977). In this respect, particularly the research and development (R&D) boundaries of the firm have attracted attention (Pisano, 1990): to secure a continuous stream of innovative products or processes, internal research and development (R&D) activities are often not the only way to success. As the institutional loci of new technology can be diverse there is a high probability that at least from time to time firms need to source technology externally (Teece, 1986, 1992). In fact, a substantial body of literature deals with external technology sourcing through cooperative R&D arrangements or strategic alliances (see Hagedoorn, 2002, for an overview). Most of the research has focused on aspects related to knowledge spillovers, access to complementary knowledge, co-development or cost- and risk-sharing in innovation projects (e.g. Cassiman and Veugelers, 2002). Generally speaking, these seem to pay off: Brown and Eisenhardt (1997) find for example that strategic alliances used to access external knowledge lead to higher success in new product introduction activities.

While there are many benefits associated with collaborative R&D activities, they also may incur significant costs for the partners involved as they engage in joint research projects. Transaction cost theory provides the argument that an efficient governance of R&D activities will be achieved through markets unless this raises transaction costs that are higher than the costs of organizational arrangements (Brockhoff, 1992). R&D cooperation and strategic alliances obviously lead to transaction *and* organization costs as they comprise both a contractual relationship as well as organizational interfaces. Such arrangements can, in other words, be characterized as "hybrid" forms of organization which emerge as a way to economize on transaction costs when "parties to the transaction maintain autonomy but are bilaterally dependent to a nontrivial degree" (Williamson, 1991: 271). In their effort to optimize the innovation process, however, firms also need to find organizational arrangements for those tasks which encompass virtually no interaction with partners and hence do not cause organization costs. Moreover, there are tasks that can be characterized as an "ad-hoc problem solving" (Winter, 2003), i.e. they require a timely reaction on a closely contoured research project. Apart from that, a firm might wish to hold the sole right to exploit the research outcome and appropriate the returns once the project is finished (Teece, 1986). This case would argue for engaging in external technology sourcing through *contract research* and simply buying the solution on the market for research services. Contract research hence represents the opposite pole to internal R&D on the continuum from markets via hybrid to hierarchy. It can be defined as the contractually agreed, non-gratuitous and temporary performance of R&D tasks for a client by a legally and economically independent contractor, whereas the research outcomes will be transferred to the client with all specific exploitation rights upon completion of the task (Teece, 1988).

With a few exceptions, surprisingly little research has been devoted to the study of contractual research arrangements since the early 1990s (see Rüdiger, 2000, for an overview).

Other ways to source technology externally like R&D collaborations, strategic alliances or firm acquisitions have covered most research agendas. With technologies becoming ever more complex, especially in the high- and medium-technology industries, these governance modes actually seem to be much more suitable to achieve innovation success anyway. Contract research, though, still accounts for a substantial share of total innovation expenditure in a large number of firms (Eurostat, 2004). While alliance formation and firm acquisitions have been studied in detail (e.g., Villalonga and McGahan, 2005; Cassiman et al., 2005), comprehensive empirical evidence on what factors lead to engage in contract research is scarce. Moreover, several authors refer to transaction cost theory to elucidate specific transaction-level characteristics that influence the choice for alternative forms of governance (Veugelers and Cassiman, 1999; Love and Roper, 2002; Gooroochurn and Hanley, 2007). Existing literature, however, provides almost no indication for the role of firm-level differences in the choice for technology sourcing modes. This is particularly surprising given the common belief that firms largely differ in their resource endowment and capabilities (e.g., Wernerfelt, 1984; Barney, 1991) which should eventually influence R&D boundary decisions (Kogut and Zander, 1992; Leiblein and Miller, 2003). Moreover, Rothaermel et al. (2006) have pointed to complementarities between internal and collaborative R&D which also argues for a more detailed exploration of such effects between internal R&D and contract research. Even less is known about the performance implications, i.e. how contract research translates into innovation success. Contract research being used only for simple (and low-interest) projects would suggest that innovation expenditure is better spent elsewhere. Nevertheless, efficiently handling ad-hoc problems and economizing on organization costs might prove to be central for innovation success.

This paper addresses the above mentioned shortcomings of existing literature in two ways: first, it provides a conceptual model explaining the R&D governance mode from a transaction and firm-level perspective. Second, the governance choice with a particular focus on complementarities between the different modes is related to innovation success. Our econometric tests are based on a comprehensive data set of around 1,400 German firms engaged in contract research.

The remainder of this study is organized as follows: Section 2 gives a short overview on the motivation to externally contract research activities while Section 3 presents our conceptual considerations and the subsequent hypotheses. Section 4 highlights our empirical study to test the latter. Empirical results are presented in Section 5. We discuss our findings in section 6. Section 7 closes with concluding remarks.

2 Motives for engaging in contract research

Technological change as well as the geographic and organizational dispersion of expertise have led to a wide variety of organizational arrangements for the generation and acquisition of knowledge. Traditionally, outsourcing, i.e. the external provision of certain services, had been largely used for rather specialized or repetitive tasks like logistics or facility management. But over time also other value chain activities closely related to the core of the firm – like production – have become subject to outsourcing decisions (Leiblein et al., 2002; Leiblein and Miller, 2003), for example in the automotive industry where a whole model series of cars could be assembled by contract manufacturers. Contract research as the outsourcing of R&D activities basically follows the same logic in that it is directed at exploiting certain advantages associated with the nature and purpose of contract research organizations, whether they may be private firms or universities and research centers. The idea of contracting research to external firms or research institutes is not new. In fact, the consulting firm Arthur D. Little roots back to the year 1886 with the offering of "investigations for the improvement of processes and the perfection of products" (Kahn, 1986). Several potential benefits for firms engaging in contract research can be identified. However, it has to be recognized that these benefits also apply to a large extent to hybrid forms of organization, i.e. R&D collaborations or alliances.

A first group of advantages centers around a reduction of costs compared with the same R&D activities performed in-house. Cost advantages may be achieved by a specialization of the contract research organization or by a cost sharing in a joint commissioning of more than one client. Moreover, fixed costs could be reduced and R&D time and budget better controlled (Tapon and Thong, 1999). Besides cost aspects, quality advantages through contract research may be possible as the contract research organizations can employ specialized know-how, equipment and infrastructure. Using external sources should also foster creativity within internal R&D as new research methods and perspectives are brought in. Another advantage relates to timing issues and undivided attention that the project may receive. This could especially be important if the firm tries catching up with competitors in an area of technology where no or little competence is available internally (Tapon and Cadsby, 1994). Apart from this, firms might choose to deliberately install competition to stimulate internal R&D. Such form of competition could also prove to be helpful in overcoming internal resistance to innovation projects. Finally, firms could get access to public R&D funding more easily when they involve public contract research organizations like universities or research institutes (David and Hall, 2000) or when the R&D activities are carried out in particular regions (Tapon and Cadsby, 1994).

A substantial body of literature has dealt with contractual research arrangements from the perspective of universities and other public research institutes which have become important players on the market for research services in recent years (Bozeman, 2000; Link and Siegel, 2007). Universities or research institutes have a particular reputation as providing access to leading-edge technological knowledge resulting from projects that are more oriented towards basic research (Dosi et al., 2006). In the U.S., it was also the enactment of the Bayh-Dole Act in 1980 that spurred a rapid rise of commercial knowledge transfers from academia to industry (Stevens, 2004). On the one hand, existing research has focused on formal university technology transfer mechanisms, i.e. those that embody or directly lead to a legal instrumentality like a patent, license or royalty agreement (Bozeman, 2000; Siegel and Phan, 2005). On the other hand, informal university technology transfer mechanisms have attracted attention as they comprise informal communication processes, such as technical assistance, consulting or collaborative research (Link et al., 2006). Most of the research focuses on the role of technology licensing in industry-science linkages (e.g., Feldman et al., 2002; Thursby and Thursby, 2002). Licensing shows important similarities with contract research in that it serves as a mechanism for external technology acquisition without a joint research effort. Hence, licensing can be considered as a viable alternative to contract research with universities and research institutes to access innovative knowledge.[1] As a matter of fact, however, the contracting firm might experience difficulties in the appropriation of the returns of the licensed technology as the licensor is still the ultimate owner of the technology.

While contract research appears to have several advantages, there are also several problems associated with the external provision of R&D services: intellectual property rights as a result of such activities might be difficult to appropriate. Moreover, the contractual relationship involves information asymmetries in that potential contractors might – other than promised – lack the required expertise compared with a firm's own R&D department (Love and Roper, 2002). Contracting firms may also have considerable steering, control and confidentiality problems of the contracted research. They lose the opportunity to learn which leads to a situation where firms may critically depend on the contract research organization. Besides that, contract research might trigger a "not invented here" syndrome which would lead to a reluctance of in-house R&D to adopt external technology (Veugelers and Cassiman, 1999). Outsourcing those R&D projects that appear to be of high strategic relevance hence constitutes a risky strategy. Using a transaction cost framework, Teece (1988) consequently explains the reluctance of firms to rely heavily on external procurement of technological knowledge with contractual uncertainty, cumulative knowledge acquisition and a limited transferability of research outcomes. Similar arguments have been provided by Pisano (1990) and Brockhoff (1992). Contract research is hence supposed to be only a viable alternative to other governance modes for certain types of R&D activities, i.e. for rather simple and less strategically relevant research tasks.

According to the above mentioned arguments for and against contract research, transaction cost theory would suggest that markets are more efficient than hierarchies unless the costs of transacting with contract research organizations turn the relationship less favorable. Moreover, differences in a firm's R&D capabilities might influence the boundary decision to create valuable firm-specific knowledge. The following section will hence adopt a transaction and firm-level perspective to determine factors that lead firms to actually engage in contract research or not. Afterwards, the analysis focuses on the question how contract research translates into innovation success.

3 Conceptual framework

This section derives our set of empirically testable hypotheses adopting a transaction and firm-level perspective for the choice of governance modes. We then proceed with the hypotheses linking these modes with innovation success.

[1] It goes without saying that licensed-in technology may also originate from private firms.

3.1 Transaction cost theory and innovation activities

A large body of literature has successfully employed transaction cost economics to describe how the conditions of contractual relationships affect the optimal form of organization (e.g., Robbertson and Gatignon, 1998; Leiblein et al., 2002; Leiblein and Miller, 2003). Transaction cost theory suggests that it is the cost associated with the governance of such relations which is central to determining the choice for a particular form of coordination of a transaction (Klein et al., 1978; Williamson, 1979). Hence, a firm will select the form of coordination that is associated with the lowest level of cost. Regarding the sourcing of technology, the choice is typically between "market", resulting in transaction costs, and "hierarchy", resulting in organization costs. In other words, firms can choose between buying a technology at the market for research services and performing the required R&D activities in-house. The resulting trade-offs between internalizing and outsourcing firm activities have been analyzed in various settings (e.g., Walker and Weber, 1984; Leiblein et al., 2002). Besides these two poles, "hybrid" forms of governance like cooperative R&D arrangements or R&D alliances have been widely used by firms and studied by researchers (e.g., Pisano, 1990; Brockhoff, 1992; Cassiman and Veugelers, 2002; Aschhoff and Schmidt, 2006). However, the setup of organizational interfaces in R&D cooperation incurs organization costs that need to be balanced with an entirely external provision of R&D services through contract research which would lead to transaction costs exclusively.

Due to the benefits of specialization in the marketplace, applications of transaction cost theory generally assume that markets represent a more efficient governance mode than hierarchy (Leiblein and Miller, 2003). There are situations, however, in which the costs of market exchange may surpass the technical efficiencies of the market. More specifically, contract research incurs costs to negotiate and write the contract as well as costs to monitor and enforce the contractual performance (Williamson, 1975). Transaction cost theory hence focuses on the identification of exchange characteristics that would best be reflected in a market, hybrid or hierarchical organization. Adopting a rather abstract level of explanation, the two main factors driving the analysis have been identified as *uncertainty* and *asset specifity* (Williamson, 1985): transaction costs seem to increase with increasing uncertainty, and the necessity to rely on transaction-specific assets (Williamson, 1979; Englander, 1988). In combination with a certain behavior, which is characterized by bounded rationality and opportunism, these attributes or dimensions will hence largely determine the transaction costs associated with contractual research arrangements (Brockhoff, 1992).

Uncertainty

Uncertainty can be described as the degree to which unforeseen environmental change influences and alters the conditions underlying the contractual arrangement (Leiblein and Miller, 2003). Uncertainty raises transaction costs through a number of channels. First, a higher number of expected contingencies will presumably raise the effort to set up and enforce a contract. Moreover, uncertainty decreases the ability to assess the contribution of any individual activity which in turn increases the risk of shirking (Demsetz, 1988). Factors that may lead to a higher perceived uncertainty during the transaction include rapid changes in the technologies employed, a short product life cycle or a high threat from a substitutability of the own product by competitor products. Moreover, firms may have experienced failures in their innovation activities that could be related to the market or technology environment. Uncertainty can be met by hierarchical organization in that this form of governance facilitates an improved measurement, monitoring and control of the activities performed. Hence, the higher the perceived uncertainty the higher the transaction costs turn out to be and the less likely the choice of contract research instead of hierarchical organization becomes. Our first hypothesis hence is:

Hypothesis 1: Uncertainty related to the innovation activities increases transaction costs and thereby reduces the propensity to engage in contract research.

Specifity of assets

The second driving factor of transaction costs is the specifity of assets employed in the contractual relationship. It defines the degree to which the assets in a contractual research arrangement are more valuable in their current application than in their second best use (Leiblein and Miller, 2003). High levels of specific assets create opportunities for an appropriation or "hold-up" of quasi-rents by opportunistic contracting firms and contract research organizations. The suppliers of research services may be subject to a hold-up situation when the contract research requires buyer-specific investments resulting in few alternatives for the supplier (Williamson, 1985). This will in turn motivate a more complex negotiation and a higher level of contractual safeguards. Moreover, by deterring investments in other efficiency-improving assets fewer opportunities for the appropriation of quasi-rents arise. In this context, Williamson (1989) puts particular emphasis on "physical asset specifity" and "human asset specifity". Asset specifity will therefore presumably be higher when an innovation project starts from scratch, i.e. when no predecessor product had successfully been introduced to the market before. In this case, costly investments into physical and human assets will be required to establish a productive relationship. Again, hierarchical organization as an alternative can serve as basis for coping with asset specifity as the often-cited example of General Motors' integration of "Fisher Body", one of its key suppliers, illustrates (Klein et al., 1978). Our second hypothesis hence reads:

Hypothesis 2: Specifity of assets increases transaction costs and thereby reduces the propensity to engage in contract research.

While providing valuable insights, it has to be recognized that transaction cost economics makes quite restrictive assumptions leading to some implications which cannot be justified in reality. In this respect, firms facing a given set of transactional attributes would in equilibrium reach the same conclusion regarding the governance mode of their R&D activities. Several examples, however, show that this proposition does not hold in the real world, for example in the fashion industry where some firms rely on a vertically integrated structure while other firms confine themselves to design and marketing activities. Instead, a firm's specific history, existing portfolio of transactions as well as other firm-specific assets and capabilities could exert a substantial influence on the decision to outsource R&D activities (Leiblein and Miller, 2003). The optimal form of governance should thus depend on both the attributes of the transaction and the pre-existing strengths and weaknesses of the firm.

3.2 Firm-level effects and innovation activities

The resource and capability based view (RBV) of the firm provides an instrument to investigate the effect of firm-level capabilities on outsourcing decisions (Leiblein and Miller, 2003). Capabilities are organizational processes which bundle strategic resources into unique combinations and constitute superior performance themselves (Eisenhardt and Martin, 2000). This follows the basic rationale that competitive advantage does not only arise from the possession of strategic resources but also from the way in which they are used (Penrose, 1959). Two main aspects have been put forward by the RBV. First, firms are heterogeneous with respect to their resource and capability endowment. Second, valuable resources and capabilities are limited in supply. Their creation is costly and involves causal ambiguities (e.g., Barney, 1991). In contrast to transaction cost theory which focuses on the characteristics of rather isolated transactions and associated costs, the RBV centers around the search for competitive advantage that stems from an exploitation of unique firm attributes and R&D governance modes. Consequently, firms will strive to choose the governance mode that leverages the value of existing capabilities or that complements capabilities in a way that knowledge gaps can be bridged (Leiblein and Miller, 2003). This implies that firms need to be open to externally available knowledge resources. For example, Pisano (1990) analyzed an established US pharmaceuticals firm that wanted to commercialize a new biotechnology-related product. It had the choice between developing the required R&D capabilities in-house and relying on external R&D procurement by a biotechnology firm which was assumed to be more efficient in carrying out the R&D tasks.

Generally speaking, any firm-specific resource and capability may influence a firm's boundary decision in R&D. However, the RBV argues that particularly those activities will be carried out in-house where the firm possesses valuable and difficult-to-imitate capabilities. Zollo and Winter (2002) conceive the acquisition of such capabilities as a continuous and deliberate learning process. This process describes a firm's systematic methods for a modification of its operating routines. Such routines constitute stable patterns of organizational behavior and reaction on internal or external stimuli (Nelson and Winter, 1982). As a consequence, this process explains why, over time, some firms are more effective in implementing specific governance structures than others. The two driving factors of the analysis hence center around the concepts of *contractual experience* as well as *openness to external knowledge*.

Contractual experience

At first glance, recurring transactions with contract research organizations have a direct influence on transaction costs. Firms need to enter into contracts several times which requires negotiating efforts and a constant monitoring of the relationships. Over time, however, firms should be able to find efficient contractual arrangements to deal with a large number of recurring transactions. In fact, relatively high one-time costs upon establishment of a contractual relationship should enable firms to economize on later transactions as possible sources of conflict can be foreseen and avoided (Brockhoff, 1992). Moreover, firms may differ in their ability to select suitable contract research organizations as well as to negotiate and monitor the contract (Leiblein and Miller, 2003). Particularly those firms are presumably inclined to engage in outsourcing activities that have developed a refined contracting experience (state dependence). In this respect, recurring transactions foster a common understanding of routines, cultures, systems, and other firm characteristics (e.g., Gulati and Singh, 1998) as they lead to the development of relational capabilities (Dyer and Singh, 1998). Contracting experience hence supports the development of organizational routines directed at an efficient collaboration with a variety of partners (Leiblein and Miller, 2003). It has to be noted, however, that not only the number of contract research arrangements may be important but also whether or not firms engaged in hybrid forms of organizations like R&D collaborations. These should presumably serve as a way to acquire experience which could be beneficial for shaping a contract research relationship. Our third hypothesis therefore assumes:

Hypothesis 3: Contractual experience increases the propensity to engage in contract research.

Openness to external knowledge

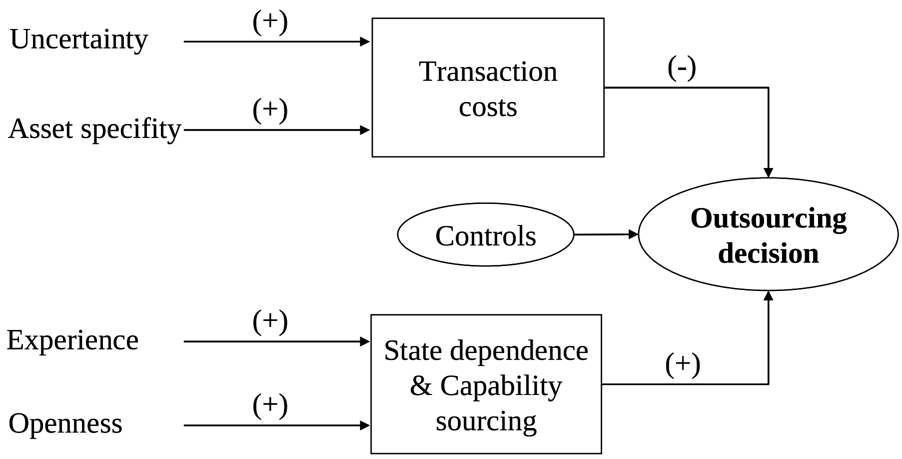
The RBV has made clear that unique knowledge resources, be they internal or external, are the most valuable assets of a firm for achieving competitive advantage (Liebeskind, 1996). Knowledge is crucial for firm success as it provides a platform for decisions on what resources and capabilities to deploy, develop or discard as the environment changes (Ndofor and Levitas, 2004). In this respect, recent literature has pointed towards the merits of acquiring external knowledge (Tsang, 2000) and moving from “research and develop” towards “connect and develop” (Huston and Sakkab, 2006). The “open innovation” model by Chesbrough (2003) extends this perspective on how firms innovate. Shorter product life cycles as well as the growing complexity of technologies and markets motivate firms to use external sources of knowledge. Moreover, external sources have become more readily available as information and communication technologies have improved. Hence, firms that reach out to actors beyond firm boundaries will presumably be in a position to maximise the benefits from inventions and ideas (Rosenkopf and Nerkar, 2001). Contract research in this sense extends and enhances the value of a firm’s capabilities. Consequently, the openness should be triggered by a lack of qualified personnel or technological information which eventually materializes as a heightened demand for external knowledge and other external inputs in the innovation process (Fagerberg, 2005; Monjon and Waelbroeck, 2003; Peters, 2003). In fact, several studies have identified positive performance effects from incorporating external knowledge into firm capabilities. Such effects range from innovation success (Gemünden et al., 1992; Love and Roper, 2004) to increased novelty of innovations (Landry and Amara, 2002) as well as higher returns to R&D investments (Nadiri, 1993).

Nevertheless, it has to be considered that the openness to external knowledge resources also depends on the ability of a firm to recognize their potential value for the innovation process. This ability has been summarized as the absorptive capacity of firms (Cohen and Levinthal, 1990). External sources of knowledge need to be identified, activated and managed for innovation success (Gottfredson et al., 2005; Stock and Tatikonda, 2004). Absorptive capacity basically comprises a set of organizational routines (Zahra and George, 2002). It has three major components: the identification of valuable knowledge in the environment, its assimilation with existing knowledge stocks and the final exploitation for successful innovation. These continuous learning engagements increase awareness for market and technology trends, which can be translated into pre-emptive actions. Absorptive capacity provides firms with a richer set of diverse knowledge which gives them more options for solving problems and reacting to environmental change (Bowman and Hurry, 1993; March, 1991). As a result, absorptive capacity enables firms to predict future developments more accurately (Cohen and Levinthal, 1994). It is often developed as a by-product of R&D activities (Cohen and Levinthal, 1989). However, 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). In effect, absorptive capacity enables firms to find and recognize relevant external knowledge sources so that it can be combined, i.e. assimilated, with existing knowledge (Todorova and Durisin, 2007). This should in turn be reflected in the increased propensity to engage in contract research. Our fourth hypothesis hence reads as follows:

Hypothesis 4: Openness to external knowledge increases the propensity to engage in contract research.

Figure 1 summarizes our theoretical considerations regarding both the transaction and the firm-level factors influencing the decision to engage in contract research activities: an increase in uncertainty and asset specifity both increase transaction cost which in turn leads to a decrease in the probability of external technology sourcing, i.e. the outsourcing of R&D activities. An increase in experience and openness to external innovation stimuli both increase state dependence and external capability sourcing which leads to an increase in the probability of outsourcing. The outsourcing decision is also influenced by "control" variables like firm size or absorptive capacity.

Figure 1: Conceptual framework integrating transaction and firm-level perspectives



3.3 Governance modes and innovation performance

There are a number of studies that have investigated the factors influencing the choice between market and hierarchy in depth. However, little attention has been paid to performance implications of this choice. In fact, several studies examine the success impact of

R&D collaboration and alliances (e.g., Belderbos et al., 2004; Rothaermel et al., 2006) or the effect of outsourced non-R&D firm activities (e.g., Leiblein et al., 2002; Leiblein and Miller, 2003) on firm performance, but little is known about the relationship between contract research and innovation success, for example in terms of new products introduced to the market. This second step of our analysis hence relates the different governance modes with innovation performance. While the transaction cost arguments presented above might at least implicitly suggest that internal and external R&D are substitutes, it has long been recognized that both forms are rather complementary (Veugelers and Cassiman, 1999). Combining internal and external R&D hints at a particular mix of innovation expenditures that will be associated with a certain level of innovation success. In this sense, internal and external knowledge acquisition opens an extensive scope for complementarities to be realized. Although the governance modes thus need to be balanced carefully depending on the objectives associated with the activity (Rothaermel et al., 2006), existing literature has confined external R&D almost exclusively to collaborative R&D arrangements. In fact, this governance mode itself balances transaction and organization costs and has proven to be a successful knowledge acquisition strategy. Moreover, contract research being used only for rather simple (and low-interest) projects would suggest that collaborative R&D is indeed a better channel to spend innovation expenditure (Teece, 1988).

However, firms also need to find organizational arrangements for those tasks which require virtually no interaction with partners and hence do not cause organization costs. In the effort to optimize the innovation process, contract research might hence be an efficient way for handling ad-hoc problems and saving organization costs. In fact, literature has pointed to the importance of timing in innovation activities in the context of first mover and follower advantages (see for example Jensen, 2003; Lieberman and Montgomery, 1988; Shankar et al., 1998). Obviously, the purchase of external R&D services through contract research is often easier and faster to establish than R&D collaborations. Thus they can be superior to hybrid forms of governance when a timely reaction on a closely contoured research project is required. Resulting efficiency gains should consequently lead to better innovation performance. It has to be acknowledged, however, that being a good “buyer” also requires to be a good “maker” (Radnor, 1991; Veugelers and Cassiman, 1999). In other words, the absorptive capacities of the firm come into play when complementarities between internal and external R&D shall be realized.

From this it follows that the effectiveness of contract research critically depends on the firm’s in-house R&D capacity (Chatterji, 1996). Internal knowledge capabilities need to be identified to effectively use external know-how (Arora and Gambardella, 1990). Another implication is that contract research should typically require higher absorptive capacities than R&D collaboration as in the latter case absorptive capacity will be built up by all partners involved as they engage in the cooperation. Consequently, we hypothesize that there is a complementary effect between in-house R&D and contract research which should prove to be particularly beneficial in handling ad-hoc problems and providing a timely reaction to research tasks. Both should have a positive impact on innovation performance. As absorptive capacity is generally developed as a by-product of internal R&D activities, our fifth hypothesis which focuses on innovation performance can be split up into three components:

Hypothesis 5a: Internal R&D activities increase innovation performance.

Hypothesis 5b: External R&D activities increase innovation performance.

Hypothesis 5c: There exists a complementary relationship between internal and external R&D activities.

4 Research design

4.1 Model

To tackle both research questions, i.e. the choice of governance mode and the performance implications of that choice, we estimate two different econometric models: first a probit model for the governance choice and then a tobit model for innovation success. Our probit approach follows other authors who have employed binary choice models to assess the effect of a set of covariates on the make-or-buy decision (e.g., Anderson, 1988; Silverman et al., 1997; Leiblein and Miller, 2003). Our dependent variable is a dummy variable indicating whether or not a firm is engaged in contract research activities. We relate the probability of a firm to outsource R&D activities to the transaction and firm-level variables as well as to control variables for observed firm heterogeneity.

The use of a tobit in the second step of our econometric procedure reflects the choice of our dependent variable as a measure for innovation success: it is measured as the share of sales with innovative products that qualify as market novelties, relative to total sales. This measure for innovation success is heavily left-censored since many firms do not have any market novelties and thus also no sales from this type of innovation. Tobit models adequately treat this specific feature of our data by treating firms without market novelties differently from firms with market novelties.

A more technical issue is that one of our variables is generated by a factor analysis which leads to a “generated regressors problem” (e.g., Wooldridge, 2007, Section 6.2) which in turn leads to biased standard errors of the coefficient estimates. We therefore bootstrap our standard errors using 100 replications.

In contrast to OLS models, the coefficient estimates in probit and tobit models do not directly translate into marginal effects – e.g., the percentage change in the outcome variable due to a one unit change in the explanatory variable – which is why we present our estimation results both in terms of coefficient estimates and marginal effects.

The probability of firm i to outsource R&D, conditional on the vector of explanatory variables X and a vector of coefficients that maps the explanatory variables to the choice probability, β, is $P[R\&D\ outsourcing_i=1|X_i,\beta]=\Phi(X_i\,\beta)$, where $\Phi(.)$ denotes the cumulated standard normal density function.[2] The marginal effect of a change in the *k*-th element of vector X_i, X_{ik} on the probability of outsourcing is

$$\frac{\partial P[R\,\&\,D\,outsourcing_i \mid X_i, \beta]}{\partial X_{ik}} = \beta_k \phi(X_i \beta).$$

There are three possible marginal effects to be calculated for the tobit model: (i) the marginal effect of the *k*-th explanatory variable on the probability of having no innovation success at all, (ii) the effect on innovation success unconditional on having any success and (iii) the effect on innovation success conditional on having any innovation success. Our focus is on the latter quantity, which we also display in our results tables, since it is the most relevant one. The conditional expected value of innovation success, *IS*, of firm *i* is

$$E[IS_i \mid Z_i, \gamma, \sigma] = Z_i \gamma\, \Phi(Z_i \gamma / \sigma) + \sigma \phi(Z_i \gamma / \sigma),$$

where the terms Z_i, γ, σ and $\phi(.)$ denote the vector of variables explaining innovation success, the vector of coefficients mapping the explanatory variables to innovation success, the standard error of the error term and the standard normal density function respectively.[3]

The marginal effect of a one unit change in one of the explanatory variables conditional on having positive new product sales is

$$\frac{\partial E[IS_i \mid Z_i, \gamma, \sigma]}{\partial Z_{ik}} = \gamma_k\, \Phi(Z_i \gamma / \sigma).$$

The marginal effects discussed above relate to changes in continuous variables. For dummy variables we calculate the change in the probability of R&D outsourcing due to a change in the dummy variable from 0 to 1 (probit model) and the change in the expected value of innovation success due to a change in the dummy variable from 0 to 1.

It is important to note that the marginal effects in the probit and tobit model, in contrast to the estimated coefficients, vary across observations. We therefore evaluate the marginal effects at the mean of the explanatory variables. Standard errors corresponding to the marginal effects are calculated using the "Delta method" (e.g. Greene, 2003, Section 5.2.4) throughout.

4.2 Data

We use cross-sectional data from the German part of the fourth European Union's Community Innovation Survey (CIS-4) conducted in 2005 to estimate both econometric

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2 Note that we normalize the standard error of the error term of the choice equation to 1 as it is common practice in applied econometrics. We assume that this error term is normally distributed which leads to the probit model. If we assume logistically distributed error terms instead, we obtain the logit model.

3 The tobit model has a probit-part (for firms with 0 new product sales) and a linear part (for firms with positive new product sales share) which identifies the standard error of the error term.

models. 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. The 2005 survey collected data on the innovation activities of enterprises during the three-year period 2002-2004. About 5,200 firms in manufacturing and services responded to the German survey and provided information on their innovation activities. We use this data to measure the concepts presented above.

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 of telephone interviews (for a discussion see 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). Second, a comprehensive non-response analysis of the German survey for more than 4,200 firms showed no systematic distortions between responding and non-responding firms with respect to their innovation activities (Rammer et al., 2005). Third, the questionnaire contains detailed definitions and examples to increase response accuracy. Longhand questions (e.g. "Please describe your most important product innovation briefly") allow robustness checks for multiple choice answers. 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).

We restrict the sample to firms with innovation activities and in particular to those with product innovations. Although contract research could also result in process innovations we use the share of turnover with market novelties as a dependent variable and success measure in the second estimation which in turn requires a restriction on product innovators to yield an unbiased effect. In total, we retain 1,398 observations without missing values for the technology sourcing decision and 1,437 observations for the product innovation success equation. We use the 2005 wave of the MIP although the MIP is a panel data set which thus in principle would allow us to control unobserved firm-specific fixed effects. There are two reasons why we stick to the 2005 wave only: (i) many variables central to our analysis were collected in the 2005 survey only and (ii) the MIP data is highly unbalanced which means that many firms only participate infrequently which does not help handling unobserved firm heterogeneity. Nevertheless, the panel structure is exploited for our concept of contractual experience which will be presented in more detail below.

4.3 Empirical proxy variables

Uncertainty

A variety of measures for uncertainty has been identified in the literature (e.g., Leiblein and Miller, 2003). Focusing on uncertainty with respect to the innovation process, we employ two measures that reflect the central dimensions of uncertainty in innovation activities: uncertainty about the outcome as well as about the technology. Innovation projects inevitably involve the risk of project failure as the outcome of any project can be considered as uncertain. In the case of failure, investments, and particularly sunk investments, can not be recovered. Hence, we measure uncertainty regarding the outcome of the innovation process by a dummy variable that is coded 1 (and 0 otherwise) if the firm conducted an innovation project in the past three years that turned out to be a failure. As project failures should trigger learning processes, we argue that firms which encountered an innovation failure within the past three years are likely to better foresee the outcome of the current innovation process, which in turn should decrease perceived uncertainty – they will presumably not repeat the same mistakes they made in the failed innovation project. Our first proxy variable should hence have a positive impact on the propensity to engage in contract research.

The impact of an uncertain technology environment on the innovation process has been widely acknowledged (e.g., Miller and Friesen, 1983; Jansen et al., 2006). Uncertainty about the technology employed in an innovation project may be high when technological change is rapid, or when products and services together with their underlying technologies become obsolete fast. Our second proxy variable for uncertainty is hence generated by a factor analysis of these two variables measuring whether or not technological change is rapid and products and services become obsolete fast. Both variables are measured on a four-point Likert scale and the scale reliability coefficient (Cronbach's alpha) equals 0.736. Our measure for the uncertainty of the technology environment can hence be regarded as satisfactory and should carry a negative sign in the model estimation.

Asset specifity

Various forms of specific assets have been analyzed in the literature, ranging from customized physical assets to human capital. Specifity arises when these assets are tailored to a specific need (Williamson, 1979). In a contract research relationship this may involve the establishment of certain facilities, infrastructure and personnel for both contracting partners. Investments into these assets will presumably be higher if no predecessor product exists, i.e. when an innovation project starts from scratch. Hence our measure for asset specifity is a dummy variable coded as 1 (and 0 otherwise) in case no predecessor product exists among the introduced product innovations. The variable should have a negative impact on the propensity to engage in contract research activities.

Contractual experience

We measure the contractual experience of a firm in two alternative ways. Our most direct measure is a dummy variable that is coded 1 if a firm engaged in contract research in the years from 1998 to 2003. The data we use is gathered from three waves of the MIP conducted in 2001, 2003 and 2004 and merged with the MIP data from 2005. We denote the corresponding variable as "state dependence dummy" since it in fact measures state dependence. A drawback of using additional survey years is that the resulting panel of firms is highly unbalanced leading to a substantial decrease in the number of observations. Including the state dependence dummy variable incurs a drop in sample size by 52 percent.

In order to avoid such substantial losses in the number of observations – which is directly related to a substantial reduction in statistical significance – we estimate a second model where we include a dummy variable that is coded 1 if the firm engaged in innovation cooperation, i.e. a hybrid governance mode, in the years from 2002 to 2004. The questionnaire lists suppliers, customers, competitors, consulting firms, universities or research centers as potential partners in innovation cooperation. The resulting variable can also be considered as a rather direct measure of interaction with the suppliers of technology. We expect both variables to have a positive effect on the propensity to engage in contract research.

Openness to external knowledge

Our measures of openness to external knowledge refer on the one hand to the perceived lack of qualified personnel or technological information and on the other hand to the demand for external knowledge and other external inputs in the innovation process. Consequently, we measure openness by four variables: (i) the perceived lack of qualified personnel, (ii) the perceived lack of technological information, (iii) the breadth of information sources employed and (iv) the depth of information sources employed. The first two proxy variables are generated from two survey questions regarding factors hampering innovation activities and measured on a four-point Likert scale. We argue that firms which state that qualified personnel and/or technological information have been obstacles in the innovation process perceive a need for knowledge inputs which in turn triggers the openness to external knowledge. We thus expect the two variables to have positive effects on the propensity to engage in contract research.

The differentiation between breadth and depth of external innovation impulses has been suggested by Laursen and Salter (2006) and provides two direct measures for a firm's openness. We are able to obtain information on a comprehensive list of potential external sources for innovation and their importance. These nine options are suppliers, customers, competitors, consultancies, universities, public research institutions, conferences, scientific journals and trade associations. Following Laursen and Salter (2006), we measure a firm's breadth of external innovation inputs as the number of different sources used (from 0 to 9) and depth as the number of sources they assigned a high importance to. We expect these variables to have a positive impact on the probability of outsourcing.

Pattern of innovation expenditure

The hypotheses on the relationship between the R&D governance modes and innovation success assume that both internal and external R&D positively impact innovation success and that there are complementarities between both governance modes that result in a positive impact on innovation success. Consequently, we measure internal R&D by the share of internal R&D expenditures over total innovation expenditures. We use the share instead of the level of expenditures in order not to estimate sheer firm size effects. Accordingly, we measure external R&D by the share of external R&D expenditures over total innovation expenditures. We test for complementarities between internal and external R&D by interacting both variables in our specification. Let *CR* denote the share of innovation expenditure spent for contract research, i.e. external R&D, and *RD* denote the share spent for internal R&D. The joint effect of internal and external R&D on innovation success *IS*, assuming linear relationships, is hence given by:

$$IS_i^* = Z_i \gamma = \alpha RD + \delta CR + \lambda RD\, CR + W_i \theta ,$$

where W_i denotes the vector of variables other than external R&D, contract research and the interaction between them. IS^* is the unobserved “latent” innovation success. If $IS^* \leq 0$, firms have no innovation success, for $IS^* > 0$, innovation success is positive and observed in our data.

The effect of internal and external R&D on innovation success are respectively:

$$\frac{\partial IS_i^*}{\partial CR_i} = \delta + \lambda RD_i \quad \text{and} \quad \frac{\partial IS_i^*}{\partial RD_i} = \alpha + \lambda CR_i ,$$

which implies that the efficacy of internal and external R&D mutually depend on one another. The parameter λ measures by how much the effect of internal R&D on innovation success changes due to contract research. If λ is positive, contract research and internal R&D are complements, if it is negative, they are substitutes:

$$\frac{\partial(\partial IS_i^* / \partial CR_i)}{\partial RD_i} = \frac{\partial(\partial IS_i^* / \partial RD_i)}{\partial CR_i} = \lambda .$$

The marginal effect of a one unit change in internal R&D expenditures now no longer varies across observations but also depends on external R&D expenditures (and vice versa):

$$\frac{\partial E[IS_i \mid Z_i, \gamma, \sigma]}{\partial RD_{ik}} = (\alpha + \lambda CR_i)\Phi(Z_i \gamma / \sigma) \quad \text{and} \quad \frac{\partial E[IS_i \mid Z_i, \gamma, \sigma]}{\partial CR_{ik}} = (\delta + \lambda RD_i)\Phi(Z_i \gamma / \sigma) .$$

We therefore plot the marginal effect corresponding to a one unit (i.e. one percentage point) change in internal R&D expenditures against external R&D expenditures (and vice versa). A positive association between the marginal effect of internal R&D expenditures and external R&D expenditures indicates that the efficacy of internal R&D expenditures increases in external R&D expenditures. In other words: the more firms spend on external R&D the more effective is internal R&D.

Moreover, our specification includes the share of expenditures for other external knowledge, i.e. for the acquisition of intellectual property or licensing, over total innovation expenditure. The reference category, which is excluded from the specification due to perfect collinearity is the share of expenditure for innovation-related investments, i.e. machinery, equipment or software, plus other innovation expenditure (marketing, testing, etc.) over total innovation expenditure. The alternative types of innovation expenditures hence constitute a characteristic pattern for the firms in our analysis.

Control variables

We control for a number of other factors that might be relevant in the two models. The first model for the choice of governance mode includes measures to control for the absorptive capacity of the firm. As absorptive capacities are developed by performing R&D activities we capture their effect in line with the literature (Cohen and Levinthal, 1990; Rothwell and Dodgson, 1991) through variables on the two major inputs for innovation activities: R&D expenditure (as a share of sales) and the expertise of employees (share of employees with college education relative to the industry average). Moreover, we add an additional dummy variable that indicates whether or not R&D activities are performed on a continuous basis and whether or not the firm had reported also process innovations since the structure of innovation expenditure may be different when product innovation is combined with process innovation. Finally, we control for regional differences between East and West Germany, company size (number of employees in logs and in squared terms to allow for non-linearities), whether or not the company is part of a group as well as industry effects (see Table 5 in the appendix for details). Our second model for the relationship between governance modes and innovation success includes the variables for regional differences, company size and industry affiliation.

5 Results

5.1 Descriptive statistics

Our results section starts with descriptive statistics of our dependent variables and our proxy variables displayed in Table 1. We show descriptive statistics for all firms and we additionally distinguish between R&D outsourcing and non-outsourcing firms. This differentiation allows us to come to a first univariate assessment of our hypotheses. We use multivariate estimation techniques, probit estimation and tobit estimation, to test whether or not our hypotheses hold in a multivariate setting that account for a wide range of proxy variables and control variables for observed heterogeneity in subsection 5.2. As it shall turn out in that subsection, a few univariate findings are overturned in the multivariate setting.

Table 1 shows that 37 percent of the firms (512 firms in total) in our data outsource R&D tasks. The mean of our other explanatory variable, the share of new product sales, is 8.1 percent. This share differs between outsourcing and non-outsourcing firms: it is 9.2 percent for outsourcing firms and 6.2 percent for non-outsourcing firms. This is consistent with *Hypothesis 5b*: external R&D activities increase innovation performance.

The table also reveals substantial differences between outsourcing and non-outsourcing firms for almost all our proxy variables we use in hypotheses testing. These differences are also statistically significant unless indicated otherwise. The means of our two “uncertainty” proxy variables are for example much larger for outsourcing firms compared to non-outsourcing firms. As many as twelve percent of the outsourcing firms have cancelled an innovation project within the past three years while this is true for only seven percent of the non-outsourcing firms. If *Hypothesis 1* was supported by the data, which states that higher uncertainty goes along with a lower propensity to outsource, then outsourcing firms should have more cancelled innovation projects – which they do as suggested by Table 1 – and a lower mean of the technology environment variable – which they do not. The univariate statistics hence come to mixed conclusions for *Hypothesis 1*.

Table 1: Descriptive statistics

		All firms		**Outsourcing firms**		**Non-outsourcing firms**	
Variable	**Obs.**	**Mean**	**S. D.**	**Mean**	**S. D.**	**Mean**	**S. D.**
Probit model for the outsourcing decision							
Dependent variable							
Engagement in contract research (dummy)	1,398	0.366	---				
Uncertainty proxies							
Cancelled innovation projects (dummy)	1,398	0.111	---	0.129	---	0.067	---
Technology environment (factor score)	1,398	0.090	0.734	0.054	0.747	-0.025	0.770
Asset specifity proxy							
No predecessor product (dummy)	1,398	0.576	---	0.632	---	0.498	---
Contractual experience proxies							
R&D collaboration (dummy)	1,398	0.338	---	0.601	---	0.192	---
Lagged engagement in contract research (dummy)	675	0.375	---	0.670	---	0.199	---
Openness to external knowledge proxies							
Lack of qualified personnel (ordinal)	1,398	1.081	0.903	1.169	0.890	0.996	0.915
Lack of technological information (ordinal)	1,398	0.774	0.729	0.812	0.712	0.734	0.747
Breadth of information sources (index score)	1,398	6.751	2.022	7.306	1.853	5.970	2.348
Depth of information sources (index score)	1,398	1.230	1.194	1.384	1.268	0.981	1.087
Control variables							
Process innovation (dummy)	1,400	0.562	---	0.645	---	0.516	---
Part of group (dummy)	1,400	0.636	---	0.731	---	0.584	---
Share of college graduates relative to sector-level	1,398	1.704	5.882	1.159	2.820	1.949	7.136
Continuous R&D activities (dummy)	1,398	0.526	---	0.743	---	0.287	---
R&D intensity	1,398	0.120	1.780	0.233	2.382	0.116	2.542
Eastern Germany (dummy)	1,398	0.300	---	0.306	---	0.316	---
# employees (in logs)	1,398	4.391	1.754	4.927	1.891	3.958	1.619
Tobit model for innovation success							
Dependent variable							
Share of sales with market novelties	1,437	0.081	0.168	9.234	17.080	6.156	14.884
Explanatory variables							
Share of internal R&D over total innovation expenditure	1,437	0.434	0.354	0.494	0.303	0.310	0.367
Share of external R&D over total innovation expenditure	1,437	0.042	0.089	0.153	0.171	0.000	0.000
Share of expenditure for other external knowledge over total innovation expenditure	1,437	0.031	0.093	0.027	0.068	0.034	0.111
Interaction internal and external R&D	1,437	0.019	0.039	0.060	0.063	0.000	0.000

Most firms have introduced a new product that had no predecessor product in the firm, our measure for asset specifity. More outsourcing than non-outsourcing firms do, however, lack such a predecessor product. This contradicts *Hypothesis 2* which predicts that asset specifity increases transaction cost and thereby reduces the propensity to outsource.

The share of firms that performed collaborative R&D and/or that outsourced R&D before is substantially larger for R&D outsourcing firms than for non-outsourcing firms. These variables are measures of contractual experience which, according to *Hypothesis 3,* increases the propensity to outsource. Our descriptive finding hence is consistent with this hypothesis.

Hypothesis 4, which predicts that openness to external knowledge sources increases the probability to outsource, is also supported by our univariate statistics: all four proxy variables have higher means for outsourcing than for non-outsourcing firms: they are more likely to lack qualified personnel, lack technological information and make both a broader and deeper use of information sources. These differences are, however, not always statistically significant.

Outsourcing and non-outsourcing firms also differ in terms of our control variables for observed firm heterogeneity. Outsourcing firms are more likely to also have process innovations, to be part of a group, to perform continuous R&D, and they have more employees. By contrast, non-outsourcing firms employ a larger share of college graduates. There is no difference between outsourcing and non-outsourcing firms with respect to regional affiliation.

5.2 Multivariate analyses

Table 2 displays probit estimation results for the probability of engaging in contract research. We specify two models: Model 1 measures contractual experience by previous R&D collaboration while Model 2 uses variables for both R&D collaboration and past contract research ("State dependence dummy"). Our focus in the interpretation of results is on Model 1 since the inclusion of the lagged dependent variable in Model 2 leads to a substantial reduction in the number of observations and therefore also in statistical significance. The results from Model 1 and Model 2 are both qualitatively and quantitatively very similar. Our results table contains both the parameter estimates ("Coeff.") and marginal effects ("M. Eff.") in order to increase the readability of our estimation results.

Hypothesis 1, which states that uncertainty increases transaction cost and thereby reduces the propensity to engage in contract research, is fully supported by our estimation. Cancelled innovation projects increase the probability of engaging in contract research by eight percentage points. Model 1, however, does not show a significant coefficient for our measure of the technology environment. Instead, Model 2 exhibits a negative and significant effect as suggested by our hypothesis.

Hypothesis 2, referring to asset specifity which goes along with a reduced propensity of engaging in contract research, cannot be supported by our data. Lacking a predecessor leads to an *increase* in the probability to engage in contract research by five percentage points, an effect that is statistically weakly significant. One explanation for the contradiction may be that firms that launch a truly new product are more likely to turn to firms outside the own organization than firms that have experience with a similar product. Our finding of a positive impact then indicates that the latter effect outweighs the asset specifity effect.

Contractual experience indeed increases the propensity to engage in contract research as suggested by *Hypothesis 3*. R&D collaboration increases the propensity by 26 percentage points as indicated by Model 1, an effect that is measured with high precision. This effect reduces to 18 percentage points in Model 2 where we additionally include lagged contract research. The lagged variable is statistically highly significant and economically large: firms with past engagement in external R&D have a 31 percentage point higher probability of outsourcing than firms without such past engagement. This hence indicates substantial state dependence in the decision to engaging in contract research.

That openness to external knowledge increases the probability to engaging in contract research, as stated by *Hypothesis 4*, is also fully supported by our estimates. All our proxy variables have a positive effect on the propensity to engage in contract research. These effects are, however, not statistically significant for the lack of technological information. For the lack of qualified personnel the effect is 3.9 percentage points, for the breadth of information sources the effect is 2.6 percentage points and for the depth of information sources the effect is 2.2 percentage points.

The results for our control variables can be summarized as follows: (i) continuous R&D increases the probability of engaging in contract research by 24.2 percentage points suggesting that absorptive capacity matters very much in the decision to outsource R&D and (ii) larger firms are more likely to engage in external R&D. The other control variables do not have statistically significant effects although in Model 2 there is additionally a small and only weakly significant negative effect of the share of college graduates.

Table 2: Probit estimation for the probability of engaging in contract research

Explanatory variables	Model 1		Model 2	
	Coeff.	M. Eff.	Coeff.	M. Eff.
Uncertainty measures				
Cancelled innovation projects	0.211*	0.078*	0.117	0.043
	(0.120)	(0.046)	(0.181)	(0.068)
Technology environment	-0.084	-0.030	-0.176**	-0.064**
	(0.059)	(0.021)	(0.075)	(0.028)
Asset specifity measure				
No predecessor product	0.149*	0.053*	0.090	0.033
	(0.083)	(0.030)	(0.117)	(0.043)
Contractual experience measures				
State dependence			0.841***	0.310***
			(0.132)	(0.047)
R&D collaboration	0.699***	0.257***	0.484***	0.179***
	(0.092)	(0.035)	(0.141)	(0.052)
Openness to external knowledge measures				
Lack of qualified personnel	0.109**	0.039**	0.092	0.034
	(0.047)	(0.017)	(0.079)	(0.029)
Lack of technological information	0.074	0.027	0.152	0.056
	(0.068)	(0.025)	(0.105)	(0.039)
Breadth of information sources	0.072***	0.026***	0.079*	0.029*
	(0.026)	(0.009)	(0.041)	(0.015)
Depth of information sources	0.063*	0.022*	0.073	0.027
	(0.036)	(0.013)	(0.054)	(0.020)
Controls				
Process innovation	0.121	0.043	-0.090	-0.033
	(0.089)	(0.032)	(0.133)	(0.049)
Part of group	0.063	0.023	0.097	0.029
	(0.088)	(0.031)	(0.141)	(0.051)
R&D intensity	-0.006	-0.002	0.969	0.354
	(0.415)	(0.149)	(0.609)	(0.224)
Share of college graduates relative to sector-level	-0.012	-0.004	-0.051*	-0.019*
	(0.013)	(0.005)	(0.027)	(0.010)
Continuous R&D activities	0.689***	0.242***	0.587***	0.208***
	(0.112)	(0.037)	(0.149)	(0.050)
Eastern Germany	0.020	0.007	-0.088	-0.032
	(0.088)	(0.032)	(0.145)	(0.052)
Employees (in logs)	0.391***	0.140***	0.323*	0.118*
	(0.104)	(0.037)	(0.179)	(0.066)
Employees (in logs)^2	-0.029***	---	-0.027*	---
	(0.009)		(0.015)	
Constant	-3.234***	---	-3.081***	---
	(0.347)		(0.577)	
6 industry dummies	LR-Chi^2 = 24.53***		LR-Chi^2 = 4.76	
Observations	1,398		675	
Wald chi^2 (21; 22)	586.26		157.66	
Prob > chi^2	0.000		0.000	
Log (pseudo)likelihood	-681.476		-306.336	
Pseudo R^2	0.258		0.321	

Standard errors in parentheses; * significant at 10%; ** significant at 5%; ***significant at 1%

Table 2 shows probit estimation results for the probability of external R&D sourcing. Both coefficient estimates ("Coeff.") and marginal effects ("M. Eff.") are displayed in the table since the coefficient estimates are economically not meaningful. The marginal effects are changes in the decision to source R&D externally caused by a one percent change in the explanatory variables. The marginal effect for the number of employees is evaluated at the means of the involved variables. Reading example: firms with previously cancelled innovation projects have a eight percentage point higher probability of technology sourcing than firms without previously failing innovation projects. This effect is statistically weakly significant.

Table 3 displays our estimation results of the tobit model for innovation success. Our measure for innovation success is the share of sales with market novelties over total sales. We specify two models, Model 1 that does not have the interaction between expenditures for internal and external R&D expenditures and Model 2 which does have that interaction. The estimation results are very similar to one another both quantitatively and qualitatively.

Consistent with *Hypothesis 5a*, internal R&D activities in fact increase innovation success. An increase in the share of internal R&D expenditures relative to total innovation expenditures by one percentage point leads to an increase in the share of turnover with market novelties over total turnover by 0.20 percentage points.

External R&D plays an even more important role than internal R&D: a one percent increase in the share of external R&D in total innovation expenditures is related to an increase in innovation success by 0.38 percentage points which is in accordance to *Hypothesis 5b*. The marginal effect of contract research even exceeds the one of internal R&D.

The estimation results shown in Table 3 also support *Hypothesis 5c* since they indicate a complementary relationship between internal and external R&D. This is indicated by the positive and statistically significant coefficient on the interaction between internal and external R&D. The extent to which an increase in internal R&D or an increase in external R&D matters for innovation success is not only firm-specific (as it is the case for any marginal effect) but it depends also on the value of the respective other variable: the effect of internal R&D depends upon how much the firm spends on external R&D (and vice versa).

Apart from that, the estimation shows a negative effect of innovation expenditure for other external knowledge which for example comprises the acquisition of licenses. This knowledge seems to be difficult to integrate into the innovation process of the firm leading to lower overall innovation performance. Regarding the control variables it turns out that firms being located in Eastern Germany exhibit a lower performance. Finally, smaller firms in terms of the number of employees tend to have a higher innovation performance although there is a turning point at a firm size of 628 employees from where innovation performance tends to increase.

Figure 2 and Figure 3 present a graphical exposition of the mutual dependencies of internal and external R&D. Figure 2 plots the marginal effects of internal against the share of external R&D in total innovation expenditure while Figure 3 plots marginal effects against the share of internal R&D. Both figures show that there is a positive relationship between internal and external R&D: the payoff from internal R&D is the higher the more a firm spends on external R&D (and vice versa). Both figures strongly reinforce our finding of complementarity between internal and external R&D.

Table 4 summarizes our theoretical hypotheses and empirical findings. It shows that all our hypotheses apart from the one related to asset specifity (*Hypothesis 2*) are supported by our estimation results.

Table 3: Tobit estimation results for the innovation success

Explanatory variables	Model 1		Model 2	
	Coeff.	**M. Eff.**	**Coeff.**	**M. Eff.**
Share of internal R&D over total innovation expenditure	0.137***	0.195***	0.121***	0.173***
	(0.026)	(0.037)	(0.027)	(0.039)
Share of external R&D over total innovation expenditure	0.264***	0.378***	0.058	0.083
	(0.093)	(0.132)	(0.145)	(0.208)
Share of expenditure for other external knowledge over total innovation expenditure	-0.313***	-0.447***	-0.307***	-0.439***
	(0.119)	(0.170)	(0.118)	(0.169)
Interaction internal and external R&D			0.625*	0.894*
			(0.335)	(0.480)
Eastern Germany dummy	-0.062***	-0.087***	-0.064***	-0.090***
	(0.019)	(0.026)	(0.019)	(0.026)
Employees (in logs)	-0.055***	-0.079***	-0.056***	-0.081***
	(0.019)	(0.027)	(0.019)	(0.027)
Employees (in logs)^2	0.004**	---	0.004**	---
	(0.002)		(0.002)	
Constant	0.028	---	0.038	---
	(0.050)		(0.051)	
6 industry dummies	F (5, 1426) = 4.43***		F (5, 1425) = 4.19***	
Observations	1,437		1,437	
LR chi^2 (11; 13)	121.33		124.82	
Prob > chi^2	0.000		0.000	
Log (pseudo)likelihood	-528.611		-526.868	
Pseudo R^2	0.103		0.106	

Marginal effects for the probability of being uncensored; standard errors in parentheses;
* significant at 10%; ** significant at 5%; ***significant at 1%

Table 3 shows tobit estimation results for new product sales relative to total sales, our measure for innovation success. Both coefficient estimates (“Coeff.”) and marginal effects (“M. Eff.”) are displayed in the table since the coefficient estimates are economically not meaningful. Reading example: a one percent increase in the share of internal R&D expenditures relative to total innovation expenditures leads to an increase in innovation performance by 0.18 percentage points. This effect is statistically highly significant.

Figure 2: Marginal effect of a one percent point change in the share of internal R&D on innovation success

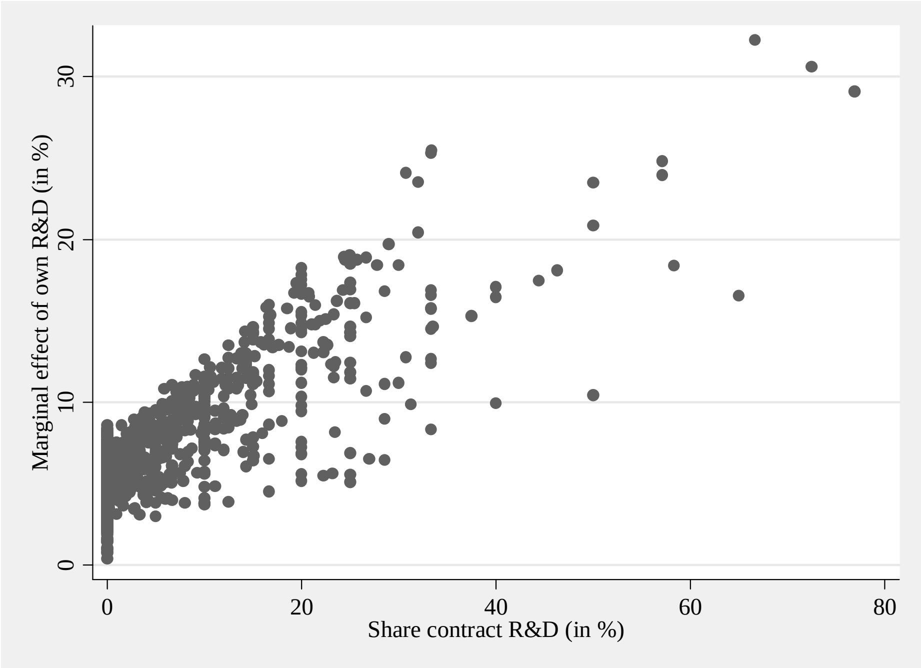

Figure 2 plots the share of external R&D in total innovation expenditure against the marginal effect of own R&D expenditures.

Figure 3: Marginal effect of a one percent point change in the share of contract research on innovation success

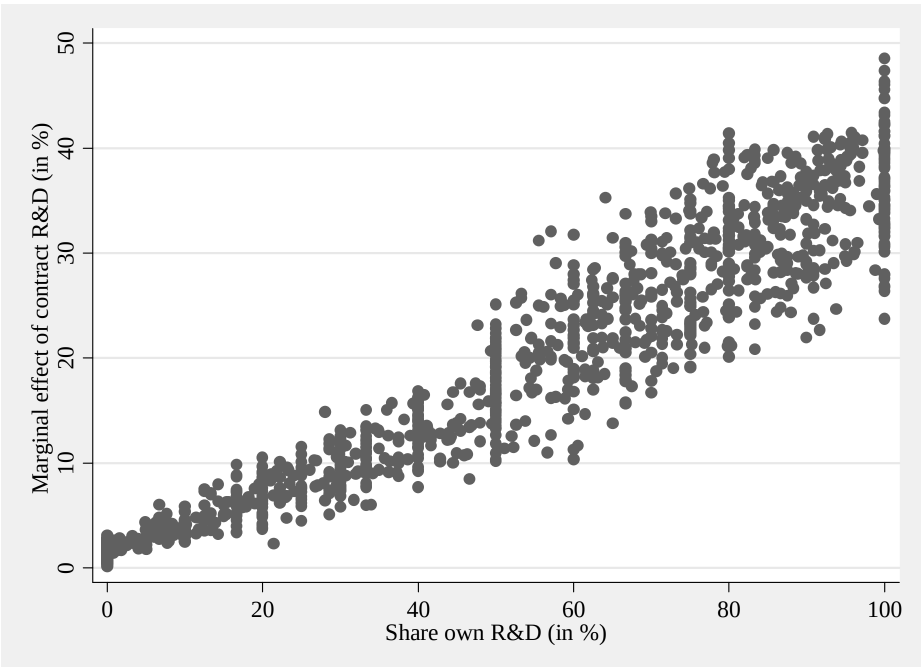

Figure 3 plots the share of internal R&D in total innovation expenditure against the marginal effect of own R&D expenditures.

Table 4: Results summary

Variable	Expected sign	Actual sign
Probit model for the outsourcing decision		
Uncertainty proxies (Hypothesis 1)		
Cancelled innovation projects (dummy)	+	+
Market/technology environment	-	-
Asset specifity proxies (Hypothesis 2)		
Lack of predecessor product (dummy)	-	+
Contractual experience proxies (Hypothesis 3)		
R&D collaboration (dummy)	+	+
Lagged engagement in contract research (dummy)	+	+
Openness to external knowledge proxies (Hypothesis 4)		
Lack of qualified personnel	+	+
Lack of technological information	+	+ (n.s.)
Breadth of information sources	+	+
Depth of information sources	+	+
Tobit model for innovation success (Hypothesis 5)		
Share of internal R&D over total innovation expenditure	+	+
Share of external R&D over total innovation expenditure	+	+
Interaction internal and external R&D	+	+

6 Discussion

This research investigates a firm's decision to engage in contract research as a rather neglected mechanism for the acquisition of technological knowledge. Contract research has been shown to be frequently used by firms that spent, however, substantially less on external R&D compared to internal R&D. Despite its frequent use, little is known about the factors that (i) influence a firm's decision to allocate innovation expenditure to contract research organizations and (ii) the resulting implications for firm performance.

We adopt a transaction and firm-level perspective to elucidate these questions. Transaction cost arguments have frequently been used in analyzing a firm's boundary decisions. Additionally, firm-specific factors are taken into account to reflect the notion that a firm's history, specific demands and capabilities may have a considerable impact on the choice for internal or external R&D. This is particularly relevant given the common belief that firms largely differ in their resource endowment and capabilities (e.g., Wernerfelt, 1984; Barney, 1991) which should eventually influence R&D boundary decisions (Kogut and Zander, 1992; Leiblein and Miller, 2003).

Our results show that both transaction and firm-level factors considerably matter in the decision to engage in contract research. First of all, following a number of related studies (e.g., Robbertson and Gatignon, 1998; Leiblein et al., 2002; Leiblein and Miller, 2003) we identify uncertainty and asset specifity as important drivers in a firm's boundary decision. Our estimation results indeed support that increased uncertainty decreases the outsourcing decision as predicted by transaction cost theory. Our results do not, however, support that asset specifity decreases the likelihood of external R&D although it should be mentioned that an empirical measure for asset specifity can never be precise. The explanatory power of the transaction cost arguments hence seems to be rather limited in that context.

Second, it has been noted in literature that not only transaction-level effects will determine the decision to outsource R&D but that a critical role is also played by the specific history, capabilities and resource endowments of a firm (Leiblein and Miller, 2003). As firms will strive to choose the governance mode that complements capabilities in a way that knowledge gaps can be bridged, our study focuses on contractual experience and the openness to external innovation stimuli to account for such firm-level factors. Both of our RBV-based hypotheses are supported by the data. This underlines the high importance of firm-level factors in explaining the choice to engage in contract research as a way to get access to externally available resources. On the one hand, experience in interacting with external research organizations apparently increases the likelihood of repeating such kind of interaction. Prior experience presumably leads to the creation of organizational routines that facilitate subsequent collaboration and outsourcing. On the other hand, our results show that being open to various types of external knowledge sources also increases the decision for contract research. It is particularly the breadth of innovation sources that triggers contract research activities. Hence, the more diverse the spectrum of knowledge sources the more likely a firm will engage in contract research. This firm behavior reflects the open innovation model of "connect and develop" (Chesbrough, 2003). In this respect, openness is triggered by a perceived lack of qualified personnel and not by a lack of technological knowledge. It seems that it is predominantly an issue of available human resources and the embodied (tacit) knowledge that is accessed through contract research. To sum up, the R&D outsourcing decision is shown to be both driven by firm-level factors and transaction-level factors.

The second step of the analysis focuses on the performance implication of engaging in contract research. While the resulting trade-offs between internalizing and outsourcing firm activities have been analyzed in various settings (e.g., Walker and Weber, 1984; Leiblein et al., 2002) little is known about how contract research translates into innovation success. Our results show positive and significant effects for both internal and external R&D expenditure. Moreover, our results strongly suggest that both governance modes are complementary to one another. This result confirms existing findings in the context of an interaction between internal R&D and R&D alliances (Rothaermel et al., 2006) which refers to a more hybrid governance mode in contrast to external R&D through contract research. There is hence strong support for the argument that internal and external R&D require a careful balancing of the organization of innovation to achieve superior innovation performance. Contract research obviously fills a gap in a firm's sourcing strategy for technological knowledge in that it provides a comparably quick access to such knowledge without engaging into a collaborative agreement with a partner. This stresses the need for firms to find organizational arrangements for those tasks which encompass virtually no interaction with partners and hence do not cause organization costs. Moreover, contract research serves as an instrument for an "ad-hoc problem solving" (Winter, 2003), i.e. it provides a timely reaction on a closely contoured research project.

The characteristics of contract research to provide a means for closing knowledge gaps and to serve as an "ad-hoc problem solving" mechanism need to be reflected by management when organizing for innovation. Managers should hence not regard contract research primarily as a cost-saving way of buying research results at the market for research services. First and foremost, contract research serves as a cornerstone in pursuing an open innovation model. In this respect, contract research needs to be carefully balanced with other types of innovation sources regarding possible complementary and substitutive effects. As the descriptive statistics indicated, while a substantial share of firms engaged in contract research, the innovation budget allocated to these activities remains rather low. Our results suggest that making more intensively use of contract research actually increases innovation performance. But this needs to be reflected against the background of other R&D alliances set up by the firm. Contractual relationships still require management attention and its limits need to be taken into account when contract research activities are intended to be increased.

7 Conclusion and further research

The existing literature on external technology acquisition has primarily focused on phenomena like alliance formation or firm acquisitions as means to access external knowledge (e.g., Villalonga and McGahan, 2005; Cassiman et al., 2005). In contrast, comprehensive empirical evidence on the choice for contract research has been scarce even though such activities are to a large extent an inherent part of any firms' innovation model. Moreover, while several authors refer to transaction cost theory to elucidate specific transaction-level characteristics that influence the choice for alternative forms of governance (Veugelers and Cassiman, 1999; Love and Roper, 2002; Gooroochurn and Hanley, 2007), the existing literature provides almost no indication for the role of firm-level differences in the choice for technology sourcing modes. Our paper sheds light on what factors actually lead to engage in contract research by drawing from transaction cost arguments and the resource-based view of the firm.

We use a large and comprehensive data set on 1,400 German firms from manufacturing and service industries to find that both the hypotheses derived from transaction cost theory and from the resource based view of the firm are at least partly supported by our data: technological uncertainty, contractual experience as well as openness to external knowledge increase the propensity to engage in contract research.

Another innovation of our paper is that we relate the technology sourcing choice to innovation performance. We find that both internal and external R&D efforts contribute to innovation success. Interestingly our estimation results provide ample evidence for complementarities between internal and external R&D, an issue that has not received attention in the existing literature so far. In other words: spending more on internal R&D increases the contribution of external R&D to innovation success (and vice versa).

8 Appendix

Table 5: Industry breakdown

Industry	NACE Code	Industry Group
Mining and quarrying	10 – 14	Other manufacturing
Food and tobacco	15 – 16	Other manufacturing
Textiles and leather	17 – 19	Other manufacturing
Wood / paper / publishing	20 – 22	Other manufacturing
Chemicals / petroleum	23 – 24	Medium high-tech manufacturing
Plastics / rubber	25	Other manufacturing
Glass / ceramics	26	Other manufacturing
Metal	27 – 28	Other manufacturing
Manufacture of machinery and equipment	29	Medium high-tech manufacturing
Manufacture of electrical equipment and electronics	30 – 32	High-tech manufacturing
Medical, precision and optical instruments	33	High-tech manufacturing
Manufacture of motor vehicles	34 – 35	Medium high-tech manufacturing
Manufacture of furniture, jewellery, sports equipment and toys	36 – 37	Other manufacturing
Electricity, gas and water supply	40 – 41	Other manufacturing
Construction	45	Other manufacturing
Retail and motor trade	50, 52	Distributive services
Wholesale trade	51	Distributive services
Transportation and communication	60 – 63, 64.1	Distributive services
Financial intermediation	65 – 67	Knowledge-intensive services
Real estate activities and renting	70 – 71	Distributive services
ICT services	72, 64.3	Technological services
Technical services	73, 74.2, 74.3	Technological services
Consulting/Advertising	74.1, 74.4	Knowledge-intensive services
Motion picture/broadcasting	92.1 – 92.2	Knowledge-intensive services
Other business-oriented services	74.5 – 74.8, 90	Distributive services

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