

The Design of Vertical R&D Collaborations*

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November 19, 2015

Abstract

Suppliers play a major role in downstream firms' innovation processes. We analyze the choice of ownership and technology in vertical research and development (R&D) collaborations. Under non-contractible R&D outcomes, there is a trade-off between R&D specifically designed towards a manufacturer (increasing investment productivity) and a general technology (hold-up reduction). More intense downstream competition shifts optimal ownership towards the supplier and favors contracting over ownership rather than specific performance contracts. Downstream ownership is combined with the specific technology if the supplier's expertise is more pronounced or the specific technology is more productive. Contracts incorporating exit clauses increase the gains from collaborations.

JEL classification: L22, L24, O31, O32

Keywords: Managing innovations, vertical R&D collaboration, choice of technology

*We would like to thank session and seminar participants at the annual EEA conference in 2009 in Barcelona, the Verein für Socialpolitik meeting 2009, the 9th annual international industrial organization conference in Boston, the German Economic Association of Business Administration 2008, the 2010 ISNIE conference, the Christmas meeting of the German Economists Abroad Network 2010 and at the University of Tuebingen 2014 for helpful comments on a previous version of the paper. We are also very grateful to Carsten Bienz, Guido Friebel, Ralf Gampfer, Michael Kosfeld, Jens Prüfer, Andreas Roeder, Tianle Zhang, and three anonymous reviewers as well as the editor Peter Norman Sorensen for helpful comments and suggestions.

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1 Introduction

Input suppliers play a major role in the innovation process of many industries¹. Input supplying firms can build on a stock of knowledge. Doing so enables them to step beyond the existing technological frontier by developing new and better products which they can use in the final production processes of their customers. However, the research and development (R&D) activity of the input supplier is often complemented by the collaborative R&D efforts of the manufacturer that exploit the manufacturer's specific knowledge. Given the productive inputs of both parties as well as substantial economies of scope on either side, neither a pure market transaction nor a fully integrative approach appear efficient, but instead vertical cooperation emerges.

Our objective in this paper is to analyze the functioning and structure of such vertical R&D collaborations and relate them to competition in output markets, i.e., to investigate how product market competition influences the design of vertical R&D collaboration. The two main research questions are: How should firms organize vertical R&D collaborations (in terms of technology and allocation of property rights)? And how do the intensity of competition in output markets, technological factors as well as upstream market characteristics affect the organizational design of vertical R&D collaborations?

Despite the empirical prominence of vertical R&D cooperations (see Cassiman and Veugelers (2002)), the literature focuses almost exclusively on horizontal R&D cooperations. The fact that vertical R&D cooperation are more often to be observed is suggested by a number of empirical studies. For instance, Harabi (1998) reports for German firms that in the majority of all cases R&D takes places in cooperation between the supplier and the buyer.² Vertical R&D collaboration as an in-between solution between the complete outsourcing of R&D (buy decision) and in-house R&D (make decision) is in particular widespread in a number of industries such as petroleum and chemicals, rubber and plastics, electrical engineering and the car industry (see Fritsch and Lucas (2001) and Belderbos *et al.* (2006) for evidence from the Netherlands). In addition, Harabi (1998) stresses that vertical R&D collaborations are also very prominent in the basic metal industry as well as in the medical and optical instrument industry. Pisano (1991) provides empirical evidence for the important role of R&D collaborations in the US biotechnology and Gassman *et al.*

¹See e.g., Gassman *et al.* (2010) on the automobile industry, Pisano (1991) for the biotechnology industry and Brusoni and Principe (2001) for the aircraft engine and chemical industry.

²See also Fritsch and Lucas (2001) for similar results. Nagaoka (2011) reveals similar patterns in his large-scale survey of Japanese inventions. In his sample, 21.6% of all patents stem from vertical R&D collaborations.

(2010) a case-study for the international automobile industry. Overall, vertical R&D collaborations play an important role in the R&D process of a number of prominent industries.

Vertical R&D collaborations differ from both horizontal R&D collaborations and standard upstream-downstream relationships in at least one decisive aspect. With arm's-length supplier-buyer relationships, selling the input to other buyers is commonplace. In horizontal R&D cooperation, the collaborating firms' objective even is to jointly develop a new product even though they are competing in the product market. Within vertical R&D collaborations a conflict of interest may arise: While the downstream firm prefers to have the exclusive use of the new technology, the supplier might be interested in marketing the technology to other, competing firms (see also the case description and discussions in Arora and Merges (2004)). As a result, a transfer of the analyses from arm's-length's transactions or from horizontal cooperation to vertical R&D collaborations would be incomplete. Thus, we still lack a detailed understanding of the design of the empirically important vertical R&D collaborations.

By focusing on R&D collaborations we concentrate not only on an economic activity which plays a key role in economic growth and development but which also differs significantly from other productivity-enhancing activities, such as capital investments. In particular, in innovation settings, performance is often very difficult to measure and hence contracts are often not enforceable. Furthermore, knowledge often easily flows between entities making knowledge appropriation difficult (see Azoulay and Lerner (2012)). We aim to capture these elements in our analysis.

We address our research questions by using an incomplete contracting framework based on the notion of contracting at will as put forward by Hart and Moore (1988). Because of the uncertainties associated with the innovative process it is not feasible to write a contract on a newly developed input nor on the supplier's knowledge, since the new input incorporates features that are difficult to understand and overlook by a third party (such as the courts). Hence, delivery of the good and the levels of trade cannot be observed by third parties. This incomplete contracting approach is standard in the literature on the management of innovative activities (see Aghion and Tirole (1994) and Rosenkranz and Schmitz (2003)) or on the financing of R&D (Anand and Galetovic (2000) and Fulghieri and Sevilir (2009)).³

Technology plays a key role in our analysis: Choosing an R&D technology specif-

³In a sample of Australian inventors, Thomson and Webster (2013) show that technological uncertainty is an important determinant for collaborative development rather than in-house or independent development.

ically tailored to the manufacturer increases the value of the new input for that firm but at the same time locks in the supplier. In order to increase ex-post bargaining power, the supplier will have to adjust and modify the input in order to be able to sell the new input to other manufacturers. We label these efforts to modify and adjust the input redesign activities.⁴ If the supplier sells the new input to a variety of manufacturers then product market competition lowers the added value of the new input for the initial manufacturer (see Czarnitzki and Kraft (2012) for evidence on the relevance of spillovers to and from competitors). The incentive for investments in redesign activities thus lowers the case for narrowly defined R&D processes and raises the question of whether a general technology should be developed in the first place and to what extent the manufacturer should invest in collaborative R&D.

In our theoretical approach, we incorporate the main characteristics of vertical R&D collaboration. These characteristics feature prominently in real-world examples. Consider, for example, the disposable contact lens project which formed the basis of the vertical R&D collaboration between Vistakon (Jacksonville, FL) and NYPRO (Clinton, MA) over a four-year period (see Christensen (1993)). The main objective of the project was to develop single-use styrene lens' molds as an input into Vistakon's production of disposable contact lenses. NYPRO's creation of molds with tolerance levels substantially lower than achievable at the time would lead to significant increases in the quality of Vistakon's lenses and reduction of its production costs. These benefits would allow Vistakon to gain a significant competitive advantage in the highly competitive market for contact lenses.

Although the technology was to be developed by NYPRO as the supplier, there was intense collaboration with Vistakon by using joint engineering teams of both companies. Additionally, the technology and molds were specifically designed to Vistakon's requirements for its production of disposable contact lenses. At the same time, the technology was potentially transferable as other companies were asking NYPRO to supply its new technology to them as well. Hence, NYPRO could have used its knowledge about producing low tolerance levels of molds acquired in the collaboration with Vistakon in order to transfer it to other companies. However, NYPRO would have had to redesign its initial invention to allow its applicability to other firms, involving significant resources of the company. Considering these

⁴Redesign activities also risk violating IP property rights relevant to the initial relationship. Therefore these activities may also include costs to differentiate the modified input technologically from the initially developed one, an activity called inventing-around. The important role of such inventing-around activities in the innovation process has been stressed in prominent surveys on the patenting behavior of US firms (see Levin *et al.* (1987) and Cohen *et al.* (2000)).

significant extra costs made the management of NYPRO very reluctant to pursue such a strategy (see Christensen (1993), p. 11).⁵

Cases from other industries depict similar key characteristics of vertical R&D collaborations. Consider, for example, the relation between the Swedwood, the Swedish manufacturer of IKEA furniture and Dutch Akzo Nobel as a specialist supplier of coatings, which was set-up to develop a new coatings technology as a substitute to the veneer used so far (see Baraldi (2008)). Or the collaboration between Germany's Freqon and NordAlu (see Cordon *et al.* (2001)), whose main objective was to develop extruded aluminium components as an input in Freqon's frequency converters. In both cases, collaborative effort and knowledge from both supplier and manufacturer was crucial to the development of the new technology. And although both technologies were developed to the manufacturer's specific requirements (for example, the fit of NordAlu's converters depended heavily on Freqon's contribution to the project), the knowledge gained potentially allowed the application to be adapted to other uses or customers. In the Swedwood/Akzo Nobel case, despite the successful development of a new coating technology, the technology was even not applied in its intended use, but was adopted to other production lines and transferred to other manufacturers.

The main findings of our model are as follows. We show that the market solution is characterized by an excessive choice of the general technology relative to a contractible investment benchmark. The two firms opt for the general technology to avoid excessive redesign costs even though the specific technology would be optimal in a first-best view. We also analyze the effect of a more intense product market competition that makes the exclusive supply to the manufacturer more worthwhile. We find that if the degree of product market competition increases, then the manufacturer will more often structure the contract to limit excessive redesign activities by allocating ownership to the supplier. This finding accords well with the earlier NYPRO/Vistakon example, as the market for contact lenses at the time was rather competitive and NYPRO remained the owner of the technology. Generally, the allocation of ownership depends on the relative importance of value-increasing collaborative R&D. If this value-increasing collaborative R&D is more productive it pays to choose the specific technology and to induce more of these investments by allocating ownership to the manufacturer.

⁵The NYPRO/Vistakon case also illustrates the relevance of the incomplete contracting approach: Within the R&D collaboration, there was great uncertainty regarding not only the technological developments but also the market size and prices achievable. Hence, the two firms could not agree ex-ante on the outcome of the project, such as the number of molds and/or the price Vistakon was supposed to pay.

In addition, our analysis reveals that the value of the supplier's expertise in the ex-post production process also affects the ex-ante choice of technology and ownership. As this expertise becomes more important, the threat of the buyer to take the new design to another supplier becomes less credible. This allows the specific R&D technology to be chosen and to be combined with ownership by the manufacturer.

We extend our analysis in two major directions. First, we consider contracts with options on ownership by allowing for exit clauses. We thereby investigate the implications of widely observed exit clauses (see for example Brooks *et al.* (2010) and Kittsteiner and de Frutos (2008)) for vertical R&D collaborations. We show that option contracts and exit rights increase the returns of R&D collaborations making these arrangements more likely to occur.

Second, we compare our results under incomplete contracting with ownership to specific performance contracts, thus representing an alternative contracting framework. Our analysis shows that such contracts do not necessarily yield an improvement over contracting about ownership. We also show that the allocation of ownership rights is a more preferred contracting structure than specific performance contracts if product market competition is intense.

The paper is organized as follows. In section 2 we relate our analysis to the literature. In section 3, we outline the basic model. In section 4 we solve the model and analyze the optimal contractual choices. In section 5, we consider the impact of allowing changes in ownership due to option contracts. In section 6 we allow for specific performance contracts, thus looking at the effect of contractibility of prices. Section 7 concludes.

2 Relationship to Literature

There is a substantial body of literature that investigates competition and research joint ventures in the industrial organization literature. However, these studies deal mostly with horizontal R&D joint ventures and focus on the effects of imperfect competition and spillovers as well as firms' motives to engage in R&D cooperations (see e.g., Amir and Wooders (2000), D'Aspremont and Jacquemin (1988), De Fraja (1993), and Katsoutacos and Ulph (1998), as well as Hagedoorn (2002) for an empirical discussion of horizontal R&D collaborations). There are only very few studies that address vertical R&D joint ventures. These exceptions (see Inkmann (1999) and Harhoff (1996)) focus on R&D spillovers and their effect on strategic R&D. All these papers, as well as the gros of the industrial organization literature on research joint ventures, conduct their analysis in a complete contracting environment and do not

examine organizational aspects of R&D cooperations and joint ventures.

A separate strand of the literature on R&D cooperations and joint ventures relies on an incomplete contracting framework and, hence, explores the organizational aspects of R&D joint ventures (see for a survey Azoulay and Lerner (2012)). Building on Aghion and Tirole (1994), this literature (see e.g. Rosenkranz and Schmitz (2003)) looks into organizational issues of R&D cooperations. We contribute to this literature in a number of dimensions. First, we merge the organizational issues with the consideration of product market competition, an issue which is treated separately in the above two strands of the literature on R&D cooperations and joint ventures. Second, we explicitly analyze vertical R&D collaborations with efforts provided by both parties, whereas most studies focus on horizontal R&D cooperation. Finally, in an extension of our analysis looking into option contracts, we contribute to the literature on research joint ventures by analyzing mechanisms to efficiently dissolve vertical R&D cooperations.

The papers most closely related to ours are Aghion and Tirole (1994), Arora and Merges (2004), Lülfesmann (2004), and Lerner and Malmendier (2010). Aghion and Tirole (1994) investigate the allocation of intellectual property rights between a research unit and its downstream customer, but in contrast to our model, they do not consider the possibility of engaging in redesign activities (the existence of further customers as well as the distribution of ex-post rents among all players is exogenous). Moreover, they show that financial constraints and the distribution of bargaining power play a crucial role in the ownership allocation. Lerner and Malmendier (2010) expand on Aghion and Tirole (1994) by considering options on the ownership theoretically and empirically.

Arora and Merges (2004) consider a hold-up problem in a supply relationship when protection of intellectual property is incomplete and knowledge spillovers occur. These authors focus on the role these effects have on the optimal make or buy decision, highlighting the role of patent protection in sustaining independent suppliers.

We distinguish ourselves from these papers by focusing on vertical R&D cooperations between independent organizations and the optimal structure of contracts rather than on pure make or buy decisions as analyzed in the vast literature on outsourcing, see e.g. Bresnahan and Levin (2012). Hence, we focus on an in-between organizational design where neither innovation inside the firm (make) nor arm-length's transactions (buy) but a mixture of both are appropriate. In this sense, we contribute to the literature on outsourcing by analyzing a case of partial outsourcing of R&D activities to the supplier, an issue which has to the best of our knowledge not yet been covered. Similarly to us, Lülfesmann (2004) considers alternative contractual

structures in horizontal R&D collaborations, specifically joint ownership and option contracts. In his set-up, sequential investments and the resolution of uncertainty of the innovative process affect the renegotiation of contracts and thus investment incentives.

Our paper complements the above literature by focusing on the endogeneity of the technological design as well as on the bargaining power of the research unit due to redesign activities. Furthermore, the effect of product market competition is a crucial and important addition in our analysis that is absent in current analyses of R&D cooperations.

Because it affects parties' outside options, technology plays an important role in incomplete contracting models of investments. However, as part of the innovation management process, technology is also a choice variable. Therefore, we include it as a variable in the initial R&D collaboration contract. This approach is similar to Schmitz and Sliwka (2001) and Inderst and Wey (2003) who also consider the choice of technology in vertical relationships. Schmitz and Sliwka (2001) focus on the joint determination of ownership and specificity against the background of a standard hold-up problem. Therefore, technology is a fixed characteristic of an asset that solely affects the value of investments. In our analysis, by tying the technology to the innovation, part of that technology may be altered ex post by redesigning the input. In Inderst and Wey (2003), technology is a fixed characteristic that determines the supplier's cost structure. These authors then consider the interaction between the choice of technology and (downstream) market structure and competition, rather than looking at organizational issues or collaborative investments.

3 The Model

3.1 Basic Set-Up

We consider the organization of innovative activities between a supplier (firm S) and a manufacturer (firm M). Innovative activities result in new or improved inputs into M's final product. These successful innovations increase the value of M's final product. Firm S is a specialized supplier with an accumulated stock of expertise in the field. Due to the high degree of uncertainty it is not feasible ex-ante to write a contract that describes the crucial characteristics of the new input in a verifiable manner. This infeasibility to write a complete contract is akin to the notion that there are many potential outcomes and it is prohibitively expensive ex-ante to describe the ex-post implementable outcome. Because both firms are active in the R&D process it is

costless to decide on the implementable outcome ex-post, but the two firms cannot commit not to renegotiate (see Hart and Moore (1999)).

Constraining the universe of potential suppliers to only one firm might ignore the fact that in many industries, there is substantial ex-ante competition on the supplier-side. The degree of ex-ante competition between suppliers would affect the distribution of rents emerging from the vertical R&D collaboration. However, once the collaboration is agreed upon, further competition is restricted as the collaborative nature of R&D would require inefficient duplication of efforts. Hence, the tie-in of the supplier restricts competition ex post. As we focus in our analysis on this latter stage and do not look into the distribution of rents emerging from ex-ante competition, we assume there is only one supplier to contract with ex ante.

Because of the contractual incompleteness, ownership rights matter. Ownership gives the right to determine on the implementation of the outcome of the research process.⁶ Specifically, ownership allows the owner to preclude the other party from using the outcome and thus affects firms' alternatives when negotiations break down. As ownership over the outcome of the innovative process can be assigned, this outcome can be interpreted as a kind of physical prototype or a patent. For simplicity, we refer to it as a patent in the following.

In the process of transforming the patent into a new input, collaborative development efforts of the manufacturer come into play. In this development phase, firm M's efforts improve the quality of the new input by fitting it to the needs of the final product. M's collaborative efforts are particularly productive if the technology is specifically designed towards M's own needs. However, with a general technology, M's collaborative investments are less productive. Simultaneously with M's collaborative development efforts, the supplier may engage in redesign activities. If these redesign activities are successful, then they allow the supplier to create a new modified input which may be sold to M's competitor, firm C. Redesigning the input is more costly under a specific than under a general technology.

In a subsequent post-development phase, the special production expertise of the supplier is required to embed the new input in M's mass production process. Hence, our notion is that the value creation process stems from two sources: The new input which consists of the patent and collaborative development efforts, and the expertise of firm S, which is required in the subsequent production process. The expertise of the supplier at this post-development stage (consisting, for example, of the human capital of employees of S) is not contractible in any stage of our analysis and depicts

⁶Allowing for the renegotiation of this right in later stages of the relationship does not affect our results.

the notion of non-alienability of human capital as stressed, for example, in Hart and Moore (1994).

The key features of our modeling approach can also be linked to our earlier real-world examples. In all cases, despite their clear aims (for example, finding a way to replace veneer in the Swedwood/Akzo Nobel case, or to improve lens' molds precision in the NYPRO/Vistakon case), the R&D projects were very vague in what technology would achieve these aims. The underlying uncertainty did not allow the firms to write complete contracts. At the same time, the examples show that some R&D projects required a high specificity to the manufacturer's products (in the Freqon/NordAlu case) or production technology (NYPRO/Vistakon case), while others appeared to be more general from the outset and thus more easily transferable to other products or customers (as in the Swedwood/Akzo Nobel case). Moreover, although the technology was to be developed by the supplier, the manufacturer contributed significantly to the process, by setting up testing facilities (in the Swedwood/Akzo Nobel case) or new production lines as part of the development process (NYPRO/Vistakon case).

Figure 1 summarizes and illustrates the overall structure of the innovation process. The sequence of decision-making is then as follows. In a first stage the two parties (M and S) agree on the allocation of ownership as well as on the R&D technology, i.e., specific or general technology. M and S also potentially decide on monetary transfers. These monetary transfers reflect different degrees of ex-ante bargaining power, which may mirror the ex-ante competition among suppliers, but do not affect our allocative results. Since we do not impose any further assumptions on ex-ante bargaining power, these monetary transfers will be ignored in the analysis.⁷

With a positive agreement, the R&D project starts with the fixed R&D investment by firm S in stage 2. In order to facilitate the analysis we assume that these initial research expenditures are contractible. Furthermore, we assume a deterministic relation between research input and outcome and normalize research expenditures to zero. Endogenizing the size of the ex-ante investment would leave our results unchanged, as long as we assume that the technology is additive separable from the other choice-variables in the later stages of the collaboration. For matters of tractability we use an additive separable technology assumption throughout the entire paper.⁸

⁷This implies that in the presence of intense ex-ante competition on the supplier side, most of the rents go to M (and vice versa). The allocation of these rents determine the monetary transfers exchanged between M and S at the beginning of the R&D collaboration. In the absence of financially constrained firms (see, in particular, Aghion and Tirole (1994)), however, there are no allocative implications on the entire interaction between the two partners.

⁸This is a common assumption as further interaction effects would mostly only confound the key mechanisms of the model (see e.g. Aghion and Tirole (1994)).

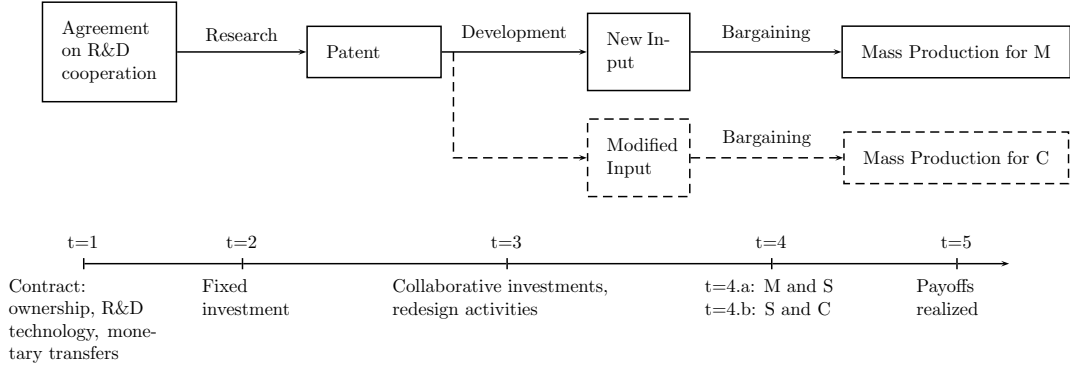


Figure 1: The structure of the R&D process

In stage 3, the two parties invest simultaneously in collaborative R&D (firm M) and redesign activities (firm S). Redesigning the input is assumed to be costless under the general technology. Hence, it is always possible to produce the modified input under the general technology. Under the specific technology, redesign activities are costly and may be unsuccessful.

Bargaining starts in stage 4. We assume that in a first step, one-shot bargaining between M and S with randomly chosen proposer will take place. We use this modeling approach to yield an equal division of the surplus by firms M and S. With a specific R&D technology chosen and unsuccessful redesign activities, bargaining takes place only between M and S, leading either to a contract entailing the exclusive use of the new product or no delivery. If S successfully created the modified input for potential sale to C, the proposing party offers a contract entailing the use of the input (exclusive or non-exclusive) as well as its price. The party receiving the offer may accept or decline it. In case of an acceptance of an exclusive offer, bargaining ends. Otherwise, S may approach C and the two firms might also engage in a random-proposer, one-shot bargaining process. In the final stage (stage 5) of the game cash flows are realized.

3.2 Design and Use of the New Input

We distinguish between the ex-post usage of the innovative product (exclusive use by firm M or non-exclusive use by both firms M and C) and the ex-ante design of the R&D technology (specific or general). Using the newly developed input ex-post exclusively in M's production creates a value of Y_M^X . If, in contrast, the innovation is also embodied in an input supplied to C, then the value of the new input for M reduces to Y_M while adding Y_C in value to C's product, where $Y_M^X > Y_M \geq Y_C \geq 0$.

We refer to $\Delta \equiv Y_M^X - Y_M$ as the intensity of product market competition between firms M and C. In the online appendix, we illustrate how this competition effect can be rationalized in a market model with product differentiation and Cournot competition between firms M and C. In such a model, the value differential of the new input $Y_M^X - Y_M$ increases in the degree of substitutability (as a measure of competition) for an innovation which either decreases the production costs (for a process innovation) or increases consumers' willingness to pay (for a product innovation).⁹

The value of the new input can be improved if firm M also contributes to R&D by investing $0.5I^2$. The effectiveness of this contribution depends on the choice of the R&D technology. With a general R&D technology, M's effort leads to an increase in value by I . However, if firms M and S decide to choose a specific R&D technology (designed towards M's needs), then the value of the new input for M is augmented by σI with $\sigma > 1$ measuring the exogenous degree of specificity of R&D.

We denote the value of the new input for M including M's investment in the case of exclusive use and specifically-designed R&D technologies by $V_{M,s}^X = Y_M^X + \sigma I$.¹⁰ For the non-exclusive use of the specific technology we have $V_{M,s} = Y_M + \sigma I$. We use corresponding notation to describe the value of the new input in the case of a general R&D technology: With exclusive use we have $V_{M,g}^X = Y_M^X + I$; with non-exclusive use the value of the new input amounts to $V_{M,g} = Y_M + I$. Since M's investments are directed towards its own product only, the value of the new input for C is not influenced by this investment (i.e., $V_C = Y_C$). We note that independent of the R&D technology chosen ex-ante, Δ measures the pure competition effect and remains unaffected by the R&D technology choice or the choice of M's investment in R&D.

Choosing a specifically designed R&D technology has a potential downside, because it limits S's ability to sell the new input to firm C. To be able to do so, S must engage in redesign activities to make it fit to the use with firm C. Redesign activities are more costly under a specific than under a general technology, and we normalize the costs of modifying the input under the general technology to zero. Given that M and S choose ex-ante a specific R&D technology, investing $0.5cq^2$ opens up with probability $q \in [0, 1]$ the possibility for S to also sell the modified input to C. This specification implies that if M and S choose ex-ante a specific R&D technology and

⁹The same relationship also holds under Bertrand competition and process innovations. Details are available from the authors. Also, the value differential might decrease if the supplier can exploit economies of scale when producing for M and C in the non-exclusive case and only for M in the exclusive case (see the market model in the online appendix for a more detailed line of argument). We are grateful to a reviewer for raising this issue.

¹⁰We use subscripts s and g to denote the specific and the general technology, respectively.

there are no or unsuccessful redesign activities, S remains locked into the relationship with M.

Because we analyze the choice of ownership over the patent, we distinguish between the case in which S owns the patent (S-ownership) and the situation in which M holds the ownership rights over the patent (M-ownership). In the former case, firm S possesses all sources of value creation (ownership and expertise) and might withhold the new input. Under M-ownership, M can take the patent to another supplier. However, since it only owns the patent but lacks the production expertise of S, M can only extract the fraction $a \in (0, 1)$ of total value. Hence, we depict the alienability of S's expertise with the parameter a . The larger the (in-)alienability of S's expertise the (smaller) larger is a .

In addition to the alienability of S's expertise, ownership of the patent can also affect the redesign costs. With M-ownership, the risk of litigation is far higher for S, making redesigning the input more costly than under S-ownership. Since redesign activities have no productive effect themselves, this effect would render M-ownership combined with the specific technology less attractive (as it would lower redesign activity levels but still result in higher overall costs). Because of the clear cut effect of these different cost structures, we reduce notational complexity in our analysis by modeling the redesign costs independent of ownership.¹¹

In order to ensure interior solutions in redesign activities (see A.3 in the online appendix) we assume that

$$c > \frac{V_C + a\Delta}{2} \quad (1)$$

in the subsequent analysis. This (sufficient) condition reduces the number of parameter ranges we need to consider in what follows without affecting the key mechanisms of our model.

4 Analysis

We solve for the subgame perfect equilibrium of the game by looking at the bargaining stage first, before then turning to an analysis of the investments in redesign activities and collaborative research. We initially consider the case of contractible investments as a benchmark and then analyze the case of interest, the market solution with incomplete contracting.

¹¹We thus bias our subsequent results towards the case of M-ownership under the specific technology, but qualitatively, our results are unaffected by this simplified structure. We are grateful to a reviewer for pointing out this issue to us.

4.1 Bargaining Stage

The key aspect in the bargaining process is the alternative use of the new product by S and M. If the parties initially choose the specific technology and S either does not pursue, or succeed in, any redesign activities, then S is unable to apply the new product at M's competitor C. In this case, bargaining takes place only between the two initial parties M and S. Conversely, if the input is successfully redesigned or the general technology is chosen initially, then S may sell the new or modified input to both M and C. This case leads to the three-party sequential bargaining process. In either bargaining structure, ownership affects M's valuation of the new input in its alternative use. In case of M-ownership, M might realize a fraction a of the final value, which itself depends on S's ability to sell to C. Additionally, in the three-party bargaining process, M and S may choose to offer contracts conditional on exclusive or non-exclusive use.

In the following Lemma, we distinguish four contractual settings – a general/specific technology and M/S-ownership, respectively. We depict the outcomes for the M-ownership case explicitly. The S-ownership case results from setting $a = 0$.

Lemma 1

1. *For the two-party bargaining process, the expected payoffs before investment costs, depending on the technology chosen, are*

$$\text{for the specific technology: } \pi_M^B = (1+a)\frac{V_{M,s}^X}{2}; \quad \pi_S^B = (1-a)\frac{V_{M,s}^X}{2} \quad (2)$$

$$\text{for the general technology: } \pi_M^B = (1+a)\frac{V_{M,g}^X}{2}; \quad \pi_S^B = (1-a)\frac{V_{M,g}^X}{2} \quad (3)$$

2. *For $\Delta \geq \frac{V_C}{2}$, three-party bargaining results in exclusive use of the good; for $\Delta < \frac{V_C}{2}$, three-party bargaining results in non-exclusive use.*

3. *Under three-party bargaining, the expected payoffs before investment costs are*

$$\begin{aligned} \text{for the specific technology: } \pi_M^B &= (1+a)\frac{V_{M,s}}{2} + \frac{1}{2}\max\{\Delta - \frac{V_C}{2}, 0\} \\ \pi_S^B &= (1-a)\frac{V_{M,s}}{2} + \frac{V_C}{2} + \frac{1}{2}\max\{\Delta - \frac{V_C}{2}, 0\} \end{aligned} \quad (4)$$

and

$$\begin{aligned} \text{for the general technology: } \pi_M^B &= (1+a)\frac{V_{M,g}}{2} + \frac{1}{2}\max\{\Delta - \frac{V_C}{2}, 0\} \\ \pi_S^B &= (1-a)\frac{V_{M,g}}{2} + \frac{V_C}{2} + \frac{1}{2}\max\{\Delta - \frac{V_C}{2}, 0\} \end{aligned} \quad (5)$$

Proof: See the online appendix.

The outcome of the two-party bargaining illustrates the role of M's alternatives. In the bargaining process, each party is equally likely to be the proposer and thus will be able to push the other party to indifference between accepting and rejecting the offer. Hence, in expectations the two parties equally share the jointly created surplus. This surplus is equal to the value of the exclusive use of the good minus the value of M's ability to realize the innovation's value on its own (zero in case of S-ownership, fraction a in case of M-ownership). The more pronounced the alienability of the supplier's expertise (i.e., the larger is a), the better is M's bargaining position in the case of M-ownership and the larger the share of surplus that M will capture. To illustrate this in detail, let us focus on M-ownership and a specific technology. With S (M) being the proposer, S (M) offers M (S) the disagreement payoff $aV_{M,s}^X(0)$ to the respective counterpart who accepts the offer. Hence, the proposer gets what is left on the table. S, when being the proposer, receives $(1 - a)V_{M,s}^X$, and M, if acting as the proposer, gets $V_{M,s}^X$. With equal probability of either player to be the proposer this gives us, for this particular case, the expected payoffs as displayed in the above Lemma.

In the case of three-party bargaining, M and S also share the jointly created surplus which is maximized by choosing exclusive use if the input's value for C is low enough, and non-exclusivity else. Additionally, S now realizes part of the innovation's value for C, V_C , because S can use non-exclusivity as a threat in bargaining with M. Finally, M still retains his alternative of producing without S, but is only able to realize the non-exclusivity value $V_{M,s}$ due to S's ability to sell to C. Consider again the case of M ownership and the specific technology (with successful redesign activities). Note that the proposer makes two alternative offers, depending on the final use of the input – exclusive or non-exclusive. Since M always can achieve $aV_{M,s}$, S will offer not less than that, hence pocketing $V_{M,s}^X - aV_{M,s}$ in the case of exclusivity and $(1 - a)V_{M,s} + 0.5V_C$ in case of non-exclusivity. The latter term stems from the sequential bargaining game between S and C which leads to a split of the surplus, V_C . If M is the proposer the breakdown of the bargaining between M and S leaves S with $V_C/2$. Hence, this has to be offered to S by M in case of exclusivity. With non-exclusivity S is offered nothing from the surplus emerging between M and S. Hence, M ends up with $V_{M,s}^X - 0.5V_C$ in case of exclusivity and $V_{M,s}$ in the non-exclusive case. Equal probability of being proposer yields the expected payoffs as stated in the Lemma.

4.2 Contractible Investments Benchmark

Here we look at the case of contractible investments as a reference solution for the subsequent analysis. Despite this contractibility, the optimal contract is not a first-best solution. This is because in the bargaining stage, C might capture rents in the three-party bargaining process which do not feature in the contracting decision of M and S. These rents accrue to C because M and S do not bargain jointly with C. We note that joint bargaining by M and S would lead to exclusive use of the good only if $\Delta \geq V_C$, which would be the socially efficient rule. Therefore, the first-best contract differs from the contract derived here. However, the contractible investments benchmark serves as a more appropriate reference point in our analysis. Specifically, using the contractible investments benchmark implies that the ex post decision about exclusive or non-exclusive use is not altered compared to the incomplete contracting scenario. Therefore, the potential efficiency losses from incomplete contracting do not arise from differences in the post-bargaining phase, but from earlier investment incentives.¹²

With contractible investments, M and S choose investment levels and technology that maximize their joint surplus. Given the earlier bargaining payoffs and taking investment costs into account, this expected surplus amounts to

$$E[\pi_M + \pi_S] = \begin{cases} Y_M + \Delta + \sigma I - \frac{1}{2}I^2 + q(\max\{0, \frac{V_C}{2} - \Delta\}) - \frac{c}{2}q^2 & \text{with specific technology} \\ Y_M + \frac{V_C}{2} + I - \frac{1}{2}I^2 + \max\{\Delta - \frac{V_C}{2}, 0\} & \text{with general technology} \end{cases} \quad (6)$$

With contractible investments, ownership does not matter since it affects only the distribution of the rents in the bargaining stage. Maximization of the expected surplus function (6) with respect to technology and investment levels I and q yields the following result.

Lemma 2

When there are contractible investments, there exists a critical level $\hat{V}_C > 2\Delta$ such that

1. *for $V_C \leq \hat{V}_C$, the optimal contract specifies choice of the specific technology and investments $I_{ci} = \sigma$ and $q_{ci} = \frac{\max\{0, \frac{V_C}{2} - \Delta\}}{c}$;*
2. *for $V_C > \hat{V}_C$, the optimal contract specifies choice of the general technology and investment $I_{ci} = 1$ (no redesign activity necessary).*

¹²Under a joint bargaining benchmark, all our subsequent results with the exception of part 1. of Proposition 1 would continue to hold (details are available from the authors).

Proof: See the online appendix.

With contractible investments, we can differentiate between two main sets of parameters. First, with $V_C \leq \hat{V}_C$, M and S choose the specific technology. We can divide this first parameter set into two subsets. In the first subset, for $V_C \leq 2\Delta$, the final input is provided exclusively to M. As can be seen in the expected joint surplus (6), redesign activities have no benefits in this case and thus are not undertaken. The specific technology is always preferable due to the higher investment productivity. In the second subset, for $2\Delta < V_C \leq \hat{V}_C$, the firms choose non-exclusive input provision whenever possible. However, M and S still choose the specific technology due to the higher investment productivity. In this case, redesign activities provide benefits, so some degree of this activity is optimal: Successful redesign allows the firms to realize the optimal, non-exclusive, use of the input despite the choice of the specific technology. Hence, higher investment productivity is traded off against redesign costs and the possible inability to sell the product to firm C.

Lastly, in the second parameter set, for $V_C > \hat{V}_C$, the risk of having to sell exclusively to M is too costly, hence M and S select the general technology. Since redesign activity is no longer required, the parties ensure non-exclusive input provision at the cost of a lower investment productivity.

4.3 Optimal Design with Incomplete Contracting

4.3.1 Investment decisions

With non-contractible investments, the choice of the optimal contract and investment decisions have to be analyzed separately. Therefore, we next consider the development stage with the choice of M's collaborative development efforts and the redesign activities of firm S. M's investments are always productive, as they directly increase the value generated by the new input. The redesign activities by S include, in varying degrees, a rent-seeking activity. Successful redesign allows S to bypass the initially specific technology and to offer the modified input to C. Since this option enables S to demand more in the bargaining process with M, redesign activities transfer rents from M to S. Nevertheless, some degree of redesign activities may be jointly beneficial. As our discussion of the contractible investments benchmark illustrates, it may be optimal for the firms to select the specific technology (because of higher investment productivity) even when non-exclusive input provision is preferable ex post. In this case, (successful) redesign activity enables the firms to pursue non-exclusive provision and thus provides joint benefits.

In the following, we denote ownership by subscripts M or S, preceding the tech-

nology subscripts s and g .

Lemma 3

1. *The optimal investment levels for M are: $I_{S,g} = \frac{1}{2}$, $I_{M,g} = \frac{1+a}{2}$, $I_{S,s} = \frac{\sigma}{2}$ and $I_{M,s} = \frac{\sigma(1+a)}{2}$. For a given ownership, M's investment levels are always higher under the specific technology than under the general technology; for a given technology, M's investment levels are always higher under M-ownership.*
2. *For $\Delta \geq \frac{V_C}{2}$ (exclusive use ex post), choice of the specific technology leads to redesign activity of $q_{S,s} = \frac{V_C}{4c}$ or $q_{M,s} = \frac{V_C}{4c} + a\frac{\Delta}{2c}$ with $q_{S,s} < q_{M,s}$.*
3. *For $\Delta < \frac{V_C}{2}$ (non-exclusive use ex post whenever feasible), choice of the specific technology leads to redesign activity of $q_{S,s} = \frac{V_C - \Delta}{2c}$ or $q_{M,s} = \frac{V_C - (1-a)\Delta}{2c}$ with $q_{S,s} < q_{M,s}$.*

Proof: See the online appendix.

The investment levels for M highlight the importance of technology and outside options offered by ownership: The investment levels are highest for M-ownership and the specific technology and lowest for S-ownership and general technology. This fact is natural given our discussion of the outcome of the bargaining stage. As the owner, M captures a larger share of the total surplus, especially if the degree of alienability is high (large a). Hence, in this case, the larger is a the greater is the incentives of M to invest in cooperative R&D. With a more specific technology, investment in cooperative R&D is more productive, leading to stronger incentives to invest. Nevertheless, given the chosen technology, M's investment levels are always below the jointly optimal levels specified in Lemma 2.

For S, redesign activities are only necessary in the case of the specific technology. Redesigning the input improves its bargaining position because S can threaten to sell to C. If there is a high value of exclusivity ($\Delta \geq V_C/2$), this increase in bargaining power is the sole driver of redesign activities. For a lower exclusivity value, redesigning the input also creates some value because it allows the firms to switch from exclusive to non-exclusive use. However, even in this case of jointly valuable redesign activity, it is still excessive: A comparison of $q_{S,s}$ (see Lemma 3, part 3) with the highest level of jointly optimal redesign activity (q_{ci} in Lemma 2) shows that $q_{S,s} > q_{ci}$. Additionally, M-ownership increases S's incentive to redesign since it reduces M's outside value by its exclusivity value $a\Delta$. Hence, under M-ownership, an increase in either the value of the new input to C or in its exclusivity value increases the costly redesign activity even further, relative to the level under S-ownership.

4.3.2 Choice of technology and ownership

We now consider the initial, incomplete contracting stage. In this stage M and S must specify both the R&D technology and the ownership of the final input. Absent any constraints on side payments, the two parties will choose the ownership/technology combination that maximizes the expected joint payoff. The optimal choice of ownership and technology will trade off M's investment incentives with S's incentives to excessively invest in redesign activities.

Proposition 1

1. *With optimal incomplete contracts, firms will choose the general technology more frequently than is optimal under the contractible investments benchmark.*
2. *The combination of S-ownership with general technology is never optimal.*
3. *For $\sigma < \sqrt{1 + \frac{2a-a^2}{3}}$, the combination of S-ownership with the specific technology is never optimal.*

Proof: See the online appendix.

The optimal ownership/technology choice involves trading off the value enhancing effects of the specific technology and M-ownership with the efficiency loss due to redesign activities. Given that M-ownership always improves M's investment and that the general technology implies redesigning the input is costless, it is never optimal to combine S-ownership with the general technology (part 2 of Proposition 1). In other words, it is always optimal to transfer some (bargaining) power to M, be it in terms of ownership, by choice of a technology that is specific to M, or both. Additionally, if the productivity increase under the specific technology is too low, then the only way to transfer bargaining power to M is via ownership (part 3). And to avoid excessive redesign activity, the contracting parties revert to the general technology more often than would be optimal under contractible investments.

We illustrate the optimal contracting choices and results also in Figure 2. The two panels of Figure 2 depict optimal contracts depending on the parameters V_C and Δ . The gray line separates the cases of ex post exclusivity ($\Delta \geq \frac{V_C}{2}$, below the line) and the case of non-exclusivity ex post whenever feasible. The dashed gray line separates the sets in which, under contractible investments, optimal contracts select the general (above the dashed line) or the specific (below the line) technology. The solid black lines separate the parameter sets in which one of the three incomplete

contracts is optimal.¹³ These optimal contracts are specified in the figures. Panels 2a. and 2b. depict two different parameter settings in which the intersection of the three lines separating optimal contracts lies in either of the two scenarios of ex post use.¹⁴

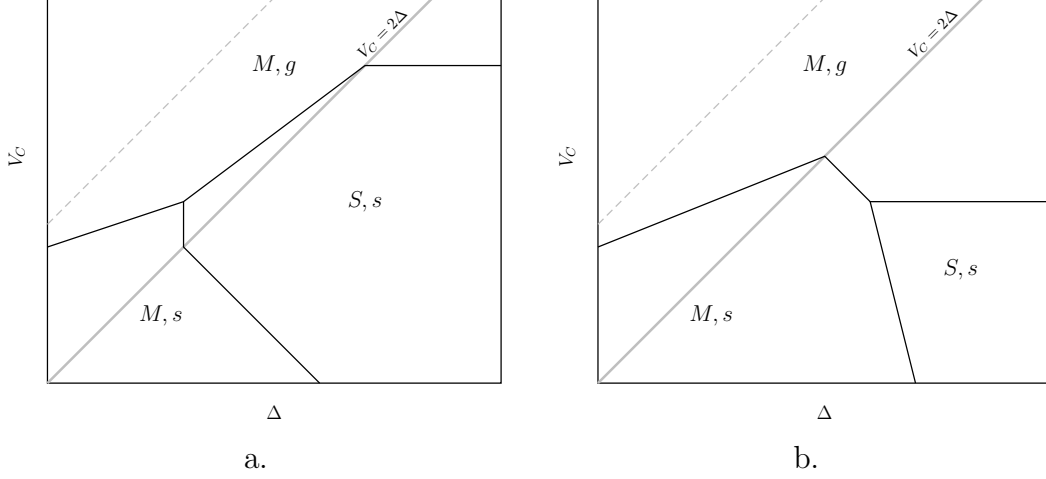


Figure 2: Optimal incomplete contracts

Figure 2 shows that the market solution might not ensure that the specific technology is chosen when it would be jointly optimal to do so (part 1 of Proposition 1), because the contractible investment benchmark would select the specific technology for all parameter combinations below the dashed line. However, optimal incomplete contracts include the general technology for some of these parameter combinations, irrespective of the ex post use of the input. This choice of the general technology is due to the cost of rent-seeking by redesign activities.

Given this structure of incomplete contracts, we can analyze how the optimal incomplete contract varies with key parameters of the model. In order to do so, we assume in the following Corollary that all three relevant contracts are possible.¹⁵

¹³The relevance of the different contractual solutions is supported by observations from our earlier real-world examples. For example, in the Swedwood/Akzo Nobel case, the manufacturer (Swedwood) appeared to retain the ownership of a general technology, corresponding to the M, g contract. On the other hand, in the NYPRO/Vistakon case, the supplier retained ownership of the specific technology, corresponding to the S, s contract. These observations suggest that the trade-offs from incomplete contracting (versus the contractible investments benchmark) captured in our model are reflected in real-world contractual structures.

¹⁴Technically, two more scenarios are possible but not depicted here: In the first, the intersection lies exactly on the solid gray line; in the second, there is no intersection for $V_C \geq 0$ (because S-ownership is never optimal).

¹⁵Part 3 of Proposition 1 shows the condition under which this is not the case. In this case, only the first result of part 2 of Corollary 1 would hold, as the other parts refer to changes in ownership

Corollary 1

Let $\sigma > \sqrt{1 + \frac{2a-a^2}{3}}$. Then a marginal increase (decrease) in

1. Δ , the intensity of product market competition, results in M and S choosing S -ownership (M -ownership) more often;
2. σ , the productivity gain offered by the specific technology, results in M and S choosing the specific (general) technology more often; moreover, M -ownership (S -ownership) is combined more often with the specific technology;
3. a , the alienability of S 's expertise, results in M and S combining S -ownership (M -ownership) more often with the specific technology.

Proof: See the online appendix.

Figure 2 confirms the first comparative static result. For low values of V_C , an increase in competition leads to a transfer of ownership from M to S . By switching from M -ownership to S -ownership the contracting parties try to reduce the degree of redesign activities. For higher values of Δ , that is, for higher product market competition, the decrease in rent-seeking by switching from M -ownership to S -ownership is more pronounced but the difference in M 's investments between the two ownership structures remains unaffected.

Figure 3 shows how changes in the benefits from choosing the specific technology (in terms of the productivity enhancement captured by σ) affects optimal incomplete contracts. Both panels in Figure 3 start with the same situation as in Figure 2. The added dashed black lines depict contractual choices when σ increases. Generally, the parameter affects the optimal investment level under either ownership allocation while leaving the incentives for redesign activities unaffected (see Lemma 3). An increase in the specific technology's productivity gain increases investment incentives and thus also increases the benefits of selecting this technology. Therefore, avoiding costly redesign activities by choosing the general technology is a less profitable option. Instead, in combination with the specific technology, a firm will choose ownership to balance investment and rent-seeking incentives. Moreover, given the choice of the specific technology, a higher productivity gain from this technology increases the sensitivity of M 's investments to ownership choice. Therefore, M -ownership is combined more often with the specific technology when σ increases.

We also consider the role of the alienability of S 's expertise, captured by a . A higher alienability (lower relevance of the supplier's production expertise) implies that ownership choices have a pronounced effect on M 's investments. However, as long as (which could never happen as S -ownership is never optimal).

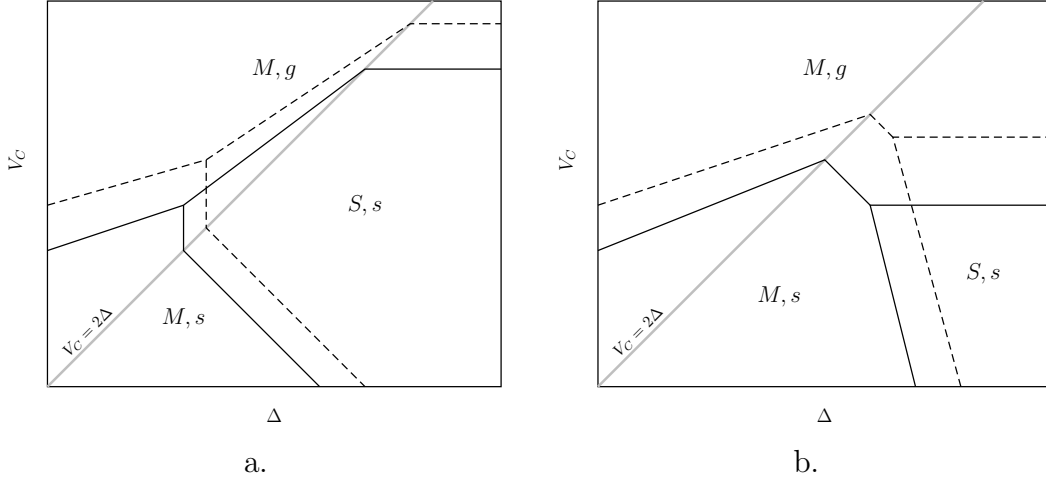


Figure 3: Changes in optimal contracts for increasing σ

the firms choose the specific technology, a higher alienability lowers S's bargaining power, thus raising his incentives to redesign the input. Since M's investment levels are at least partially upheld by the specific technology, the latter effect is countered by combining S-ownership more often with this technology.

5 Options on Ownership

We now extend our analysis by introducing option contracts on ownership, thereby building on the literature on exit clauses (see Brooks *et al.* (2010) and Kittsteiner and de Frutos (2008), for example) and empirically observable contracts in R&D outsourcing contracts (see, for example, Kloyer and Scholderer (2012)). These option contracts enable the reallocation of ownership: Ownership is allocated ex-ante to one firm and can be reallocated on the basis of an option contract with a pre-specified strike price in stage 4, before the start of the bargaining process.¹⁶ This kind of option contract can be implemented by giving one firm an exit right. With one firm holding a call right by paying the prespecified fee (the strike price), this firm can terminate the contract and appropriate the ownership of the patent. Equivalently, a put right allows the firm to terminate the initial contract and entitles it to a payment in exchange for relinquishing all ownership. Similar exit rights/options are frequently used in the venture capital industry (see, for example, Chemla *et al.* (2007) or Bienz and Walz (2010)). Lerner and Malmendier (2010) also study exit options for research agreements in the biotechnology industry. We show that while improving the effi-

¹⁶The option contracts considered here do not change our incomplete contracting assumption, because they do not specify rights to trade the good (as e.g. in Nöldeke and Schmidt (1995)).

ciency of the outcome, these option contracts do not change our basic mechanisms and results qualitatively. To simplify the analysis, we focus in the following only on the case of ex-post exclusive use, that is, we assume that

$$\Delta \geq \frac{V_C}{2} \quad (7)$$

Option contracts only affect our previous analysis if the optimal exercise depends on the outcome of the redesign activities. If options are always or never exercised, then our earlier analysis applies because strike prices are fixed transfers not affecting incentives to invest in cooperative R&D or in redesign activities. A direct consequence of this result is that option contracts only matter if combined with the specific technology.

Although there are four potential cases of allocating option contracts, only the allocation of the exit right to either S or M matters. Here, we focus on the case of S holding the exit right.¹⁷ An exit right for S implies a put right under initial S-ownership or a call right under initial M-ownership. We consider both cases which are structurally identical but lay out the analysis by focusing on the latter case in detail. Let P denote the agreed strike price defined as a payment from S to M. Then the payoff structure including the call option payoff is as given in Table 1.

Redesign activity successful		... not successful	
Base payoff	Option payoff	Base payoff	Option payoff
$\pi_M = \frac{1}{2}(Y_M^X + aY_M + (1+a)\sigma I - V_C/2)$	$-\frac{a}{2}(Y_M + \sigma I) + P$	$\pi_M = \frac{1}{2}(1+a)(Y_M^X + \sigma I)$	$-\frac{a}{2}(Y_M^X + \sigma I) + P$
$\pi_S = \frac{1}{2}(Y_M^X - aY_M + (1-a)\sigma I + V_C/2)$	$+\frac{a}{2}(Y_M + \sigma I) - P$	$\pi_S = \frac{1}{2}(1-a)(Y_M^X + \sigma I)$	$+\frac{a}{2}(Y_M^X + \sigma I) - P$

Table 1: Payoff structure with option contracts

With a low (high) strike price, S will exercise the call in either (neither) case and equilibrium investments will be as under S-ownership (M-ownership). For intermediate levels of the strike price, S will only exercise the call in case of failed redesign activities. For this case, the expected payoffs of the two firms can be expressed as:

$$E[\pi_M] = \frac{q}{2}(Y_M^X + aY_M + (1+a)\sigma I - \frac{V_C}{2}) + \frac{1-q}{2}(Y_M^X + \sigma I + 2P) - \frac{I^2}{2}, \quad (8)$$

and

$$E[\pi_S] = \frac{q}{2}(Y_M^X - aY_M + (1-a)\sigma I + \frac{V_C}{2}) + \frac{1-q}{2}(Y_M^X + \sigma I - 2P) - \frac{cq^2}{2}. \quad (9)$$

¹⁷We also considered the case of M holding the exit right. However, the analysis in this case is more complex but leaves the general mechanisms and trade-offs intact. We therefore do not present this case in the paper.

However, these objective functions only apply if the asymmetric exercise is optimal after the investment decisions have been realized. This fact restricts the combination of the option strike price and M's investments: The strike P must be in the range $P \in [0.5a(Y_M + \sigma I), 0.5a(Y_M^X + \sigma I)]$, which itself depends on the investment I . Hence, the choice of investments and the applied objective functions must be consistent in equilibrium.

Lemma 4

Consider choice of the specific technology and an exit right for S (i.e., either M-ownership and a call option for S or S-ownership and a put option for S) at price P (defined as a transfer to the initial owner).

1. *Equilibrium investments I and q are continuous in P ;*
2. *M's equilibrium investment I is strictly increasing in P for $P \in [P_1, P_4]$ and constant else ($I = I_{S,s}$ for $P < P_1$ and $I = I_{M,s}$ for $P > P_4$);*
3. *S's equilibrium level of redesign activity q is strictly increasing in P for $P \in [P_2, P_3]$ and constant else ($q = q_{S,s}$ for $P < P_2$ and $q = q_{M,s}$ for $P > P_3$);*

where

$$\begin{aligned} P_1 &\equiv \frac{a}{2} \left(Y_M + \frac{\sigma^2}{2} \right), & P_2 &\equiv \frac{a}{2} \left(Y_M + \frac{\sigma^2}{2} (1 + a \frac{V_C}{4c}) \right), \\ P_3 &\equiv \frac{a}{2} \left(Y_M^X + \frac{\sigma^2}{2} (1 + a \frac{V_C + 2a\Delta}{4c}) \right), & P_4 &\equiv \frac{a}{2} \left(Y_M^X + \frac{(1+a)\sigma^2}{2} \right), \end{aligned}$$

and $P_1 < P_2 < P_3 < P_4$.

Proof: See the online appendix.

Including an option for S in the contract allows the two firms to increase the set of attainable investment levels by varying the strike price. For intermediate levels ($P \in [P_2, P_3]$), both firm's investments increase in the strike and lie between the levels under either M-ownership or S-ownership. The most important effect of including an option for S occurs at levels of the strike price that are close to but still above the level where S always exercises its call, $P \in [P_1, P_2]$. At these strike prices, the two firms can realize higher investments by M without increasing S's level of redesign activity. This improvement is achievable because by raising its investment from the S-ownership level, M can offset the negative payoff that would arise if S exercises the call. Simultaneously, this behavior leaves S indifferent with respect to the exercise and thus leaves the incentives for redesign activities unaltered.

Given that there is generally too little investment by M in cooperative R&D, an option contract can improve the overall outcome of the R&D cooperation. This is

particularly the case if S-ownership is not too inferior. Since an exit option for S improves the investment relative to S-ownership, the option contract is more likely to be preferred over a fixed ownership contract. Generally, the optimal strike price will be equal to or higher than P_2 but below P_3 : P_2 will only be optimal if choice of S-ownership and the specific technology is the (weakly) preferred contract design initially; setting the strike price at or above P_3 will always be inferior to M-ownership because the latter yields the same level of redesign activity but higher investments by M. Moreover, since it is always combined with the specific technology, this technology will be implementable more often than without an option contract. We summarize the above arguments in the following proposition:

Proposition 2

Allowing for option contracts on ownership by giving S an exit right (weakly) improves the return from the R&D cooperation and shifts the choice of technological design in favor of the specific technology.

Despite (weakly) improving the outcome of the R&D allocation, option contracts on ownership are not able to achieve first-best as they do in Nöldeke and Schmidt (1998). This result is due to the simultaneity of the agents' investment decisions, weak ownership of the patent for M (reflected in $a < 1$), and the possibility to engage in redesign activities. Even allowing for sequentiality of moves as in Nöldeke and Schmidt (1998) would not lead to first-best results with options on ownership. Because of partial ownership, M cannot be induced to invest optimally even with M-ownership. Furthermore, S may change its outside option via its redesign activities (thus opening up the possibility of a non-exclusive use of the new technology), which is a purely rent-seeking activity given the parameter restriction (7). Our analysis is thus related to Edlin and Hermalin (2000) who show that options on ownership do not achieve the first-best in cases in which the option contract expires before the agent's final decision is undertaken.

6 Specific Performance Contracts

In what follows, we analyze the effect of specific performance contracts in which both parties can request that trade takes place at certain, prespecified prices (see Aghion *et al.* (1994) on this type of contracting environment). These prices are enforceable if the technological features of the new input can be specified ex ante and, at a later stage, can either be verified or at least be observed by a third party. The latter case

requires additionally that reputational concerns then ensure that both parties adhere to the contract.

In contrast to our main analysis, initially agreed-upon prices define default options that the parties can enforce, hence allowing for a contracting environment which is different to the environment of our main analysis. Thus, our point in conducting this second analysis is to examine under which conditions such an environment – with specific performance contracts but no choice of ownership allocation – offers efficiency improvements. We compare our earlier findings with a scenario where the parties can agree on a single price \bar{p} ex ante, but cannot make prices contingent on ex-post usage (exclusivity or non-exclusivity).¹⁸ Under this scenario, it is not possible for a third party to verify whether or not an input delivered to C is based on the technology developed within the R&D collaboration. In addition, we consider only those contracts that embody the specific technology, because this technology is selected in the contractible investments benchmark. As in the previous section, we continue to assume $\Delta \geq \frac{V_C}{2}$.

The bargaining game with a single price specific performance contract (see the online appendix) yields the following expected profits for M and S:

$$E[\pi_M] = (1 - q)V_M^X + q\left(\frac{V_M^X}{2} + \frac{V_M}{2} - \frac{V_C}{4}\right) - \bar{p} - 0.5I^2 \quad (10)$$

$$E[\pi_S] = \bar{p} + q\left(\frac{V_M^X - V_M}{2} + \frac{V_C}{4}\right) - 0.5cq^2 \quad (11)$$

Taking first-order derivatives gives optimal investments

$$I_{1p} = \sigma \quad (12)$$

$$q_{1p} = \frac{1}{c} \left(\frac{V_M^X - V_M}{2} + \frac{V_C}{4} \right) \quad (13)$$

The specific performance contracts result in M being the residual claimant to its investment returns; hence, it produces investments as in the contractible investments benchmark. However, S engages in redesign activities, as the ability to sell to C increases its bargaining power. Because of the latter effect, it is not clear whether a single price specific performance contract offers an improvement over the incomplete contracts with ownership.

Proposition 3

1. *Incomplete contracts that specify ownership rights can be preferable to specific performance contracts with one price.*

¹⁸Allowing for usage-contingent prices in specific performance contracts would allow the two firms to implement the contractible investments benchmark.

2. *The more intense product market competition, the more preferable are incomplete contracts that specify ownership rights in comparison to specific performance contracts with one price.*

Proof: See the online appendix.

This result shows that even if single-price specific-performance contracts are feasible, M and S might prefer to write incomplete contracts specifying ownership to govern their R&D collaboration. This result is particularly true when there is strong product market competition, because the returns to redesigning the input then increase more in case of specific performance contracts than they do under any of the ownership contracts.

7 Conclusion

A major source for the successful development of firms is the innovative efforts of their suppliers that lead to technological enhancements of the final product. At the same time the supplier's innovative efforts are often undertaken at least to some degree collaboratively with the buyer. These joint R&D processes allow both parties to combine their stocks of knowledge. Obviously, given the problems associated with contracting on the output of R&D this process leaves room for potential exploitation of one side by the other and hence to inefficiency. Against this setting, we explore the design and structure of vertical R&D collaborations which we observe in many instances.

Using an incomplete contracting framework, our model aims to capture important issues related to vertical R&D cooperation while still being simple enough to detect clear-cut mechanisms. Our analysis yields the following empirically testable hypotheses for R&D collaborations:

- H1: The more intense the product market competition, the more often the supplier becomes the owner of the innovation (see Corollary 1).
- H2: The higher the productivity gain from the specific technology, the more often the firms choose the specific technology and, conditional on the choice of this technology, the more often the manufacturer becomes the owner of the innovation (see Corollary 1).
- H3: If the firms choose the specific technology, then the more important the supplier's production expertise, the more often the manufacturer becomes the owner of the innovation (see Corollary 1).

H4: Option contracts/exit rights increase the returns to R&D cooperations. Therefore, the lower the costs of contracting on contingent ownership, the more often option contracts should be used, and the more we should observe R&D cooperations (see Proposition 2).

H5: The more intense the product market competition, the more often firms will use incomplete contracts that specify ownership rights rather than specific performance contracts (see Proposition 3).

Although we believe that the model incorporates crucial feature of vertical R&D collaborations, obviously our model abstracts from several aspects. First and most notably we concentrate only on fixed-investment projects. In doing so, we ignore potential hold-up problems associated with ex-ante investment decisions. Endogenizing the size of the ex-ante investment clearly aggravates the contractual problems associated with vertical R&D cooperations but leaves our main mechanisms in place. Second, we pay no attention to the repeated interaction between the supplier and the buyer as a mechanism to mitigate contractual problems. Repeated interaction is, given the focus of our analysis, clearly an important aspect. But even if we accept the validity of repeated interaction, it is unlikely to eliminate all contractual problems, which leaves enough room for the mechanisms stressed in the paper. Consequently, our model provides a starting point for analyzing vertical R&D collaborations more closely.

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