The Design of Vertical R&D Collaborations*

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Abstract

Suppliers play a major role in the downstream firm's innovation processes. We analyse ownership allocations and the choice of R&D technology in vertical R&D cooperations. Given incomplete contracts on the R&D outcome, there is a trade-off between R&D specifically designed towards a manufacturer (increasing investment productivity) and a general technology (hold-up reduction). We find that the market solution yields the specific technology in too few cases. More intense product market competition shifts optimal ownership towards the supplier. The use of exit clauses increases the gains from the collaboration.

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1 Introduction

Input suppliers play a major role in the innovation process of many industries (see e.g., Clark (1987) for the automobile industry and Pisano (1991) for the biotechnology industry). Given their specific expertise, input supplying firms can build on a stock of knowledge. This enables them to step beyond the existing technological frontier by developing new and better products which are used in the final production processes of their customers. Often, however, the research and development (R&D) activity of the input supplier is complemented by collaborative R&D efforts of the manufacturer. Given substantial economies of scope on either side, neither a pure market transaction (full-scale outsourcing) nor a fully integrative approach appear efficient. Consequently, we observe in very many instances vertical R&D cooperations between suppliers and buyers. Jorde and Teece (1990) stress that a significant number of industries, most notably in Europe and Japan, are characterized by (vertical) R&D collaborations. 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.[1]

The main objective of this paper is to analyse the functioning and structure of such vertical R&D collaborations and relate them to competition in output markets i.e. investigate how product market competition influences the design of vertical R&D collaboration. Our main research questions are: (i) How should firms organize vertical R&D collaborations (in terms of technology and allocation of property rights)? (ii) How does the intensity of competition in output markets affect the organizational design of vertical R&D collaborations?

Vertical R&D collaborations differ from both horizontal R&D collaborations and standard upstream-downstream relationships in several important aspects. In the latter, the supplier uses its own or joint assets to provide (intermediary) goods. The same types of goods usually are also delivered to other firms in the industry, as the supplier leverages his expertise. In R&D collaboration, however, often a unique innovation results that is initially available only to the collaborating parties. Intellectual property rights can be used to prevent the technology to spread to competitors, thus giving the downstream firm a competitive advan-

[1]In his sample of 3112 innovative German firms the overall percentage of firms reporting vertical R&D cooperations is 84%. This number is even higher (99%) when only companies with a formal R&D department are taken into account.

tage. The extent of this advantage depends on the competitive environment of the downstream firm. However, while the downstream firm prefers to use the new technology exclusively, the supplier is potentially interested in marketing the technology to other, competing firms (see e.g. the the case description and discussions in Arora and Merges (2004)). Hence, there is a potential conflict of interest, the extent of which depends on the degree of downstream competition and the ability to protect innovations from unwanted use. This conflict of interest is less prevalent in horizontal collaborations: There, innovations are usually developed for joint usage of the technology (either independently or within a separate, jointly owned entity) from the outset. Hence, when entering these collaborations, the parties engaged fully acknowledge the effect this has on market competition.

Our set-up and the resulting research questions can be illustrated best by considering an example from the car industry. A specialized supplier of fuel-injection systems produces a wide range of these systems using its accumulated expertise in dealings with different customers. A car manufacturer, in turn, produces and designs a number of differentiated car types. As there are economies of scope at the level of the two firms, it is efficient to undertake R&D with respect to the development a new injection system for a particular type of car in a non-integrated manner. At the same time, the value of the new system can be improved with collaborative R&D whereby the car manufacturer also contributes his knowledge. The more narrowly the R&D efforts are designed towards the particular needs of the manufacturer the more valuable the new input is. However, designing R&D efforts closely towards the needs of the customer limits the applicability of the new input to other potential car manufacturers. As this limits his opportunities to profit from the innovation, the supplier might think about simultaneously exploring techniques which allow him to sell the new technology to a competing manufacturer, i.e. he engages in inventing around. If the supplier sells the new input to a variety of manufacturers, product market competition lowers the added value of the fuel-injection system to the initial manufacturer. The incentive for investments in inventing-around activities lowers the case for narrowly defined R&D processes and raises the question to which extent the manufacturer should invest in collaborative R&D in the first place.

We address our research questions in an incomplete contracting framework based on the notion of contracting at will as put forward by Hart and Moore

(1988). Due to 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. This is because the new input incorporates features that are difficult to understand and overlook by a third party (courts). Hence, delivery of the good and the levels of trade can not be observed by third parties. This incomplete contracting approach is standard in the literature on the management of innovative activities (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)).

There are two major contracting decisions to be made. The first concerns ownership of the output of the research process (such as a patent or a prototype) which can be assigned to either party of the cooperation. Ownership in our model is on intellectual property. The second contracting decision is whether the new technology should be general or tailor-made (specific) to fit the needs of the final producer. Choosing a specific R&D technology increases the value of the new input for the manufacturing firm while at the same time increasing the lock-in of the supplier. In order to increase ex-post bargaining power, the supplier will engage in inventing-around activities to be able to sell the new input to other manufacturers. The important role of such inventing-around activities in the innovation process has been stressed in prominent survey studies on the patenting behavior of US firms (see Levin, Klevorick, Nelson, Winter, Gilbert, and Griliches (1987) and Cohen, Nelson, and Walsh (2000)).

Realizing the full value of the new technology requires, besides the patent, the expertise of the supplying firm. Therefore, ownership of the patent by the manufacturing firm allows only to appropriate parts of the rents (by using the expertise of an alternative supplier). In case of the supplying firm owning the patent, full value realization is secured. When deciding on the allocation of ownership, however, both the impact on value appropriation as well as the effect on value creation (i.e. on investment incentives) have to be taken into account.

We find that the market solution is characterized by an excessive choice of the general technology: The two firms opt for the general technology in order to avoid excessive investment into inventing-around even though the specific technology would be optimal in a first-best view. Furthermore, we analyse the effect of a more intense product market competition which makes the exclusive supply to the manufacturer more worthwhile. If the degree of product market competition increases, the contract is structured to limit excessive inventing-around by either choosing a general technology or allocating ownership of the patent to the supplier. 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 makes ownership by the manufacturer as well as the specific R&D technology more attractive.

We extend our analysis in two major directions. First, we compare our results under incomplete contracting with ownership to specific performance contracts, i.e. to a more complete contracting framework. The analysis shows that such contracts do not necessarily yield an improvement over contracting about ownership. We then consider contracts with options on ownership by allowing for exit clauses. For example, the supplier might be entitled to terminate the R&D cooperation by acquiring the patent. By choice of an appropriate price for the patent, the firms can improve investment incentives and are thus able to choose the specific technology more often.

There exists a substantial literature investigating competition and research joint ventures. This literature (see e.g., Amir and Wooders (2000), D'Aspremont and Jacquemin (1988), and De Fraja (1993)) is, however, almost entirely concerned with horizontal R&D joint ventures. There are only very few addressing 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. They hence neglect organizational issues concerning vertical R&D cooperations. Rosenkranz and Schmitz (2003) look into organizational issues of horizontal R&D cooperation. However, by focusing on horizontal rather than vertical R&D cooperation their approach addresses a quite different set of questions than ours.

The papers most closely to ours are Aghion and Tirole (1994) and Arora and Merges (2004). Aghion and Tirole (1994) investigate the allocation of intellectual property rights between a (financially constrained) research unit and its downstream customer. In contrast to our model, they do not consider the possibility of investing in inventing-around (the existence of further customers as well as the distribution of ex-post rents among all players is exogenous). Consequently, the decision on the design of the technology (specific vs. general) is not an issue in their paper. Hence, we consider our paper as complementary to theirs by focusing on the endogeneity of the technological design as well as on the bargaining power of the research unit due to inventing around.

Arora and Merges (2004) consider a hold-up problem in a supply relationship when protection of intellectual property is incomplete and knowledge spillovers occur. They focus on the role of these effects 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. Furthermore, the effect of product market competition is a crucial and important addition in our analysis that is absent in both Aghion and Tirole (1994) and Arora and Merges (2004).

The effect of competition on the innovative activities has been discussed in the literature on entrepreneurship and the development of ideas, such as Anton and Yao (1994), Biais and Perotti (2008) and Baccara and Razin (2007). In these models, the threat of competition ensures that the original developer of a business idea or technology captures a sufficient share of the profits when disclosing information to business partners needed for the commercialization. In contrast, our analysis shows that the threat of competition can have adverse effects on R&D investments as it induces the supplier to actively invest in bargaining power.

Technology plays an important role in incomplete contracting models of investments, as it affects parties' outside options. However, as part of the innovation management process, technology is also a choice variable. We therefore include it as a variable in the initial R&D collaboration contract. This is akin 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 contrast, in our analysis, by tying the technology to the innovation, part of that technology may be altered ex post by inventing-around. Hence, by choice of the technology the parties also decide about the ease of applying the technology at competing firms. This affects both investments and the later-stage bargaining process. In Inderst and Wey (2003), technology – determining the supplier's cost structure – is also a fixed characteristic. The 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.

The paper is organized as follows. In section 2, we outline the basic model. Section 3 solves the model and analyses the optimal contractual choices. We thereby restrict the analysis to the case of ex-post exclusivity of the innovation. In section 4, we allow for specific performance contracts, thus looking at the effect of contractibility of prices. In section 5, we consider the impact of allowing changes in ownership due to option contracts or renegotiation. Section 6 analyses the case of non-exclusive use of the innovation ex-post. Section 7 concludes.

2 The Model

2.1 The Innovation Process

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. Thereby, 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. The supplier has to incur an investment in order to initiate the R&D process. Since we aim to focus our analysis on the interaction of firms M and S in later stages of the innovation process we choose a fixed-investment approach for the investment in the research phase. For matters of notational simplicity we normalize these investment costs to zero. Furthermore, without loss of generality we assume a deterministic relationship between R&D input and the value of the R&D outcome.

Due to the high degree of uncertainty it is not feasible ex-ante to write a contract which describes the crucial characteristics of the new input in a verifiable manner. This is akin to the notion that there are many potential outcomes and it is prohibitively expensive ex-ante to describe which should be implemented but costless to do so ex-post (given that both firms are active in the R&D process) and the two firms cannot commit not to renegotiate (see Hart and Moore (1999)). Due to contractual incompleteness ownership rights matter. Ownership gives the right to determine on the implementation of the outcome of the research process.[2] We refer to this outcome in the following as patent.[3]

In the process of transforming the patent into a new input, collaborative development efforts of the manufacturer come into play. In this development phase, the efforts of firm M improve the quality of the new input by fitting it to the needs of the final product (e.g., by bringing in the engineering capabilities of firm M into the development process in the form of joint development teams of firms S and M). These collaborative efforts by M are particularly productive if the technology is specifically designed towards its own needs. With a general technology, collaborative investments by firm M are less productive. Simultaneously with M's collaborative development efforts, the supplier may engage in inventing-around activities. In case of success these inventing-around activities allow the supplier to create a new modified input which may be sold to M's competitor, firm C.

In a subsequent post-development phase the special production expertise of the supplier is required in order to implement the new input into the mass production process of firm S. Hence, our notion is that the value creation process stems from two sources: The new input (consisting 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 (e.g., consisting of the human capital of employees of S) is not contractible in any stage of our analysis and depicts the notion of non-alienability of human capital as stressed e.g., in Hart and Moore (1994). Figure 1 summarizes and illustrates the overall structure of the innovation process.

We endogenise the choice of ownership over the patent and 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 both sources of value creation and can potentially withhold the new input. Under M-ownership, M can take the patent to another supplier but, since he only owns the patent while lacking the production expertise of S, he 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

[2] In section 5.2, we allow for the renegotiation of this right in later stages of the relationship.

[3] Alternatively, one could interpret it as a physical prototype which emerges from the innovative process.

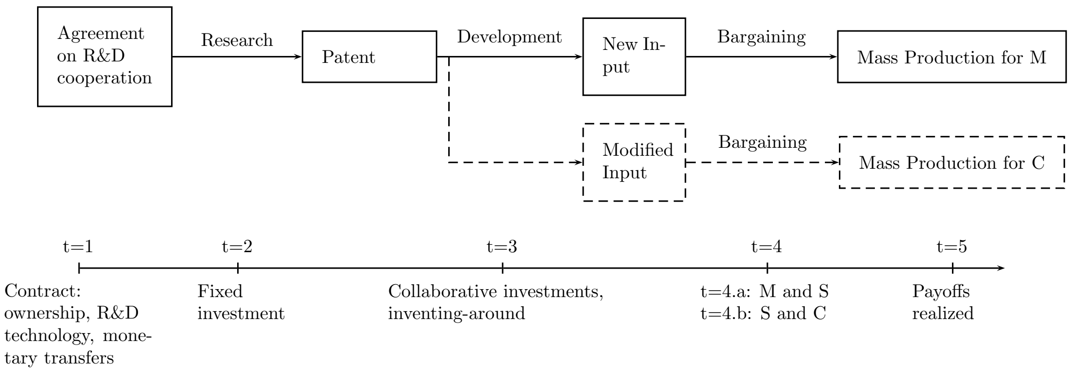

Figure 1: The structure of the R&D process

of S's expertise the (smaller) larger is a.

2.2 Design and Usage of the New Input

In the following we distinguish between the ex-post usage of the innovative product (exclusive use by M or non-exclusive use by both 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, the value of the new input for M reduces to $Y_M (Y_M^X > Y_M)$ while adding Y_C in value to C's product. We refer to $\Delta \equiv Y_M^X - Y_M$ as the intensity of product market competition between M and C. We show in appendix A.1 that 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).

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

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 $V_{M,\sigma}^X = Y_M^X + \sigma I$. In the case of non-exclusive use of the specific technology we have $V_{M,\sigma} = Y_M + \sigma I$. 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 $V_{M,0}^X = Y_M^X + I$ while with non-exclusive use the value of the new input amounts to $V_{M,0} = Y_M + I$. 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., $V_C = Y_C$). 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 as it limits the possibility to sell the new input to firm C. In order to be able to do so, S has to engage in inventing-around activities. Given that ex-ante a specific R&D technology has been chosen, investing $0.5cq^2$ opens up with probability q the possibility for S to sell the new input ex-post to C as well. This implies that if ex-ante a specific R&D technology has been chosen it might be still feasible ex-post to sell the new input to the competitor. In case of no or unsuccessful inventing-around activities, however, S remains locked into the relationship with M. If a general R&D technology is selected ex-ante the new input can be sold to C without any further costs. For the parameter c, which measures the cost of inventing-around activities, we assume

$$c > \frac{V_C + 2\Delta}{2}. \tag{1}$$

This assumption ensures interior solutions in the inventing-around decision.

2.3 Sequence of Decisions

The sequence of decision-making is as follows (see also figure 1). In a first stage (t=1) the two parties (M and S) agree about undertaking research (or not, in this case the game ends). In addition, the parties agree on the allocation of ownership as well as on the R&D technology chosen (i.e., specific or general technology). The design of the technology is fixed thereafter. Furthermore, monetary transfers might be agreed on.[4]

With a positive agreement, the R&D project will be started with the R&D investment by firm S. In order to facilitate the analysis we assume that the R&D expenditures (which are normalized to zero) are contractible at stage 1 thereby allowing us to neglect the individual incentives of R&D investing in stage 2 later on. Given our chosen set-up (zero R&D costs and non-cooperative decisions on collaborative R&D) this is for ease of exposition rather than having an impact on our results.

In stage three, the two parties invest in collaborative R&D (firm M) and inventing-around activities (firm S) simultaneously. In the subsequent stage (t=4), bargaining starts. We assume that in a first step, one-shot bargaining between M and S with randomly chosen proposer will take place. We use this simple modelling approach to approximate the equal division of the surplus. With a specific R&D technology chosen and unsuccessful inventing-around, bargaining takes place between M and S only, leading either to a contract entailing exclusive usage of the new product or no delivery. If a non-specific R&D technology has been used or if inventing-around has been successful, the proposing party offers a contract entailing the usage of the input (exclusive or non-exclusive) as well as its price. The other party may accept or decline this offer. In case of an acceptance of an exclusive offer, bargaining ends. Otherwise, S may approach C and the two firms engage also in a random-proposer, one-shot bargaining process. In the final stage of the game (t=5) cash flows are realized.

We solve this game in the following by looking at the bargaining stage first, before then turning to an analysis of the investments in inventing-around and collaborative research. We initially consider the case of contractible investments as a benchmark. In the last step, we analyse the case of interest, the market solution with incomplete contracting.

[4] These monetary transfers reflect different degrees of ex-ante bargaining power, but do not affect our allocative results. Since we do not impose any further assumptions on ex-ante bargaining power, these monetary transfers can be neglected in the analysis.

3 Exclusive Use of the New Input

To simplify the analysis, we consider the case in which

$$\Delta \geq \frac{V_C}{2} \tag{2}$$

is fulfilled. Section 6 considers the reverse case. Hence, we first focus on the case in which ex-post the technology will be used exclusively by firm M rather than being sold to competitor C as well (see the subsequent analysis for this to be indeed the case). One of the crucial questions with respect to the cooperation's organization in this case therefore is: Anticipating the ex-post exclusive use of the technology are there reasons for choosing a general technology ex-ante?

3.1 Bargaining Stage

We solve the model by backward induction, starting with the bargaining process as the final stage. The key aspect in the bargaining process is the alternative use of the new product by S and M. In case the parties initially chose the specific technology and S did not pursue any (or did not succeed in) inventing-around, 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 inventing-around was successful or the general technology was chosen initially, then S may sell the new input to both M and C. This 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 may realize a fraction a of the final value (which again depends on S's ability to sell also 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, we denote ownership and technology by subscripts (M or S gives ownership, 0 and σ denote the general and the specific technology, respectively). We find for the result of the bargaining process:

Lemma 1
Let $a_i \in \{a_S = 0, a_M = a\}$*, and* $\hat{\sigma} \in \{0, \sigma\}$*.*

1. *For the case of the two-party bargaining process, the expected payoffs are*

$$\pi_M = (1 + a_i)\frac{V_M^X(\hat{\sigma})}{2} \tag{3}$$

$$\pi_S = (1 - a_i)\frac{V_M^X(\hat{\sigma})}{2} \tag{4}$$

2. *Three-party bargaining results in exclusive use of the good. The expected payoffs of the bargaining process are,*

$$\pi_M = \frac{V_M^X(\hat{\sigma})}{2} + a_i\frac{V_M(\hat{\sigma})}{2} - \frac{V_C}{4} \tag{5}$$

$$\pi_S = \frac{V_M^X(\hat{\sigma})}{2} - a_i\frac{V_M(\hat{\sigma})}{2} + \frac{V_C}{4} \tag{6}$$

Proof: See the 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 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 M's ability to realize this value on its own (zero in case of S-ownership, proportion 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 case of M-ownership and the larger the share of surplus M is capturing.

In the case of three-party bargaining, M and S also share the jointly created surplus which is maximized by choosing exclusive use as the value for C is low enough. However, S now realizes part of the new input's value for C as he can use non-exclusivity as a threat in bargaining with M. M still retains his alternative of producing without S, but is only able to realize the non-exclusivity value due to S's ability to sell to C.

3.2 Contractible Investments Benchmark

Before turning to the incomplete contracting solution, 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 potentially captures 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.[5]

With contractible investments, M and S choose investment levels and technology which maximize the joint surplus. Given exclusive use of the good ex-post, this expected surplus amounts to

$$E[\pi_M + \pi_S] = Y_M^X + \hat{\sigma} I - \frac{c}{2} q^2 - \frac{1}{2} I^2 \ , \ \hat{\sigma} \in \{0, \sigma\} \tag{7}$$

where $\hat{\sigma}$ denotes the choice of the general or specific technology.[6] Maximization of (7) with respect to technology and investment levels I and q yields the following result.

Lemma 2 *In case of contractible investments, the optimal contract specifies investments $I_{ci} = \sigma$ and $q_{ci} = 0$ as well as choice of the specific technology.*

Due to its higher productivity it is always preferable to implement the specific technology. Moreover, anticipating exclusive use ex-post, inventing around is a wasteful activity and consequently not undertaken.

3.3 Optimal Design with Incomplete Contracting

With non-contractible investments, the choice of the optimal contract and investment decisions have to be analysed separately. Moreover, ownership now plays an important role in determining individual investment levels. We will first look at investment decisions before then turning to the optimal incomplete contract.

Consider the development stage with the choice of M's collaborative development efforts and the inventing-around activity of firm S. Investments by M are always productive, as they directly increase the value generated by the new input. The inventing-around investment by S is a pure rent-seeking activity: Successful inventing-around allows S to bypass the initially specific technology and to offer the new input to C. As this enables S to demand more in the bargaining process with M, inventing-around simply transfers rents from M to S.

[5] Joint bargaining by M and S would lead to exclusive use of the good only if $\Delta \geq V_C$. 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.

[6] Ownership does not matter in this case as it affects only the distribution of the rents in the bargaining stage.

Lemma 3

1. *The optimal investment levels for M are:* $I_{S,0} = \frac{1}{2}$, $I_{M,0} = \frac{1+a}{2}$, $I_{S,\sigma} = \frac{\sigma}{2}$ *and* $I_{M,\sigma} = \frac{\sigma(1+a)}{2}$. *For given ownership, M's investment levels are always higher under specific technology than under general technology; for given technology, M's investment levels are always higher under M-ownership.*

2. *Choice of the general technology always leads to zero inventing-around* ($q_{S,0} = q_{M,0} = 0$)

3. *Choice of the specific technology leads to inventing-around of* $q_{S,\sigma} = \frac{V_C}{4c}$ *or* $q_{M,\sigma} = \frac{V_C}{4c} + a\frac{\Delta}{2c}$ *with* $q_{S,\sigma} < q_{M,\sigma}$.

Proof: See the appendix.

The investment levels for M highlight the importance of technology and outside options offered by ownership: Investment levels are highest for M-ownership and the specific technology and lowest for S-ownership and general technology. This is quite intuitive given our discussion of the outcome of the bargaining stage: As 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 larger 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.

For S, inventing-around is only necessary in case of the specific technology where it improves his bargaining position as he can threaten to sell to C. Finally, M-ownership additionally increases S's incentive to invent around as 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 inventing-around activity (relative to the level under S-ownership).

Finally, consider the initial contracting stage where M and S have to specify the R&D technology as well as 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 choice of ownership and technology will take place such that M's investment incentives are distorted as little as feasible while minimizing at the same time the incentives to invest in inventing-around activities.

Proposition 1

1. *The combination of S-ownership with general technology is never optimal.*

2. *M and S are indifferent between choosing S-ownership with specific technology, M-ownership with specific technology and M-ownership and general technology if*

$$\frac{\Delta(V_C + a\Delta)}{(2-a)\sigma^2} = c = \frac{V_C^2}{4(3(\sigma^2-1)-2a+a^2)} \tag{8}$$

Proof: See the 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 inventing-around. Given that M-ownership always improves M's investment and that the general technology requires no inventing-around, it is never optimal to combine S-ownership with the general technology. Or, put differently, it is always optimal to transfer some (bargaining) power to M, be it in terms of ownership and/or by choice of a technology that is specific to M. Additionally, there can be combinations of the exogenous parameters, such that all remaining three combinations yield the same joint payoff. This yields the following comparative static results.

Corollary 1
Let (8) be fulfilled. Then a marginal increase (decrease) in

1. *a results in M and S choosing M-ownership and the general technology (M-ownership/specific technology)*

2. *σ results in M and S choosing M-ownership and the specific technology (M-ownership/general technology)*

3. *V_C results in M and S choosing M-ownership and the general technology (M-ownership/specific technology)*

4. *Δ results in M and S choosing either S-ownership and the specific technology or M-ownership and general technology (M-ownership/specific technology)*

Change in	$M,\sigma/S,\sigma$	$M,\sigma/M,0$	$M,0/S,\sigma$	$M,\sigma/M,0/S,\sigma$
$a\uparrow(\downarrow)$	$S,\sigma\uparrow$	$M,0\uparrow$	$M,0\uparrow$	$M,0\uparrow(M,\sigma\uparrow)$
$\sigma\uparrow(\downarrow)$	$M,\sigma\uparrow$	$M,\sigma\uparrow$	$S,\sigma\uparrow$	$M,\sigma\uparrow(M,0\uparrow)$
$V_C\uparrow(\downarrow)$	$S,\sigma\uparrow$	$M,0\uparrow$	$M,0\uparrow$	$M,0\uparrow(M,\sigma\uparrow)$
$\Delta\uparrow(\downarrow)$	$S,\sigma\uparrow$	$M,0\uparrow$	no change	$S,\sigma/M,0\uparrow(M,\sigma\uparrow)$

Table 1: Optimal ownership and technology – comparative static results

Proof: See the appendix.

Table 1 presents the optimal ownership/technology choices for parameter changes at indifference, both pairwise and overall. In order to illustrate the trade-offs of the model more clearly, it is helpful to consider only variations in two parameters at the same time. Figures 2 and 3 show how optimal ownership and technology depend on the extent of market competition (captured by Δ) and one other parameter.

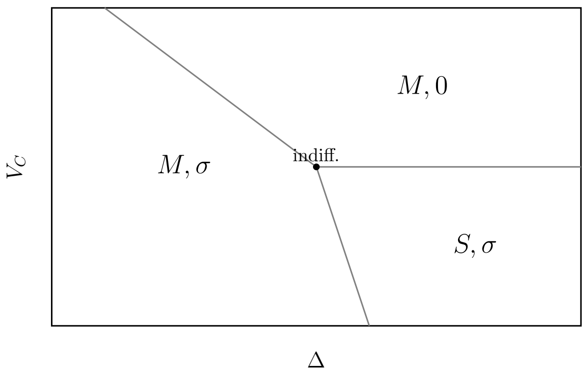

Figure 2: Optimal choices depending on V_C and Δ

Figure 2 illustrates the effect of changes in the new input's value for the two manufacturers. The first conclusion to be drawn is that the market solution may fail to ensure that the specific technology is chosen when it would be efficient. As $\Delta \geq V_C/2$ is assumed to hold, implying that ex-post bargaining will result in exclusive use of the new product (see Lemma 1), choice of the general technology would be inefficient if investments were contractible. However, the cost of rent-seeking by inventing-around are excessively high for sufficiently high values of V_C and Δ, such that the apparently inefficient general technology is chosen instead.

Additionally, figure 2 shows that – 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 inventing-around. For higher values of Δ, i.e., higher product market competition, the decrease in rent-seeking by switching from M-ownership to S-ownership is more pronounced while the difference in M's investments between the two ownership structures remains unaffected. Furthermore, a reduction in the degree of product market competition (decreasing Δ) makes investments in the specific technology more profitable.

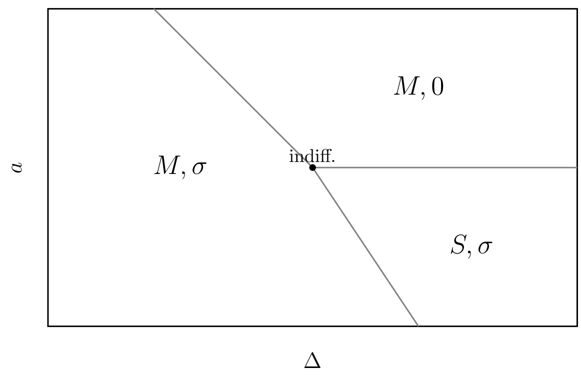

Figure 3: Optimal choices depending on a and Δ

Figure 3 illustrates the role of the alienability of S's expertise, captured by a. High inalienability of the supplier's production expertise (low values of a) make ownership relatively less important for M's investment incentives. Rather, the choice of the specific technology is the main driver of investment. It is consequently chosen more often. Additionally, for low values of a, the specific technology is always. Reducing a even further decreases the benefits in terms of low inventing-around under S-ownership. As a result, M-ownership is chosen more often. For sufficiently high values of a, ownership already provides strong investment incentives and the general technology is chosen to avoid costly inventing-around.

The technology parameter σ measures the benefits of choosing the specific technology (in terms of productivity enhancement). It increases the optimal investment level under either ownership allocation while leaving the incentives for inventing-around unaffected (see Lemma 3). Intuitively, a low productivity gain due to specificity makes choice of the general technology more likely as costs of inventing-around are avoided. Increasing σ makes the specific technology more profitable.

We summarize our main findings in

Proposition 2

1. *The market solution exhibits too little specificity (in too many cases a general technology is chosen).*

2. *The more intense product market competition, the more often S becomes the owner.*

3. *Technologies with pronounced inalienability lead to choice of specific technologies and allocation of ownership towards firm M.*

4 Specific Performance Contracts

In the following, we extend the previous analysis by allowing for specific performance contracts where both parties can request trade to take place at certain, pre-specified prices. In contrast to our main analysis, initially agreed prices define default options that the parties can enforce, hence allowing for a much more complete contracting environment than in our main body of analysis. We compare our earlier findings with two scenarios: In the first, two-price scenario, ex ante prices can be made contingent on the ex-post usage (exclusivity or non-exclusivity). In the second scenario, only one price can be agreed on ex ante. In both scenarios, we only consider consider contracts that embody the specific technology, as this technology is selected in the contractible investments benchmark.

4.1 Specific Performance Contracts with Two Prices

If the ex-post usage of the good is verifiable, then the parties are able to agree on usage-contingent prices ex-ante. We refer to them as p_E, the price of the good in case of exclusive use of the good, and p_{NE}, the price in case of non-exclusivity. As these prices are always enforceable, they determine the receiver's disagreement payoff in the bargaining process. From the analysis of the bargaining stage (which is in appendix A.6), we find that these prices will not be changed in the negotiations. However, the relative prices determine whether exclusive or non-exclusive use of the good results from the bargaining. Specifically, for $p_E - p_{NE} \geq V_C/2$, exclusive use of the good always prevails and the expected profits of M and S are, respectively

$$E[\pi_M] = V_M^X - p_E - \frac{1}{2}I^2 \quad \text{and} \tag{9}$$

$$E[\pi_S] = p_E - \frac{c}{2}q^2 \tag{10}$$

Given these payoffs, we can state the following result:

Proposition 3 *Using specific performance contracts with usage-contingent prices, M and S can achieve the contractible investments benchmark,* $I_{2p} = I_{ci} = \sigma$ *and* $q_{2p} = q_{ci} = 0$.

Specific performance contracts in this analysis serve two purposes. First, the existence of pre-specified prices which can (and will) always be enforced ensures that firm M is the sole residual claimant to the returns from its investments. As will be seen in the subsequent analysis, this is true regardless of whether there are one or two prices. Second, by setting the difference in the two usage-contingent prices sufficiently high, exclusivity is the dominant use of the input, even in case of offers being rejected in the bargaining process. Hence, inventing-around does not increase S's bargaining power and is therefore not undertaken.

4.2 Specific Performance Contracts with One Price

If the contracting of usage-contingent prices is not feasible due to the lack of verifiability of the usage, it may only be feasible to contract on a price ($\bar{p}$) which is independent of ex-post usage of the product. Hence, it is not possible to ensure the exclusive use of the input ex-ante. The bargaining game (see appendix A.7) yields the following expected profits for M and S:

$$E[\pi_M] = (1-q)V_M^X + q\left(\frac{V_M^X}{2} + \frac{V_M}{2} - \frac{V_C}{4}\right) - \bar{p} - 0.5I^2 \tag{11}$$

$$E[\pi_S] = \bar{p} + q(\frac{V_M^X - V_M}{2} + \frac{V_C}{4}) - 0.5cq^2 \tag{12}$$

Taking first-order derivatives gives optimal investments

$$I_{1p} = \sigma \tag{13}$$

$$q_{1p} = \frac{1}{c}\left(\frac{V_M^X - V_M}{2} + \frac{V_C}{4}\right) \tag{14}$$

The specific performance contracts again result in M being the residual claimant to its investment returns and hence produces investments as in the contractible investments benchmark. However, S engages in inventing-around 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 4

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

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

Proof: See the appendix.

This result shows that even if single-price specific performance contracts were feasible, incomplete contracts specifying ownership can be selected by M and S to govern their R&D collaboration. This is particularly true in case of strong product market competition, as the returns to inventing-around then increase more in case of specific performance contracts than under any of the ownership contracts.

5 Interim Changes in Ownership

We now address two cases which might lead to changes in ownership during the course of the R&D cooperation. First, we investigate the consequences of introducing option contracts on ownership. Second, we allow for the possibility of renegotiation of ownership.

5.1 Options on Ownership

In the following, we consider option contracts which allow re-allocation of ownership. Specifically, ownership is allocated ex-ante to one firm and can be re-allocated on the basis of an option contract with a pre-specified strike price at $t = 4$, before the start of the bargaining process.[7] This kind of option contract can be implemented by giving one firm an exit right: With one firm holding a call, this firm can, by paying the pre-specified fee (the strike price), terminate the contract and appropriate 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.[8] We show in the following that while improving the efficiency of the outcome, these option contracts do not change our basic mechanisms and results qualitatively.[9]

Option contracts only affect our previous analysis if the optimal exercise depends on the outcome of the inventing-around process. If options are always or never exercised our earlier analysis applies because strike prices are fixed transfers not affecting incentives to invest in cooperative R&D or in inventing-around. A direct consequence of this 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. In the following, we focus on the case of S holding the exit right (the case of M holding the exit right is discussed thereafter). 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 2.

With a low (high) strike price, S will exercise the call in either (neither) case

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

[8]Similar exit rights/options are frequently used in the venture capital industry and allow one party (typically the venture capitalist) to terminate the cooperation. See, for example, Chemla, Habib, and Ljungqvist (2007) or Bienz and Walz (2010)).

[9]Our analysis of option contracts with one innovation thereby significantly differs from the one of Aghion and Tirole (1994) who consider split ownership in the case of multiple innovations.

Inventing-around 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 2: Payoff structure with option contracts

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 inventing-around. For this case, the expected payoffs of the two firms can be expressed as:

$$E[\pi_M] = \frac{q}{2}(Y_M^X + aY_M + (1+a)\sigma I - \frac{V_C}{2}) + \frac{1-q}{2}(Y_M^X + \sigma I + 2P) - \frac{I^2}{2}, \quad (15)$$

and

$$E[\pi_S] = \frac{q}{2}(Y_M^X - aY_M + (1-a)\sigma I + \frac{V_C}{2}) + \frac{1-q}{2}(Y_M^X + \sigma I - 2P) - \frac{cq^2}{2}. \quad (16)$$

However, these objective functions only apply if the asymmetric exercise is optimal after the investment decisions have been realized. This puts a restriction on the combination of the option strike price and M's investments. Specifically, 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 need to 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 ($I = I_{S,\sigma}$ for $P < P_1$ and $I = I_{M,\sigma}$ for $P > P_4$);*

3. *S's equilibrium level of inventing-around q is strictly increasing in P for $P \in [P_2, P_3]$ and constant else ($q = q_{S,\sigma}$ for $P < P_2$ and $q = q_{M,\sigma}$ for $P > P_3$);*

where

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

and $P_1 < P_2 < P_3 < P_4$.

Proof: See the 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 and lie between the extreme levels under M-ownership or S-ownership. An increase in the strike in case of asymmetric exercise raises S's return from inventing-around as ownership (by exercising the call) after inventing-around failed is more costly. Hence, M is also more likely to remain owner which increases its own investment return. Thus, the two types of investment affect each other for intermediate strike prices.

The most important effect of including an option for S occurs at levels of the strike price which 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 inventing-around. This improvement is achievable because by raising its investment from the S-ownership level, M can offset the negative payoff that would arise when S exercises the call. Simultaneously, this behaviour leaves S indifferent with respect to the exercise and thus leaves the incentives for inventing-around 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: As an exit option for S improves the investment relative to S-ownership, the option contract is more likely to yield the most preferable outcome. 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 as the latter yields the same level of inventing-around but higher investments by M. Moreover, as it is always combined with the specific technology, this technology will be implementable more often than without an option contract.

Proposition 5
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 favour 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 is due to the simultaneity of the agents' investment decisions, weak ownership of the patent for M (reflected in $a < 1$) as well as the possibility to engage in inventing-around. Hence, even permitting 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 inventing-around investment (opening up the possibility of a non-exclusive use of the new technology), which is a purely rent-seeking activity. 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.

Finally, instead of giving S an exit right, an option contract may allocate this right to M. This kind of contract will also enable the firms to realize investments at levels between those under M-ownership and S-ownership. However, there is no unambiguous improvement over either of the pure ownership cases. In case of S holding the exit right, M could adjust its investment I to counter an undesirable option exercise by S. If M holds the option, the interaction between its investment and the subsequent exercise is more complex. By choosing different levels of its investment, M may commit to different exercise strategies for given strike prices. This gives rise to multiplicity of equilibria and issues of equilibrium selection. However, the general mechanisms and trade-offs remain intact.

5.2 Renegotiation

Allowing for renegotiation before the investment decisions in $t = 3$ does not change matters at all. All variables are not yet contractible making renegotiation pointless. Neither renegotiation of ownership (which yields the same result as in the absence of renegotiation) nor of monetary transfers change anything compared to the initial stage since the contracting environment has not changed yet.

The same is true with respect to renegotiating ownership after stage 3 when investments in cooperative R&D have been realized. This is due to the fact that bargaining leads to an outcome which maximizes the joint payoffs of firms S and M irrespective of ownership. Hence, renegotiation does not have any impact on the outcome realized and the distribution of profits, thereby leaving the results of the overall game unchanged.

6 Non-exclusive Use of the New Input

We now review the results of our initial analysis when the assumption about the strength of the competitive effect is reversed. Hence, we change the parameter restriction of the base model by allowing for parameter constellations which lead to non-exclusive use of the technology in the three-party bargaining process. Specifically, let

$$\Delta < \frac{V_C}{2} \tag{17}$$

in the following.

In the bargaining stage, the new parameter assumption only matters in case of three-party bargaining. The jointly created surplus that is now shared between M and S is now maximized by choosing a non-exclusive use of the new input.[10] Although this affects the expected payoffs of the two firms, it does not alter M's investment incentives as the marginal value of his investments does not depend on exclusivity. However, S's incentives are altered under non-exclusivity ex-post. In contrast to the base model, inventing-around is now a (partly) productive activity in case the specific technology was chosen: Opening up the possibility of a sale to C increases the rents created by the new input. Hence, some degree of inventing-around is value-enhancing. Nevertheless, even in this case inventing-around is excessive: It not only enables the two firms to increase the joint surplus, but also improves S's bargaining position by creating an outside option.

[10]The payoffs accruing to C in the bargaining process do not matter for the cooperation and are therefore disregarded here.

Overall, we get the following results:

Proposition 6

1. *Successful inventing-around results in non-exclusive use of the new input.*

2. *The combination of S-ownership with general technology is never optimal.*

3. *M and S are indifferent between choosing S-ownership with specific technology, M-ownership with specific technology and M-ownership and general technology if*

$$\frac{\Delta(2+a)}{(2-a)\sigma^2} = c = \frac{(V_C - 2\Delta)^2 - \Delta^2}{2a - a^2 + 4(V_C - 2\Delta) - 3(\sigma^2 - 1)} \tag{18}$$

Proof: See the appendix.

The result is very similar to the base model: It is never optimal to give all (bargaining) power to S, because that would reduce M's investment incentives too much, while inventing-around can always be avoided by the choice of technology. Even more important, the market solution again leads to too little specificity in this setting as well. Despite the fact that ex-post non-exclusivity maximizes the joint surplus, it can be efficient to choose a specific technology in order to raise M's investment productivity. Non-exclusivity may then still be realized by S's inventing-around. However, since this inventing-around is excessive under the specific technology, the general technology is chosen too frequently by the firms. Finally, the following corollary shows that the general structure of our earlier comparative static results for optimal contract choices remain valid under ex-post non-exclusivity.

Corollary 2

Let (18) be fulfilled. Then a marginal increase (decrease) in

- a *results in M and S choosing M-ownership and the general technology (M-ownership/specific technology)*

- σ *results in M and S choosing M-ownership and the specific technology (M-ownership/general technology)*

- V_C *results in M and S choosing M-ownership and the general technology (M or S-ownership/specific technology)*

- Δ *results in M and S choosing S-ownership and the specific technology (M-ownership/general technology)*

Proof: See the appendix.

7 Conclusion

A major source for the successful development of firms are the innovative efforts of their suppliers which lead to technological enhancements of the final product. At the very same time these innovative efforts of the supplier are often undertaken at least to some degree collaboratively with the buyer. These joint R&D processes allow the combination of both parties' stock of knowledge. Obviously, given the problems associated with contracting on the output of R&D this leaves room for potential exploitation of one side by the other and hence to inefficiency. Against this setting, this paper explores 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 product market competition, the more often the supplier becomes the owner of the innovation (see Proposition 2).

H2: The more intense product market competition, the more often incomplete contracts specifying ownership rights will be used, rather than specific performance contracts (see Proposition 4).

H3: Conditional on the choice of a specific technology, the more important the supplier's production expertise, the more often the manufacturer becomes the owner of the innovation (see Proposition 2 and Table 1).

H4: Option contracts/exit rights increase the returns to R&D cooperations. Therefore, the lower the costs of contracting on contingent ownership (a) the more often option contracts should be used, and (b) the more R&D cooperations should be observed (see Proposition 5).

Putting these hypotheses to the data is obviously an interesting next step.

While we believe that the model incorporates crucial feature of vertical R&D collaborations, obviously, our model abstracts from a number of aspects. First and most notably we concentrate on fixed-investment projects only. Thereby, we neglect potential hold-up problems associated with ex-ante investment decisions. Endogenising 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 have neglected the repeated interaction between the supplier and the buyer as a mechanism to mitigate contractual problems. This is, given the focus of our analysis, clearly an important aspect. But even if one accepts 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 analysing vertical R&D collaborations more closely.

A Appendix

A.1 A Detailed Market Model

Consider a duopolistic product market in which M and C produce with constant marginal costs c_M and c_C and face a linear demand curve:

$$p_i = A_i - q_i - dq_j \quad i \neq j; i, j = M, C$$

where $d < 1$ is the degree of substitution of the firms' products. The Cournot-Nash equilibrium quantities are:

$$q_i = \frac{2(A_i - c_i) - d(A_j - c_j)}{4 - d^2}$$

Hence, equilibrium profits amount to:

$$\Pi_i = \frac{\left(2(A_i - c_i) - d(A_j - c_j)\right)^2}{(4 - d^2)^2}$$

The value of the new input can be defined as the change in profits due to changes in A (a product innovation increases A) or c (a process innovation decreases of c). As can be seen in the profit term, both types of innovation have identical effects. Hence, without loss of generality, it suffices to consider only changes in A. Given an initial equilibrium under symmetry ($A_M = A_C = A$), consider a marginal change in A_M. This (marginal) increase in profits represents the additional value of the new input in the exclusive case:

$$Y_M^X \equiv \left.\frac{\partial \Pi_M}{\partial A_M}\right|_{A_M = A_C = A} = \frac{4(A - c)}{(2 - d)(2 + d)^2}$$

Correspondingly, the non-exclusive case can be represented as a marginal increase in A_M and A_C

$$Y_M \equiv \left.\frac{\partial \Pi_M}{\partial A_M}\right|_{A_M = A_C = A} + \left.\frac{\partial \Pi_M}{\partial A_C}\right|_{A_M = A_C = A} = \frac{2(A - c)}{(2 + d)^2}$$

Our interpretation in the main body of the paper is that an increasing level of the differential value ($Y_M^X - Y_M$) indicates an increase in competition. Since in our model an increase in the parameter d implies more pronounced competition, we can verify that this interpretation is appropriate in the above Cournot model since

$$\frac{\partial (Y_M^X - Y_M)}{\partial d} = \frac{4(A - c)(2 - d + d^2)}{(2 - d)^2(2 + d)^3} > 0.$$

A.2 Proof of Lemma 1

Part 1. In the two-party bargaining process, exclusive use is the only available option with $a_i V_M^X$ as M's payoff in case of disagreement and zero alternative payoff for S.[11] In the random proposer bargaining, the proposer offers this disagreement payoff to the other party (who accepts the proposal) and pockets the difference between V_M^X and the offer. With equal probability of being the proposer, this yields the expected payoffs given in (3) and (4).

Part 2. In the three-party bargaining process, the disagreement payoff of M depends not only on ownership (via a_i) but also on the final use of the new input (V_M^X versus V_M). Similarly, S also receives some payoff from bargaining with C in case bargaining with M breaks down or results in non-exclusive use. Given zero disagreement payoffs for both S and C in their bargaining, the expected (potential) payoff for S is $V_C/2$.

In the M-S bargaining process, the proposer not only offers the responder some payoff but combines this payoff with the final use of the new input. Hence, the proposer chooses between two potential offers – under non-exclusivity or exclusivity, taking into account the corresponding disagreement payoffs. Consider the optimal offers for S: In case of disagreement, M may always realize $a_i V_M$ because S is then free to sell the new input to C. Thus, S offers this to M and receives:

$$\pi_S(S \text{ proposer}) = \begin{cases} V_M^X - a_i V_M & \text{under exclusivity} \\ (1-a_i)V_M + \frac{V_C}{2} & \text{under non-exclusivity} \end{cases} \tag{19}$$

For $\Delta \geq \frac{V_C}{2}$, see (2), exclusivity yields a (weakly) higher payoff.

Next, let M be the proposer. In case bargaining breaks down or yields non-exclusivity, S receives $V_C/2$. This has to be offered in order to induce S to accept an exclusivity agreement. The payoff structure for M is then

$$\pi_M(M \text{ proposer}) = \begin{cases} V_M^X - \frac{V_C}{2} & \text{under exclusivity} \\ V_M & \text{under non-exclusivity} \end{cases} \tag{20}$$

Again, for $\Delta \geq \frac{V_C}{2}$, exclusivity yields a (weakly) higher payoff. Combination of these proposer payoffs and disagreement payoffs (for the receiver) yields the expected payoffs and the final use of the new input as specified in the lemma. ■

[11] For the sake of brevity, we omit denoting V_M^X and V_M as functions of σ.

A.3 Proof of Lemma 3

Using the results of lemma 1, we can specify the expected payoffs depending on the final use of the good (exclusivity/non-exclusivity), ownership (determining the value of a_i), and the technology (specific/general). Note that for general technology, bargaining always takes place between the three parties, while it is only possible with probability q (successful inventing-around) for the specific technology.

$$E[\pi_M] = \begin{cases} \frac{1}{2}(Y_M^X + I) - \frac{V_C}{4} - \frac{1}{2}I^2 & \text{for } S, 0 \\ \frac{1}{2}(Y_M^X + I) + \frac{a}{2}(Y_M + I) - \frac{V_C}{4} - \frac{1}{2}I^2 & \text{for } M, 0 \\ \frac{1}{2}(Y_M^X + \sigma I) - q\frac{V_C}{4} - \frac{1}{2}I^2 & \text{for } S, \sigma \\ \frac{1+a}{2}(Y_M^X + \sigma I) - q(\frac{V_C}{4} + \frac{a}{2}\Delta) - \frac{1}{2}I^2 & \text{for } M, \sigma \end{cases} \tag{21}$$

$$E[\pi_S] = \begin{cases} \frac{1}{2}(Y_M^X + I) + \frac{V_C}{4} - \frac{c}{2}q^2 & \text{for } S, 0 \\ \frac{1}{2}(Y_M^X + I) - \frac{a}{2}(Y_M + I) + \frac{V_C}{4} - \frac{c}{2}q^2 & \text{for } M, 0 \\ \frac{1}{2}(Y_M^X + \sigma I) + q\frac{V_C}{4} - \frac{c}{2}q^2 & \text{for } S, \sigma \\ \frac{1-a}{2}(Y_M^X + \sigma I) + q(\frac{V_C}{4} + \frac{a}{2}\Delta) - \frac{c}{2}q^2 & \text{for } M, \sigma \end{cases} \tag{22}$$

The optimal levels of investment and inventing-around and their relative magnitudes follow then directly. (1) ensures interior solutions for inventing-around. ■

A.4 Proof of Proposition 1

Inserting the optimal levels of investment and inventing-around of lemma 3 into the payoff functions (21) and (22) yields the following structure of joint surplus $TS \equiv E[\pi_S + \pi_M]$:

$$TS = \begin{cases} Y_M^X + \frac{3}{8} & \text{for } S, 0 \\ Y_M^X + \frac{3+2a-a^2}{8} & \text{for } M, 0 \\ Y_M^X + \frac{3\sigma^2}{8} - \frac{V_C^2}{32c} & \text{for } S, \sigma \\ Y_M^X + \frac{(3+2a-a^2)\sigma^2}{8} - \frac{(V_C+2a\Delta)^2}{32c} & \text{for } M, \sigma \end{cases} \tag{23}$$

Part 1. $TS_{S,0}$ is always smaller than $TS_{M,0}$ for $a \in (0, 1)$.

Part 2. (8) follows from solving $TS_{S,\sigma} = TS_{M,\sigma}$ and $TS_{S,\sigma} = TS_{M,0}$ with respect to c. ■

A.5 Proof of Corollary 1

The pairwise differences in joint surplus are

$$
\begin{aligned}
TS_{S,\sigma} - TS_{M,\sigma} &= \frac{a}{8c}\big(a(V_C\Delta + a\Delta^2) - c\sigma^2(2a - a^2)\big) && (24)\\
TS_{M,0} - TS_{M,\sigma} &= \frac{1}{32c}\big((V_C + 2a\Delta)^2 - 4c(\sigma^2 - 1)(3 + 2a - a^2)\big) && (25)\\
TS_{M,0} - TS_{S,\sigma} &= \frac{1}{32c}\big(V_C^2 - 4c(3(\sigma^2 - 1) - 2a + a^2)\big) && (26)
\end{aligned}
$$

The pairwise comparative static effects can then be confirmed directly, where the signs are immediately visible (given the indifference condition) with one exception:

$$
\begin{aligned}
\frac{d(TS_{M,0} - TS_{M,\sigma})}{da} &= \frac{1}{32c}\big(4\Delta(V_C + 2a\Delta) - 4c(\sigma^2 - 1)(2 - 2a)\big)\\
&= \frac{12\Delta V_C - 2V_C^2 + 2a(\Delta^2(12 + 4a) + V_C^2 + 2a\Delta V_C)}{32c(3 + 2a - a^2)} && (27)\\
&> 0
\end{aligned}
$$

where we used the indifference condition $c = \frac{(V_C+2a\Delta)^2}{4(\sigma^2-1)(3+2a-a^2)}$ and the condition $\Delta \geq V_C/2$. Finally, combination of all three pairwise comparisons yields the overall changes at indifference between all three ownership/technology structures (see also table 1). ■

A.6 Bargaining under Specific Performance Contracts with Two Prices

We have to distinguish the two-party from the three-party bargaining game. In the two-party bargaining game, matters are straightforward. Both players can always revert to p^E. Hence, S receives p_E whereas M gets $V_M^X - p_E$.

In the three-party bargaining game, M can not enforce exclusivity but S can threaten to sell the input to C. Hence, with S being the proposer, S can not charge more than p_E contingent on the exclusive use of the good and p^{NE} with a non-exclusive usage of the input (leaving $p_{NE} + 0.5V_C$ for S in this case). S makes an exclusivity offer if $p_E - p_{NE} \geq V_C/2$. With M being the proposer, M has to leave $\max\{p_{NE} + 0.5V_C, p_E\}$ with S, irrespective of offering exclusive or non-exclusive use: S can always reject the offer and revert to the use which offers him the highest payoff. As a result, the exclusive contract always dominates for

M. For $p_E - p_{NE} \geq V_C/2$, weighing the three-party (two-party) bargaining payoffs with the the probability of successful (unsuccessful) inventing-around yields the expected profits as stated in the text.

A.7 Bargaining under Specific Performance Contracts with One Price

Again, we have to distinguish the two-party from the three-party bargaining game. With two-party bargaining (i.e. in cases in which inventing around has not been successful), the outside option is always to revert to the price $\bar{p}$ agreed on ex-ante. Hence, with S (M) being the proposer, M (S) can always enforce the initial contract leading in both cases to a payment of $\bar{p}$ for the input. S receives $\bar{p}$ whereas M gets $V_M^X - \bar{p}$.

With three-party bargaining, the fact that M can not enforce exclusivity, implies that S can threaten to take the input to C. Hence, with S being the proposer, S will propose $\bar{p} + \Delta$ contingent on the exclusive use of the good and $\bar{p}$ with a non-exclusive usage of the input. Because $\Delta \geq V_C/2$, the former dominates the latter for S, and S will offer the exclusive contract. S will receive $\bar{p} + \Delta$ while M's payoff is $V_M - \bar{p}$. With M being the proposer, M has to leave $\bar{p} + 0.5V_C$ with S in either case. Hence, the exclusive contract dominates for M, implying a payoff of $V_M^X - (\bar{p} + 0.5V_C)$ for M and $\bar{p} + 0.5V_C$ for S. Weighing the three-party (two-party) bargaining payoffs with the the probability of successful (unsuccessful) inventing-around yields the expected profits as stated in the text.

A.8 Proof of Proposition 4

Part 1. Using the optimal investment levels I_{1p} and q_{1p} allows us to compute the total social surplus in this setting

$$TS_{1p} = Y_M^X + \frac{\sigma^2}{2} - \frac{(2\Delta + V_C)^2}{32c} \tag{28}$$

Comparing this with the total surplus in the M, σ case (see the Proof of Proposition 1):

$$TS_{M,\sigma} = Y_M^X + \frac{(3 + 2a - a^2)\sigma^2}{8} - \frac{(V_C + 2a\Delta)^2}{32c}$$

reveals that the two are identical at $a = 1$. However, at $a = 1$, $TS_{M,\sigma}$ decreases in a locally. Hence, a marginal decrease in a from $a = 1$ implies that the total surplus under the ownership approach increases, whereas the total surplus under the specific performance contract remains unchanged.

Part 2. This follows from $\frac{dTS_{S,\sigma}}{d\Delta} = \frac{dTS_{M,0}}{d\Delta} = 0$,

$$\frac{dTS_{1p}}{d\Delta} = -\frac{2\Delta + V_C}{8c} < 0 \tag{29}$$

and

$$\frac{d(TS_{1p} - TS_{M,\sigma})}{d\Delta} = -\frac{(1-a)V_C + 2(1-a^2)\Delta}{8c} \leq 0 \tag{30}$$

■

A.9 Proof of Lemma 4

We will first derive and characterize the equilibrium in case of initial M-ownership and a call for S. Afterwards, we will show how initial S-ownership and a put for S yield the same equilibrium conditions.

Consider first the optimal exercise strategy by S: After successful inventing-around, S exercises the option if

$$\frac{a}{2}(Y_M + \sigma I) - P \geq 0 \tag{31}$$

If inventing-around failed, the option is exercised if

$$\frac{a}{2}(Y_M^X + \sigma I) - P \geq 0 \tag{32}$$

If both inequalities are (neither inequality is) satisfied, the equilibrium is the same as under S-ownership (M-ownership).

Next, we derive the equilibrium conditions in case of asymmetric option exercise. (15) and (16) yield the best response functions

$$I^C = \frac{\sigma}{2}(1 + aq^C) \tag{33}$$

and

$$q^C = \frac{V_C}{4c} + \frac{1}{c}\left(P - \frac{a}{2}(Y_M + \sigma I^C)\right) \tag{34}$$

where I^C and q^C denote equilibrium choices under asymmetric option exercise. These two equations yield equilibrium investments

$$I^C = \frac{\sigma(4c + aV_C - 2a^2Y_M + 4aP)}{2(4c + a^2\sigma^2)} \tag{35}$$

and

$$q^C = \frac{V_C - a\sigma^2 - 2aY_M + 4P}{4c + a^2\sigma^2} \tag{36}$$

Solving conditions (31) and (32) for P at equality yields the minimum and maximum strike for asymmetric exercise. Evaluating S's best response function at these levels yields, at the lower boundary, $q^C = q_{S,\sigma}$ and, at the upper boundary, $q^C = q_{M,\sigma}$. Hence, equilibrium inventing-around by S is continuous in P and increases in P in case of asymmetric exercise. For M's investment, note that the equilibrium level in case of asymmetric exercise is increasing in P (see (35)) and lies strictly between the levels under S-ownership and M-ownership (see (33) and note that $0 < a < 1$ and $0 < q^C < 1$).

In order to ensure consistency of M's investments with the subsequent exercise by S, solve conditions (31) and (32) for I and combine these conditions with M's optimal investments: Combining $I_{S,\sigma}$ and condition (31) yields $P \leq P_1$; combining $I_{M,\sigma}$ and the reverse of condition (32) yields $P \geq P_4$; and for I^C to satisfy condition (32) and violate condition (31) requires $P_2 \leq P \leq P_3$.

For $P \in (P_1, P_2)$, neither I^C nor $I_{S,\sigma}$ are consistent with S's optimal option exercise: If S were expected to exercise asymmetrically, then the equilibrium investment by M would be high enough to induce S to always exercise the option; if S were expected to exercise always, the equilibrium investment would be so low that asymmetric exercise would be optimal. Hence, M's optimal feasible investment is such that S is indifferent about exercising in case of successful inventing-around. This implies that the investment is such that (31) holds with equality, $I(P) = \frac{2P}{a\sigma} - \frac{Y_M}{\sigma}$, for $P \in (P_1, P_2)$. Consequently, $q = q_{S,\sigma}$ over the same interval. The equivalent holds for $P \in (P_3, P_4)$: M's optimal investment is such that (32) holds with equality, $I(P) = \frac{2P}{a\sigma} - \frac{Y_M^X}{\sigma}$, and $q = q_{M,\sigma}$. This shows that both investments are continuous functions in P and increasing in the respective intervals.

Lastly, consider the case of initial S-ownership and a put option for S: As the strike price is now a transfer from M to S, asymmetric exercise is now optimal if inventing-around was successful. For a low (high) strike price, S never (always) exercises the option and investments are as under S-ownership (M-ownership). The critical levels triggering changes in the optimal exercise remain the same, as does the post-exercise ownership structure. As a consequence, the structure of payoffs given P is identical to the previous case of initial M-ownership and a call for S. Hence, we get the same equilibrium as before. ■

A.10 Proof of Proposition 6

Part 1. This follows directly from $\Delta < V_C/2$ and the proof of lemma 1. The expected payoffs of the bargaining process are then

$$\pi_M = (1+a_i)\frac{V_M(\hat{\sigma})}{2} \tag{37}$$

$$\pi_S = (1-a_i)\frac{V_M(\hat{\sigma})}{2} + \frac{V_C}{2} \tag{38}$$

Parts 2. and 3. Expected payoffs depending on the final use of the good, ownership and the technology (specific/general) are:

$$E[\pi_M] = \begin{cases} \frac{1}{2}(Y_M + I) - \frac{1}{2}I^2 & \text{for } S, 0 \\ \frac{1+a}{2}(Y_M + I) - \frac{1}{2}I^2 & \text{for } M, 0 \\ \frac{1}{2}(Y_M^X + \sigma I) - \frac{q}{2}\Delta - \frac{1}{2}I^2 & \text{for } S, \sigma \\ \frac{1+a}{2}(Y_M^X + \sigma I) - \frac{q}{2}(1+a)\Delta - \frac{1}{2}I^2 & \text{for } M, \sigma \end{cases} \tag{39}$$

$$E[\pi_S] = \begin{cases} \frac{1}{2}(Y_M + I) + \frac{V_C}{2} - \frac{c}{2}q^2 & \text{for } S, 0 \\ \frac{1-a}{2}(Y_M + I) + \frac{V_C}{2} - \frac{c}{2}q^2 & \text{for } M, 0 \\ \frac{1}{2}(Y_M^X + \sigma I) + \frac{q}{2}(V_C - \Delta) - \frac{c}{2}q^2 & \text{for } S, \sigma \\ \frac{1-a}{2}(Y_M^X + \sigma I) + \frac{q}{2}(V_C - (1-a)\Delta) - \frac{c}{2}q^2 & \text{for } M, \sigma \end{cases} \tag{40}$$

These yield the investment levels of M equal to those of lemma 3 and, given assumption (1) and choice of the specific technology, inventing-around of $q_{S,\sigma} = \frac{1}{2c}(V_C - \Delta)$ or $q_{M,\sigma} = \frac{1}{2c}(V_C - (1-a)\Delta)$ with $q_{S,\sigma} < q_{M,\sigma}$.

With these investments, we get the joint surplus:

$$TS = \begin{cases} Y_M + \frac{V_C}{2} + \frac{1}{8} & \text{for } S, 0 \\ Y_M + \frac{V_C}{2} + \frac{3+2a-a^2}{8} & \text{for } M, 0 \\ Y_M^X + \frac{3\sigma^2}{8} + \frac{V_C^2+3\Delta^2-4V_C\Delta}{8c} & \text{for } S, \sigma \\ Y_M^X + \frac{(3+2a-a^2)\sigma^2}{8} + \frac{V_C^2+(3-2a-a^2)\Delta^2-4V_C\Delta}{8c} & \text{for } M, \sigma \end{cases} \tag{41}$$

For part 2., note that $TS_{S,0}$ is always smaller than $TS_{M,0}$ for $a \in (0,1)$. Part 3. follows from solving $TS_{S,\sigma} = TS_{M,\sigma}$ and $TS_{S,\sigma} = TS_{M,0}$ with respect to c. ■

A.11 Proof of Corollary 2

The pairwise differences in joint surplus are

$$TS_{S,\sigma} - TS_{M,\sigma} = \frac{a}{8c}\left(\Delta^2(2+a) - (2-a)c\sigma^2\right) \tag{42}$$

$$\begin{aligned} TS_{M,0} - TS_{M,\sigma} = \frac{1}{8c}\Bigg(& 8c(\frac{V_C}{2} - \Delta) - c(\sigma^2 - 1)(3 - 2a + a^2) \\ & - (V_C - (1-a)\Delta)(V_C - (3+a)\Delta)\Bigg) \end{aligned} \tag{43}$$

$$\begin{aligned} TS_{M,0} - TS_{S,\sigma} = \frac{1}{8c}\Bigg(& 8c(\frac{V_C}{2} - \Delta) - c(3(\sigma^2 - 1) + 2a - a^2) \\ & - (V_C - 2\Delta)^2 + \Delta^2\Bigg) \end{aligned} \tag{44}$$

The pairwise comparative static effects can then be confirmed directly, where the signs are either immediately visible or follow from (1) and proposition 6). Finally, combination of all three pairwise comparisons yields the overall changes at indifference between all three ownership/technology structures. ■

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