The design of vertical R&D collaborations

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Abstract

Suppliers play a major role in innovation processes. We analyze 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. If the expertise of the supplier is important ex-post, combining manufacturer ownership with the specific technology becomes optimal. More intense product market competition shifts optimal ownership towards the supplier.

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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. Hence, neither a pure market transaction (full-scale outsourcing) nor a fully integrative approach are efficient. Rather we observe in very many instances vertical R&D cooperations between supplier and buyer of different types. 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 (1997) 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 analyze the functioning and determinants of vertical R&D cooperation and relate them to competition in output markets. Our main research questions thereby are: How does the organization of vertical R&D cooperation look like (in terms of technology and allocation of property rights)? How does the intensity of competition in output markets affect the organizational design of vertical R&D cooperations?

We investigate these questions in an incomplete contracting framework in which due to the uncertainties associated with the innovative process it is not feasible to write a contract on the output of an emerging new technology. The innovation process leading to mass production of the new input consists of three phases: An initial research phase, a subsequent development phase in which collaborative efforts are undertaken by the manufacturing firm as well, and a production phase which requires the production expertise of the supplying firm. There are two major decisions to be made. The first concerns the specificity of the R&D technology. Choosing a specific R&D technology increases the value of the new input for the manufacturing firm while at the same time increasing the

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

hold-up problem for the supplier. Hence, the specific R&D technology comes at a cost: In order to 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 second concern is with ownership of the output of the research process (a patent or some other output of the research process) which can be assigned to either party of the cooperation. Hence, ownership in our model is on intellectual property. 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.

Taking the choice of ownership and R&D specificity together allows us to investigate in detail various degrees of R&D collaboration between a supplier and a manufacturer. We are able to not only look into the effects of technological factors but also of product market characteristics which affect the choice of the R&D collaboration regime. The focus of our analysis is thus on later stages of the innovation process rather than on the initial research phase and its related hold-up problems.

To illustrate our set-up more specifically, consider the relationship between a supplier and an OEM in the automotive industry. Given the accumulated expertise of the specialized supplier which develops a wide range of automotive inputs with economies of scope it is efficient to undertake R&D with respect to the development of a particular input in an arm's length manner. At the same time, the value of the new input can be improved with collaborative R&D whereby the OEM also contributes its knowledge. The more narrowly the R&D efforts are designed towards the particular needs of the manufacturer the more valuable the new input (say, a fuel-injection system) is. Designing R&D efforts, however, closely towards the needs of the automotive OEM obviously limits the applicability of the new input with other potential buyers. As this reduces his bargaining power, the supplier might think about simultaneously exploring techniques which allow him to sell the new fuel-injection system to another OEM (i.e. to invest in inventing-around activities). In this case, product market competition lowers the added value of the fuel-injection system to the initial OEM. This induced incentive for investments in inventing-around activities lowers the case for narrowly defined R&D processes and opens up the question to which extent the OEM should invest in collaborative R&D in the first place.

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 analyze the effect of a more intense product market competition which makes the exclusive supply to the OEM more attractive. If the degree of product market competition increases, the contract is structured to minimize 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 the OEM ownership as well as the specific R&D technology more attractive.

The paper is organized as follows. In the subsequent chapter we relate our analysis to the literature. In chapter three we outline the basic model. The subsequent fourth chapter solves the model and analyzes the optimal (contractual and technological) choices. In chapter five we consider extensions to the base model. The sixth chapter concludes.

2 Relationship to Literature

Our paper relates to four different branches of the literature. First, and foremost, there is a growing literature dealing with innovation management issues on the basis of incomplete contracting arguments. The papers most closely to ours are Aghion and Tirole (1994) and Rosenkranz and Schmitz (2003). Aghion and Tirole (1994) investigate the management of innovation of mature firms in vertical relationships. Their analysis rests on the notion that the allocation of ownership affects incentives for a research unit. We distinguish ourselves mainly from their paper by focusing on vertical R&D cooperations rather than on pure make or buy decisions. Rosenkranz and Schmitz (2003), in a dynamic incomplete contracting approach based on Hart and Moore (1988), look into organizational issues of horizontal R&D cooperation. By focusing on horizontal rather than vertical R&D cooperation their approach addresses a quite different set of questions than ours. Bias and Perotti (2006) and Baccara and Razin (2004) are part of a larger literature which rather than looking at the organization of the innovation process in mature firms as a whole focus on creation of new ideas in organizations and the problem of information leakages. By doing this they very much address the problem of the creation of new start-up firms and contrast the advantages of entrepreneurial spirit with the creation of new ideas in established organizations.

Second, Anand and Galetovic (2000) are akin to our approach by stressing weak property rights and hold-up in R&D. However, they consider the financing of R&D (venture capital financing vs. financing in a corporation) rather than looking into the design of the R&D process itself. Thereby, they form part of a second related branch of the literature which considers the interaction of the design of the innovation process and its financing. Similarly Fulghieri and Sevilir (2003) address this interaction by investigating the competition between two upstream firms with one downstream firm for the provision of a newly designed input. Their approach is somewhat complimentary to ours by not only looking at the reverse type of vertical competition but also by focusing on the financial aspects of the innovation process rather than on the organizational implications per se.

Third, our analysis is based on the incomplete contracting literature. We thereby rely on the notion of contracting at will as put forward by Hart and Moore (1988). We consider this notion which assumes that the levels of trade can not be observed by courts most applicable for our analysis of providing and trading a newly designed input which incorporate features being very difficult to understand and overlook by a third party (courts). We thereby abstract from the idea of ex-ante option contracts on the pricing of the newly designed input as proposed in Nöldeke and Schmidt (1995). This makes our approach also different from Edlin and Hermalin (2000) with whom our approach shares the notion of an investment in the threat point of one party. The focus of their analysis which rests on contracting at will is, however, completely different than ours. Our paper is also akin to Schmitz and Sliwka (2001) who allow for the endogeneity of the specificity of the technology. In contrast to our approach they focus on the joint determination of ownership and specificity against the background of a standard hold-up problem of the supplier in the research phase while we specifically focus on later stages of the innovation process and analyse collaborative R&D efforts of both parties. One of the main driving forces of our analysis, namely the possibility to change ex-post the degree of specificity of the ex-ante chosen technology via inventing-around activities is absent in Schmitz and Sliwka (2001).

Fourth, 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. In contrast to our analysis, 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. In that respect, our paper is also somewhat related to Inderst and Wey (2003) who consider technology choice and product market competition in vertically structured oligopolies, leaving, however, the organizational issues completely aside.

3 The Model

3.1 Basic Set-Up

The innovation process We consider the organization of innovative activities between a supplier (firm S) and a manufacturer (firm M). Innovative activities are concerned with 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 to write ex-ante a contract which describes the crucial characteristics of the new input in a verifiable manner. Hence, it is not possible to contract on the specific output of the R&D process. 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 first step of the R&D process, the research process. We refer to this outcome in the following as patent.[2] In an extension we allow for the renegotiation of this right in a later stages.

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 the new input 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 wasteful inventing-around activities. In case of success these inventing-around activities allow the supplier to create a new modified input which can potentially be sold the 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.

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

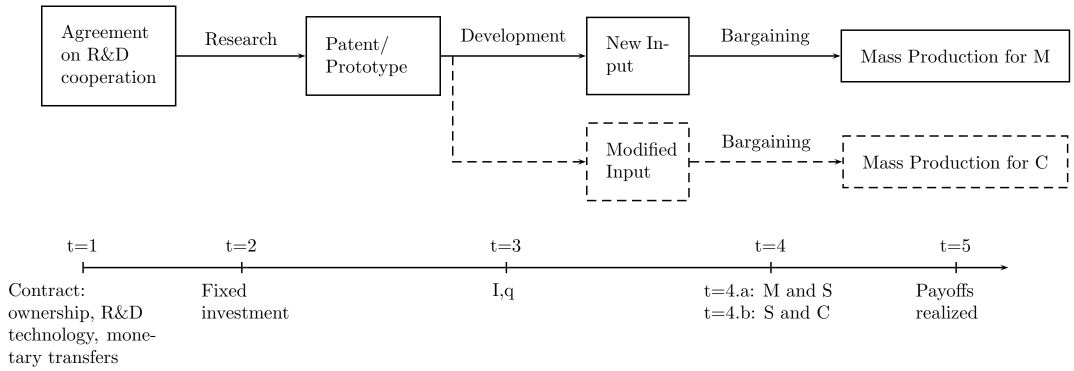

Figure 1: The structure of the R&D process

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

Design and usage of the new input In the following we distinguish between the ex-post usage of the innovative product (allowing either for an exclusive use only in M's production or a non-exclusive use by supplying the product to M as well as C) and the ex-ante design of the R&D technology being either specific (leading to a higher productivity of M's investment) 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. Hence, we refer to $\Delta \equiv Y_M^X - Y_M$ as the intensity of product market competition between M and C. To simplify the analysis, we consider the case in which $\Delta \geq Y_C/2$ in the base model.[3] Hence, we focus in our base model on the case in which ex-post the technology will be used exclusively by firm M rather

[3]Section 5.3 considers the reverse case.

than being sold to competitor C as well (see our later analysis for this to be indeed the case). The crucial question 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?

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 (non-exclusive) use and specifically-designed R&D technologies by $V_{M,\sigma}^X = Y_M^X + \sigma I$ ($V_{M,\sigma} = Y_M + \sigma I$). We use corresponding notation to describe the value of the new input in the case of a general R&D technology. With exclusive (non-exclusive) use we have $V_{M,0}^X = Y_M^X + I$ ($V_{M,0} = Y_M + I$). 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 ex-post it might be feasible to sell the new input to the competitor as well. $c > 0$ measures the cost of inventing-around activities. In case of no or unsuccessful inventing-around activities, however, S is ex-post locked into the relationship with M. If a general R&D technology is ex-ante selected the new input can be sold to C without any further costs. Note that in the base model, investments in inventing-around activities are from an efficiency point of view a pure waste. However, they stochastically increase the outside options of firm S in the case of a specific R&D technology.

3.2 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 rationality 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.[5] In the subsequent stage (t=4), three-party bargaining will occur. At the bargaining stage 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 modeling 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,

[4] These monetary transfer 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.

[5] Allowing for sequential moves of the two firms at this point leaves our results unaltered.

before then turning to an analysis of the choice over inventing-around and collaborative research. Finally, we analyze the design of the cooperation in the first stage of the game.

4 Analysis

4.1 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.

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*

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

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

2. *For $\Delta \geq \frac{V_C}{2}$, three-party bargaining results in exclusive use of the good. The expected payoffs of the bargaining process are,*

$$\pi_M = \frac{V_M^X(\hat{\sigma})}{2} + a_i\frac{V_M(\hat{\sigma})}{2} - \frac{V_C}{4} \tag{3}$$

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

Proof: See the appendix.

The outcome of the two-party bargaining illustrates the role of M's alternatives: The two parties equally share the joint surplus which 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.

4.2 Development stage

We next consider the development stage with the choice of M's collaborative development efforts and the inventing-around activities 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 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.

In the following, we denote the four potential ownership/technology combinations by subscripts (M or S gives ownership, o and σ denote the general and the specific technology, respectively). Thereby, we can state:

Lemma 2

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. *For $\Delta \geq \frac{V_C}{2}$ (exclusive use ex post) and $c > \Delta/2 + V_C/4$, 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 $q_{S,\sigma} \leq q_{M,\sigma}$.*

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 not least against the background of 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).

4.3 Contracting stage

In the initial contracting stage, 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 as little distorted 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, for $\Delta \geq \frac{V_C}{2}$,

$$\frac{\Delta(V_C + a\Delta)}{(2-a)\sigma^2} = c = \frac{V_C^2}{4(3(\sigma^2 - 1) - 2a + a^2)} \tag{5}$$

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* $\Delta \geq \frac{V_C}{2}$ *and (5) 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-ownership/specific technology)*
- Δ *results in M and S choosing either S-ownership and the specific technology or M-ownership and general technology (M-ownership/specific technology)*

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 to 4 show how optimal ownership

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

and technology depend on the extent of market competition (captured by Δ) and one other parameter.[6]

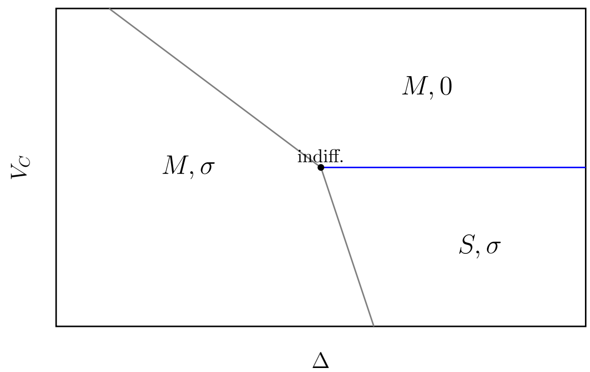

Figure 2: Optimal choices depending on V_C and Δ

Figure 2 illustrates the effect of changes in the new input's value in its two possible uses. 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.

Additionally, the figure shows that – for low values of V_C – an increase in competitiveness leads to a transfer of ownership from M to S. By switching from M to S-ownership the contracting parties try to reduce the degree of inventing-around.

[6]In the figures, we always assume that the parameters are such that there is a indifference point where each ownership/technology choice yields the same joint payoff.

For higher values of Δ, i.e. higher product market competition, the decrease in rent-seeking under S-ownership (relative to M-ownership) is more pronounced while the difference in 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.

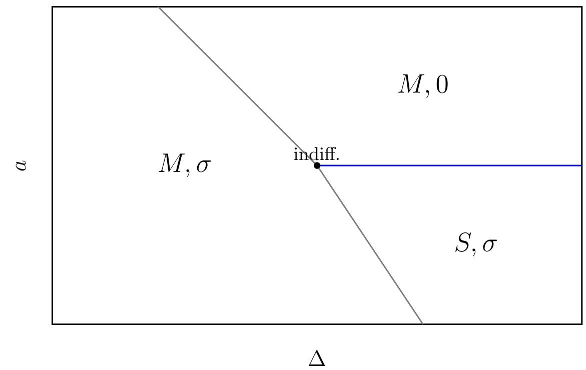

Figure 3: Optimal choices depending on a and Δ

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, lower values of a also reduce the gains in terms of low inventing-around under S-ownership. As a result, M-ownership is also chosen more often.[7] 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 in figure 4 measures the benefits of choosing the specific technology (in terms of productivity enhancement). 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, but then requires balancing investment and rent-seeking incentives. For intermediate values, this requires giving ownership to S. However, for even higher levels of the gains from specificity, M's ivestment

[7] On the other hand, for lower initial values, an increase in a makes S-ownership potentially more profitable.

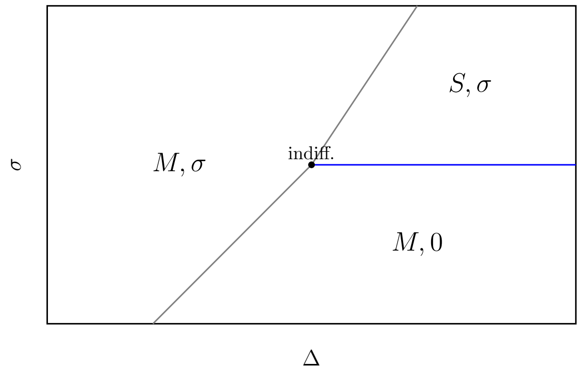

Figure 4: Optimal choices depending on σ and Δ

incentives are more strongly affected by the choice of ownership (while inventing-around is not affected by σ). Hence, M-ownership combined with the specific-technology choice is optimal when specificity yields high productivity gains.

We summarize our main findings in

Proposition 2 *(i) The market solution exhibits too little specificity (in too many cases a general technology is chosen).*
(ii) The more intense product market competition the more often S becomes the owner.
(iii) Technologies with pronounced inalienability lead to choice of specific technologies and allocation of ownership towards firm M.

5 Extensions

In the following we discuss extending our analysis in three directions. First, we investigate the consequences of introducing option contracts on ownership which might potentially lead to ownership changes during or after the innovation process. Second, we allow for the possibility of renegotiation. Finally, we relax 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.

5.1 Option contracts

In a next step we look into the possibility of ownership allocated via option contracts on the overall outcome of our R&D cooperation. 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. We show in the following that while improving the efficiency of the outcome, option contracts do not change our basic mechanisms and results qualitatively.

Option contracts only affect our previous analysis if the optimal exercise depends on whether inventing-around has been successful or not. If options are always or never exercised our earlier analysis applies, given that 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.

Rather than discussing all cases at length we carve out the main implication of option contracts with the help of one specific case. All other cases with the choice of a specific technology share the same patterns. For this purpose, consider initial S-ownership and a call option for M.[8] Let P denote the agreed strike price defined as a payment from M to S. Then the payoff structure is as given in table 2.

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

Table 2: Payoff structure with option contracts

If M holds the call, he will first exercise it in case of failed inventing-around. With a low (high) strike price, the call will be exercised in both (neither) cases. Given that we want to ensure asymmetric exercise of the option, the strike P must be in the range $P \in (0.5a(Y_M + \sigma I); 0.5a(Y_M^X + \sigma I))$. In this case, the expected payoffs of the two firms can be expressed as:

$$E[\pi_M] = \frac{q}{2}(Y_M^X + \sigma I - \frac{V_C}{2}) + \frac{1-q}{2}((1+a)(Y_M^X + \sigma I) - 2P) - \frac{I^2}{2}, \qquad (6)$$

[8] The case of S holding a put option is qualitatively the same.

and

$$E[\pi_S] = \frac{q}{2}(Y_M^X + \sigma I + \frac{V_C}{2}) + \frac{1-q}{2}((1-a)(Y_M^X + \sigma I) - 2P) - \frac{cq^2}{2}. \tag{7}$$

For S's inventing-around activities we get in the equilibrium of this stage:

$$q^C = \frac{V_C}{4c} + \frac{1}{c}\left[\frac{a}{2}(Y_M^X + \sigma I^C) - P\right], \tag{8}$$

with I^C denoting the respective choice of M's cooperative R&D investment which we will derive below. Hence, the level of inventing-around decreases continuously with the exercise price starting with $q_{M,\sigma}$ for $P^{min} = \frac{a}{2}(Y_M + \sigma I^C)$ and reaching $q_{S,\sigma}$ for $P^{max} = \frac{a}{2}(Y_M^X + \sigma I^C)$. The intuition for this is that with a higher exercise price S anticipates a higher payoff in case of a failure of the inventing-around activities. Hence, the incentives to invest in inventing-around steadily decrease with an increased exercise price allowing for a continuous move from M to S-ownership with respect to the inventing-around activities.

Things are somehow different with respect to M's investment in cooperative R&D in the case of option contracts. In our particular case, for M's optimal investment we find

$$I^C = \frac{(1-q^C)\sigma a}{2} + \frac{\sigma}{2} = I_{S,\sigma} + 0.5(1-q^C)\sigma = I_{M,\sigma} - q^C\frac{\sigma a}{2}. \tag{9}$$

Via q^C the level of investment in cooperative R&D increases with the exercise price.[9] In contrast to the level of inventing-around, M's cooperative R&D investment levels do not move continuously with the exercise price in-between the respective levels for S and M-ownership. Rather, for an exercise price close to P^{max} (leading to a low level of inventing-around, $q_{S,\sigma}$) the investment levels strictly exceed $I_{S,\sigma}$. For low levels of the exercise price (but still above P^{min}), the level of cooperative R&D decreases. The intuition behind this is the following. If firm M anticipates that it will exercise the option contract this leads to a discontinuous increase in its incentive to undertake cooperative R&D investments. This increase in incentive is the more pronounced the lower the probability of successful inventing-around (since it is exercised in the case of unsuccessful inventing-around). Hence, for an exercise price close to P^{max}, q is marginally close to $q_{S,\sigma}$

[9]Reversing the option contract, i.e. allocating a put option to S does not change this general pattern. The only difference is with respect to the levels of M's investment levels which depend on q rather than on $1-q$. Hence, depending on the particular equilibrium level of inventing-around activities either option contract might be preferable.

while I is strictly above $I_{S,\sigma}$. Obviously, this case is a candidate for which option contracts can improve the allocation. We argue in the following that this can indeed be the case.

Given that we observe too little cooperative R&D, achieving only marginally higher levels of q while giving M incentives to induce a jump in I, this seems to be an obvious way to improve the overall allocation. However, the interior solutions above derived form part of an equilibrium only if firm M does not have an incentive to unilaterally deviate from (I^C, q^C) and choose a level of I which makes it worthwhile to always exercise the option. This may be the case because the objectives of firm M differ from the joint payoff of firm M and S. Hence, exercise in both cases may be in the interest of M even if both firms are indifferent ex-ante between M-ownership and S-ownership given the choice of the specific technology.

If the call option is exercised in both cases, M's incentive to undertake R&D are the same as with M-ownership. That is, for proving that M may not have an incentive to deviate from I^C it suffices to show that choosing $I_{M,\sigma}$ for $q_{S,\sigma}$ does not make firm M better off. Comparing the respective payoffs gives us a condition for which M as the holder of the call option (worth $P^{\max}$) does not have an incentive to deviate from I^C given that it anticipates q^C as S's equilibrium choice:

$$E[\pi_M(I_{M,\sigma}, q^C)] - E[\pi_M(I^C, q^C)] = \frac{q}{2}\left(\left[\frac{1}{2} - q - \frac{qa}{4}\right]\sigma^2 a - \Delta\right) < 0 \qquad (10)$$

With P^{min}, however, $q^C = q_{M,\sigma}$ while I^C is strictly lower than $I_{M,\sigma}$, leading to an inferior allocation compared to M-ownership in the absence of option contracts.

Hence, we can state

Proposition 3 *i) Allowing for option contracts on ownership may improve the allocation and shift the choice of technological design in favor of the specific technology. A sufficient condition for the possibility of an improved allocation is that (10) holds.*
ii) There exist, however, exercise price for which option contracts lead to an inferior outcome and hence are dominated by a fixed ex-ante allocation of ownership.

Hence, option contracts may (but need not) improve the outcome leading to the fact that the specific technology design is chosen more often. In general, however, the mechanisms discussed in the main body of the paper remain qualitatively unchanged.

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 an edgeless weapon. 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 after 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. In sum, renegotiation is not an issue here.

5.3 Non-exclusive use of the new input

We now review the result of our base model when the assumption about the strength of the competitive effect is reversed. Hence, let $\Delta < V_C/2$ 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-

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

around is excessive: S not only enables the two firms to increase the joint surplus, but also improves its bargaining position by creating an outside option.

Overall, we get the following results:

Proposition 4 *Let $\Delta < V_C/2$ and $c > V_C/2$. Then*

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, for $\Delta < \frac{V_C}{2}$,*

$$\frac{\Delta(2+a)}{(2-a)\sigma^2} = c = \frac{(V_C - 2\Delta)^2 - \Delta^2}{2a - a^2 + 4(V_C - 2\Delta) - 3(\sigma^2 - 1)} \tag{11}$$

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 $\Delta < \frac{V_C}{2}$ and (11) 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.

6 Conclusion

A major source for the innovative 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 cooperations which we observe in many instances. Given that the vertical integration solution is often not really an option (e.g. due to potential economies of scope with other activities of the supplier as well as the buying firm), analyzing the in-between solution is in our view important. 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 and empirically testable hypotheses. 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. 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. Secondly, 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, therefore still leaving enough room for the mechanisms stressed in the present paper. Consequently, our model provides a starting point for analyzing vertical R&D cooperations more closely.

A Appendix

A.1 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 payoff given in (1) and (2).

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

$$\pi_S(S \text{ proposer}) = \begin{cases} V_M^X - a_i V_M & \text{under exclusivity} \\ (1-a_i)V_M + \frac{V_C}{2} & \text{under non-exclusivity} \end{cases} \tag{12}$$

For $\Delta \geq \frac{V_C}{2}$, 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

$$\pi_M(M \text{ proposer}) = \begin{cases} V_M^X - \frac{V_C}{2} & \text{under exclusivity} \\ V_M & \text{under non-exclusivity} \end{cases} \tag{13}$$

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

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. ■

A.2 Proof of Lemma 2

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.

$$E[\pi_M] = \begin{cases} \frac{1}{2}(Y_M^X + I) - \frac{V_C}{4} - \frac{1}{2}I^2 & \text{for } S, 0 \\ \frac{1}{2}(Y_M^X + I) + \frac{a}{2}(Y_M + I) - \frac{V_C}{4} - \frac{1}{2}I^2 & \text{for } M, 0 \\ \frac{1}{2}(Y_M^X + \sigma I) - q\frac{V_C}{4} - \frac{1}{2}I^2 & \text{for } S, \sigma \\ \frac{1+a}{2}(Y_M^X + \sigma I) - q(\frac{V_C}{4} + \frac{a}{2}\Delta) - \frac{1}{2}I^2 & \text{for } M, \sigma \end{cases} \tag{14}$$

$$E[\pi_S] = \begin{cases} \frac{1}{2}(Y_M^X + I) + \frac{V_C}{4} - \frac{c}{2}q^2 & \text{for } S, 0 \\ \frac{1}{2}(Y_M^X + I) - \frac{a}{2}(Y_M + I) + \frac{V_C}{4} - \frac{c}{2}q^2 & \text{for } M, 0 \\ \frac{1}{2}(Y_M^X + \sigma I) + q\frac{V_C}{4} - \frac{c}{2}q^2 & \text{for } S, \sigma \\ \frac{1-a}{2}(Y_M^X + \sigma I) + q(\frac{V_C}{4} + \frac{a}{2}\Delta) - \frac{c}{2}q^2 & \text{for } M, \sigma \end{cases} \tag{15}$$

The optimal levels of investment and inventing-around and their relative magnitudes follow then directly. In order to ensure interior solutions for inventing-around ($q < 1$), we need $c > \Delta/2 + V_C/4$. ■

A.3 Proof of Proposition 1

Inserting the optimal levels of investment and inventing-around of lemma 2 into the payoff functions (14) and (15) yields the following structure of joint surplus $TS \equiv E[\pi_S + \pi_M]$:

$$TS = \begin{cases} Y_M^X + \frac{3}{8} & \text{for } S, 0 \\ Y_M^X + \frac{3+2a-a^2}{8} & \text{for } M, 0 \\ Y_M^X + \frac{3\sigma^2}{8} - \frac{V_C^2}{32c} & \text{for } S, \sigma \\ Y_M^X + \frac{(3+2a-a^2)\sigma^2}{8} - \frac{(V_C+2a\Delta)^2}{32c} & \text{for } M, \sigma \end{cases} \tag{16}$$

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

Part 2.: (5) follows from solving $TS_{S,\sigma} = TS_{M,\sigma}$ and $TS_{S,\sigma} = TS_{M,0}$ with respect to c. ■

A.4 Proof of Corollary 1

For $\Delta \geq V_C/2$, the pairwise differences in joint surplus are

$$\begin{aligned} TS_{S,\sigma} - TS_{M,\sigma} &= \frac{a}{8c}\left(a(V_C\Delta + a\Delta^2) - c\sigma^2(2a - a^2)\right) && (17)\\ TS_{M,0} - TS_{M,\sigma} &= \frac{1}{32c}\left((V_C + 2a\Delta)^2 - 4c(\sigma^2 - 1)(3 + 2a - a^2)\right) && (18)\\ TS_{M,0} - TS_{S,\sigma} &= \frac{1}{32c}\left(V_C^2 - 4c(3(\sigma^2 - 1) - 2a + a^2)\right) && (19)\end{aligned}$$

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

$$\begin{aligned} \frac{d(TS_{M,0} - TS_{M,\sigma})}{da} &= \frac{1}{32c}\left(4\Delta(V_C + 2a\Delta) - 4c(\sigma^2 - 1)(2 - 2a)\right) && (20)\\ &= \frac{12\Delta V_C - 2V_C^2 + 2a(\Delta^2(12 + 4a) + V_C^2 + 2a\Delta V_C)}{32c(3 + 2a - a^2)} && (21)\\ &> 0 \end{aligned}$$

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.5 Proof of Proposition 4

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

$$\begin{aligned} \pi_M &= (1 + a_i)\frac{V_M(\hat{\sigma})}{2} && (22)\\ \pi_S &= (1 - a_i)\frac{V_M(\hat{\sigma})}{2} + \frac{V_C}{2} && (23)\end{aligned}$$

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

$$E[\pi_M] = \begin{cases} \frac{1}{2}(Y_M + I) - \frac{1}{2}I^2 & \text{for } S, 0 \\ \frac{1+a}{2}(Y_M + I) - \frac{1}{2}I^2 & \text{for } M, 0 \\ \frac{1}{2}(Y_M^X + \sigma I) - \frac{q}{2}\Delta - \frac{1}{2}I^2 & \text{for } S, \sigma \\ \frac{1+a}{2}(Y_M^X + \sigma I) - \frac{q}{2}(1+a)\Delta - \frac{1}{2}I^2 & \text{for } M, \sigma \end{cases} \tag{24}$$

$$E[\pi_S] = \begin{cases} \frac{1}{2}(Y_M + I) + \frac{V_C}{2} - \frac{c}{2}q^2 & \text{for } S, 0 \\ \frac{1-a}{2}(Y_M + I) + \frac{V_C}{2} - \frac{c}{2}q^2 & \text{for } M, 0 \\ \frac{1}{2}(Y_M^X + \sigma I) + \frac{q}{2}(V_C - \Delta) - \frac{c}{2}q^2 & \text{for } S, \sigma \\ \frac{1-a}{2}(Y_M^X + \sigma I) + \frac{q}{2}(V_C - (1-a)\Delta) - \frac{c}{2}q^2 & \text{for } M, \sigma \end{cases} \tag{25}$$

These yield the investment levels of M equal to those of lemma 2 and, for $c > V_C/2$ 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 $q_{S,\sigma} \leq q_{M,\sigma}$.

With these investments, we get the joint surplus:

$$TS = \begin{cases} Y_M + \frac{V_C}{2} + \frac{1}{8} & \text{for } S, 0 \\ Y_M + \frac{V_C}{2} + \frac{3+2a-a^2}{8} & \text{for } M, 0 \\ Y_M^X + \frac{3\sigma^2}{8} + \frac{V_C^2 + 3\Delta^2 - 4V_C\Delta}{8c} & \text{for } S, \sigma \\ Y_M^X + \frac{(3+2a-a^2)\sigma^2}{8} + \frac{V_C^2 + (3-2a-a^2)\Delta^2 - 4V_C\Delta}{8c} & \text{for } M, \sigma \end{cases} \tag{26}$$

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.6 Proof of Corollary 2

For $\Delta < V_C/2$, the pairwise differences in joint surplus are

$$TS_{S,\sigma} - TS_{M,\sigma} = \frac{a}{8c}\left(\Delta^2(2+a) - (2-a)c\sigma^2\right) \tag{27}$$

$$TS_{M,0} - TS_{M,\sigma} = \frac{1}{8c}\bigg(8c(\frac{V_C}{2} - \Delta) - c(\sigma^2 - 1)(3 - 2a + a^2) - (V_C - (1-a)\Delta)(V_C - (3+a)\Delta)\bigg) \tag{28}$$

$$TS_{M,0} - TS_{S,\sigma} = \frac{1}{8c}\bigg(8c(\frac{V_C}{2} - \Delta) - c(3(\sigma^2 - 1) + 2a - a^2) - (V_C - 2\Delta)^2 + \Delta^2\bigg) \tag{29}$$

The pairwise comparative static effects can then be confirmed directly, where the signs are either immediately visible or follow from $c > V_C/2$ (see proposition 4). Finally, combination of all three pairwise comparisons yields the overall changes at indifference between all three ownership/technology structures. $\blacksquare$

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