

# Disclosing vs. Withholding Technology Knowledge in a Duopoly\*

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## Abstract

We study firms' incentives to transfer knowledge about production technology to a rival in a Cournot duopoly. In a setting where two technologies are available, a technology is characterized by its associated cost function and no single technology is strictly superior to the other. A firm has superior information if it knows both techniques and the other only one. Cost efficiency may be "reversed" after the voluntary disclosure, so that the rival's costs are improved at the equilibrium level of output. Adding R&D investments to the picture, we find that a firm can decide to invest just for the purpose of acquiring knowledge that will be transferred and not used. Furthermore, for the same point in the parameters space, the acquisition of full knowledge may occur or not as a function of the initial distribution of information.

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## 1 Introduction

Firms may strategically decide to share information with rivals in informal or formal ways. Informally, a firm may decide to leave unprotected the findings of its laboratories, or the accumulated know-how, and therefore deliberately allow competitors to get information. This contrasts with a decision to maintain the

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property of the know-how by patenting or keeping secret the relevant information about production techniques (See Denicoló and Franzoni 2004). Formally, firms may decide to form cooperative R&D joint ventures, or consortia, or to sign other agreements to share information.

Clearly, prior to the creation of a formal agreement, firms have different knowledge about production techniques. Furthermore, also after the formal agreement is signed, a firm can develop knowledge either through the R&D activity executed within the cooperative framework, or acquire knowledge independently, namely outside the agreement. The sharing of knowledge developed within the agreement is generally subject to contractual terms, as discussed in the large literature on the topic. Some papers treat adverse selection and moral hazard (see, for instance, Bhattacharya, Glazer and Sappington 1990 and 1992, d'Aspremont, Bhattacharya and Gérard-Varet 1998 and 2000, Brocas 2004). Under moral hazard (Bhattacharya, Glazer and Sappington 1990) and adverse selection (d'Aspremont *et al.*), the defection of participants, namely withholding information, is a possible occurrence. This kind of defection justifies clauses that specify how the knowledge produced within a cooperative framework must be used. Many contributions tackled the issue of the firms' incentives to disclose knowledge to competitors and the mechanism that, from a cooperative or social point of view, lead to the desired rate of disclosure. Bhattacharya *et al.* (1990, 1992) study multi-stage games in which firms may decide to share the knowledge resulting from costly R&D investments, and examine the mechanisms leading to efficient (possibly full) knowledge sharing and efficient R&D levels. D'Aspremont *et al.* (2000) analyze disclosure between two participants to an R&D race, when one firm enjoys a superior knowledge level and may transfer it to its rival. They show that mechanisms defined by sure-agreement and full disclosure are efficient, and incentive-compatible.<sup>1</sup>

Other works assume away, as we shall also do, information asymmetries. Under perfect information, Katsoulakos and Ulph (1998) study endogenous spillovers and find that voluntary spillovers may be maximal if research has the character of complementarity, namely if the investment of one firm has a positive effect on the rival's profit, as when firms belong to different industries. In the model we study complementarity does not play a role. Voluntary spillovers, this time due to reciprocal strategic effects, can be found in Milliou

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<sup>1</sup>De Fraja (1993), in the context of a memoryless patent race with stochastic outcome, shows that duopolist may freely reveal (a part of) their knowledge.

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Knowledge acquired *outside* any agreement may not be subject to contractual obligations. This is the type of knowledge that would more clearly fit our model. Our model, also, does not define the superior technology as one that can benefit all the firms adopting it, a case arising, e.g., with technologies improved through some R&D effort aimed at cost reductions. In an oligopoly setting, any firm that could prevent its partners-competitors from sharing such an innovation, would try to do so. Poyago-Theotoky (1999), in a model in which two firms first choose the amount invested in cost-reducing R&D, then the fraction of the cost reduction to be shared with the competitor, shows that, unless firms are allowed to coordinate their R&D efforts, they do not disclose any share of their knowledge to the rival.<sup>2</sup>

In the literature, a superior knowledge translates in a higher efficiency (at the R&D or production stage) for any level of investment or output. We look at a different kind of "superior" knowledge. In particular, we assume that technologies can be more or less efficient, *depending upon the level of production*. A firm has superior knowledge if it knows a larger number of different techniques, allowing it to tailor the production technology to the level of output better than its rivals.

We analyze a simple game between two firms that compete *à la Cournot* in the output market. There exist two alternative technologies to produce a homogeneous good: the first leads to a positive fixed cost and to a low (for our purposes nil) variable cost; the second leads to a zero fixed cost and to a positive variable cost. Hence the first is more efficient for high levels of output and the second for low levels.<sup>3</sup> One of the two firms, firm 1, is endowed with knowledge of both techniques, while the other only knows one of the two. We shall fully develop only the case where this firm knows the technique with a positive fixed cost, while we shall only state the results for the other case. Prior to adoption, the firm with superior knowledge has a larger production set, which is indeed the union of two production sets derived each by one technology. However, once a technology has been adopted, the production set reduces to one. The game is as follows. At the first stage firm 1 decides what technology to adopt and

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<sup>2</sup>Perez-Castrillo and Sandonis (1996) also expand on the difficulties to exchange information.

<sup>3</sup>This is a special case of more general cost asymmetries, see Garella and Richelle (1999) and Flaherty (1980), where high fixed costs can be associated to low variable costs.

whether to disclose (transfer) the knowledge of the second technology to firm 2; at the second stage firm 2 decides what technology to adopt, conditional on the decision of firm 1; finally, at the third stage, they play a simultaneous Cournot game.

By disclosing the knowledge about variable cost technology, firm 1 alters the strategy space of firm 2, making it larger, indeed. However, as we shall show, this need not be harmful to firm 1.

In an extension we consider the incentives to invest in R&D by the two firms. This is done by assuming that prior to the play of the game described above, firms can undertake a costly R&D investment in order to obtain know-how about the technology.

Our results for the game without R&D, and for the case where it is the increasing returns to scale technology that is common knowledge, are the following: (i) firm 1 almost always transfers the knowledge about the variable cost technology, where "almost" means that there is a region in the parameters space such that a transfer and a no transfer choice are irrelevant alternatives. (ii) The transferred technology is adopted by firm 2 except in the region just mentioned. (iii) By adopting the received technology, firm 2 becomes more efficient, namely its production costs for the equilibrium quantity are lower than they would be with the originally owned technology. (iv) There exist equilibria where firm 1 chooses to transfer the variable cost technology and adopt the technology with fixed cost, possibly achieving a *lower* cost efficiency at the produced quantity than it would have got by using the variable cost technology. Points (iii) and (iv) imply that it is not by looking at "direct" cost advantages that one can explain the decision whether to disclose knowledge to a rival or withhold it. Indeed, in our example, these cost effects at the equilibrium output levels may go against the "raise your rival's cost" strategy. (v) Although our analysis is based on disclosure which is free of charge for the receiver, the results imply that there is room for contracts specifying a payment for the transfer of knowledge.

The results for the game without R&D, and for the case where it is the constant returns to scale technology that is common knowledge, indicate that the free transfer of know-how does not occur, except when the receiving firm would not adopt the transferred technology. If the increasing returns technology is relatively efficient, the firm with superior knowledge would keep it for itself. We do not investigate the payment at which a transfer would occur, as licensing

of technologies is not the topic of the present paper.

As for the extension about the incentives to invest in R&D, we obtain the following results. (i) A firm may invest to discover the technology with constant returns just to transfer it to the rival, without adopting it. (ii) If the technology with increasing returns is common knowledge there is a lower tendency to duplication of R&D efforts than when the other technology is commonly known. (iii) Similarly the region of parameters where no firm invests is smaller in the former than in the latter case, indicating that technologies with increasing returns may remain undiscovered more persistently. The reasons for investing to discover are different in the two cases. This implies that in the same points in the parameters space, one can observe different R&D decisions by firms as a function of the initial distribution of technologies. The model does not predict that more investment occurs to discover the increasing returns to scale technologies, where transfers do not occur and knowledge is acquired but kept private.

## 2 The Model

### 2.1 Symmetric knowledge.

Consider an industry represented by two firms labeled 1 and 2, producing a homogeneous good. Inverse market demand is linear and it is equal to

$$p = 1 - Q,$$

where  $Q = q_1 + q_2$  and  $q_i$ ,  $i \in \{1, 2\}$ , is the quantity produced by firm  $i$ . Firms compete *à la* Cournot on the product market. We assume, following Gabszewicz and Garella (1995) (G-G henceforth), that two production technologies are available. The first, denoted  $K$  is characterized by a fixed "plant installation" cost, denoted  $F$ , with  $F > 0$ , and very small variable costs; as a first approximation we set these variable costs equal to zero; the second, denoted  $V$ , is characterized by nil fixed costs but a constant positive unit cost  $c > 0$ . Clearly, technological adoption precedes quantity competition. Therefore we analyze here a multi-stage game, where first firms (sequentially) choose technologies and at then they (simultaneously) choose quantities. In particular, a firm that is endowed with knowledge of both techniques is assumed to be able to adopt first and transfer. This way, we intend to represent a situation where technology adoption creates a commitment (technologies cannot be changed after adoption). We represent

the technological choices of firm 1 and 2 respectively by the vector  $(T_1, T_2)$ , such that  $T_i \in \{V, K\}$ , for  $i = 1, 2$ . Following G-G it is straightforward to obtain the firms' optimal quantities and profits *given* their technological choices and simultaneous quantity competition. Similarly to Gabszewicz and Garella (1995) we assume that  $F < \frac{1}{9}$  and  $c < \frac{1}{2}$ . Let  $q_i^{T_1, T_2}$  denote the quantity produced at a Cournot equilibrium, given the first stage technology choices represented by the vector  $(T_1, T_2)$ . Four possible equilibrium quantity pairs can arise:

$$(q_2^{V,V}, q_1^{V,V}) = \left( \frac{1-c}{3}, \frac{1-c}{3} \right), \quad (q_1^{K,K}, q_2^{K,K}) = \left( \frac{1}{3}, \frac{1}{3} \right); \quad (1)$$

$$(q_1^{V,K}, q_2^{V,K}) = \left( \frac{1-2c}{3}, \frac{1+c}{3} \right), \quad (q_1^{K,V}, q_2^{K,V}) = \left( \frac{1+c}{3}, \frac{1-2c}{3} \right). \quad (2)$$

Profits write as

$$\pi_1^{V,V} = \pi_2^{V,V} = \frac{(1-c)^2}{9}, \quad \pi_1^{K,K} = \pi_2^{K,K} = \frac{1}{9} - F; \quad (3)$$

$$\pi_1^{V,K} = \pi_2^{K,V} = \frac{(1-2c)^2}{9}, \quad \pi_1^{K,V} = \pi_2^{V,K} = \frac{(1+c)^2}{9} - F. \quad (4)$$

In particular, as shown in G-G, the technology pair  $(K, K)$  arises if  $0 \leq F \leq \frac{4c}{9}(1-c)$ ; the asymmetric pairs  $(K, V)$  or  $(V, K)$ , arise if  $\frac{4c}{9}(1-c) \leq F \leq \frac{4c}{9}$ ; and finally, the pair  $(V, V)$  arises if  $\frac{4c}{9} \leq F \leq \frac{1}{9}$ . Obviously, for  $c > 1/4$ , the choice  $(V, V)$  cannot arise at equilibrium.

## 2.2 Asymmetric knowledge

From now on we drop Gabszewicz and Garella's (1995) assumption of symmetry between firms. In particular, we assume that the knowledge of firm 1 is broader than that of firm 2. We denote by  $\omega_i$  the list of all the technologies that are known at the outset to firm  $i$ , and by  $\Omega = \{\omega_1, \omega_2\}$  the list of technologies that are known at the outset. The first case we analyze is  $\omega_1 = (K, V)$  and  $\omega_2 = K$  so that  $\Omega = \{(K, V), K\}$ .

*A. Case of non transferable technology.* If technology were not transferable, firm 1 can still decide whether to implement the  $K$  or  $V$  production technology, while firm 2 is forced to use the  $K$  technology. Accordingly, the only possible technological configurations which can emerge at equilibrium are  $(T_1, T_2) = (V, K)$  and  $(T_1, T_2) = (K, K)$ , depending on the choice of firm 1. Obviously this

firm chooses to adopt technology  $V$  if, and only if,  $\pi_1^{V,K} > \pi_1^{K,K}$ , namely if and only if

$$F > \frac{4c}{9}(1-c). \quad (5)$$

Therefore, according to (5) a unique equilibrium exists for any parameter pair  $(V, K)$ , in the region of feasible parameter values, with either asymmetric or symmetric technology outcomes, "dictated" by firm 1.

*B. Transferable technologies.* Assume now that firm 1 has the option to transfer the  $V$  technology to firm 2. To be more formal, we modify the structure of the interaction between firms in the following way: at the first stage of the game firm 1 decides which technology to adopt and whether or not to transfer to firm 2 the  $V$  technology. Firm 1 has four possible actions:  $VT$ : adopt the  $V$  technology and transfer it,  $VH$ : adopt the  $V$  technology but do not transfer it,  $KT$ : adopt the  $K$  technology and transfer the  $V$  one and finally  $KH$ : adopt the  $K$  technology and do not transfer the  $V$  one. After firm 1's move, firm 2 chooses its technology given the set of available options. Finally firms simultaneously compete in quantities in the goods market. Firms aim at maximizing profits. The following tree represents the game.

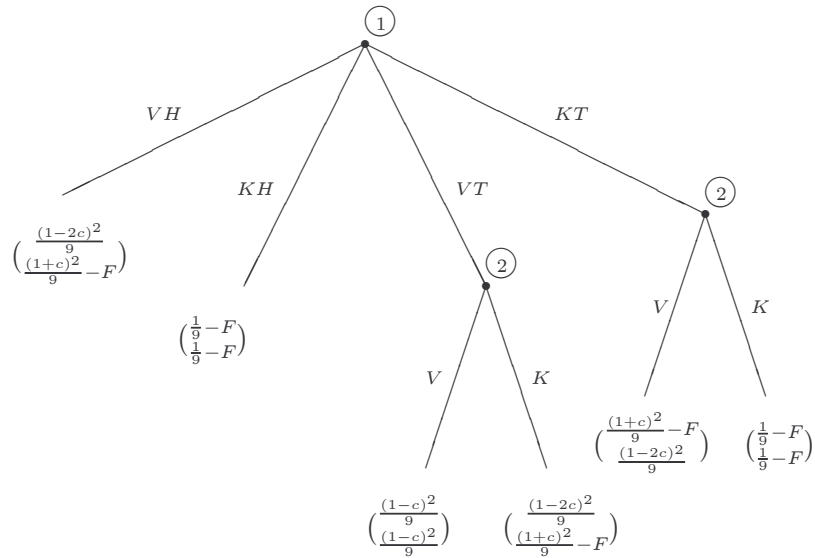


Figure 1: *The game tree.*

### 3 Equilibrium analysis

A strategy for firm 1 is a vector  $S_1 = (a_1, \mathbf{q}_1(T_1, T_2))$  where the first element is taken from the set  $A_1 = \{VT, KT, VH, KH\}$  and the second one is a vector of quantities, belonging to  $\mathfrak{R}_+^4$ , with entries corresponding to the quantity that apply to the effectively chosen technology pair. A strategy for firm 2 is a vector  $S_2 = (t_2, u_2, \mathbf{q}_2(T_1, T_2))$  where  $t_2$  represents the technological choice of firm 2 at its left node (namely when technology transfer has been done by firm 1, and firm 1 has chosen technology  $V$  for itself), while  $u_2$  represents the action at the right decision node, when firm 1 has chosen  $KT$  (see Figure 1), with  $t_2, u_2 \in T_2$ ; obviously,  $\mathbf{q}_2(T_1, T_2) \in \mathfrak{R}_+^4$  is the vector of quantities for firm 2 in the last stage, conditional on the reached node.<sup>4</sup> We look for subgame-perfect Nash equilibria of the game. The profits of firms at the last stage *given* the previous play coincide with those in (3) and (4). In order to simplify notation we will omit, from now on, the quantity produced by firms in the description of equilibria. So, for instance,  $(KT, (K, K))$  is a strategy profile with firm 1 choosing  $K$  and transferring  $V$ , firm 2 choosing  $K$  at both decision nodes and finally firms selecting the optimal quantities conditional on their previous actions. We state the following

**Proposition 1** (*SPNE*)

(i) Let  $0 < F < \frac{4}{9}(c - c^2) = F^I$ , then the game has two SPNE:

$$((KT), (K, K)) \text{ and } ((KH), (K, K)),$$

leading to the (same) technology pair  $(T_1, T_2) = (K, K)$ .

(ii) Let  $\frac{4}{9}(c - c^2) < F < \frac{4}{9}c = F^{II}$ , then the game has a unique SPNE:

$$((KT), (K, V)),$$

leading to the technology pair  $(T_1, T_2) = (K, V)$ ,

(iii) Let  $\frac{4}{9}c < F < \frac{1}{9}$ , then the game has a unique SPNE:

$$((VT), (V, V)),$$

leading to the technology pair  $(T_1, T_2) = (V, V)$ .

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<sup>4</sup>The set  $T_2$  depends on firm 1's decision concerning technology transfer, it is clearly restricted to the  $K$  technology only if firm 1 has decided not to transfer the  $V$  one, and includes both options if firm 1 transferred its knowledge to the rival.



**Proof.** See appendix. ■

The last proposition shows that firm 1 -except when the  $K$  technology is extremely cheap with respect to the  $V$  one<sup>5</sup>- always transfers the  $V$  technology to firm 2 which, in turn, along the equilibrium path adopts it. The reasons which drive firm 1 to adopt such an "altruistic" behavior are purely strategic: by expanding the set  $T_2$  firm 1 affects in his own advantage the ensuing quantity competition.

It is interesting to notice that the last proposition implies that firm 1 by transferring the  $V$  technology to firm 2 may be, in a sense, helping its rival to improve its efficiency at equilibrium. Indeed, consider the case  $F^{II} < F < 1/9$ . The total production cost borne at equilibrium by firm 2, given quantity  $q_2^{V,V}$ , is  $\frac{c-c^2}{3}$ . It is easy to check that for  $F < 1/9$ , this cost falls short of  $F$ , the cost that firm 2 would have borne for producing the same quantity  $q_2^{V,V}$  by means of the  $K$  technology. Remember that firm 2 can use the  $V$  technology thanks to the disclosure operated by firm 1 only.

At the equilibrium in case  $F^I < F < F^{II}$  the cost borne by firm 2 to produce the equilibrium quantity is  $\frac{c(1-2c)}{3}$ , which is again smaller than  $F$ , the cost in the absence of technology transfer. Interestingly, at this equilibrium firm 1's production costs could have been lower if it used the alternative  $V$  technology, as  $\frac{c+c^2}{3} < F \Leftarrow c < \frac{1}{7}$ .<sup>6</sup> Therefore it is possible that Firm 1, by transferring technology, could reduce its efficiency but increase that of the opponent. Indeed, it transfers to firm 2 the  $V$  technology, while at the same time adopting the  $K$  one, thereby inducing firm 2 to choose the transferred technology. Finally notice that, ruling out the possibility of technological transfer the only equilibrium configuration would have been  $(V, K)$ , with firm 1 choosing the cost-minimizing technology given the quantity  $q_1^{V,K}$ .

## 4 Withholding knowledge

So far we have treated the case where the distribution of know-how is such that the technology tailored for high output levels is common knowledge and the other is private information of one firm. The natural counterpart is the symmetric case, where the firm with poorer information, say firm 2, is endowed

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<sup>5</sup>Namely when  $0 < F < F^I$ .

<sup>6</sup>Sufficient conditions for obtaining the previous inequalities are that the total costs using the  $V$  technology fall short of the minimum value of  $F$  admissible in each interval.

only with technology  $V$ , namely the case  $\Omega = \{(K, V), V\}$ . We shall not perform the complete analysis here, as it goes along the same lines as for the case treated in the previous sections. One can show that if technology  $K$  leads to a low fixed cost, so that it is relatively very efficient, then there will be no disclosure (this corresponds exactly to the region  $0 < F < F^I$  identified in section 3. In all other cases, if a transfer was made, the receiving firm 2 would not adopt it at equilibrium, and therefore, the transfer would be inessential; indeed, if there was the slightest cost to implement a transfer, firm 1 would not find it worth bearing it. The reason why firm 2 does not adopt the received technology  $K$  differs in the two regions  $F^I \leq F \leq F^{II}$  and  $F^{II} \leq F < 1/9$ . In the former the reason is that firm 1 adopts technology  $K$  for itself, so that firm 2 responds with the alternative technology. In the latter, the reason is that no firm adopts technology  $K$ , as it is relatively very inefficient. As a comment, therefore, we can conclude that the technology leading to the existence of scale economies tends to be withheld within the firm that owns it privately if it is efficient, and could be given up in the other cases, but with no adoption by the receiving firm.

It is instructive to inspect the costs firms incur in as a consequence of strategic disclosure and the subsequent adoption and production choices. Following a procedure similar to the one in section 3, it can be shown that for  $0 < F < F^I$ , if  $\frac{c(1-2c)}{9} < F < F^I$ , the  $K$  technology is less efficient given the quantity  $q_2^{K,V}$  than the  $V$  one, so that firm 1 is not "increasing its rival's costs" by withholding the former. In addition, if simultaneously  $c < \frac{1}{7}$  and  $\frac{c(1+c)}{3} < F$ , firm 1 is less cost-efficient than it would be by choosing the alternative technology. Similarly, if  $F^I < F < F^{II}$ , firm 2's costs are higher producing by means of the  $K$  technology.<sup>7</sup> Also, a sufficient condition for showing that firm 1's technological choice is not cost-minimizing at the equilibrium quantity is  $c < \frac{1}{7}$ . Again, cost minimization (or the rival's costs maximization) is not the only force driving firms' behavior.

As a consequence of the incentives to withhold technology  $K$ , one would expect that resources be spent to avoid information leakages from firms that possess superior information about technologies with increasing returns to scale. For instance, managers would then try to avoid their knowledgeable employees from leaving the firm by bidding up their wages (see Gersbach and Schmutzler 2003 for an original interpretation of spillovers along these lines).

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<sup>7</sup>In this latter case *even in the convenience of disclosure* firm 1 would choose the "less efficient" technology, forcing firm 2 to select the remaining one.

## 5 Investments in R&D

Suppose that, prior to the play of the game analyzed above, and given that the technology opportunity set of firm 1 is composed of both  $K$  and  $V$ , so that  $\Omega = \{(K, V), K\}$ , and that firm 2 is enabled to invest in R&D. For instance assume that firm 2 can obtain full knowledge of both technologies by paying a fixed cost, denoted  $R$ , or can obtain knowledge of only technology  $K$ , for free. It is easy to analyze the equilibrium choices of firm 2 at the subgame perfect equilibria of the game. First, it is clear that if  $K$  is larger than  $F_I$ , firm 2 will not pay the cost  $R$ , whatever its value. Indeed, at the following equilibria of the game, firm 2 will transfer the technology for free to firm 2, whether this firm wants it or not.

Then, turn to the case where  $F < F_I$  obtains. Here, if firm 2 does not pay  $R$  it may not have access to the  $V$  technology (there are two equilibria of the game, one with and one without technology transfer). While if it pays  $R$  it has access to both technologies and will choose, in the technology game, according to profit maximization. However, from Proposition 1, part (i), we conclude that when the technology is transferred for free, for such low values of  $F$ , firm 2 always prefers the  $K$  to the  $V$  technology. A fortiori, therefore, it will not pay any positive cost in order to acquire the  $V$  technology.

As a result we can state the following

**Proposition 2** *If the technology opportunity set of firm 1 contains both  $K$  and  $V$  technologies, and if firm 2's set only contains the  $K$  technology, then this firm will not invest in R&D any positive amount, in order to acquire access to the  $V$  technology.*

Let us now assume that firms are symmetric at the start. First we analyze the case in which both only have access to the  $K$  technology, namely  $\Omega = \{K, K\}$ . Assume, again, that each firm can gain knowledge of the  $V$  technology by investing a fixed positive amount  $R$ . Denote the investment choice by  $I_1$  and  $I_2$ , with  $I_i \in \{0, R\}$ .

We develop the analysis for the three intervals defining the equilibria of the game. The easiest case naturally arises when the  $K$  technology is very efficient with respect to the  $V$  one, namely when  $0 < F < F^I$ . It is clear from the previous analysis that no firm has an incentive to invest to acquire knowledge about technology  $V$ . Indeed, if it does, neither it will use it nor it will be able to

induce its rival to adopt it. Let us consider the intermediate case  $F^I < F < F^{II}$  and start with investigating if both firms investing  $((I_1, I_2) = (R, R))$  is an equilibrium. In this case, both firms acquire full knowledge, and there are two equilibria in technology adoption:  $(K, V)$  and  $(V, K)$ . We shall assume that, prior to investment, a firm expects to be able to commit first to its preferred technology (namely  $K$ ) with probability  $1/2$ , so that its expected profits from playing  $I_i = R$  against  $I_j = R$  are equal to

$$\frac{1}{2}\pi_1^{KV} + \frac{1}{2}\pi_2^{KV} - R \quad (6)$$

Clearly,  $(I_1, I_2) = (R, R)$  are mutual best replies if (6) is greater or equal than the profit from not investing when the rival invests, namely  $\pi_2^{KV}$ . This condition writes as  $R < \frac{c(2-c)}{6} - \frac{F}{2} \equiv R^I$ .

Similarly, a necessary condition for having an equilibrium with one firm only investing is that  $\pi_1^{KV} - R \geq \pi_1^{KK}$ . Indeed if the rival does not invest, and firm 1 invests, it will play as a "leader" and use technology  $K$ . Condition  $\pi_1^{KV} - R \geq \pi_1^{KK}$  is equivalent to

$$R \leq \frac{c(c+2)}{9} \equiv R^{III}$$

It can be shown that if  $F \in [F^I, F^{II}]$  then  $R^I < R^{III}$ .

Finally, consider case  $F > F^{II}$ . Without loss of generality, let us analyze firm 1's choice given that firm 2 chooses  $I_2 = 0$ . Then, if firm 1 invests the equilibrium configuration, from Proposition 1 above, will be  $(T_1, T_2) = (V, V)$ . It is immediate to see that this is an improvement for firm 1 if and only if  $R < F - \frac{c(2-c)}{9}$ . Therefore, for  $F^{II} < F$ , there is a unique equilibrium in R&D choices, where at most one firm invests (if  $R < F - \frac{c(2-c)}{9}$ ), or where no firm invests, if  $R < F - \frac{c(2-c)}{9}$ . Thus we have completely characterized the set of Nash equilibria of the extended game, and we can summarize them in the following Proposition.

**Proposition 3** *If both firms' opportunity set consists only of the  $K$  technology and if they can extend this set to include the  $V$  technology by paying a R&D cost,  $R$*

- (i) if  $F < F^I$ , there is a unique equilibrium with no firm investing;
- (ii) if  $F^I < F < F^{II}$ , (a) both firms invest if  $R < \frac{c(2-c)}{6} - \frac{F}{2}$ , (b) only one firm invests if  $\frac{c(2-c)}{6} - \frac{F}{2} < R < \frac{c(c+2)}{9}$ , (c) no firm invests otherwise;

(iii) if  $F^{II} < F < 1/9$ , only one firm invests if  $R < F - \frac{c(2-c)}{9}$ , otherwise no firm invests

It is clear that in case (i) the technology to be discovered is too inefficient to be worth investing.

By contrast, in the "intermediate" region  $F^I < F < F^{II}$ , if  $R$  is small (case (a)) both firms invest to obtain knowledge (a dominant strategy) in the rush to become a "leader" in the ensuing game: if one firm has the acquired the  $V$  technology it will *not* adopt it, but it will disclose it and simultaneously commit to the use of technology  $K$ . This is a very interesting cause of duplication of efforts, and much different from the search of a direct cost advantage to which one is used to think. In case (b), the cost of discovery is so high as to eliminate the incentive to duplicate efforts and it is worth investing only as a best reply to the other firm not investing. Case (c) is obvious.

Finally, in case (iii) both firms, if they know it, will adopt technology  $V$ , which is relatively efficient and hence worth discovering; however the technology is transferred so as to induce the rival to a less aggressive strategy in the quantity game. This explains why there is no investment if the rival invests.

The study of the incentives to perform R&D activity by the two competitors if  $\Omega = \{V, V\}$  develops along the same lines as in the previous section but the result differ. They are summarized in the following

**Proposition 4** *If both firms' opportunity set consists only of the  $V$  technology and if they can extend this set to include the  $K$  technology by paying a R&D cost,  $R$*

(i) if  $0 < F < F^I$ , (a) both firms invest if  $R < F^I - F$ , (b) only one firm invests if  $F^I - F < R < F^{II} - F$ , (c) no firm invests if  $R > F^{II} - F$ ;

(ii) if  $F^I < F < F^{II}$ , (a) both firms invest if  $R < F^{II} - F$ , (b) if  $F^{II} - F < R < \frac{c(2-c)}{6} - \frac{F}{2}$ , two equilibria exist, one with both firms and one with no firm investing; (c) no firm invests if  $R > \frac{c(2-c)}{6} - \frac{F}{2}$ ;

(iii) if  $F^{II} < F < \frac{1}{9}$ , then there is a unique equilibrium with no firm investing.

Some comments and comparisons with the results in propositions 3 and 4 are worth. First, in case (i) the technology to be discovered is relatively highly efficient. Both firms want it and both firms want to use it without transferring

it if the other has not acquired it. This contrasts with case (iii) in Proposition 3.

In addition, in case (ii), as compared with the same case in Proposition 3, the region where investment occurs (either by both or by one firm) is smaller. Furthermore, in the case of multiple equilibria, the equilibrium with both firms investing is Pareto preferred to no firm investing iff  $F < \frac{c(2+3c)}{9}$ . In the case of multiple equilibria an easy intuition is tit-for-tat: be aggressive against your rival if and only if your rival is also aggressive.

Further comments can be made regarding the implications of the results presented in the two last propositions for welfare issues. One can show that the welfare maximizing technology configurations are a function of  $c$  and  $F$ . Simple calculations show that the interval for  $F$  where asymmetric technologies prevail in oligopoly is too narrow, on both sides, with respect to the socially optimal size.<sup>8</sup> This feeds back on the comparison between the socially optimal and the equilibrium investment choices, given  $R$ . For instance, in case (ii)-(a) of proposition 3 both firms invest—with the aim to disclose to the rival—given a low value of  $R$ , but only one firm will adopt the technology. The adopting firm, which would have received the technology know-how from the rival, has then simply wasted the amount  $R$ . We do not expand further on welfare issues in this paper, as this is out of the scope of the present analysis.

## 6 Conclusion

In this paper we have studied, by means of a multi-stage game, the incentives of a firm to disclose knowledge about a production technology to a rival. Two technologies involving different marginal and fixed costs are available; no technology is absolutely more efficient than the other, rather their efficiency ranking depends on the output level. We have analyzed in detail the case where the technology which is common knowledge is the one with increasing returns to scale, showing that the "more informed" firm "almost always" discloses the technology unknown to the rival, which in turns adopts it along the equilibrium path. The disclosure of knowledge allows the uninformed firm to decrease its production costs, given the equilibrium quantities; by converse the disclosing firm, in

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<sup>8</sup>Social welfare is measured as the sum of firms profits and consumers' surplus. An asymmetric configuration for  $(T_1, T_2)$  is socially desirable for  $F^0 < F < F^{III}$ , where  $F^0 = (4/9)c - (11/18)c^2$  and  $F^{III} = (4/9)c + (c^2/6)$ . Clearly,  $F^0 < F^I < F^{II} < F^{III}$ .

some cases, may adopt the "less appropriate" of the two technologies for the equilibrium quantity it produces.

Moreover, if the transferable technology requires a costly R&D investment to be made available, one firm can find it justifiable bearing the R&D cost just for the purpose of disclosure, without adopting it. No equilibria in which two firms invest exist.

For the case where the initial distribution of information entails the common knowledge of the technology with constant returns to scale, we have summarized that a free of charge transfer does not occur, indicating that one should expect in this case technology transfers only in licensing agreements, if at all.

The analysis herein developed may be extended in several directions. First, the assumption of complete information about the characteristics of the transferable technology can be relaxed. The uninformed firm may not enjoy complete *a priori* knowledge about the features of the technique the rival ought disclose. Symmetrically, the agent endowed with both technologies may have incomplete information about the knowledge level of the rival. Also, knowledge disclosure, through the influence it exerts on the competition in the product market, is likely to determine the degree of profitability and hence entry conditions in the industry. One may speculate that a firm may avoid disclosure of the constant returns to scale technology if it loses control of the diffusion process; for instance, entry of new competitors at a low scale of production could become possible, and firms with positive fixed costs may be forced to exit the industry.

## References

- [1] d'Aspremont, Claude, Sudipto Bhattacharya and Louis-André Gérard-Varet (1998). Knowledge as a Public Good: Efficient Sharing and Incentives for Development Effort; *Journal of Mathematical Economics*, 30, 389-404.
- [2] d'Aspremont, Claude, Sudipto Bhattacharya and Louis-André Gérard-Varet (2000). Bargaining and Sharing Innovative Knowledge; *Review of Economic Studies*, 67, 255-271.
- [3] Bhattacharya, Sudipto, Jacob Glazer and David E. M. Sappington (1990). Sharing Productive Knowledge in Internally Financed R&D Contests; *Journal of Industrial Economics*, 39(2), 187-208.

- [4] Bhattacharya, Sudipto, Jacob Glazer and David E. M. Sappington (1992). Licensing and the Sharing of Knowledge in Research Joint Ventures; *Journal of Economic Theory*, 56(1), 43-69.
- [5] Brocas, Isabelle (2004). Optimal Regulation of Cooperative R&D Under Incomplete Information, *Journal of Industrial Economics*, 52(1), 81-119.
- [6] De Fraja, Giovanni (1993). Strategic Spillovers in Patent races, *International Journal of Industrial Organization*, 11, 139-146.
- [7] Denicoló, Vincenzo, and Luigi Alberto Franzoni (2004). Patents, Secrets and the First-Inventor Defense; *Journal of Economics and Management Strategy*, 13 (3), 517-538.
- [8] Flaherty, M. Therèse (1980), Industry Structure and Cost-Reducing Investment, *Econometrica*, 48, 1187-209.
- [9] Gabszewicz, Jean and Paolo G. Garella (1995). Buy it or make it yourself: a paradox; *CORE Discussion Paper* 9514.
- [10] Garella, Paolo G. and Yves Richelle (1999), Exit, Sunk Costs, and the Selection of Firms, *Economic Theory*, 13, 643-70.
- [11] Gersbach, Hans and Armin Schmutzler (2003), Endogenous Spillovers and Incentives to Innovate, *Economic Theory*, 21, 59-79.
- [12] Katsoulakos, Yannis and David Ulph (1998), Endogenous Spillovers and the Performance of research Joint ventures, *Journal of Industrial Economics*, 46, 333-357.
- [13] Milliou, Chrysovalantou (2006), Endogenous Protection of R&D Investments, mimeo, Department of Economics, Universidad Carlos III, Madrid.
- [14] Perez-Castrillo, David and Joel Sandonis (1996), Disclosure of Know-How in Research Joint ventures, *International Journal of Industrial Organization*, 15, 51-75.
- [15] Poyago-Theotoky, Joanna (1999). A note on Endogenous Spillovers in a Non-Tournament R&D Duopoly; *Review of Industrial Organization*, 15, 253-262.



## APPENDIX

### *Proof of Proposition 1*

In the description of equilibria we abstract from the quantities chosen by firms in the last stage.

(i) Let  $0 < F < \frac{4}{9}(c - c^2)$ . Then the following inequalities hold:

$$\begin{aligned}\pi_1^{V,V} &< \pi_1^{K,V} \quad \text{and} \quad \pi_2^{V,V} < \pi_2^{V,K} \\ \pi_1^{V,K} &< \pi_1^{K,K} \quad \text{and} \quad \pi_2^{K,V} < \pi_2^{K,K}\end{aligned}$$

Hence player 2 chooses the action  $K$  at both its decision nodes. Consequently player 1 is indifferent between its  $KH$  and  $KT$  actions.

(ii) Let  $\frac{4}{9}(c - c^2) < F < \frac{4}{9}c$ . Then the following inequalities hold:

$$\begin{aligned}\pi_1^{V,V} &< \pi_1^{K,V} \quad \text{and} \quad \pi_2^{V,V} < \pi_2^{V,K} \\ \pi_1^{V,K} &> \pi_1^{K,K} \quad \text{and} \quad \pi_2^{K,V} > \pi_2^{K,K}\end{aligned}$$

Player 2 chooses action  $K$  at its left-hand decision node and action  $V$  at the right-hand one (see Figure 1). Consequently player 1 chooses action  $KT$ .

(iii) Let  $\frac{4}{9}c < F < \frac{1}{9}$ . Then the following inequalities hold:

$$\begin{aligned}\pi_1^{V,V} &> \pi_1^{K,V} \quad \text{and} \quad \pi_2^{V,V} > \pi_2^{V,K} \\ \pi_1^{V,K} &> \pi_1^{K,K} \quad \text{and} \quad \pi_2^{K,V} > \pi_2^{K,K}\end{aligned}$$

Hence player 2 selects the  $V$  action at both its decision nodes. consequently player 1 takes action  $VT$ .