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# Licensing interim R&D knowledge*

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*Abstract:* This paper examines licensing of interim R&D knowledge among firms engaged in a winner-takes-all R&D contest to come up with particular commercially profitable innovation. Interim knowledge represents basic research knowledge which the firms already posses and it enhances the chances of the licensees to win the contest. The paper shows that there is a wide range of parameters for which the leading firm in the contest will prefer to either license or sell its knowledge to one of its rivals or to both. Although licensing erodes its technological lead, it also allows the leading firm to play the rival firms against one another by charging them fees that reflect not only the value for getting a license but also the value of preventing the other firm from getting an exclusive license.

*Keywords:* Interim R&D knowledge, licensing

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## Introduction

This paper examines licensing agreements between firms that compete against one another in the product market. The paper departs from most of the literature on licensing in that it examines licensing of interim R&D knowledge rather than of licensing of well-developed technologies. The difference is that interim knowledge represents basic research knowledge which enhances the chances of the firms who posses it to ultimately come up with commercially profitable innovation. That is, while licensing of well-developed technologies affects competition in the product market directly, licensing of interim R&D knowledge affects competition indirectly through its effect on the licensees' chances to develop a commercially useful technology.

Specifically, the model considers a winner-takes-all R&D contest between three firms for the development of a specific new technology (e.g., a new drug, a superior production technique). The outcome of the contest is binary in the sense that each firm either succeeds to develop the technology in a given time span or it does not. After the contest begins, but before it is decided, the knowledge of the three firms can be Blackwell ranked in the sense that the knowledge of the leading firm includes all of the knowledge of the second firm, which in turn includes all of the last firm's knowledge. The question then is whether, at some interim stage before the contest is decided, the firm that is leading the contest and has the best chance of successfully develop the new technology would prefer to hold on to its technological lead or whether it would prefer to license its interim knowledge or even sell it to one of the two lagging firms or to both. The main difference between licensing and selling is that under licensing, the leading firm stays in the contest, whereas under selling it exits the contest after transferring its knowledge to the acquirer.

From the leading firm's perspective, the advantage of licensing or selling knowledge is that it allows it to extract surplus from its rivals and in particular, play the rivals "against one another" by threatening them that if they will not obtain its knowledge, it will transfer it exclusively to the other firm.

In this case, the refusing firm is left behind in the contest and its chances to be the sole winner of the contest are lowered. The cost of transfering knowledge is that it lowers the probability that the leading firm will be the sole winner of the contest. The paper shows that for a wide set of parameters, the benefit of licensing/selling knowledge exceeds the associated costs. In fact, if the leading firm can choose between licensing and selling, the benefit will always exceed the cost. Consequently, the leading firm will license its knowledge to both rivals when this knowledge does not ensure a high probability of success, license it exclusively to the second firm in the contest (the "strong" rival) if its knowledge ensures an intermediate probability of success, and will sell it to the strong rival and exit the contest if the knowledge ensures a high probability of success. Only when the leading firm is restricted to either license its knowledge or sell it (but cannot choose between these alternatives) will it find it profitable, under some conditions, to hold on to its technological lead and not deal with its rivals. In the case of licensing, this occurs when the knowledge of the leading firm implies a high probability of success. Then, when the knowledge is licensed, it is highly likely that at least two firms will successfully develop the new technology and will therefore get a zero payoff each. This implies that paradoxically, a license is not worth much when it the licensor has a lot of knowledge to transfer. By contrast, selling knowledge is particularly valuable in this case since the leading firm exits the contest following the sale, and hence the acquirer is left with a high probability of being the sole winner of the contest.

Interestingly, the leading firm will never wish to deal exclusively with the last firm in the contest (the weak rival). In other words, it will either license or sell to both firms or exclusively to the strong rival who poses a greater competitive threat from the leading firm’s perspective. The reason for this is that transfering knowledge to the weak rival compromises the leading firm’s chances to be the sole winner of the contest to a larger extent as it converts a weak rival into an equal strength rival. Moreover, since the weak rival faces a higher threat from the strong rival than vice versa, his willlingness to pay for knowledge is typically lower than that of the strong rival.

There is a sizeable literature that deals with how a patentee who is outside the industry should license his knowledge to firms that are active in the market (see Kamien, 1992, for a survey of this literature).[1] This paper differs from that literature in that the licensor is an active firm that can compete in the market with its licensees. Licensing to rivals or potential rivals has also been studied by Gallini (1984) and Rockett (1990). Gallini shows that a firm might license its superior knowledge to a potential rival in order to lower its incentive to try and invent a yet better product. Unlike in my paper, in her model there is only one potential rival. Like my paper, Rockett (1990) also considers an industry with three firms. The motivation for licensing in her model is to invite a weaker competitor to establish itself in the market and thereby ensure that the stronger competitor will be crowded out of the market. Although in my paper the leading firm also affects the composition of firms in the industry, this is done only probablistically since the leading firm can only decide which of its rivals will get access to its superior knowledge and will therefore have a higher chance to succeed in developing the new technology. Moreover, the main motivation for licesning is not to select the rivals but rather to extract as much surplus from them. Thus, unlike in Rockett, the leading firm would license or sell its knowledge either exclusively to the strong rival or to both rivals but would never deal exclusively with the weak rival which is the case that Rockett focuses on.

The structure of my model is similar to that in Bhattacharya, Glazer, and Sappington (1992) and d'Aspremont, Bhattacharya, and Gerard-Varet (2000). As in the current paper, these papers also consider winner-takes-all R&D contests in which firms can license their interim R&D knowledge to rivals and this knowledge boosts the licensees' chances to win the contest. Bhattacharya, Glazer, and Sappington (1992),

[1] Recent closely related paper in this spirit are Anton and Yao (1994, 2002a, 2002b). In the first two papers they ask how an independent inventor who is outside the industry can sell his ideas to one of two active firms in the industry when the quality of his idea is private information and the idea is not protected by property right and therefore can be easily immitated once it is revealed. They show that the inventor can capture a sizeable share of the value of the invention by revealing his idea to one of the firms and threatening it that he will reveal the idea to the rival firm if it will not pay him a suffociently large sum for his idea. In Anton and Yao (2002b) they....

however, are interested in the optimal design of research joint ventures. Therefore, their model has an early stage before the R&D contest begins in which firms can commit to the rules by which they will license their interim knowledge to one another. d'Aspremont, Bhattacharya, and Gerard-Varet (2000) are interested in bargaining between two rival firms for the transfer of interim knowledge under asymmetric information. Their paper characterizes the class of incentive compatible and individually rational direct bargaining mechanisms that implement the efficient outcome and shows that this class is surprisingly large.

The rest of the paper is organized as follows. Section 2 presents the model. In Section 3, I characterize the equilibrium when the leading firm can either license its knowledge to one of its rivals in the contest, license it to both rivals, or simply holds on to its technological lead and does not license its knowledge. In addition, I consider three extensions of the basic model. In the first extension, I show that the second firm in the contest may wish to license its knowledge to the last firm even before both of them are approached by the leading firm. This licensing agreement can favorably affect the fees that will eventually pay for licensing the leading firm's knowledge. The second extension considers the possibility of partial transfers of knowledge. Here I show that the leading firm will not necessarily wish to license the full extent of its knowledge if its chance to win the contest is relatively large. The third extension shows that a ban on exclusive licenses may promote dissemination of R&D knowledge if the leading firm's chance to win is not too large, but otherwise it may backfire as the leading firm will prefer to not issue any licenses rather than license its knowledge to both of its rivals. In Section 4, I consider the case where the leading firm can only sell rather than license its knowledge. Again, I fully characterize the resulting equilibrium. Section 5 fully characterizes the equilibrium when the leading firm can choose between licensing and selling. Section 6....

## The model

Consider an R&D contest between three firms for developing a particular commercially profitable technology (e.g., a new drug, a superior production technique). The R&D contest evolves in three stages. In the first stage (which is not modelled), the three firms (independently) conduct basic research which enables them to accumulate knowledge. This stage ends with firm 1 being ahead in the sense that its probability to successfully develop the new technology in a given time span is higher than that of firms 2 and 3. In the second stage, firm 1 can license its superior knowledge either to firm 2 or to firm 3 or to both. I shall therefore refer to the second stage as the licensing stage. In the third stage, all firms continue with their R&D and in the end of this stage, each firm either successfully develops the new technology or else it fails and develops nothing. Finally, firms that successfully developed the new technology use it in the product market.

Assume that the knowledge that firms accumulated by the end of the first stage of the game can be summarized by a vector $(\lambda_1, \lambda_2, \lambda_3)$, where $\lambda_i$ represents the probability that firm i will succeed to develop the new technology. The vector $(\lambda_1, \lambda_2, \lambda_3)$ is common knowledge. Assume without a loss of generality that $\lambda_1 > \lambda_2 \geq \lambda_3$, so that firm 1 is the current leader in the contest with firm 2 being second and firm 3 being last. Moreover, assume that the knowledge levels of the three firms can be Blackwell ordered. That is, firm 1's knowledge includes all firm 2's knowledge which in turn includes all of firm 3's knowledge. Given this knowledge structure and assuming that knowledge can be fully transferred, firm 1 may wish to license its knowledge either to firm 2 or to firm 3 or to both (for the moment I assume away the possibility that firm 2 will license its knowledge to firm 3, but I return to this possibility in Section 3 below). If firm 1 licenses its knowledge, the probability that the licensee will successfully develop the new technology at the end of the third stage increases to $\lambda_1$. Firm 1's decision on whether or not to license its knowledge to firm j (j = 2,3) is denoted by $x_j = \{y, n\}$, where y means that firm 1 licenses its knowledge to firm j and n means that it does not. An outcome of the licensing stage is therefore given by a pair ($x_2$, $x_3$).

For simplicity, assume that developing the new technology allows the developing firm to produce a homogenous product at a constant marginal cost. Moreover, assume that the firms compete in the product market by setting prices (i.e., there is Bertrand competition in the product market). Consequently, if more than one firm successfully develops the new technology, competition in the product market drives the profit of each firm to 0. If only one firm is successful, then this firm monopolizes the product market and earns monopoly profits that I will normalize to 1. That it, the R&D contest is a stochastic "winner-takes-all" contest.

In the absence of a licensing agreement, the expected payoff of firm i is given by:

$$\pi_i(n,n) = \lambda_i(1-\lambda_j)(1-\lambda_k), \qquad i \neq j,k, \tag{1}$$

where (n,n) indicates that firm 1 did not license its knowledge to neither of its rivals. Equation (1) shows that firm i earns monopoly profits in the product market only if it succeeds to develop the new technology while both of its rivals fail.

## 3. Exclusive and nonexclusive licenses

In the second stage of the game, firm 1 needs to decide whether or not to license its superior knowledge to its rivals. If firm 1 decides to license its knowledge, it can either issue an exclusive license to only one of its rivals or it can issue nonexclusive licenses to both rivals.[2] In both cases, a firm that obtains a license fully obtains firm 1's knowledge and hence its probability to successfully develop the new technology jumps to $\lambda_1$.

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[2] If firm 1 issues an exclusive license to say firm 2 then it commits not to transfer the technology to firm 3 as well. Likewise, firm 2 on its part also commits not to transfer the licensed technology to firm 3. I assume that both commitments (by firm 1 and by firm 2) are binding.

In order to find out whether firm 1 will issue licenses and whether these licenses will be exclusive or nonexclusive, suppose that at the beginning of the licensing stage, firm 1 can make a pair of take-it-or-leave-it offers to firms 2 and 3 at fees $T_2$ and $T_3$, respectively. If both firms reject their respective offers then none of them gets a license and no payments are made. If only one firm accepts firm 1's offer then this firm obtains an exclusive license and pays the associated fee to firm 1. The rejecting firm pays nothing and does not get access to firm 1's knowledge. If both firms accept then there is a tie breaking rule that specifies whether firm 2 gets an exclusive license or whether firm 3 gets an exclusive license, or whether both firms get licenses. The precise type of the tie breaking rule is chosen by firm 1 along with the fees $T_2$ and $T_3$ and will be specified in Lemma 1 below.

If firm 1 licenses its knowledge exclusively to firm 2 for a license fee $T_2$, the expected payoffs of the three firms are given by:

$$\pi_1(y,n) = \lambda_1(1-\lambda_1)(1-\lambda_3) + T_2, \tag{2}$$

$$\pi_2(y,n) = \lambda_1(1-\lambda_1)(1-\lambda_3) - T_2, \tag{3}$$

and

$$\pi_3(y,n) = \lambda_3(1-\lambda_1)^2. \tag{4}$$

The three equations are similar to equation (1) except that now, firm 2's probability of success is $\lambda_1$ instead of $\lambda_2$. The expected payoffs of the three firms are completely analogous when firm 1 licenses its knowledge exclusively to firm 3 at a fee $T_3$ instead of licensing it to firm 2.

If firm 1 issues nonexclusive licenses to both firms 2 and 3 then the expected payoffs of the three firms become:

$$\pi_1(y,y) = \lambda_1(1-\lambda_1)^2 + T_2 + T_3, \tag{5}$$

and

$$\pi_j(y,y) = \lambda_1(1-\lambda_1)^2 - T_j, \qquad j = 2,3. \tag{6}$$

The main difference between these expressions and those that were derived above for the exclusive licenses case is that now, all firms have the same probability, $\lambda_1$, of developing the new technology.

**Lemma 1:** *Suppose that firm 1 wishes to issue an exclusive license to firm j, j = 2,3. Then, the optimal scheme from its perspective is to set*

$$T_2 = T_2(y,n) \equiv (1-\lambda_1)\left(\lambda_1(1-\lambda_3) - \lambda_2(1-\lambda_1)\right),$$

*and*

$$T_3 = T_2(n,y) \equiv (1-\lambda_1)\left(\lambda_1(1-\lambda_2) - \lambda_3(1-\lambda_1)\right),$$

*and set a tie breaking rule that specifies that only firm j gets a license if both firms accept their respective offers. If firm 1 wishes to issue nonexclusive licenses to both firms 2 and 3, then the optimal scheme from its perspective is to set*

$$T_j = T_j(y,y) \equiv (\lambda_1 - \lambda_j)(1-\lambda_1)^2, \qquad j = 2,3,$$

*and set a tie breaking rule that specifies that both firms get licenses if both accept their respective offers.*

**Proof:** First, consider the case where firm 1 is interested in issuing an exclusive license to firm i. Given the tie breaking rule specified in the lemma, this can be achieved by inducing both firms to accept their respective offers. Assuming that firm 3 accepts, $T_2(y,n)$ leaves firm 2 indifferent between accepting and rejecting.[3] To see why, note that if the tie breaking rule specifies that, when both firms accept their respective offers, firm 2 obtains an exclusive license, then by accepting, firm 2 ensures itself an expected

[3] Of course, to ensure that firm 2 has a strict preference to accept its offer, $T_2$ could always be lowered slightly. Since this point is trivial, I will not mention it in the sequel.

payoff of $\pi_2(n,y)$ which is what it would get by rejecting the offer (in which case an exclusive license is issued to firm 3). Hence, firm 2 is indifferent between accepting and rejecting. If the tie breaking rule specifies that, when both firms accept their respective offers, firm 3 obtains an exclusive license, then the license is issued to firm 3 even if firm 2 accepts the offer (recall that I assume that firm 3 accepts its offer). Hence, once again firm 2 is indifferent between accepting and rejecting. Similar arguments apply for firm 3. Hence (accept, accept) is a Nash equilibrium in the subgame that begins after firm 1 made the pair of take-it-or-leave-it offers.

Next, consider the case in which firm 1 is interested in issuing nonexclusive licenses to both firms 2 and 3. Then, $T_2(y,y)$ is set by equating $\pi_2(y,y)$ and $\pi_2(n,y)$ and $T_3(y,y)$ is set by equating $\pi_3(y,y)$ and $\pi_3(y,n)$. It is easy to see that these offers induce both firms to accept their respective offers. Hence, it is clear that the tie breaking rule in this case should specify that in case both firms accept their respective offers, both obtain a license.

Finally, it is clear that the fees stated in the lemma are the highest fees that firms 2 and 3 will agree to pay for licenses since they represent for each firm the difference between its expected payoff when it gets a license (the "best" the firm can hope for) and its expected payoff when only the other firm gets a license (the "worst" situation from the firms perspective). ■

Lemma 1 shows that whenever firm 1 wants to issue licenses, it can do so by making take-it-or-leave-it offers to firms 2 and 3 that both firms accept. The tie-breaking rule then specifies whether both firms or only one of them will get a license. The fees $T_2$ and $T_3$ are designed such that if a firm gets a license, then the fee that it pays not only extracts its entire surplus from getting firm 1's knowledge but also the surplus from preventing the rival firm from getting an exclusive access to this knowledge. In a sense then, firm 1 plays firms 2 and 3 against one another and "threatens" them that if they will reject their respective offers, the rival firm will receive an exclusive license. This situation is of course the worst case scenario for each firm since then it is left behind in the R&D contest and its chances to win the contest are diminished. Hence, $T_2$ and $T_3$ can be viewed as reflecting a payment for firm 1's knowledge as well as for preventing the rival firm from being the exclusive licensee of this knowledge.

Interestingly, $T_2 > T_3$ (firm 2 pays a higher fee for an exclusive license) when $\lambda_1 < 1/2$ and $T_2 < T_3$ (firm 3 pays a higher fee for an exclusive license) when $\lambda_1 > 1/2$. This is true irrespective of precise values of $\lambda_2$ or $\lambda_3$ (although recall that by assumption, $\lambda_1 > \lambda_2 \geq \lambda_3$). This reflects the fact that licensing firm 1's knowledge is more valuable to firm 2 since $\lambda_3 \leq \lambda_2$ means that the expected payoff of firm 2 from being an exclusive licensee exceeds the corresponding increase in the expected payoff of firm 3. But on the other hand, firm 2's expected payoff if a license is issued exclusively to firm 3 is higher than the expected payoff of firm 3 in the reverse situation. It turns out that the first effect dominates when $\lambda_1 < 1/2$ whereas the second effect dominates when $\lambda_1 > 1/2$.

When firm 1 issues licenses it has to trade off the fees that it receives against the erosion in its chances to ultimately be the sole developer of the new technology. The next proposition studies this tradeoff and fully characterizes firm 1's decision regarding whether to issue licenses at all, and if yes, which type of licenses to issue and to whom.

**Proposition 1**: *In the equilibrium of the licensing stage, firm 1 will*

*(i)* *issue nonexclusive licenses to both firms 2 and 3 if* $\lambda_1 < 1/3$,

*(ii)* *issue an exclusive license to firm 2 if* $1/3 \leq \lambda_1 < \lambda_1^*$, *where* $\lambda_1^*$ *is defined implicitly by*

$$\boldsymbol{B}(\lambda_1, \lambda_2, \lambda_3) \equiv \lambda_1(1-\lambda_3)(1-2\lambda_1+\lambda_2) - \lambda_2(1-\lambda_1)^2 = 0,$$

*and is such that* $1/2 < \lambda_1^* < 1$,

*(iii)* *not issue any licenses if* $\lambda_1 \geq \lambda_1^*$.

**Proof:** If firm 1 issues an exclusive license to firm 2 at $T_2(y,n)$, then its expected payoff is

$$\pi_1^*(y,n) = \lambda_1(1-\lambda_1)(1-\lambda_3) + \left[\lambda_1(1-\lambda_1)(1-\lambda_3) - \lambda_2(1-\lambda_1)^2\right]$$
$$= (1-\lambda_1)\big(2\lambda_1(1-\lambda_3) - \lambda_2(1-\lambda_1)\big). \tag{7}$$

If firm 1 issues an exclusive license to firm 3 at $T_3$(n,y), then its expected payoff is

$$\pi_1^*(n,y) = \lambda_1(1-\lambda_2)(1-\lambda_1) + \left[\lambda_1(1-\lambda_1)(1-\lambda_2) - \lambda_3(1-\lambda_1)^2\right]$$
$$= (1-\lambda_1)\big(2\lambda_1(1-\lambda_2) - \lambda_3(1-\lambda_1)\big). \tag{8}$$

If firm 1 issues nonexclusive licenses at $T_2$(y,y) and $T_3$(y,y), then its expected payoff is

$$\pi_1^*(y,y) = \lambda_1(1-\lambda_1)^2 + \left[\lambda_1(1-\lambda_1)^2 - \lambda_2(1-\lambda_1)^2\right] + \left[\lambda_1(1-\lambda_1)^2 - \lambda_3(1-\lambda_1)^2\right]$$
$$= (1-\lambda_1)^2(3\lambda_1 - \lambda_2 - \lambda_3). \tag{9}$$

Finally, if firm 1 does not issue any licenses, its expected payoff is

$$\pi_1(n,n) = \lambda_1(1-\lambda_2)(1-\lambda_3). \tag{10}$$

Comparing equations (7)-(9) reveals that since $\lambda_1 > \lambda_2 \geq \lambda_3$, then $\pi_1$*(y,y) > Max{$\pi_1$*(y,n), $\pi_1$*(n,y)} for all $\lambda_1 < 1/3$, and $\pi_1$*(y,n) > Max{$\pi_1$*(y,y), $\pi_1$*(n,y)} for all $1/3 < \lambda_1 < 1$ (when $\lambda_1 = 1$, $\pi_1$*(y,y) = $\pi_1$*(y,n) = $\pi_1$*(n,y)). That is, if firm 1 wishes to issue licenses at all, it will issue nonexclusive licenses to both firms 2 and 3 if $\lambda_1 < 1/3$ and will issue an exclusive license to firm 2 if $1/3 < \lambda_1 < 1$.

To examine whether firm 1 will issue licenses at all, suppose that $\lambda_1 < 1/3$. Then, if firm 1 issues licenses at all, it issues nonexclusive licenses to both firms 2 and 3. Using equations (9) and (10) yields,

$$\pi_1^*(y,y) - \pi_1(n,n) = (1-\lambda_1)^2(3\lambda_1 - \lambda_2 - \lambda_3) - \lambda_1(1-\lambda_2)(1-\lambda_3)$$
$$= (2\lambda_1 - \lambda_2 - \lambda_3)(1 - 3\lambda_1 + \lambda_1^2) + \lambda_1(\lambda_1^2 - \lambda_2\lambda_3) > 0, \tag{11}$$

where the inequality follows because $1/3 > \lambda_1 > \lambda_2 \geq \lambda_3$. Hence, whenever $\lambda_1 < 1/3$, firm 1 is better off issuing nonexclusive licenses than not issuing any licenses.

Next, suppose that $\lambda_1 \geq 1/3$. Then, if firm 1 issues licenses at all, it issues an exclusive license to firms 2. Using equations (7) and (10), yields

$$\boldsymbol{B}(\lambda_1, \lambda_2, \lambda_3) \equiv \pi_1^*(y,n) - \pi_1(n,n) = \lambda_1(1-\lambda_3)(1-2\lambda_1+\lambda_2) - \lambda_2(1-\lambda_1)^2. \tag{12}$$

This expression is concave in $\lambda_1$. Evaluated at $\lambda_1 = 1/3$,

$$\boldsymbol{B}\left(\frac{1}{3}, \lambda_2, \lambda_3\right) = \frac{(1-\lambda_2)(1-\lambda_3) - 4\lambda_2\lambda_3}{9} > 0, \tag{13}$$

where the inequality follows because, given that $1/3 = \lambda_1 > \lambda_2 \geq \lambda_3$, the first term in the numerator is bounded from below by 4/9, whereas the second term is bounded from above by 4/9. On the other hand, evaluated at $\lambda_1 = 1$,

$$\boldsymbol{B}(1, \lambda_2, \lambda_3) = -(1-\lambda_3)(1-\lambda_2) < 0. \tag{14}$$

Since $B(\lambda_1,\lambda_2,\lambda_3)$ is concave in $\lambda_1$, $B(1/3,\lambda_2,\lambda_3) > 0$ and $\lambda_1$, $B(1,\lambda_2,\lambda_3) < 0$, it follows that there exists a unique value of $\lambda_1$, denoted $\lambda_1$*, such that $B(\lambda_1,\lambda_2,\lambda_3) > 0$ for all $1/3 < \lambda_1 < \lambda_1^*$ and $B(\lambda_1,\lambda_2,\lambda_3) < 0$ for all $\lambda_1^* < \lambda_1 < 1$. The value of $\lambda_1$* is implicitly defined by $B(\lambda_1,\lambda_2,\lambda_3) = 0$. Finally, to note that $\lambda_1^* > 1/2$, note that at $\lambda_1 = 1/2$, $B(1/2,\lambda_2,\lambda_3) > 0$. ■

Proposition 1 shows that when $\lambda_1$ is close to 1, firm 1 is better off holding on to its technological lead and not issuing any licenses. To see why, note from Lemma 1 that as $\lambda_1$ approaches 1, the fees that firm 1 can get by licensing its knowledge approach 0. The reason for this is that whenever $\lambda_1$ is close to 1, it is highly likely that after firm 1's knowledge has been licensed, more than one firm will ultimately develop the new technology, in which case the resulting product market competition will drive profits to 0. Therefore, in this case, firm 1 stands to gain very little from licensing its knowledge. Since firm 1 stands to lose significantly from giving up its technological lead when $\lambda_1$ is large, it is clear that it is better off not issuing any licenses.

By contrast, when $\lambda_1$ is above 1/3 but not too close to 1 (i.e., below $\lambda_1$*), firm 1 prefers to issue an exclusive license to its closest rival, firm 2. Although Lemma 1 shows that firm 3 is willing to pay more than firm 2 for an exclusive license when $\lambda_1 < 1/2$, licensing knowledge exclusively to firm 2 also implies a smaller erosion of firm 1's technological lead as firm 1's chances to be the sole winner of the contest is then $\lambda_1(1-\lambda_1)(1-\lambda_3)$ instead of $\lambda_1(1-\lambda_1)(1-\lambda_2)$.

When $\lambda_1 < 1/3$, firm 1 is better off licensing its knowledge to both firms 2 and 3. This is because in this case, firm 1's chance to develop the new technology is relatively small; hence, licensing its knowledge is associated with only a relatively small loss of technological lead. The fees that firm 2 and 3 are willing to pay in this case to ensure that they are not left behind in the contest are sufficiently large to more than make up for this loss.

Finally, note that Proposition 1 implies that firm 1 never wishes to issue an exclusive license to firm 3 which is lagging behind the firms 1 and 2 in the contest. Such an option is dominated by issuing nonexclusive licenses to firms 2 and 3 when $\lambda_1 < 1/3$ and by issuing an exclusive license to firm 2 when $\lambda_1 > 1/3$.

□ **Partial transfer of knowledge:** Thus far I assumed that when firm 1 licenses its knowledge to firms 2 and 3, it transfers it fully. The question is what happens when firm 1 can transfer only parts of its superior knowledge: will it have an incentive to transfer limited amounts of knowledge or transfer as much knowledge as possible?

To examine this question, suppose that firm 1 can transfer a limited amount of its superior knowledge to firms 2 and 3 and let $\Delta_2 \leq \lambda_1-\lambda_2$ be the amount of knowledge transferred to firm 2 and $\Delta_3 \leq \lambda_1-\lambda_3$ the amount of knowledge transferred to firm 3. Moreover, suppose as before that firm 1 can threaten firms 2 and 3 that if they do not accept their respective offers, it will transfer its entire knowledge to their rival. Then, firm 1's expected payoffs when it issues an exclusive license to firm 2 is given by

$$\pi_1^{**}(y,n) = \lambda_1(1-\lambda_2-\Delta_2)(1-\lambda_3) + \left[(\lambda_2+\Delta_2)(1-\lambda_1)(1-\lambda_3) - \lambda_2(1-\lambda_1)^2\right], \qquad (15)$$

and its expected payoff when it issues nonexclusive licenses to both firms 2 and 3 is

$$\begin{aligned}\pi_1^{**}(y,y) &= \lambda_1(1-\lambda_2-\Delta_2)(1-\lambda_3-\Delta_3) \\ &+ \left[(\lambda_2+\Delta_2)(1-\lambda_1)(1-\lambda_3-\Delta_3) - \lambda_2(1-\lambda_1)^2\right] \\ &+ \left[(\lambda_3+\Delta_3)(1-\lambda_1)(1-\lambda_2-\Delta_2) - \lambda_3(1-\lambda_1)^2\right].\end{aligned} \qquad (16)$$

These two equations lead to the following result:

**Proposition 2**: *Suppose that firm 1 can transfer partial amounts of knowledge if it chooses to do so.*

*(i)* *If 1/3 ≤ $\lambda_1 < \lambda_1$*, firm 1 will have an incentive to transfer its entire knowledge to firm 2 if $\lambda_1$ < 1/2 and transfer as little amount of knowledge as possible otherwise.*

*(ii)* *If $\lambda_1$ < 1/3, firm 1 will have an incentive to transfer its entire knowledge to firms 2 and 3.*

**Proof:** From equation (15) it is easy to see that $\pi_1^{**}$(y,n) increases with $\Delta_2$ if $\lambda_1 < 1/2$ and decreases with $\Delta_2$ when $\lambda_1 > 1/2$. To see how $\Delta_2$ and $\Delta_3$ affect equation (16), let's differentiate it with respect to $\Delta_2$ (the analysis is similar in the case of $\Delta_3$). Then

$$\begin{aligned}\frac{\partial \pi_1^{**}(y,y)}{\partial \Delta_2} &= -\lambda_1(1-\lambda_3-\Delta_3) + (1-\lambda_1)(1-\lambda_3-\Delta_3) + (1-\lambda_1)(\lambda_3+\Delta_3) \\ &= 1 - \lambda_1(2-\lambda_3-\Delta_3).\end{aligned} \qquad (17)$$

This expression is decreasing with $\lambda_1$. Since the case where firm 1 issues nonexclusive licenses to both firms 2 and 3 arises when $\lambda_1 < 1/3$, this expression attains its lowest value at $\lambda_1 = 1/3$. However evaluated at $\lambda_1 = 1/3$, the derivative is positive. Hence, $\pi_1^{**}$(y,y) increases with $\Delta_2$ and $\Delta_3$. ■

To understand the logic behind Proposition 2, note that when firm 1 issues an exclusive license to firm 2, a slight increase in the amount of knowledge that it transfers to firm 2 will affect firm 1's expected payoff by $-\lambda_1(1-\lambda_3) + (1-\lambda_1)(1-\lambda_3)$. The first, negative, term reflects the decrease in the probability that firm 1 will be the sole developer of the new technology. The second, positive, term reflects the increase in the fee that firm 2 pays for a license when it receives more knowledge from firm 1. The second effect outweighs the first effect if $\lambda_1 < 1/2$, in which case firm 1 will license as much knowledge as possible to firm 2. Otherwise, firm 1 will prefer to transfer to firm 2 as little knowledge as possible. In the latter case, the agreement is still valuable from firm 1's point of view because it allows it to extract money from firm 2 in return for firm 1's promise not to transfer its knowledge exclusively to firm 3. Since a naked extortion from firm 2 (getting money from firm 2 in return for the promise not to transfer knowledge exclusively to firm 3, without actually transferring any knowledge to firm 2) is probably illegal per se, firm 1 will have to transfer some amount of knowledge to firm 2 just in order to make the agreement appear legal. Nonetheless, Proposition 2 shows that when $1/3 \leq \lambda_1 < 1/2$, firm 1 will license the minimal amount of knowldge to firm 2 subject to not being sued for antitrust violation.

Equation (17) shows that when firm 1 issues nonexclusive licenses to both firms 2 and 3, then a small increase in the amount of knowledge that is transferred to firm 2 has three effects on firm 1's expected payoff (the effects of a small increase in the amount of knowledge that is transferred to firm 3 are completely analogous). First, it lowers the likelihood that firm 1 will be the sole developer of the new technology. Second, it raises the likelihood that firm 2 will be the sole developer of the new technology and hence raises the amount that firm 2 is willing to pay for a nonexclusive license. Third, it lowers the likelihood that firm 3 will be the sole developer of the new technology and hence lowers the amount that firm 3 is willing to pay for a nonexclusive license. Since the case where firm 1 issues nonexclusive licenses is associated with low values of $\lambda_1$, the second positive effect outweighs the first and third negative effects. Hence, firm 1 unambiguously wishes to transfer as much knowledge as possible to firms 2 and 3.

□ **Transfer of knowledge between firms 2 and 3:** The fact that firm 1 plays firms 2 and 3 against one another when it issues licenses suggests that the firms 2 and 3 may wish to engage in a licensing agreement, according to which firm 2 transfers its knowledge to firm 3, before they are approached by firm 1. The advantage of such an agreement, is that it can favorably affect the terms of a licensing agreement that firm 1 will eventually offer firms 2 and 3.

To explore this possibility, note from Lemma 1 that if firm 1 issues nonexclusive licenses to both firms 2 and 3 then the fees $T_2(y,y)$ and $T_3(y,y)$ leave firms 2 and 3 with expected payoffs that are equal to their expected payoff when their rival gets an exclusive license, i.e., $\lambda_2(1-\lambda_1)^2$ and $\lambda_3(1-\lambda_1)^2$, respectively. Both firms obtain the same expected payoffs even when firm 1 issues an exclusive license to firm 2 because $T_2(y,n)$ leaves firm 2 with an expected payoff of $\lambda_2(1-\lambda_1)^2$, while firm 3 does not get a license so its expected payoff is $\lambda_3(1-\lambda_1)^2$. Since the joint expected payoff of firms 2 and 3, $(\lambda_2+\lambda_3)(1-\lambda_1)^2$, increases with $\lambda_3$, it is clear that the two firms can benefit from reaching a licensing agreement before being approached by firm 1. According to this agreement, firm 2 transfers knowledge to firm 3 and thereby boosts firm 3's chance to succeed from $\lambda_3$ to $\lambda_2$. Such a licensing agreement does not affect firm 1's decision on whether to issue nonexclusive licenses or issue an exclusive license to firm 2 because this decision depends only on $\lambda_1$. On the other hand, such an agreement will affect firm 1's decision on whether to issue an exclusive license to firm 2 or not to issue any licenses. To see why, recall from the proof of Proposition 1 that firm 1 issues an exclusive license to firm 2 if $B(\lambda_1,\lambda_2,\lambda_3) > 0$ (firm 1's expected payoff when it licenses its knowledge exclusively to firm 2 exceeds its expected payoff when it does not issue any licenses) and does not issue any licenses if $B(\lambda_1,\lambda_2,\lambda_3) < 0$. Since a licensing agreement between firms 2 and 3 raises $\lambda_3$ to $\lambda_2$, it lowers $B(\lambda_1,\lambda_2,\lambda_3)$ if $1-2\lambda_1+\lambda_2 > 0$ and raises it otherwise. Consequently, such an agreement will induce firm 1 to issue no licenses for a wider set of parameters if $1-2\lambda_1+\lambda_2 > 0$ or $\lambda_1 < (1+\lambda_2)/2$ and for a narrower set of parameters if $\lambda_1 > (1+\lambda_2)/2$.

Even when firm 2 and 3 do not expect that firm 1 will offer any licenses, i.e., $\lambda_1 > \lambda_1^* \geq 1/2$, then they will still reach a licensing agreement among themselves provided that $\lambda_2 < 1/2$. This is because such an agreement raises their joint expected payoff from $(1-\lambda_1)(\lambda_2(1-\lambda_3)+\lambda_3(1-\lambda_2))$ to $2\lambda_2(1-\lambda_2)(1-\lambda_1)$. The reason why $\lambda_2$ needs to be below 1/2 for such an agreement to be jointly profitable is that it must raise firm 3's chances to be the sole winner of the R&D contest by more than it lowers firm 2's chances to be the sole winner.

**Proposition 3**: *Suppose that firms 2 and 3 expect that firm 1 will issue licenses (either exclusive or nonexclusive). Then, they can benefit from licensing firm 2's knowledge to firm 3 before either firm is being approached by firm 1. This licensing agreement widens the set of parameters for which firm 1 issues no licenses if $\lambda_1 < (1+\lambda_2)/2$ ($\lambda_1$ is not too far from $\lambda_2$) and narrows it otherwise. If firms 2 and 3 expect that firm 1 will not issue any licenses, then they can still benefit from a licensing agreement between them provided that $\lambda_2 < 1/2$.*

□ **Bans on exclusive licenses:** At first blush it might appear that it would be a good idea to ban exclusive licenses in order to force firm 1 to license its knowledge to both firms 2 and 3 and thereby raise the likelihood that the new technology will be developed, and moreover, raise the likelihood that it will be developed by more than one firm in which case there will be competition in the product market rather than a monopoly.[4] However, as the next proposition shows, such bans may in fact induce firm 1 to refrain from issuing any licenses. In that case, instead of issuing an exclusive license to firm 2, firm 1 will not issue any licenses and will simply hold on to its technological lead.

**Proposition 4:** *If firm 1 is not allowed to issue exclusive licenses then it will issue nonexclusive licenses*

[4] In the U.S., exclusive licensing is treated under the "rule of reason," see *Morraine Products v. ICI America Inc.*, 538 F.2d.134 (7th Cir) cert denied, 429 U.S. 941 (1976).

*to both firms 2 and 3 if $\lambda_1 < \lambda_1$**, where $\lambda_1$** $< \lambda_1$*, and will not issue any licenses otherwise.*

**Proof:** Absent exclusive licenses, it is enough to compare $\pi_1^*(y,y)$ and $\pi_1(n,n)$. To this end, note from equation (11) that $\pi_1^*(y,y) - \pi_1(n,n) > 0$ when $\lambda_1 = 1/3$ and $\pi_1^*(y,y) - \pi_1(n,n) < 0$ when $\lambda_1 = 1$. Moreover, $\pi_1^*(y,y) - \pi_1(n,n)$ is concave for small values of $\lambda_1$ but may be convex for high values of $\lambda_1$ (whether this is the case or not also depends on the values of $\lambda_2$ and $\lambda_3$). This implies in turn that there exists a unique value of $\lambda_1$, denoted, $\lambda_1^{**}$, such that $\pi_1^*(y,y) > \pi_1(n,n)$ for all $\lambda_1 < \lambda_1^{**}$ and $\pi_1^*(y,y) < \pi_1(n,n)$ for all $\lambda_1^{**} < \lambda_1 < 1$.

To compare $\lambda_1^{**}$ with $\lambda_1^*$ (the value at which $\pi_1^*(y,n) = \pi_1(n,n)$), recall from Proposition 1 that when firm 1 can issue exclusive licenses, $\pi_1^*(y,y) > \pi_1^*(y,n)$ for all $\lambda_1 < 1/3$ and $\pi_1^*(y,y) < \pi_1^*(y,n)$ for all $1/3 < \lambda_1 < 1$. Since both $\lambda_1^*$ and $\lambda_1^{**}$ exceed 1/3, it follows that $\lambda_1^{**} < \lambda_1^*$. ■

Proposition 4 shows implies that whenever $1/3 < \lambda_1 < \lambda_1^{**}$, a ban on exclusive licenses has the intended effect: firm 1 licenses its knowledge to both firms 2 and 3 instead of licensing it exclusively to firm 2. However, when $\lambda_1^{**} < \lambda_1 < \lambda_1^*$, a ban on exclusive licenses backfires in the sense that now firm 1 will not issue any licenses instead of issuing an exclusive license to firm 2. As a result, there will be less dissemination of knowledge in this range rather than more.

## 4. Acquisition of knowledge

In this section I consider the possibility that firm 1 sells rather then licenses its knowledge. The difference between the two possibilities is that when firm 1 sells its knowledge, it exits the R&D contest altogether whereas when it licenses its knowledge, it stays in the contest. For instance, an exclusive sale of knowledge could correspond to a situation where firm 1 simply puts itself up for sale and is acquired by one of its rivals. In other words, this possibility corresponds to a merger. Another possibility is that firm

1 sells the relevant R&D lab or division to one of its rivals. The case where firm 1 sells its knowledge rather than licenses it raises several interesting questions including, whether firm 1 would prefer to sell its knowledge to rivals, license it, or simply hold on to its technological lead, and in case it prefers to sell its knowledge, whether it will sell it exclusively to one of its rivals or to sell it to both rivals.

To address this questions, assume that after the vector ($\lambda_1$, $\lambda_2$, $\lambda_3$) is realized, there is a selling stage in which, analogously to the situation in Section 3, firm 1 can make a pair of take-it-or-leave-it offers to firms 2 and 3 at fees, $\hat{T}_2$ and $\hat{T}_3$, respectively. If both firms reject their respective offers then no sales take place. If only one firm accepts firm 1's offer then this firm exclusively acquires firm 1's knowledge. If both firms accept then there is a tie breaking rule that specifies which firm gets to acquire firm 1's knowledge. The precise type of the tie breaking rule will be specified in Lemma 2 below.

The resulting expected payoffs of the three firms when firm 1's knowledge is sold exclusively to firm 2 are given by:

$$\hat{\pi}_1(y,n) = \hat{T}_2, \tag{18}$$

$$\hat{\pi}_2(y,n) = \lambda_1(1-\lambda_3) - \hat{T}_2, \tag{19}$$

and

$$\hat{\pi}_3(y,n) = \lambda_3(1-\lambda_1). \tag{20}$$

The expected payoffs when firm 1 sells its knowledge exclusively to firm 3 are analogous. And, if firm 1 sells its knowledge to both firms 2 and 3 the expected payoffs are:

$$\hat{\pi}_1(y,y) = \hat{T}_2 + \hat{T}_3, \tag{21}$$

and

$$\hat{\pi}_j(y,y) = \lambda_1(1-\lambda_1) - \hat{T}_j, \qquad j = 2,3. \tag{22}$$

The following lemma is the analog of Lemma 1 for the case of sales of knowledge:

**Lemma 2:** *Suppose that firm 1 wishes to sell its knowledge exclusively to firm j, j = 2,3. Then, the optimal scheme from its perspective is to set*

$$\hat{T}_2 = \hat{T}_2(y,n) = \lambda_1(1-\lambda_3) - \lambda_2(1-\lambda_1),$$

*and*

$$\hat{T}_3 = \hat{T}_2(n,y) \equiv \lambda_1(1-\lambda_2) - \lambda_3(1-\lambda_1),$$

*and set a tie breaking rule that specifies that firm 1's knowledge will be exclusively sold to firm j if both firms accept their respective offers. If firm 1 wishes to sell its knowledge to both firms 2 and 3, then the optimal scheme from its perspective is to set*

$$\hat{T}_j = \hat{T}_j(y,y) \equiv (\lambda_1 - \lambda_j)(1-\lambda_1), \qquad j = 2,3,$$

*and set a tie breaking rule that specifies that firm 1's knowledge will be sold to both firms if both accept their respective offers.*

The proof is completely analogous to the proof of Lemma 1 and hence is omitted. Note that the fees that firm 1 gets when it sells its knowledge are $1/(1-\lambda_1)$ times the corresponding fees when firm 1 licenses its knowledge. This reflects the fact that when firm 1 sells it knowledge it exits the contest and hence does not pose a competitive threat to firms 2 and 3.

The next result characterizes firm 1's decision when it can only sell its knowledge to rival but not license it.

**Proposition 5**: *In the equilibrium of the selling stage, if $\lambda_1 < 1/2$, then firm 1 will sell its knowledge to both firms 2 and 3 provided that*

$$\left(\lambda_1 - \lambda_2 - \lambda_3\right)\left(1 - 2\lambda_1\right) > \lambda_1 \lambda_2 \lambda_3,$$

*and will not sell it at all otherwise. If $1/2 \leq \lambda_1 < 1/(2-\lambda_3)$, where $1/(2-\lambda_3) < \lambda_1^*$, firm 1 will not sell its knowledge at all, and if $\lambda_1 > 1/(2-\lambda_3)$, firm 1 will sell its knowledge exclusively to firm 2.*

**Proof:** If firm 1 sell its knowledge exclusively to firm 2 at $\hat{T}_2(y,n)$, then its expected payoff is

$$\hat{\pi}_1^*(y,n) = \lambda_1\left(1 - \lambda_3\right) - \lambda_2\left(1 - \lambda_1\right). \tag{23}$$

If it sells its knowledge exclusively to firm 3 at $\hat{T}_3(n,y)$, then its expected payoff is

$$\hat{\pi}_1^*(n,y) = \lambda_1\left(1 - \lambda_2\right) - \lambda_3\left(1 - \lambda_1\right). \tag{24}$$

If firm 1 issues nonexclusive licenses at $\hat{T}_2(y,y)$ and $\hat{T}_3(n,y)$, then its expected payoff is

$$\hat{\pi}_1^*(y,y) = \left(1 - \lambda_1\right)\left(2\lambda_1 - \lambda_2 - \lambda_3\right). \tag{25}$$

Finally, if firm 1 does not issue licenses at all, its expected payoff is given by equation (10).

Comparing equations (23)-(25) reveals that since $\lambda_1 > \lambda_2 \geq \lambda_3$, then $\hat{\pi}_1^*(y,y) > \text{Max}\{\hat{\pi}_1^*(y,n), \hat{\pi}_1^*(n,y)\}$ for all $\lambda_1 < 1/2$, and $\hat{\pi}_1^*(y,n) > \text{Max}\{\hat{\pi}_1^*(y,y), \hat{\pi}_1^*(n,y)\}$ for all $\lambda_1 > 1/2$. That is, if firm 1 wishes to sell its knowledge, it will sell it to both firms if $\lambda_1 < 1/2$ and will sell it exclusively to firm 2 if $\lambda_1 > 1/2$.

To examine whether firm 1 will sell its knowledge at all, suppose that $\lambda_1 < 1/2$. Then, firm 1 needs to decide between selling its knowledge to both firms 2 or 3 or not selling it all. Using equations (25) and (10) yields,

$$\hat{\pi}_1^*(y,y) - \hat{\pi}_1(n,n) = \left(1-\lambda_1\right)\left(2\lambda_1-\lambda_2-\lambda_3\right) - \lambda_1\left(1-\lambda_2\right)\left(1-\lambda_3\right)$$
$$= \left(\lambda_1-\lambda_2-\lambda_3\right)\left(1-2\lambda_1\right) - \lambda_1\lambda_2\lambda_3. \tag{26}$$

Hence, the expression in the proposition.

Next, suppose that $\lambda_1 \geq 1/2$, so that if firm 1 sells its knowledge at all, it will sell it exclusively to firms 2. Using equations (23) and (10), yields

$$\hat{\pi}_1^*(y,n) - \hat{\pi}_1(n,n) = \lambda_2\left(\lambda_1\left(2-\lambda_3\right)-1\right). \tag{27}$$

Noting that this expression increases with $\lambda_1$ implies that firm 1 will sell its knowledge exclusively to firm 2 if $\lambda_1 > 1/(2-\lambda_3)$, and will not sell it at all if $1/2 \leq \lambda_1 < 1/(2-\lambda_3)$.

Finally, to compare $1/(2-\lambda_3)$ with $\lambda_1*$, recall from Proposition 1 that $\lambda_1*$ (the critical value of $\lambda_1$ above which firm 1 stops licensing its knowledge when selling is not an option), is implicitly defined by $B(\lambda_1,\lambda_2,\lambda_3) = 0$. Evaluated at $1/(2-\lambda_3)$, we get $B(1/(2-\lambda_3),\lambda_2,\lambda_3) = (1-\lambda_3)(\lambda_2-\lambda_3)/(2-\lambda_3)^2 > 0$. Recalling from the proof of Proposition 1 that $B(\lambda_1,\lambda_2,\lambda_3)$ is concave and $B(1,\lambda_2,\lambda_3) < 0$, implies that $1/(2-\lambda_3) < \lambda_1*$. ■

Proposition 5 shows that when $\lambda_1$ is sufficiently large, i.e., above $1/(2-\lambda_3)$, firm 1 would prefer to sell its knowledge exclusively to firm 2. How large $\lambda_1$ needs to be for that to be the case depends on $\lambda_3$. The higher $\lambda_3$ is, the larger $\lambda_1$ has to be to ensure that firm 1 finds it optimal to sell its knowledge to firm 2. Intuitively, both $\hat{T}_2(y,n)$ and $\hat{T}_2(n,y)$ decreases with $\lambda_3$, since the more likely is firm 3 to develop the new technology, the less keen firm 2 is on acquiring firm 1's knowledge and thereby boost its own chance of developing the technology, and the less valuable is firm 1's knowledge to firm 3. That is, the more knowledge firm 3 has to begin with, the less money firm 1 can make by selling its knowledge. This makes firm 1 more likely to hold on to its technological lead and not to sell its knowledge.

When $\lambda_1$ is large but not too large, i.e., below $1/(2-\lambda_3)$, firm 1 would prefer to hold on to its technological lead and will therefore not sell its knowledge. As $\lambda_1$ drops below 1/2, firm 1 would sell its knowledge to both firms 2 and 3 if it would sell it at all. However, whether firm 1 wishes to sell its knowledge at all depends in this case on both $\lambda_1$, $\lambda_2$, and $\lambda_3$. In the extreme case where $\lambda_1 = 1/2$, the condition stated in the proposition always fails since the left hand side of the inequality vanishes. By continuity then, firm 1 would not wish to sell its knowledge whenever $\lambda_1$ is sufficiently close to 1/2. But when $\lambda_1$ is sufficiently below 1/2, firm 1 may wish to sell its knowledge to firms 2 and 3 depending on how far $\lambda_2$ and $\lambda_3$ are below $\lambda_1$. In particular, the condition stated in the proposition is more likely to hold the further $\lambda_2$ and $\lambda_3$ are from $\lambda_1$. When $\lambda_3 = 0$ (firm 3 is far behind firm 1), the condition stated in the proposition surely holds since the right side of the inequality vanishes, while the left side is positive (recall that $\lambda_1 > \lambda_2$). If on the other hand $\lambda_2+\lambda_3 = \lambda_1$ (firms 2 and 3 are not lagging too much behind firm 1), the condition surely fails since then left side of the inequality vanishes while the right side is positive.

## 5. Sell or license?

The next step is to examine whether firm 1 would wish to license its knowledge or sell it if it can choose between the two alternatives. To examine this question, let us consider two alternative situations: (i) firm 1 can only license its knowledge but cannot sell it, (ii) firm 1 can only sell its knowledge but cannot license it. Now there are several cases depending on the extent of firm 1's knowledge. These cases are illustrated in Figure 1. The figure shows for each value of $\lambda_1$ the best option from firm 1's perspective under possibility (i) and under possibility (ii). The next Proposition compares these options for each value of $\lambda_1$ and fully characterizes the best option from firm 1's perspective.

**Proposition 6**: *Suppose that firm 1 can either license its knowledge, sell its knowledge, or hold on to its technological lead. Then, firm 1 will*

*(i)* *license its knowledge to both firms 2 and 3 if* $1/3 \le \lambda_1 < \lambda_1^*$,

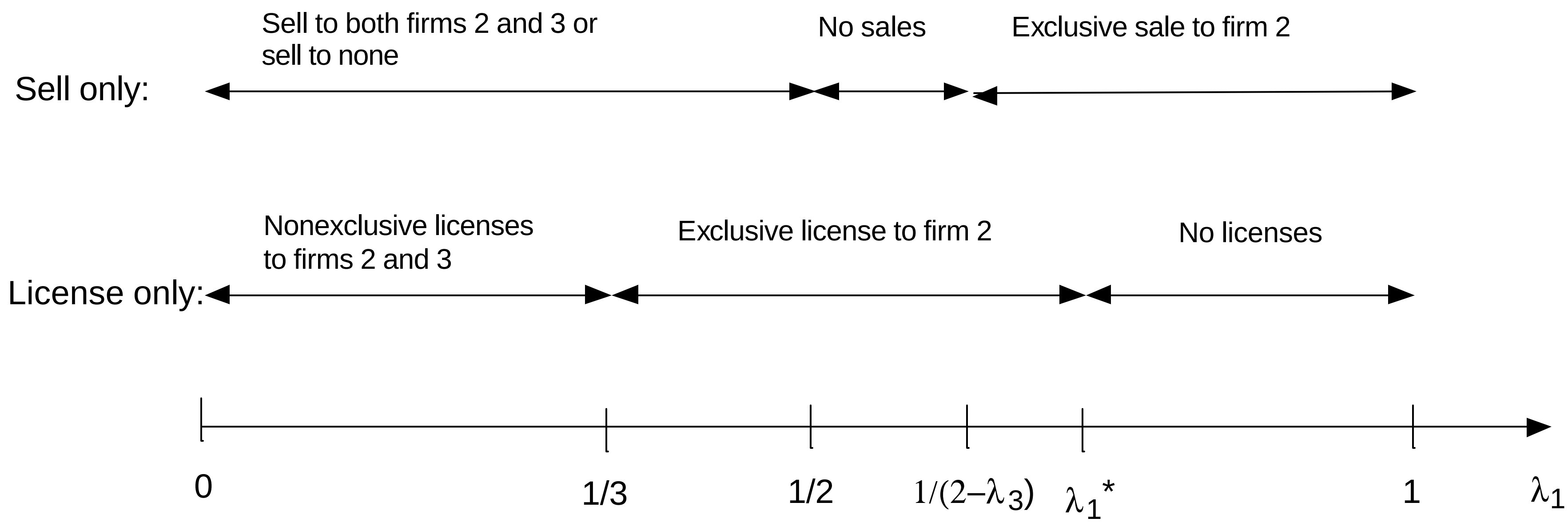


Figure 1: illustrating firm 1's incentive to license or sell its knowledge

*(ii)* *license its knowledge exclusively to firm 2 if $1/3 \leq \lambda_1 < \lambda_1$*, and*

*(iii)* *sell its knowledge exclusively to firm 2 if $\lambda_1 \geq \lambda_1$*.*

**Proof:** Suppose that $\lambda_1 < 1/3$. Under possibility (i), firm 1 will license its knowledge to both firms 2 and 3 and its expected payoff will be $\pi_1^*(y,y)$. Under possibility (ii), firm 1 will either sell its knowledge to both firms 2 and 3 or will not sell it at all, so its expected payoff will be Max$\{\hat{\pi}_1^*(y,y), \pi_1(n,n)\}$. The proof of Proposition 1 shows that $\pi_1^*(y,y) > \pi_1(n,n)$ for all $\lambda_1 < 1/3$. Moreover, since $\lambda_1 < 1/3$, it follows that

$$\begin{aligned} \pi_1^*(y,y) - \hat{\pi}_1^*(y,y) &= (1-\lambda_1)^2(3\lambda_1 - \lambda_2 - \lambda_3) - (1-\lambda_1)(2\lambda_1 - \lambda_2 - \lambda_3) \\ &= \lambda_1(1-\lambda_1)(1 - 3\lambda_1 + \lambda_2 + \lambda_3) > 0. \end{aligned} \tag{28}$$

Hence, $\pi_1^*(y,y) >$ Max$\{\hat{\pi}_1^*(y,y), \pi_1(n,n)\}$ for all $\lambda_1 < 1/3$, implying that in this range, the best option from firm 1's perspective is to license its knowledge to both firms 2 and 3.

Next, suppose that $1/3 \leq \lambda_1 < 1/2$. Then, firm 1 will license its knowledge exclusively to firm 2 under possibility (i), and will either sell it to both firms 2 and 3 or will not sell it at all under possibility (ii). Hence under possibility (i) firm 1's expected payoff is $\pi_1^*(y,n)$, whereas under possibility (ii) it is Max$\{\hat{\pi}_1^*(y,y), \pi_1(n,n)\}$. The proof of Proposition 1 shows that $\pi_1^*(y,n) > \pi_1(n,n)$ for all $1/3 \leq \lambda_1 < \lambda_1^*$. Since $1/2 \leq 1/(2-\lambda_3) < \lambda_1^*$, it follows that $\pi_1^*(y,n) > \pi_1(n,n)$ for all $\lambda_1 < 1/2$. Moreover, since $\lambda_1 < 1/2$,

$$\begin{aligned} \pi_1^*(y,n) - \hat{\pi}_1^*(y,y) &= (1-\lambda_1)(2\lambda_1(1-\lambda_3) - \lambda_2(1-\lambda_1)) - (1-\lambda_1)(2\lambda_1 - \lambda_2 - \lambda_3) \\ &= (1-\lambda_1)\left[\lambda_3(1-2\lambda_1) + \lambda_1\lambda_2\right] > 0. \end{aligned} \tag{29}$$

Hence, $\pi_1^*(y,n) >$ Max$\{\hat{\pi}_1^*(y,n), \pi_1(n,n)\}$ for all $\lambda_1 < 1/2$, implying that in this range, firm 1 will prefer to license its knowledge exclusively to firm 2.

Now let $1/2 \leq \lambda_1 < 1/(2-\lambda_3)$. Then, firm 1 will licenses its knowledge exclusively to firm 2 and will get an expected payoff of $\pi_1^*(y,n)$ under possibility (i), but will hold on to its technological lead and will get an expected payoff of $\pi_1$(n,n) under possibility (ii). The proof of Proposition 1 shows however that $\pi_1$*(y,n) > $\pi_1$(n,n) for all 1/3 < $\lambda_1$ < $\lambda_1$*. Since 1/(2-$\lambda_3$) < $\lambda_1$*, it follows that when 1/2 ≤ $\lambda_1$ < 1/(2-$\lambda_3$), firm 1 will prefer to licenses its knowledge exclusively to firm 2, just like as in the previous case.

If 1/(2-$\lambda_3$) ≤ $\lambda_1$ < $\lambda_1$*, then under possibility (i), firm 1 will license its knowledge exclusively to firm 2 and its expected payoff will be $\pi_1$(y,n), whereas under possibility (ii) it will sell its knowledge exclusively to firm 2 and will get an expected payoff $\hat{\pi}_1$*(y,n). Now,

$$\begin{aligned} \pi_1^*(y,n) - \hat{\pi}_1^*(y,n) &= (1-\lambda_1)\big(2\lambda_1(1-\lambda_3) - \lambda_2(1-\lambda_1)\big) - \big(\lambda_1(1-\lambda_3) - \lambda_2(1-\lambda_1)\big) \\ &= \lambda_1\big[(1-2\lambda_1)(1-\lambda_3) + \lambda_2(1-\lambda_1)\big]. \end{aligned} \tag{30}$$

The sign of this expression depends on the square bracketed term. This term decreases with $\lambda_1$ so it is minimized at 1/(2-$\lambda_3$). Evaluated at $\lambda_1$ = 1/(2-$\lambda_3$), the square bracketed term becomes ($\lambda_2$-$\lambda_3$)(1-$\lambda_3$)/(2-$\lambda_3$) > 0. Hence, $\pi_1$*(y,n) > $\hat{\pi}_1$*(y,n) for all $\lambda_1$ ≥ 1/(2-$\lambda_3$), implying that whenever 1/(2-$\lambda_3$) ≤ $\lambda_1$ < $\lambda_1$*, firm 1 will prefer to license its knowledge exclusively to firm 2.

Finally, suppose that $\lambda_1$ ≥ $\lambda_1$*. Then, under possibility (i), firm 1 will prefer to hold on to its technological lead so its expected payoff will be $\pi_1$(n,n). Under possibility (ii), firm 1 will prefer to sell its knowledge exclusively to firm 2 so its expected payoff will be $\hat{\pi}_1$*(y,n). Proposition 5 reveals that $\hat{\pi}_1$*(y,n) > $\pi_1$(n,n) for all $\lambda_1$ > 1/(2-$\lambda_3$). Since $\lambda_1$* > 1/(2-$\lambda_3$), it follows that $\hat{\pi}_1$*(y,n) > $\pi_1$(n,n), for all $\lambda_1$ ≥ $\lambda_1$*, implying that firm 1 will prefer to sell its knowledge exclusively to firm 2. ■

Proposition 6 shows that firm 1 will always prefer to either license or sell its superior knowledge to its rivals than hold on to its technological lead. The option of selling is preferred when firm 1's chances to develop the new technology are particularly large. Licensing is not attractive in these case because it raises the likelihood that more than one firm will develop the new technology in which case competition in the product market will drive profits to 0. Selling is attractive however because firm 1 exits the context after it sells its knowledge.

## Non Blackwell ordered knowledge

So far I have assumed that the success probability of each of the three firms is independent of the success probabilities of its rivals. While this assumption seems natural if there are no transfers of knowledge, it looks less natural in the presence of such transfers. To capture the idea that the success probabilities of the licensor and the licensee(s) become correlated, it is possible to assume that there are many possible ways to conduct R&D. Initially, each of the 3 firms approaches the R&D process in its own unique way. As before, the success probabilities of the three firms at the interim stage are $\lambda_1 > \lambda_2 \geq \lambda_3$. However, unlike before, this knowldge can no longer be Blackwell ordered since each of the 3 probabilities corresponds to a different approach to R&D. In particular, if firm j licenses firm i's knowledge, it now has two different approaches to R&D: its orginal approach and firm i's approach. Consequently, the success probability of firm j becomes $\lambda_j\lambda_i + \lambda_j(1-\lambda_i) + \lambda_i(1-\lambda_j) = \lambda_j + \lambda_i - \lambda_j\lambda_i$.

To be continued!!!

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