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Technology transfer with commitment*

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Summary. This paper considers technology transfer in a duopoly where the firms have two types of commitment strategies: incentive delegation and capacity installation. It turns out that the possibility of technology transfer significantly differs under these two types of commitment as well as depending on whether one or both firms commit. Under strategic incentive delegation, the possibility of technology transfer is minimal when both firms use the incentive delegation strategy and the costs of incentive delegation are negligible. If both firms choose the incentive delegation strategy and the costs of incentive delegation are significant then the possibility of technology transfer rises compared to a situation with no pre-commitment. In case of commitment to a capacity level before production, the possibility of technology transfer does not change when both firms simultaneously commit to their capacity levels. Different sets of results arise when only one firm can pre-commit.

Keywords and Phrases: Capacity installation, Incentive delegation, Technology licensing.

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1 Introduction

Transfer of modern technology is a topic of growing interest. In case of technology transfer, the technologically advanced firm licenses its superior knowledge to the technologically backward firm(s) and charges an appropriate price to the licensee. Here researchers are mainly concerned with issues such as the feasibility of technology licensing, the quality of the transferred technology, the optimal patent licensing contract and the concentration effects of technology licensing. As a representative sample, one may look at Rockett (1990), Gallini and Wright (1990), Marjit (1990), Kabiraj and Marjit (1992a,b, 1993), Singh (1992) and Kabiraj (1994).[1] Although the topic of technology licensing has attracted a fair amount of attention, the authors ignored the role of strategic pre-commitment by the licenser and/or the licensee while addressing the licensing problem in oligopoly. The ability to pre-commit can change the optimal behavior of the firms and renders a firm strategic advantage against its competitor in the product market, which in turn, may influence the technology licensing decision. Furthermore, the identity of the player (licenser and/or licensee) who can commit may also influence the licensing decision. Hence, we think it is important to examine technology licensing when the firms have pre-commitment strategies. This paper is an attempt to examine this area of research.

In this paper we consider two types of pre-commitment strategies: strategic incentive delegation and capacity commitment. Strategic incentive delegation refers to the design of an incentive payment scheme to the manager to deal with oligopolistic rivalry in the product market, independent of considerations such as moral hazard or adverse selection (see, e.g., Vickers, 1985; Fershtman and Judd, 1987; Sklivas, 1987; Basu, 1995; Basu et al., 1997; Das, 1997).[2] The strategic incentive delegation strategy helps a firm, in oligopoly, to play more aggressively in the product market. The other pre-commitment strategy, capacity commitment, implies building up capacity up to a certain output level prior to production. Thus, capacity building prior to production helps a firm to commit credibly to its intended output level and it helps to reduce marginal cost at the production stage. This pre-commitment possibility also provides strategic advantage to a firm in the product market (see Spence, 1977; Dixit, 1980; Basu and Singh, 1990; Gabszewicz and Poddar, 1997; etc.). The present paper shows that the type of pre-commitment strategy has significant influence on the market outcome. Hence, one purpose of this analysis is to examine how attractive the patent licensing contract is when the firms can take actions prior to production so that they can get advantage in the product market.

The present paper is closely related to the paper by Marjit (1990). In his paper, Marjit considers the possibility of technology transfer in a duopoly where the

[1] Marjit and Mukherjee (1995, 1998) consider relative profitability and likelihood of better-quality technology transfer when the firms have the option to make a licensing arrangement and a joint venture.

[2] Following the works on strategic incentive delegation, the present paper also uses the term ‘manager’ to refer to an ‘agent’ who takes decision in the product market to maximize an objective function delegated to him/her by a profit maximizing ‘owner’ or ‘principal’.

licenser and the licensee compete in the product market as Cournot duopolists. Using a fixed fee licensing contract[3], Marjit provides a condition under which the technologically superior[4] firm licenses its technology to the technologically inferior firm. It shows that licensing is profitable provided that the initial technologies of these firms are sufficiently close. The firms, however, have no pre-commitment strategies. In the following analysis, we shall refer to the model of Marjit (1990) as the 'no-commitment equivalence model'.

The present paper also considers fixed fee licensing contracts but it focuses on the possibility of strategic incentive delegation and capacity commitment. In the course of analysis, we find that the work of Marjit (1990) turns out to be a special case of this work. In what follows, Section 2 considers a Cournot duopoly with a technologically advanced firm and a technologically backward firm. These firms, in the first stage, decide on technology licensing. Then, in the second stage, one or both firms takes a decision on incentive delegation. Incentive delegation takes place through the hiring of a manager and delegating the decision-making power to that manager. However, hiring a manager requires some costs. Following Basu (1995), we endogenize the decision of hiring a manager. At stage three, production takes place.

Initially, we assume that the effective cost of hiring a manager is the same for both firms. It turns out that if the effective cost of hiring a manager is negligible then the possibility of technology licensing is fairly low and less than in the no-commitment equivalence model. However, if there exist moderate symmetric costs of hiring a manager, the possibility of licensing may increase relative to the problem in the no-commitment equivalence model. Then, Subsection 2.5 focuses on different effective costs of hiring a manager for these firms such that only one firm has the credible option to use the incentive delegation strategy. In case of asymmetric costs of hiring a manager, we show that if only the technologically inefficient firm uses the incentive delegation strategy then technology licensing is more attractive compared to the case where only the technologically efficient firm has the credible option to use the incentive delegation strategy. However, if only one of these firms uses an incentive delegation strategy, the technology licensing possibility is always lower than in the no-commitment equivalence model.

In the literature, another frequently used pre-commitment strategy is through capacity installation prior to production. This helps a firm to reduce its marginal cost at the production stage and, therefore, provides a strategic advantage to that firm. Like the literature on strategic incentive delegation, however, the literature on strategic capacity commitment has also ignored the possibility of other strategic action, such as licensing. Section 3, focuses on this issue and considers licensing with strategic capacity commitment. In particular, we introduce the pos-

[3] The implicit assumption is that the provision of an output royalty in the licensing contract is not possible. The possibility of imitation or inventing around the technology easily by the licensee after getting the technology or lack of information needed for a royalty provision may be the reason for fixed fee licensing contract (see, e.g., Katz and Shapiro, 1985; Rockett, 1990).

[4] Here technology corresponding to the lower marginal cost of production implies superior technology.

sibility of simultaneous and sequential (which may be due to some incumbency advantages) capacity commitment by the firms after deciding on technology licensing. We find that commitment to a capacity level prior to production has implications for technology licensing that are significantly different from the situations that arise when firms engage in strategic incentive delegation. Hence, this analysis also points out the importance of different pre-commitment strategies on technology licensing. More specifically, the analysis shows that if both firms have an option for capacity commitment then the incentive for technology licensing is the same as in the no-commitment equivalence model. But, in case of capacity commitment by a single firm, the possibility of technology licensing depends on the market size compared to the marginal cost of production and on the identity of the player (i.e., licenser or licensee) who has the ability to pre-commit.

The rest of the paper is organized as follows. Section 2 considers the possibility of strategic incentive delegation by the firm(s). In Section 3, we focus on the pre-commitment to a capacity level prior to production. Section 4 concludes. Proofs are relegated to the Appendix.

2 Incentive delegation

Suppose that there are two firms - firm 1 and firm 2. In the product market these firms behave like Cournot duopolists. These firms produce homogenous products and face the inverse market demand function

$$p = a - q_1 - q_2, \quad a > 0 \tag{1}$$

where p is the price of the product and q_1 and q_2 are the outputs of firm 1 and firm 2 respectively. Assume constant marginal costs of production of firm 1 and firm 2, denoted by c_1 and c_2 respectively, with $0 < c_2 < c_1$ and $c_1 \in (c_2, \frac{a+c_2}{2})$. The restriction of $c_1 < \frac{a+c_2}{2}$ guarantees that both firms produce positive amounts in case of no-commitment by any of these firms. Assume that there are no other costs of production.

Consider the following game. In stage 1, these firms decide on technology licensing. In the case of licensing, firm 2 licenses its technology to firm 1 and charges an up-front fixed fee. In stage 2, the owner of each firm decides whether to hire a manager or not. In particular, each owner i selects $m_i \in \{0, 1\}$, where $m_i = 0$ means owner i does not hire a manager and $m_i = 1$ means owner i hires a manager. We assume that an owner does not hire a manager if it gets the same profit from hiring and not hiring a manager. Once a manager is chosen and the manager's objective function is specified (which happens in stage 3), the manager decides how much to produce in stage 4. In the absence of a manager, the owner takes the decision in stage 4. In stage 3, each owner, if a manager is hired, picks an objective function for the manager. Following Fershtman and Judd (1985), Sklivas (1987), Basu (1995), etc., we consider that manager i's objective function can only belong to the following class

$$R_i = \alpha_i \Pi_i + (1 - \alpha_i) S_i, \quad i = 1, 2 \tag{2}$$

where Π_i and S_i are respectively the profits and revenues of the ith firm and the owner has to ensure that the manager gets the reservation income $E_i > 0$.[5] Following Basu (1995), we define effective cost of hiring a manager as

$$Z_i \equiv E_i - X_i \tag{3}$$

where X_i is the amount that owner i can earn elsewhere in the time that elapses after appointing a manager. Here, $X_i \leq E_i$ and it depends on whether some supervision by the owner is needed.

2.1 Symmetric cost of hiring a manager

In this section, we assume that both firms face the same effective costs of hiring a manager, i.e., $Z_1 = Z_2 = Z \geq 0$. We focus on the following three situations - (1) the effective cost of hiring a manager is prohibitive, (2) the effective cost of hiring a manager is negligible, and (3) the effective cost of hiring a manager is modest.

Decisions on hiring a manager and corresponding industry profits

Before going further, we report the equilibria of the game of hiring a manager and corresponding industry profits under no-licensing and licensing for $Z \geq 0$. Equilibria are defined as (0,0), (0,1), (1,0) and (1,1) (first (second) term stands for firm 1 (firm 2)) to explain that neither firm hires a manager, only firm 2 hires a manager, only firm 1 hires a manager and both firms hire a manager, respectively.

First, look at the situation under no technology licensing. Under no-licensing, c_1 and c_2 are the marginal costs of firm 1 and firm 2 respectively. Then (0,0) is an equilibrium provided[6]

$$Z > \frac{(a - 2c_2 + c_1)^2}{72}. \tag{4}$$

(0,1) is an equilibrium[7] if and only if

$$\frac{7(a - 3c_1 + 2c_2)^2}{400} < Z < \frac{(a - 2c_2 + c_1)^2}{72} \tag{5}$$

[5] Owner 1 and 2 select α_1 and α_2, respectively, in stage 3. Actually, manager i gets $A_i + R_i B_i$ where A_i and B_i are constants. Since maximizing $A_i + R_i B_i$ and maximizing (2) are the same if the choice variables are q_i, we will act as if the manager's objective function is R_i. A_i and B_i are chosen by owner i to simply ensure that manager i gets the reservation income $E_i > 0$.

[6] (0,0) is an equilibrium provided $\frac{(a-2c_1+c_2)^2}{9} > \frac{(a-2c_1+c_2)^2}{8} - Z$ and $\frac{(a-2c_2+c_1)^2}{9} > \frac{(a-2c_2+c_1)^2}{8} - Z$, i.e., $Z > \frac{(a-2c_1+c_2)^2}{72}$ and $Z > \frac{(a-2c_2+c_1)^2}{72}$. Both conditions hold for $Z > \frac{(a-2c_2+c_1)^2}{72}$.

[7] (0,1) is an equilibrium provided $\frac{(a-3c_1+2c_2)^2}{16} > \frac{2(a-3c_1+2c_2)^2}{25} - Z$ and $\frac{(a-2c_2+c_1)^2}{8} - Z > \frac{(a-2c_2+c_1)^2}{9}$, i.e., $\frac{7(a-3c_1+2c_2)^2}{400} < Z < \frac{(a-2c_2+c_1)^2}{72}$. Further, it is easy to check that (1,0) cannot be an equilibrium.

and (1,1) is an equilibrium[8] if and only if

$$Z < \frac{7(a - 3c_1 + 2c_2)^2}{400}. \tag{6}$$

From (5) it is clear that for (0,1) to be an equilibrium c_1 must be sufficiently larger than c_2, say, greater than $\underline{c}_1$, where $\underline{c}_1 < \frac{a+2c_2}{3}$. Further, we see that for $c_1 \geq \frac{a+2c_2}{3}$, firm 1's optimal output is zero irrespective of its choice on hiring a manager, given that firm 2 hires a manager.[9] Hence, given that firm 2 hires a manager, firm 1 gets zero profit for $c_1 \geq \frac{a+2c_2}{3}$. So, in this situation, (1,1) is not an equilibrium. Therefore, for $c_1 \geq \frac{a+2c_2}{3}$, firm 1 never hires a manager, given that firm 2 hires a manager and the owner of firm 2 sets α_2 in such a way that its manager produces $q_2 = (a - c_1)$[10] and, therefore, its profit will be $(c_1 - c_2)(a - c_1) - Z$. But, firm 2 actually hires a manager if and only if[11]

$$(c_1 - c_2)(a - c_1) - \frac{(a - 2c_2 + c_1)^2}{9} > Z. \tag{7}$$

Since $(c_1 - c_2)(a - c_1) > \frac{(a-2c_2+c_1)^2}{9}$ for all $c_1 \in [\frac{a+2c_2}{3}, \frac{a+c_2}{2})$, it follows that $\forall c_1 \in [\frac{a+2c_2}{3}, \frac{a+c_2}{2})$, $\exists Z > 0$ such that (7) holds.

Let us consider the industry profits under no-licensing. If the equilibrium is (0,0) then industry profit is

$$\Pi_1^0 + \Pi_2^0 = \frac{(a - 2c_1 + c_2)^2 + (a - 2c_2 + c_1)^2}{9}. \tag{8}$$

If (0,1) is the equilibrium then industry profits are

$$\Pi_1^0 + \Pi_2^0 = \frac{(a - 3c_1 + 2c_2)^2}{16} + \frac{(a - 2c_2 + c_1)^2}{8} - Z, \quad \textit{for} \quad c_1 \leq \frac{a + 2c_2}{3} \tag{9}$$

$$\textit{and} \quad \Pi_1^0 + \Pi_2^0 = (c_1 - c_2)(a - c_1) - Z, \quad \textit{for} \quad c_1 \geq \frac{a + 2c_2}{3}. \tag{10}$$

If (1,1) is the equilibrium then industry profit is

$$\Pi_1^0 + \Pi_2^0 = \frac{2(a - 3c_1 + 2c_2)^2 + 2(a - 3c_2 + 2c_1)^2}{25} - 2Z. \tag{11}$$

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[8] (1,1) is an equilibrium provided $\frac{2(a-3c_1+2c_2)^2}{25} - Z > \frac{(a-3c_1+2c_2)^2}{16}$ and $\frac{2(a-3c_2+2c_1)^2}{25} - Z > \frac{(a-3c_2+2c_1)^2}{16}$. Both the conditions hold for $Z < \frac{7(a-3c_1+2c_2)^2}{400}$.

[9] If both firms use the incentive delegation strategy then the optimal outputs of firm 1 are $\frac{2(a-3c_1+2c_2)}{25}$ for $c_1 < \frac{a+2c_2}{3}$ and 0 for $c_1 \geq \frac{a+2c_2}{3}$. If only firm 2 uses the incentive delegation strategy then the optimal outputs of firm 1 are $\frac{(a-3c_1+2c_2)}{4}$ for $c_1 < \frac{a+2c_2}{3}$ and 0 for $c_1 \geq \frac{a+2c_2}{3}$.

[10] From the reaction functions of firm 1 and 2, one can check that, in this situation, this is the optimal output of firm 2. The logic is similar to the one given in Appendix H later.

[11] If $c_1 > \frac{a+2c_2}{3}$ and firm 2 hires a manager then the owner of firm 2 chooses α in such a way that $q_2 = (a - c_1)$. Therefore, net profit of firm 2 is $(c_1 - c_2)(a - c_1) - Z$. Here firm 2 takes this action provided $(c_1 - c_2)(a - c_1) - Z > \frac{(a-2c_2+c_1)^2}{9} \Rightarrow (c_1 - c_2)(a - c_1) - \frac{(a-2c_2+c_1)^2}{9} > Z$.

If licensing takes place at the first stage, then the licenser and the licensee both can produce at the marginal cost of production c_2 because under patent licensing contract, the licenser charges only up-front fixed fee. Hence, given that licensing has occurred at stage 1, (0,0) is equilibrium provided

$$Z > \frac{(a - c_2)^2}{72} \tag{12}$$

and (1,1) is equilibrium provided[12]

$$Z < \frac{7(a - c_2)^2}{400}. \tag{13}$$

Now, look at the industry profits in case of technology licensing. If technology licensing takes place, industry profits for (0,0) and (1,1) are, respectively

$$\Pi_1^t + \Pi_2^t = \frac{2(a - c_2)^2}{9} \tag{14}$$

$$\Pi_1^t + \Pi_2^t = \frac{4(a - c_2)^2}{25} - 2Z. \tag{15}$$

2.2 Prohibitive effective cost

From the expressions (4)-(6), (12) and (13), it is easy to understand that if the costs of hiring a manager are sufficiently high, then neither firm hires a manager irrespective of their decisions on technology licensing.[13] Hence, in this situation, the incentive delegation strategy is not credible and the analysis of Marjit (1990) comes out as a special case of our model. Hence, we have the following proposition.[14]

Proposition 2.1 *Suppose the effective cost of hiring a manager is symmetric and prohibitive. Then technology licensing is profitable if and only if* $c_1 < \frac{2a+3c_2}{5}$ *(as in Marjit, 1990).*

Proof. See Appendix A. □

[12] Easy to check that under licensing there are no other equilibria than (0,0) and (1,1). Under licensing, the firms are symmetric and so it is intuitive too that there exist symmetric equilibria only.

[13] In fact, for $Z > \frac{(a-2c_2+c_1)^2}{72}$, none hires a manager under no-licensing and licensing.

[14] Since we are considering fixed fee licensing, it is enough to consider the industry profits under no-licensing and licensing for examining the profitability of technology licensing. Licensing is profitable provided the industry profits under licensing are greater than the industry profits under no-licensing. Then the licenser can charge an up-front fee as a price for the licensed technology so that none is worse-off under licensing compared to no-licensing.

2.3 Negligible effective cost

This subsection considers an opposite situation to the one just described above. Here, we assume that effective cost of hiring a manager is zero.[15]

First, consider the equilibrium under the history of no technology licensing. We have seen that for $c_1 < \frac{a+2c_2}{3}$, both firms hire a manager and get positive profit in (1,1) equilibrium; but for $c_1 \geq \frac{a+2c_2}{3}$, firm 1 does not get positive profit irrespective of its choice on hiring a manager if firm 2 hires a manager. So, for $c_1 \geq \frac{a+2c_2}{3}$, only firm 2 hires a manager and the owner of firm 2 sets α_2 in such a way that its manager produces $q_2 = (a - c_1)$. Therefore, the industry profits under no-licensing are

$$\Pi_1^0 + \Pi_2^0 = \frac{2(a - 3c_1 + 2c_2)^2}{25} + \frac{2(a - 3c_2 + 2c_1)^2}{25}, \quad for \quad c_1 \leq \frac{a + 2c_2}{3} \tag{16}$$

$$and \quad \Pi_1^0 + \Pi_2^0 = (c_1 - c_2)(a - c_1), \quad for \quad c_1 \geq \frac{a + 2c_2}{3}. \tag{17}$$

If the firms make a licensing contract at stage 1 then both firms produce with marginal costs of production c_2. Expression (13) shows that in this situation both firms hire a manager. Therefore, the industry profit under licensing is given by (see (15) with $Z = 0$)

$$\Pi_1^t + \Pi_2^t = \frac{4(a - c_2)^2}{25}. \tag{18}$$

Hence, we have the following proposition.

Proposition 2.2 *Suppose the effective cost of hiring a manager is negligible ($Z = 0$). Then (i) technology licensing is profitable if and only if $c_1 \in (c_2, c_1^*)$, where $c_1^* = \frac{2a+11c_2}{13}$, and (ii) the possibility of technology licensing is lower compared to the no-commitment equivalence model.*

Proof. See Appendix B. □

For sufficiently large cost differences, only the technologically efficient firm (firm 2) hires a manager. Hence, firm 2 becomes a restrictive monopolist[16] for $c_1 \geq \frac{a+2c_2}{3}$. But, hiring a manager is optimal for both firms as long as both of them produce positive outputs. This induces both firms to act more aggressively in the product market and, therefore, reduces the benefit from licensing. Hence, the incentive for licensing is less compared to the situation with no possibility of strategic incentive delegation.

[15] Result of this section is also valid for sufficiently small positive effective-cost provided hiring a manager is a dominant strategy for both firms under no-licensing and licensing for c_1 less than c_1^* (where c_1^* is defined in Proposition 2.2). For example, for $Z < .004(a - c_2)^2$, this result holds.

[16] By restrictive monopoly we mean that only one firm actually produces the good but it charges a price which is less than the price if there were no other (potential) firm in the market.

2.4 Modest effective cost

Now, consider a situation where hiring a manager is costly, but not so costly that neither firm prefers to hire a manager. The expressions (4)–(6), (12) and (13) show that depending on the values of marginal costs of production and costs of hiring a manager, at stage 2, various equilibria can arise and these, in turn, generate different industry profits.

First, we prove the following lemma.

Lemma 2.1 *(a) Assume that* $c_1 < \frac{a+2c_2}{3}$. *Suppose the equilibrium is (0,1) under the history of no-licensing and the equilibrium is (0,0) under the history of licensing. Then licensing is always profitable.*

(b) Suppose the equilibrium is (0,1) under the history of no-licensing and the equilibrium is (1,1) under the history of licensing. Then licensing is never profitable.

Proof. See Appendix C. □

Lemma 2.1 considers different equilibria under no-licensing and licensing for the game of hiring a manager. It shows that if the firms behave less (more) aggressively after technology licensing compared to no-licensing in the sense that neither firm hires (both firms hire) a manager under licensing while only the technologically advanced firm hires a manager under no-licensing then technology transfer is a profitable (non-profitable) strategy.

Now, we are in a position to prove the following proposition.

Proposition 2.3 *Suppose the effective cost of hiring a manager is positive. Then there exist costs of hiring a manager such that technology licensing is profitable for higher (initial) technological differences between these firms compared to the no-commitment equivalence model.*

Proof. See Appendix D. □

Proposition 2.3 shows that even if the cost of hiring a manager is the same for both firms, the marginal costs of production and costs of hiring a manager may be such that it increases the possibilities of technology licensing relative to other cases mentioned in this section. Here, technology may be transferred even for higher values of c_1 relative to the no-commitment equivalence model (Marjit, 1990).

Marjit's paper can be looked upon as a special case of this article where the cost of hiring a manager is so high that neither firm hires a manager. Proposition 2.3 considers situations where the costs of hiring a manager are such that only one firm hires a manager under no-licensing but the costs of hiring a manager *along with the choice of license fees*[17] restrict both firms to hire a manager under

[17] Note that in this situation hiring of a manager by both firms may be a Nash equilibrium. But this will not be equilibrium with signaling through license fee.

licensing. Hence, from Proposition 2.1 and Proposition 2.3 one can say that if the costs of hiring a manager restrict only one firm from hiring a manager under no-licensing then the possibility of licensing may be greater compared to a situation where the costs of hiring a manager restrict both firms from hiring a manager under no-licensing. Therefore, ceteris paribus, a less restrictive commitment cost may cause a higher possibility of technology transfer. But, if commitment costs are low enough (e.g., see Subsection 2.3) then the possibility of technology transfer is lower compared to a situation with sufficiently higher commitment cost of hiring a manager.

To show the importance of the cost of hiring a manager now we mention an interesting possibility. It can be shown that if $Z > 0$, then for the same values of marginal cost of production of the technologically inefficient firm (i.e., c_1), technology transfer is profitable for some Z but technology transfer is not profitable for some other values of Z. For example, one can consider the values of $Z \in (\frac{7(a-3c_1+2c_2)^2}{400}, \frac{(a-c_2)^2}{72})$ and $c_1 \in (\overline{c}_1, \frac{a+2c_2}{3}]$ where at $\overline{c}_1$, $\frac{7(a-3c_1+2c_2)^2}{400} = \frac{(a-c_2)^2}{72}$ and $\overline{c}_1 > \underline{c}_1$. One can easily check that here technology transfer does not occur but in Proposition 2.3 we have shown the possibility of technology transfer for these values of c_1 where the values of Z are different.

2.5 Asymmetric cost of hiring a manager

Now, we examine the possibility of licensing when only one firm has the credible option for incentive delegation under no-licensing and licensing. Hence, consider that costs of hiring a manager are such that strategic incentive delegation is a credible option to only one of these firms. While the previous subsection has considered the equilibria where only one firm hires a manager under no-licensing and neither firm hires a manager under licensing, this subsection focuses on a scenario where only one firm hires a manager under no-licensing and licensing.

Technologically inefficient firm hires a manager

For simplicity, we assume that $Z_1 = 0$ and $Z_2 > 0$ and very high so that only firm 1 hires a manager but firm 2 never hires a manager.[18] Therefore, industry profit in the case of no-licensing is given by

$$\Pi_1^0 + \Pi_2^0 = \frac{(a - 2c_1 + c_2)^2}{8} + \frac{(a - 3c_2 + 2c_1)^2}{16}. \tag{19}$$

In the case of licensing both firms have marginal costs of production c_2. However, only firm 1 hires a manager and the industry profit under licensing is

$$\Pi_1^t + \Pi_2^t = \frac{3(a - c_2)^2}{16}. \tag{20}$$

Hence, we have the following proposition.

[18] Given the demand specification, firm 2 does not hire a manager when firm 1 hires a manager provided $Z_2 > \frac{2(a-3c_2+2c_1)^2}{25} - \frac{(a-3c_2+2c_1)^2}{16}$.

Proposition 2.4 *Suppose that only the technologically inefficient firm (firm 1) has the credible option for incentive delegation. Then technology transfer is less profitable compared to a situation with no possibility of commitment.*

Proof. See Appendix E. □

The possibility of incentive delegation by the technologically inefficient firm alone helps that firm to play more aggressively in the product market. Hence, the technologically efficient firm can reduce its loss-of-profit due to the aggressive behavior of the technologically inefficient firm by licensing its technology to the technologically inefficient firm. However, the possibility of more aggressive play by the technologically inefficient firm provides less benefit from licensing and, therefore, it reduces the incentive for licensing compared to the case when neither uses incentive delegation strategy. Given the demand specification, technology licensing is profitable for $c_1 \in (c_2, \frac{a+2c_2}{3})$ when only the technologically inefficient firm uses the incentive delegation strategy. Hence, in this case, technology licensing is more profitable than a situation with symmetric and negligible effective cost of hiring a manager.

Technologically efficient firm hires a manager

Consider that $Z_2 = 0$ and $Z_1 > 0$ but very high so that only the technologically efficient firm hires a manager under no-licensing and licensing.[19] Here, the technologically inefficient firm does not produce anything under the no-licensing regime provided its marginal cost of production exceeds $\frac{a+2c_2}{3}$. Hence, for $c_1 \geq \frac{a+2c_2}{3}$, the owner of firm 2 sets α_2 in such a way that its manager produces $q_2 = (a - c_1)$, as mentioned in Subsection 2.1. Therefore, the industry profits under no-licensing are

$$\Pi_1^0 + \Pi_2^0 = \frac{(a - 3c_1 + 2c_2)^2}{16} + \frac{(a - 2c_2 + c_1)^2}{8}, \quad \textit{for} \quad c_1 \leq \frac{a + 2c_2}{3} \tag{21}$$

$$\textit{and} \quad \Pi_1^0 + \Pi_2^0 = (c_1 - c_2)(a - c_1), \quad \textit{for} \quad c_1 \geq \frac{a + 2c_2}{3}. \tag{22}$$

In the case of licensing the marginal costs of both firms are c_2 and the outputs of both firms are always positive. However, the technologically efficient firm engages in strategic incentive delegation and industry profit under licensing is

$$\Pi_1^t + \Pi_2^t = \frac{3(a - c_2)^2}{16}. \tag{23}$$

Hence, we have the following proposition.

Proposition 2.5 *Suppose that only the technologically efficient firm (firm 2) has the credible option for incentive delegation. Then technology licensing is less profitable compared to a situation where only the technologically inefficient firm uses the incentive delegation strategy.*

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[19] Given that firm 2 hires a manager, firm 1 does not hire a manager, provided $Z_1 > \frac{2(a-c_2)^2}{25} - \frac{(a-c_2)^2}{16}$.

Proof. See Appendix F. □

The possibility of strategic incentive delegation by the technologically efficient firm alone helps that firm to play more aggressively in the product market. Hence, it creates less incentive for gaining through licensing its technology to the technologically inefficient firm and charging an up-front fixed fee. In this case, licensing is profitable provided $c_1 \in (c_2, \hat{c_1})$, where $\hat{c_1} = \frac{2a+9c_2}{11}$. This however implies that here licensing is less (more) profitable compared to a situation with no-commitment (symmetric and negligible cost of hiring a manager).

Let us summarize the findings of this section. The findings are as follows:

1. Suppose the firms face symmetric effective costs of hiring a manager.
   (a) If the effective costs of hiring a manager are prohibitive, then technology transfers are profitable for $c_1 < \frac{2a+3c_2}{5}$.
   (b) If the effective costs of hiring a manager are negligible ($Z = 0$), then technology transfers are profitable for $c_1 < \frac{2a+11c_2}{13} (< \frac{2a+3c_2}{5})$.
   (c) If the effective costs of hiring a manager are modest, then there always exist costs of hiring a manager such that technology transfers are profitable for $c_1 < c_1'$, where $c_1' > \frac{2a+3c_2}{5}$.
2. Suppose the firms face sufficiently asymmetric effective costs of hiring a manager so that only one of these firms hires a manager under no-licensing and licensing.
   (a) If only the technologically inefficient firm hires a manager then technology licensing is profitable for $c_1 < \frac{a+2c_2}{3} (< \frac{2a+3c_2}{5})$.
   (b) If only the technologically efficient firm hires a manager then technology licensing is profitable provided $c_1 < \frac{2a+9c_2}{11} (< \frac{2a+3c_2}{5})$.

3 Capacity commitment

In this section we consider another well-known pre-commitment strategy, viz., capacity commitment. Assume that production requires capacity installation and the unit cost of capacity reflects the marginal costs of production of these firms. Consider the following game. At stage 1, the firms decide on technology licensing. Then at stage 2, the firm(s) commit to a capacity level. We consider the possibility of commitment by both firms as well as commitment by only one firm. Assume that if firm i installs capacity level up to k_i then its marginal cost of production is 0 for $q_i \leq k_i$ but its marginal cost of production equals c_i for $q_i > k_i$. One may think that different technologies require different types of inputs to produce the product and the competitive per unit costs of these inputs indicate the marginal costs of production of these firms. Alternatively, one may think that even if these firms require the same inputs to produce the product, different technologies refer to different input combinations to produce the product.[20] Then at stage 3, the firms produce outputs in a Cournot-Nash fashion.

3.1 Simultaneous capacity installation

This subsection considers the situation that after the decision on technology licensing, both firms simultaneously decide on capacity installation at stage 2. Then at stage 3, they produce simultaneously.[21] Since both firms have an option to credibly commit to an output level through the capacity choice prior to production, each of them can eliminate the strategic advantage of its competitor through capacity installation. Hence, it is optimal for these firms to install a capacity level which implies that in the output stage these firms will produce their Cournot output level corresponding to their actual marginal costs of production. Therefore, each firm commits to a capacity level up to its Cournot output level corresponding to its actual marginal cost of production c_i.[22] Thus, the possibility of simultaneous capacity installation by these firms generates equilibrium profits similar to the no-commitment equivalence model. Hence, the technology transfer decision in the simultaneous capacity choice game is similar to the no-commitment equivalence model.

Formally, under simultaneous capacity choice, industry profits in case of no-licensing and licensing are

$$\Pi_1^0 + \Pi_2^0 = \frac{(a - 2c_1 + c_2)^2 + (a - 2c_2 + c_1)^2}{9} \tag{24}$$

$$\textit{and} \quad \Pi_1^t + \Pi_2^t = \frac{2(a - c_2)^2}{9}. \tag{25}$$

Hence, the following proposition.

Proposition 3.1 *Assume that both firms can choose the capacity level simultaneously. Then the possibility of technology licensing is the same as in the no-commitment equivalence model.*[23]

The above proposition shows that given the demand and cost parameters, technology licensing occurs if and only if $c_1 \in (c_2, \frac{2a+3c_2}{5})$. Thus, the analysis of the previous section and Proposition 3.1 show the importance of different ways of commitment. In the previous section, we have shown that if both firms face the

[20] The introduction of only one component to produce the good is a simplification. One may think that production requires more than one input to produce the product. However, the result does not change if we allow the firms to choose the capacity level as well as the number of inputs consumed before the production stage. Therefore, a larger number of input consumption implies lower marginal cost at the production stage. This helps the firms to commit to the unit cost of capacity as well as to the capacity level (see Basu and Singh, 1990).

[21] Recently, Gabszewicz and Poddar (1997) consider the problem of simultaneous capacity choice in a duopoly market with demand uncertainty.

[22] The logic is similar to Tirole (1989, pp. 231–232).

[23] Given the expressions (24) and (25), the proof is similar to the Proposition 2.1.

same negligible effective cost of hiring a manager then the possibility of technology licensing is lower compared to the no-commitment equivalence model (Subsection 2.3). Since hiring a manager is a dominant strategy to these firms, both firms hire a manager and, in turn, end up with less profits compared to the no-commitment equivalence model. But, in case of capacity commitment, these firms can commit to their intended output level and each firm can credibly eliminate the strategic advantage of its competitor. Hence, the possibility of higher output is lower compared to the no-commitment equivalence model.

3.2 Sequential capacity installation

This subsection considers a game similar to the incumbent-entrant framework addressed in the literature (see, e.g., Dixit, 1980). Hence, after the decision on technology licensing at stage 1, the incumbent, at stage 2, commits to a capacity level prior to production. Then, at stage 3, these firms produce like Cournot duopolists.

Technologically inefficient firm commits

We assume that the incumbent firm is technologically inefficient. Therefore, in our framework, we consider that, at stage 2, firm 1 commits to a capacity level. It is clear that since the technologically inefficient firm alone commits to a capacity level prior to production, whenever possible firm 1 commits up to a capacity level that helps firm 1 to produce its Stackelberg leader's output corresponding to firm 1's marginal cost of production c_1 or, c_2 under no-licensing and licensing respectively. However, this is a subgame perfect capacity commitment provided the Cournot-Nash output of firm 1 producing with a marginal cost of production 0 is as much as firm 1's Stackelberg leader's output if it produces with a marginal cost of production c_i (where $c_i = c_1$ in case of no-licensing and $c_i = c_2$ in case of licensing). Now, consider the industry profits under no-licensing and licensing.

First, look at the industry profits under no-licensing. It is easy to check that in case of no-licensing firm 1 can attain its Stackelberg leader's output for $a \leq 5c_2$; but, for $a > 5c_2$, firm 1 cannot attain its Stackelberg leader's output whenever $c_1 \leq \frac{a+c_2}{6}$ and, therefore, in this situation, firm 1 commits to a capacity level up to its Cournot-Nash output with firm 1's marginal cost of production equal to 0.[24] Hence, the market size[25] plays an important role to determine the level of commitment. Both the firms, however, get positive profits always. Therefore, for $a \leq 5c_2$, the industry profit under no-licensing is given by

$$\Pi_1^0 + \Pi_2^0 = \frac{(a - 2c_1 + c_2)^2}{8} + \frac{(a - 3c_2 + 2c_1)^2}{16}. \tag{26}$$

[24] To get this condition, compare the Cournot output of firm 1 if it produces with a marginal cost of production 0 and firm 1's Stackelberg leader's output if it operates with marginal cost of production c_1.

[25] In this analysis, the intercept term of the market demand function stands for the market size.

For $a > 5c_2$ and $c_1 \geq \frac{a+c_2}{6}$, the industry profit under no-licensing is also given by the expression (26). But, for $a > 5c_2$ and $c_2 < c_1 \leq \frac{a+c_2}{6}$, the industry profit is given by

$$\Pi_1^0 + \Pi_2^0 = \frac{(a + c_2)(a - 3c_1 + c_2) + (a - 2c_2)^2}{9}. \tag{27}$$

Next, consider the industry profits under licensing. Following the above logic, it can be shown that, under licensing, firm 1 can attain its Stackelberg leader's output for $a \leq 5c_2$, but for $a > 5c_2$, firm 1 cannot attain the Stackelberg leader's output. Therefore, for $a > 5c_2$, firm 1 commits up to its Cournot-Nash output level with firm 1's marginal cost of production equals 0. Hence, for $a \leq 5c_2$, the industry profit under licensing is given by

$$\Pi_1^t + \Pi_2^t = \frac{3(a - c_2)^2}{16}. \tag{28}$$

But, for $a \geq 5c_2$, the industry profit under licensing is given by

$$\Pi_1^t + \Pi_2^t = \frac{(a - 2c_2)(2a - c_2)}{9}. \tag{29}$$

Hence, from (26)-(29), we have the following proposition.

Proposition 3.2 *Suppose the technologically inefficient firm alone commits to a capacity level before production.*
(a) The possibility of technology licensing is lower compared to the no-commitment equivalence model if the market size is sufficiently small ($a \leq 5c_2$).
(b) If the market is sufficiently large ($a > 5c_2$), then the possibility of technology licensing may be higher compared to the no-commitment equivalence model.

Proof. See Appendix G. □

Proposition 3.2 shows that if the technologically inefficient firm has the advantage of being an incumbent and can commit to the capacity level prior to production, then whether the possibility of technology licensing increases or decreases compared to the no-commitment equivalence model depends on the relative market size. Technology licensing helps the technologically efficient firm to reduce its loss-of-profit due to the aggressive behavior of the technologically inefficient firm. Further, sufficiently large market size restricts the aggressive strategy of the technologically inefficient firm. Hence, the gain from technology licensing may be such that it increases the possibility of technology licensing compared to a situation with no-commitment.

Technologically efficient firm commits

Consider a situation where the technologically efficient firm (firm 2) has the incumbency advantage and can commit to a capacity level prior to production. Like the previous case just described above, here the technologically efficient firm wants to install capacity up to its Stackelberg leader's output level corresponding to its marginal cost of production c_2 (when firm 1's marginal costs of production are c_1 and c_2 under no-licensing and licensing, respectively). But, this is a subgame perfect equilibrium provided the Cournot-Nash output of firm 2 producing with marginal cost of production 0 is as much as firm 2's Stackelberg leader's output produced with a marginal cost of production c_2. However, unlike the previous situation, here no production by firm 1 may be an outcome under no-licensing. Since the possibility of commitment helps firm 2 to pre-commit to a higher output level, this in turn, may induce firm 1 to produce zero output if the marginal cost of firm 1 is sufficiently large. Thus, we have the following lemma.

Lemma 3.1 *Consider the game under no-licensing.*
(a) If the technologically efficient firm can attain its Stackelberg leader's output then it produces $\frac{a-2c_2+c_1}{2}$ *for* $c_1 \in (c_2, \frac{a+2c_2}{3}]$ *and* $(a-c_1)$ *for* $c_1 \in [\frac{a+2c_2}{3}, \frac{a+c_2}{2})$.
(b) If the technologically efficient firm cannot attain its Stackelberg leader's output level, then it produces $\frac{a+c_1}{3}$ *for* $c_1 \in (c_2, \frac{a}{2}]$ *and* $(a-c_1)$ *for* $[\frac{a}{2}, \frac{a+c_2}{2})$.

Proof. See Appendix H. □

Lemma 3.1 considers firm 2's optimal output under no-licensing when firm 2 can or cannot attain its Stackelberg leader's output. Now, we need to know when firm 2 produces its Stackelberg leader's output under no-licensing. From firm 2's Stackelberg leader's output, i.e., $\frac{a-2c_2+c_1}{2}$, and firm 2's Cournot-Nash output with firm 2's marginal cost of production 0, i.e., $\frac{a+c_1}{3}$, we can say that firm 2 can attain its Stackelberg leader's output provided $c_1 < 6c_2 - a$. Lemma 3.1(a) shows that if firm 2 can attain its Stackelberg leader's output, it produces $\frac{a-2c_2+c_1}{2}$ or $(a-c_1)$ when $c_1 \leq \frac{a+2c_2}{3}$ or $c_1 \geq \frac{a+2c_2}{3}$, respectively. Therefore, from $c_1 \leq \frac{a+2c_2}{3}$ and $c_1 < 6c_2 - a$, we can say that firm 2 always produces its Stackelberg leader's output for $c_1 \leq \frac{a+2c_2}{3}$ provided $a \leq 4c_2$ as for $a \leq 4c_2$, $6c_2 - a \geq \frac{a+2c_2}{3}$. But, for $4c_2 < a \leq 5c_2$, firm 2 can attain its Stackelberg leader's output provided $c_1 < 6c_2 - a$ and firm 2 can never attain its Stackelberg leader's output for $a > 5c_2$.

Therefore, for $a \leq 4c_2$, industry profits under no-licensing are

$$\Pi_1^0 + \Pi_2^0 = \frac{(a-3c_1+2c_2)^2}{16} + \frac{(a-2c_2+c_1)^2}{8}, \quad \textit{for} \quad c_1 \leq \frac{a+2c_2}{3} \tag{30}$$

$$\textit{and} \quad \Pi_1^0 + \Pi_2^0 = (c_1-c_2)(a-c_1), \quad \textit{for} \quad c_1 \geq \frac{a+2c_2}{3}. \tag{31}$$

If $a > 5c_2$, then industry profits under no-licensing are

$$\Pi_1^0 + \Pi_2^0 = \frac{(a-2c_1)^2}{9} + \frac{(a+c_1)(a-3c_2+c_1)}{9}, \quad \textit{for} \quad c_1 \leq \frac{a}{2} \tag{32}$$

$$\textit{and} \quad \Pi_1^0 + \Pi_2^0 = (c_1-c_2)(a-c_1), \quad \textit{for} \quad c_1 \geq \frac{a}{2}. \tag{33}$$

But, for $4c_2 < a \leq 5c_2$, industry profits under no-licensing are given by (30) for $c_1 < 6c_2 - a$ and by (32) and (33) for $c_1 > 6c_2 - a$ as $6c_2 - a < \frac{a}{2}$ for $4c_2 < a$.

Next, consider the situation under technology licensing. Here also firm 2 wants to attain its Stackelberg leader's output but firm 2 can (cannot) attain its Stackelberg leader's output provided $a \leq (>) 5c_2$. However, under licensing, firm 1 always produces positive output in equilibrium. Hence, for $a \leq 5c_2$, industry profit under licensing is given by

$$\Pi_1^t + \Pi_2^t = \frac{3(a - c_2)^2}{16}. \tag{34}$$

But, for $a \geq 5c_2$, industry profit under licensing is given by

$$\Pi_1^t + \Pi_2^t = \frac{(a - 2c_2)(2a - c_2)}{9}. \tag{35}$$

Hence, we have the following proposition.

Proposition 3.3 *Assume that the technologically efficient firm alone commits to a capacity level prior to production. Then technology licensing possibility is minimal compared to the other situations (i.e., when both firms commit or only the technologically inefficient firm commits).*

Proof. See Appendix I. □

The incumbency advantage helps the technologically efficient firm to play more aggressively in the product market and it increases the profit of the technologically efficient firm. Hence, it reduces the incentive for licensing compared to other situations as licensing encourages more competition from the licensee.

The main findings of this section are as follows:

1. If both firms pre-commit to a capacity level prior to production then the incentive for technology licensing remains unchanged compared to the no-commitment equivalence model.
2. If only the technologically inefficient firm pre-commits to a capacity level prior to production then the technology licensing possibility is lower compared to the no-commitment equivalence model if market size is small; but, for sufficiently large market size the possibility of technology licensing is higher than in a situation with no pre-commitment.
3. If only the technologically efficient firm pre-commits to a capacity level prior to production then the technology licensing possibility is lower than in both other situations.

Table 1 shows the critical values of c_1 up to which technology transfers are profitable when the firms can pre-commit to a capacity level prior to production.

4 Conclusion

In this paper we examine the possibility of technology licensing when the firms have pre-commitment strategies. We consider a duopoly model where the licenser

Table 1

	Small market size ($a \leqq 4c_2$)	Medium market size ($4c_2 < a \leqq 5c_2$)	Large market size ($a > 5c_2$)
Both firms commit simulataneously	$(2a + 3c_2)/5$	$(2a + 3c_2)/5$	$(2a + 3c_2)/5$
Technologically inefficient firm commits	$\check{c}_1$ ($= (a + 2c_2)/3$)	$\check{c}_1$ ($= (a + 2c_2)/3$)	c_1^0 $\left(\gtreqless (2a + 3c_2)/5\right)$
Technologically efficient firm commits	$\hat{c}_1$ ($< (a + 2c_2)/3$)	$\hat{c}_1$ or, $\check{c}_1$ ($< (a + 2c_2)/3$)	$\tilde{c}_1$ ($< (2a + 3c_2)/5$)

and the licensee compete in a market and the licensee can 'imitate' or 'invent around' the licensed technology costlessly after getting it.

Section 2 considers the possibility of strategic incentive delegation. If only one firm has the ability for strategic incentive delegation or if both firms use incentive delegation strategies and the effective costs of hiring a manager are negligible then the possibility of technology transfer is lower than in a situation with no pre-commitment. Further, in this situation, the technology transfer possibility is minimal when both firms hire a manager and the effective costs of hiring a manager are negligible. But, with modest effective costs of hiring a manager, technology licensing may occur for cost parameters which do not allow licensing in the no-commitment equivalence model.

Assuming that the firm(s) pre-commit to a capacity level prior to production, we see that the possibility of technology transfer is minimal if only the technologically efficient firm commits to a capacity level. For relatively small market size, the possibility of technology transfer is maximal when both firms commit to a capacity level simultaneously or when capacity commitment is not possible. But, for sufficiently large market size, the possibility of technology transfer is maximal if only the technologically inefficient firm commits in the first stage. If these firms commit to the capacity levels simultaneously then the technology transfer possibility remains unchanged compared to its no-commitment equivalence model.

Therefore, the possibility of technology licensing depends on the relative market size, the form of commitment, the identity of the player who commits, the commitment cost and the number of firms who commit. The relationship between the possibility of technology transfer and the market size also depends on the form of commitment and on the commitment cost.

Appendix

A Proof of Proposition 2.1

Assume that (0,0) is the equilibrium both under no-licensing and licensing. Then technology licensing is profitable if and only if $\Pi_1(c_2, c_2; 0, 0) + \Pi_2(c_2, c_2; 0, 0) > \Pi_1(c_1, c_2; 0, 0) + \Pi_2(c_1, c_2; 0, 0)$. This implies that for profitable technology licensing we need

$$\frac{2(a-c_2)^2}{9} > \frac{(a-2c_1+c_2)^2}{9} + \frac{(a-2c_2+c_1)^2}{9}$$

$$\Rightarrow c_1 < \frac{2a+3c_2}{5}.$$

□

B Proof of Proposition 2.2

At $c_1 = \frac{a+2c_2}{3}$, (16) and (17) are equal. Further, we have $(\Pi_1^0 + \Pi_2^0)\mid_{c_1=c_2} = (\Pi_1^t + \Pi_2^t)$ and $(\Pi_1^0 + \Pi_2^0)\mid_{c_1=\frac{a+c_2}{2}} > (\Pi_1^t + \Pi_2^t)$. Also $(\Pi_1^0 + \Pi_2^0)$ is quadratic, continuous and convex in c_1 on the range $[c_2, \frac{a+2c_2}{3}]$ with $\frac{\partial(\Pi_1^0+\Pi_2^0)}{\partial c_1}\mid_{c_1=c_2} < 0$ and $(\Pi_1^0+\Pi_2^0)$ is positively sloped for $c_1 \in [\frac{a+2c_2}{3}, \frac{a+c_2}{2}]$ (where slope is zero at $\frac{a+c_2}{2}$). This implies that $\exists c_1 = c_1^*$ such that $(\Pi_1^0 + \Pi_2^0)\mid_{c_1=c_1^*} = (\Pi_1^t + \Pi_2^t)$. Therefore, technology transfer is profitable provided $c_1 \in (c_2, c_1^*)$. From (16)-(18), we get $c_1^* = \frac{2a+11c_2}{13} < \frac{a+2c_2}{3} < \frac{2a+3c_2}{5}$. Hence, the results. □

C Proof of Lemma 2.1

(a) Consider that $c_1 < \frac{a+2c_2}{3}$. Assume that the pre-transfer equilibrium is (0,1) and the post-transfer equilibrium is (0,0). Now technology licensing is profitable provided

$$\Pi_1(c_2, c_2; 0, 0) + \Pi_2(c_2, c_2; 0, 0) > \Pi_1(c_1, c_2; 0, 1) + \Pi_2(c_1, c_2; 0, 1),$$

$$i.e., \quad \frac{2(a-c_2)^2}{9} > k - Z$$

where, $k = \frac{(a-3c_1+2c_2)^2}{16} + \frac{(a-2c_2+c_1)^2}{8}$. Note that $k\mid_{c_1=c_2} = \frac{3(a-c_2)^2}{16} < \frac{2(a-c_2)^2}{9}$ and $k\mid_{c_1=\frac{a+2c_2}{3}} = \frac{2(a-c_2)^2}{9}$. Further, we get that k is quadratic, continuous and convex in c_1 on the cost range $[c_2, \frac{a+2c_2}{3}]$ and $\frac{\partial k}{\partial c_1}\mid_{c_1=c_2} < 0$. This implies that $\forall c_1 \in (c_2, \frac{a+2c_2}{3})$, technology transfer is profitable.

(b) Assume that the pre-transfer equilibrium is (0,1) and the post-transfer equilibrium is (1,1). In the pre-transfer situation industry profits are given by (see (9) and (10) in the text)

$$\frac{(a-3c_1+2c_2)^2}{16} + \frac{(a-2c_2+c_1)^2}{8} - Z, \quad for \quad c_1 \leq \frac{a+2c_2}{3}$$

$$\text{and} \quad (c_1 - c_2)(a - c_1) - Z, \quad \text{for} \quad c_1 \geq \frac{a + 2c_2}{3}.$$

The post-transfer industry profit is given by (see (15) in the text)

$$\frac{4(a - c_2)^2}{25} - 2Z.$$

First, assume that $c_1 \leq \frac{a+2c_2}{3}$. Denote $g = \frac{(a-3c_1+2c_2)^2}{16} + \frac{(a-2c_2+c_1)^2}{8}$ and this is quadratic, continuous and convex on the range $[c_2, \frac{a+2c_2}{3}]$ with $\frac{\partial g}{\partial c_1} \mid_{c_1=c_2} < 0$. Further, $g \mid_{c_1=c_2} = \frac{3(a-c_2)^2}{16} > \frac{4(a-c_2)^2}{25}, g \mid_{c_1=\frac{a+2c_2}{3}} = \frac{2(a-c_2)^2}{9} > \frac{4(a-c_2)^2}{25}$ and $g \mid_{min.c_1=\frac{a+10c_2}{11}} > \frac{4(a-c_2)^2}{25}$. Therefore, $\forall c_1 \in [c_2, \frac{a+2c_2}{3}], g > \frac{4(a-c_2)^2}{25} - Z$.

Now assume that $c_1 \geq \frac{a+2c_2}{3}$. Here denote $h = (c_1 - c_2)(a - c_1)$ and this is positively sloped on the range $[\frac{a+2c_2}{3}, \frac{a+c_2}{2})$ and $h \mid_{c_1=\frac{a+2c_2}{3}} > \frac{4(a-c_2)^2}{25}$.

This proves the result that in this situation technology transfer is never profitable. □

D Proof of Proposition 2.3

First we shall prove the following three results.

Result 1. Assume that $c_1 \in (c_2, \underline{c_1}]$ and $Z > \frac{7(a-c_2)^2}{400}$. Then technology transfer is profitable.

Proof of Result 1. For these values of c_1 and Z, we get (0,0) as the equilibrium both under no-licensing and licensing (see (4) and (12) in the text). Following Proposition 2.1 we can say that here technology transfer is profitable as $\underline{c_1} < \frac{2a+3c_2}{5}$.

Result 2. If $c_1 \in [\underline{c_1}, \frac{a+2c_2}{3}]$ and $Z \in (max.\{\frac{7(a-3c_1+2c_2)^2}{400}, \frac{(a-c_2)^2}{72}\}, min.\{\frac{(a-2c_2+c_1)^2}{72}, \frac{7(a-c_2)^2}{400}\})$, then technology transfer is profitable.

Proof of Result 2. Assume that $c_1 \in (\underline{c_1}, \frac{a+2c_2}{3}]$ and $Z \in (max.\{\frac{7(a-3c_1+2c_2)^2}{400}, \frac{(a-c_2)^2}{72}\}, min.\{\frac{(a-2c_2+c_1)^2}{72}, \frac{7(a-c_2)^2}{400}\})$. Therefore, under the history of no technology transfer the equilibrium is (0,1) (see (5) in the text) but there are two Nash equilibria (0,0) and (1,1) under the history of technology transfer as $Z > \frac{(a-c_2)^2}{72}$ and $Z < \frac{7(a-c_2)^2}{400}$. Now from Lemma 2.1(a) we can say that technology transfer is profitable if and only if the post-transfer equilibrium is (0,0). So, if one can get (0,0) as the Nash equilibrium after perfection and can eliminate (1,1) as the post-transfer equilibrium then technology licensing takes place. Here, we use the concept of 'forward induction' (see, Van Damme, 1989) to get the perfect equilibrium. The reason is as follows. Assume that firm 2 charges an up-front fixed fee, f, as a price for its technology so that its payoff under no technology transfer and under technology transfer are the same when the equilibrium is (0,1),[26] i.e.,

[26] Actually firm 2 charges $f - \delta$, $\delta > 0$.

$$\frac{(a-2c_2+c_1)^2}{8} - Z = \frac{(a-c_2)^2}{8} - Z + f$$

$$\Rightarrow f = \frac{(a-2c_2+c_1)^2}{8} - \frac{(a-c_2)^2}{8} > 0. \qquad (D.1)$$

This amount of f gives a signal to firm 1 that firm 2 does not want to hire a manager under technology licensing because it does not give firm 2 more payoff than its no technology transfer payoff.[27] So, firm 2 will not hire a manager, if it transfers its technology and realizing this firm 1 will not hire a manager also as $Z > \frac{(a-c_2)^2}{72}$. However, firm 2 will actually transfer its technology with this f given in (D.1) and it will be accepted by firm 1 if and only if both parties get at least their payoffs under no-licensing. First, consider the participation constraint of firm 2, i.e., firm 2 is better-off under technology transfer equilibrium if and only if

$$\frac{(a-c_2)^2}{9} + f > \frac{(a-2c_2+c_1)^2}{8} - Z$$

$$or,\ Z > \frac{(a-c_2)^2}{72} \qquad (D.2)$$

and this holds. Again it is easy to understand that here firm 2 chooses f in such a way that firm 1 accepts it because firm 2 can always choose f less than the amount specified in (D.1) so far as it satisfies firm 2's participation constraint with equality. Since, in this situation, industry profit increases compared to no-licensing, this process satisfies the participation constraints of both firms.

Result 3. Suppose that $c_1 \in [\frac{a+2c_2}{3}, \frac{a+c_2}{2}]$ and $Z \in (\frac{(a-c_2)^2}{72}, (c_1-c_2)(a-c_1) - \frac{(a-2c_2+c_1)^2}{9})$. Then technology transfer is profitable $\forall c_1 \in [\frac{a+2c_1}{3}, c_1']$ where, $c_1' = (a-c_2)(\sqrt{2}-1) + c_2 < \frac{a+2c_2}{2}$.

Proof of Result 3. Consider the values of $c_1 \in [\frac{a+2c_2}{3}, \frac{a+c_2}{2}]$ and assume that $Z \in (\frac{(a-c_2)^2}{72}, (c_1-c_2)(a-c_1) - \frac{(a-2c_2+c_1)^2}{9})$. However, for Z to be in this range, we need this interval to be non-empty, i.e., $(c_1-c_2)(a-c_1) - \frac{(a-2c_2+c_1)^2}{9} - \frac{(a-c_2)^2}{72} = P$ (say) > 0. We see that $P\ |_{c_1=\frac{a+2c_2}{3}} > 0$ but $P\ |_{c_1=\frac{a+c_2}{2}} < 0$ and P is continuous in c_1 on $[\frac{a+2c_2}{3}, \frac{a+c_2}{2}]$. So, $\exists \tilde{c_1} = \frac{9a+11c_2}{20} > \frac{a+2c_2}{3}$ such that $\forall c_1 \in [\frac{a+2c_2}{3}, \frac{9a+11c_2}{20})$ we have a non-empty interval.

Now we see that for these values of c_1 and Z, the equilibrium is (0,1) under no technology transfer but we can have (0,0) and (1,1) as equilibria under technology transfer. However, following the logic of Result 2, we can eliminate (1,1) as an equilibrium when we have two Nash equilibria (0,0) and (1,1) under licensing.

Now consider the profitability of technology transfer for $c_1 \in (\frac{a+2c_2}{3}, \frac{9a+11c_2}{20})$. Technology transfer is profitable if industry profit is greater under licensing than no-licensing, i.e.,

[27] If the equilibrium is (1,1) after the technology transfer then this amount of f makes the firm 2 worse-off relative to no technology transfer.

$$\frac{2(a-c_2)^2}{9} > (c_1-c_2)(a-c_1) - Z. \tag{D.3}$$

If (D.3) is satisfied at the maximum value of Z (i.e., at $Z = (c_1-c_2)(a-c_1) - \frac{(a-2c_2+c_1)^2}{9}$) for all $c_1 \in [\frac{a+2c_2}{3}, \frac{9a+11c_2}{20}]$, then there exists some values of Z for any c_1 in this range so that technology transfer is profitable. So $M > 0$ is the sufficient condition where,

$$M = \frac{2(a-c_2)^2}{9} - \frac{(a-2c_2+c_1)^2}{9}. \tag{D.4}$$

We have $M \mid_{c_1=\frac{a+2c_2}{3}} > 0$, $M \mid_{c_1=\frac{9a+11c_2}{20}} < 0$ and $\frac{\partial M}{\partial c_1} < 0$. Therefore, there exists some values of Z so that technology transfer is profitable for $c_1 \in (\frac{a+2c_2}{3}, c_1')$, where at c_1', $\frac{2(a-c_2)^2}{9} = \frac{(a-2c_2+c_1)^2}{9}$. This implies that

$$c_1' = (a-c_2)(\sqrt{2}-1) + c_2.$$

We get the proposition by combining the above three results. □

E Proof of Proposition 2.4

From (19) and (20) we see that $(\Pi_1^0 + \Pi_2^0)$ is quadratic, convex and continuous in $c_1 \in [c_2, \frac{a+c_2}{2}]$. Also we have $(\Pi_1^0+\Pi_2^0) \mid_{c_1=c_2} = (\Pi_1^t+\Pi_2^t)$, $(\Pi_1^0+\Pi_2^0) \mid_{c_1=\frac{a+c_2}{2}} > (\Pi_1^t + \Pi_2^t)$ and $(\Pi_1^0 + \Pi_2^0) \mid_{c_1=\frac{a+2c_2}{3}} = (\Pi_1^t + \Pi_2^t)$. Further, $\frac{\partial(\Pi_1^0+\Pi_2^0)}{\partial c_1} \mid_{c_1=c_2} < 0$. This implies that $\forall c_1 \in (c_2, \frac{a+2c_2}{3})$, technology transfer is profitable. Further, $\frac{2a+3c_2}{5} > \frac{a+2c_2}{3} > \frac{2a+11c_2}{13}$. □

F Proof of Proposition 2.5

From (21), (22) and (23) we see that $(\Pi_1^0 + \Pi_2^0) \mid_{c_1=c_2} = (\Pi_1^t + \Pi_2^t)$, $(\Pi_1^0 + \Pi_2^0) \mid_{c_1=\frac{a+c_2}{2}} > (\Pi_1^0 + \Pi_2^0) \mid_{c_1=\frac{a+2c_2}{3}} > (\Pi_1^t + \Pi_2^t)$. Further, $(\Pi_1^0 + \Pi_2^0)$ is quadratic, convex and continuous in c_1 on $[c_2, \frac{a+c_2}{2}]$ and $\frac{\partial(\Pi_1^0+\Pi_2^0)}{\partial c_1} \mid_{c_1=c_2} < 0$. This implies that $\exists c_1 = \hat{c}_1$ so that $(\Pi_1^0+\Pi_2^0) \mid_{\hat{c}_1} = (\Pi_1^t+\Pi_2^t)$ and for $c_1 \gtreqless \hat{c}_1$, $(\Pi_1^0+\Pi_2^0) \gtreqless (\Pi_1^t + \Pi_2^t)$. From (21)-(23) we get that $\hat{c}_1 = \frac{2a+9c_2}{11}$ and $\frac{2a+11c_2}{13} < \frac{2a+9c_2}{11} < \frac{a+2c_2}{3}$. □

G Proof of Proposition 3.2

(a) In this situation, the payoffs under (26) and (28) are the same to the payoffs under (19) and (20). Hence, the proof is similar to the Proposition 2.4 and here technology transfer takes place for $c_1 < \check{c}_1 = \frac{a+2c_2}{3}$.

(b) From (27) we see that $(\Pi_1^0 + \Pi_2^0)$ is negatively sloped with respect to c_1, $\forall c_1 \in [c_2, \frac{a+c_2}{6}]$ with $(\Pi_1^0 + \Pi_2^0) \mid_{c_1=c_2} = (\Pi_1^t + \Pi_2^t)$ and $(\Pi_1^0 + \Pi_2^0) \mid_{c_1=\frac{a+c_2}{6}} <$

$(\Pi_1^t + \Pi_2^t)$. Further, for $c_1 \geq \frac{a+c_2}{6}$, the relevant expression for $(\Pi_1^0 + \Pi_2^0)$ is (26) and here $(\Pi_1^0 + \Pi_2^0)$ is quadratic, convex and continuous in c_1 on $[\frac{a+c_2}{6}, \frac{a+c_2}{2}]$ with $(\Pi_1^0 + \Pi_2^0)\mid_{c_1=\frac{a+c_2}{2}} > (\Pi_1^t + \Pi_2^t)$. This implies $\exists c_1 = c_1^0 \in (c_2, \frac{a+c_2}{2})$ so that $\forall c_1 \in (c_2, c_1^0)$ technology transfer takes place. Further, we see that $(\Pi_1^0 + \Pi_2^0)\mid_{c_1=\frac{a+2c_2}{3}} < (\Pi_1^t + \Pi_2^t)$ and

$$(\Pi_1^0 + \Pi_2^0)\mid_{c_1=\frac{2a+3c_2}{5}} \;\gtreqless\; (\Pi_1^t + \Pi_2^t) \;\; (compare \;\; (26) \;\; and \;\; (29))$$

$$as \;\; 0 \;\gtreqless\; 53a^2 + 53c_2^2 - 506ac_2. \tag{G.1}$$

RHS of (G.1) is increasing in a for $a > 5c_2$. At $a \to 5c_2$, we get RHS of (G.1) is negative. This implies that $c_1^0 < \frac{2a+3c_2}{5}$. But $\exists a$ such that RHS of (G.1) is positive, which in turn, implies that $c_1^0 > \frac{2a+3c_2}{5}$. For example, at $a = 6c_2$, RHS of (G.1) is negative but for $a = 10c_2$, RHS of (G.1) is positive.

Therefore, in this case, licensing is profitable if and only if $c_1 \in (c_2, c_1^0)$, where $c_1^0 > \frac{a+2c_2}{3}$ but $c_1^0 \gtreqless \frac{2a+3c_2}{5}$. □

H Proof of Lemma 3.1

Consider the situation under no-licensing. If firm 2 can attain its Stackelberg leader's output then optimal outputs of firm 1 and firm 2 are respectively

$$q_1 = \frac{a - 3c_1 + 2c_2}{4} \;\; and \;\; q_2 = \frac{a - 2c_2 + c_1}{2}. \tag{H.1}$$

Assume that firm 2 faces 0 marginal cost of production. Then the Cournot-Nash outputs of firm 1 and firm 2 are

$$q_1 = \frac{a - 2c_1}{3} \;\; and \;\; q_2 = \frac{a + c_1}{3}. \tag{H.2}$$

Further, the maximization problem of firm 1 is

$$\max_{q_1}(a - q_1 - q_2 - c_1)q_1. \tag{H.3}$$

Maximization of (H.3) gives us the first order condition as

$$q_1 = \frac{a - c_1 - q_2}{2}. \tag{H.4}$$

From (H.4), it is clear that firm 1 does not produce any positive output for $q_2 \geq (a - c_1)$. If firm 1 produces 0 output, then firm 2 has no incentive to increase its output from $(a - c_1)$ since this amount is greater than the unconstrained[28] monopoly output of firm 2, i.e., $\frac{a-c_2}{2}$.

[28] We use the term unconstrained to imply if there is no other (potential) firm in the market except firm 2.

(a) Assume that firm 2 can attain its Stackelberg leader's output, i.e., $\frac{a+c_1}{3} \geq \frac{a-2c_2+c_1}{2}$. Since, firm 1 does not produce positive output for $q_2 \geq (a-c_1)$, the optimal output of firm 2 is $min.\{\frac{a-2c_2+c_1}{2}, (a-c_1)\}$. Further, $(a-c_1) \gtreqless \frac{a-2c_2+c_1}{2}$ as $c_1 \lesseqgtr \frac{a+2c_2}{3}$.

(b) Assume that firm 2 cannot attain its Stackelberg leader's output, i.e., $\frac{a-2c_2+c_1}{2} > \frac{a+c_1}{3}$. Since, firm 1 does not produce positive output for $q_2 \geq (a-c_1)$, the optimal output of firm 2 is $min.\{\frac{a+c_1}{3}, (a-c_1)\}$. Further, $(a-c_1) \gtreqless \frac{a+c_1}{3}$ as $c_1 \lesseqgtr \frac{a}{2}$. □

I Proof of Proposition 3.3

Assume that the market size is sufficiently small, i.e., $a \leq 4c_2$. In this situation, the payoffs under (30), (31) and (34) are the same to the payoffs under (21), (22) and (23). Hence, the proof is similar to the Proposition 2.5 and here technology transfer takes place if and only if $c_1 < \hat{c_1} = \frac{2a+9c_2}{11} < \frac{a+2c_2}{3}$.

Next, consider that the market size is fairly large, i.e., $a > 5c_2$. From (33) and (35) we see that $(\Pi_1^0 + \Pi_2^0) \mid_{c_1=\frac{a}{2}} > (\Pi_1^t + \Pi_2^t)$. Further, from (33) it is clear that $\frac{\partial(\Pi_1^0+\Pi_2^0)}{\partial c_1} > 0$, $\forall c_1 \in [\frac{a}{2}, \frac{a+c_2}{2})$. Therefore, $\forall c_1 \in [\frac{a}{2}, \frac{a+c_2}{2})$, technology transfer never takes place.

From (32) we find that $(\Pi_1^0 + \Pi_2^0)$ is quadratic, continuous and convex in c_1 on the range $[c_2, \frac{a}{2}]$. Also, $(\Pi_1^0 + \Pi_2^0) \mid_{c_1=c_2} = (\Pi_1^t + \Pi_2^t)$. Further, (32) and (35) show that

$$(\Pi_1^t + \Pi_2^t) \gtreqless (\Pi_1^0 + \Pi_2^0) \text{ if and only if } \frac{2a-2c_2}{5} \gtreqless c_1$$

and $\frac{2a-2c_2}{5} < \frac{2a+3c_2}{5}$. Therefore, here licensing is profitable for $c_1 \in (c_2, \tilde{c_1} = \frac{2a-2c_2}{5})$.

Further, from (26) and (29) (as here $\frac{2a-2c_2}{5} > \frac{a+c_2}{6}$), one can see that at $c_1 = \frac{2a-2c_2}{5}$, technology transfer is profitable when only the technologically inefficient firm can commit. It shows that the possibility of technology licensing is lower when only the technologically efficient firm commits compared to a situation where only the technologically inefficient firm commits.

Finally, consider that $4c_2 < a \leq 5c_2$. Assume that the relationship between a and marginal costs of production are such that $\hat{c_1} < 6c_2 - a$. Then the possibility of technology transfer is the same to the one shown above for fairly small market size $(a \leq 4c_2)$.

If $\hat{c_1} > 6c_2 - a$ then for $c_1 > 6c_2 - a$, one has to compare (32) and (33) with (34). Since the procedure is similar to the cases mentioned above (i.e., in $a \leq 4c_2$ and $a > 5c_2$), we are not repeating it here. However, even in this situation technology transfer takes place provided c_1 is less than a critical value, say $\check{c_1}$. This $\check{c_1}$ is less than $\frac{a+2c_2}{3} < \frac{2a+3c_2}{5}$ as from (32) and (34) (as here $\frac{a}{2} > \frac{a+2c_2}{3}$), we get that at $c_1 = \frac{a+2c_2}{3} (< \frac{2a+3c_2}{5})$, technology transfer is unprofitable. Hence, the possibility of technology transfer is lower compared to a situation where only the technologically inefficient firm pre-commits. This proves the result. □

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