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Technology Transfer in a Duopoly with Horizontal and Vertical Product Differentiation

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Abstract

This paper discusses licensing agreements between duopolistic firms in a model of horizontal and vertical product differentiation. It is shown that a profitable technology transfer deal under a fee contract can be signed if and only if the quality differential is sufficiently larger than the technology differential. Technology transfer under a royalty contract, however, does not require such a condition. The paper also examines the possibility of trading a better technology for a superior quality. Finally, we show that the existence of a sufficiently high trading cost (in an open economy) can always make a fee transfer mutually profitable. The paper also provides a welfare analysis.

Key words: Technology transfer, horizontal differentiation, vertical differentiation, trading costs, licensing contracts.

JEL classifications: D43, F12, L13.

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1. Introduction

Technology transfer between two firms within a country or across countries is a common practice in almost all industries; by this both the transferor and the transferee can gain from the use of superior production knowledge. Technology transfer literature is already vast and it deals with various issues.[1] But the existing analysis presumes that the products are either homogeneous or horizontally differentiated. *No works so far have considered the possibility of technology transfer when the products are both horizontally and vertically differentiated.* So the purpose of the present paper is to examine the possibility of technology transfer between two asymmetric firms when the products have both these dimensions. Vertical differentiation reflects that the competing firms produce distinct quality levels, and consumers perfectly perceive the quality difference and hence are willing to pay a higher price for the higher quality. And horizontal differentiation is characterized by different locations of the firms in a Hotelling (1929) linear city; it also reflects consumers' preferences for different brands in the product space. In such a model, given that the consumers are distributed along the city, a particular location of a consumer reflects the consumer's choice for an ideal variant of the product, and to the extent his actual choice differs from his ideal position, he perceives a loss of utility.

We restrict to the scenario where both the pre-transfer and the post-transfer market structures are duopoly of the competing firms. By this we focus our attention on those technology transfer agreements which are self enforceable. So we don't need any institutional assumption to enforce the contract. Perhaps it could be optimal for the transferor to transfer its superior knowledge at an appropriate price and leave the market to the transferee. But in the absence of an effective institutional arrangement, there is a commitment problem, because the transferor always has an incentive to enter the market once the agreement has been signed. Hence in our analysis the post-transfer market structure is duopoly and the patentee is an insider.

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[1] Such issues are, for instance, strategic technology transfer (Gallini (1984), Rockett (1990a)), obsolete technology transfer (Rockett (1990b), Kabiraj and Marjit (1993)), transfer under asymmetric information (Gallini and Wright (1990), Beggs (1992), Choi (2001)), optimal licensing contracts (Kamien and Tauman (1986, 2002), Katz and Shapiro (1986), Mukherjee and Balasubramanian (2001), Wang (1998, 2002), Kabiraj (2005)).

In our study we mostly focus our attention on a fixed fee contract, although we also discuss the question of technology transfer under royalty contracts. One reason is that under royalty contracts vertical product differentiation does not play any special role in our model. There are other reasons. In a static one period model like ours, technology licensing is equivalent to technology sale; hence only an upfront fee payment should naturally arise. In a royalty contract royalty payment occurs only at the end of the production period. Then without any institutional assumption a royalty contract cannot be implemented credibly. Further, in a model of duopoly where patentee is an insider, generally either fee contracts are not profitable or royalty contracts strictly dominates fee contracts, because technology transfer under a fee contract increases competitiveness of the transferee, whereas under a royalty contract the transferor can keep the competitiveness of the rival under check (for instance, see Kamien and Tauman (1984, 1986, 2002), Katz and Shapiro (1986), Kamien et al. (1992), Wang (1998), and Wang and Yang (1999)). Hence it is an open question whether a fixed fee contract is at all feasible in a model where products are vertically and horizontally differentiated, and if feasible, under what conditions.[2] Finally, in the empirical literature there is evidence to show that technology transfer agreements involving only fixed fee have been signed (e.g., Rostoker (1984)).

One important question that we like to examine in this context is the following. Can there be a technology transfer agreement between two firms if the same firm owns superior production technology as well as superior product quality? This is a hypothesis which needs verification empirically. In our setting we show that in a closed economy framework, or in an open economy with no trade or tariff restrictions, a high-quality low-cost firm has no incentive to share its technology with a low-quality high-cost firm. The reason is that the firm having advantages in both product quality and technoloy already owns a large market share; in such a situation transfer of technology to the inefficient rival will erode the transferor's market share significantly. Therefore, in our model it is

[2] There is a literature that assumes that licensing results in a shift of market demand and when such a shift is sufficient, technology transfer becomes profitable (e.g., Shepard (1987), and Boivin and Langinier (2005)).

necessary that, given that one firm has technological advantage, the other firm must have superiority in other respect.[3] In an open economy when a foreign firm holds a superior production technology, a tariff or trade restriction will benefit the local firm and hence relax the condition of transfer. We show that there always exists a trade cost, sufficiently high, that makes technology transfer mutually profitable for both firms, irrespective of their product qualities.[4] The reason is that by transferring a superior technology to the local firm, the foreign firm can otherwise capture at least a part of the trading costs of the consumers in the form of technology transfer fee. To the extent liberalization reduces trading costs, it also reduces the possibility of transfer of superior quality or knowledge. In a duopoly with homogeneous goods Marjit (1990) has shown that technology transfer between two firms is profitable if and only if the firms are reasonably close in terms of their initial technologies. Mukhopadhyay, et al. (1999) reexamine the question in the presence of product differentiation and behavioral interactions other than Cournot conjectures. It is shown that if the initial situation is one of near collusion, or the products are sufficiently (horizontally) differentiated, a profitable technology transfer deal between the firms always exists, whatever be the initial technological gap. On the other hand, if product differentiation is of Hotelling type, as in Poddar and Sinha (2004), then there will be no technology transfer under the fee contract. In contrary, in our model, with products being horizontally and vertically differentiated, for technology transfer to be profitable we need the quality differential to be sufficiently large.

Generally, a firm producing a higher quality product has a larger unit cost of production, but this may not always be the case for all products. For instance, a firm may be an original entrant in a market, and another firm may be an imitator. The latter is capable to imperfectly imitate the product and process, so ends up with higher cost and lower quality. If a firm has control over some critical resources (or even `better people'), then it is possible to produce a higher quality at a lower cost. Therefore, to discuss the question of technology transfer in our framework, we assume that the quality of the

[3] But such a condition is not necessary for technology transfer to be profitable under royalty contracts (see the analysis in section 4).

[4] In a Cournot duopoly with homogeneous goods Kabiraj and Marjit (2003) have shown that a tariff restriction can be chosen strategically such that technology transfer becomes feasible and consumers' welfare goes up (see also Mukherjee and Pennings (2006)).

product and the unit cost of production are independent. To be more precise, there is a firm which holds an inferior technology of producing a higher quality product compared to a firm which holds a better production process but produces a relatively inferior quality. Such a scenario is obviously possible if we assume that product innovations and process innovations are independent. In particular, assume that the quality of a product depends on the choice of a vector X, whereas the unit cost of production depends on the choice of a vector Y, where X contains relevant information related to innovation of the product, and Y contains information for process innovation. Note that the cost of innovating a higher product quality should always be larger, but this does not matter to us because we are not modeling innovation in this paper. We start with the situation where product qualities are already given to the respective firms, and assume that a given quality product can be produced by different processes. In the context of technology transfer, innovation cost is sunk.

Since we assume that the quality of the product is independent of the unit cost of production, this also permits us to discuss the possibility of transfer of knowledge associated with the higher quality (to distinguish it from the technology transfer we call this transfer of product knowledge), and in particular, to examine whether cross licensing of advantages between the firms will be profitable. As far as product knowledge transfer is concerned, our basic result is the same, that is, for a profitable knowledge transfer (in a situation of zero trade restriction) it is necessary that the firm which owns a superior product quality does not, at the same time, hold the low-cost production technology. Given that each firm has advantage in one direction, there are situations where only technology transfer or only knowledge transfer is profitable. And again there are situations where transfer of each of these is profitable. But in our model the firms have no incentive to trade a better technology for a better quality.

We have also studied welfare implications of technology transfer and knowledge transfer associated with production of a better quality. A profitable transfer implies that no firm is worse off and at least one firm comes up with a higher profit. Therefore, producers' surplus as a whole must go up. Consumers also benefit, because in case of technology transfer both firms use the low-cost technology, and given price competition, prices of all products fall; moreover, some consumers can now buy a better quality product; and in case of product knowledge transfer, the better quality results in a higher consumer welfare.

The setup of the paper is the following. In the second section we provide the model: in subsection 2.1 and 2.2 we examine the possibility of technology transfer and product quality transfer respectively; subsection 2.3 examines whether cross-licensing of each other's advantages can be mutually profitable; and subsection 2.4 studies the welfare effect of such a transfer. Section 3 derives an implication of the existence of a trade cost in the context of technology transfer between two firms across borders. In section 4 we discuss technology transfer under royalty contracts. Section 5 concludes the paper.

2. Model

Consider a differentiated duopoly where two firms, call firm 1 and 2, are competing in prices. The products have two dimensions: products are vertically as well as horizontally differentiated.[5]

Vertical differentiation is captured by the consideration that the firms produce two distinct product qualities, exogenously specified and denoted by θ_1 and θ_2 ; $\theta_i \geq 0$. Obviously, $\theta_1 = \theta_2$ means that both the firms produce the same quality products. And $\theta_i > \theta_j$ implies that the i^{th} firm produces the superior quality product.[6] The qualities are perfectly perceived by the consumers.

[5] Here we follow the framework of Garella (2003) characterizing a duopoly with products differentiated horizontally and vertically. The paper develops an R&D model and shows that that the implementation of a minimum quality standard induces the high quality producer to lower its quality level if the consumers have strong horizontal preferences.

[6] In the Hotelling structure vertical product differentiation may be introduced in terms of differential transport cost (see, for instance, Ferreira and Thisse (1996)).

Horizontal differentiation is characterized by the different locations of the firms in a Hotelling linear city. To interpret it otherwise, it implies distribution of consumers' preference for these two products in the product space. We assume that the length of the city is unity and the firms are located at the opposite end points; in particular firm 1 is located at $x = 0$ and firm 2 at $x = 1$.

Consumers are assumed to be uniformly distributed over the length of the city, and each consumer has an address or ideal variant characterized by $x \in [0,1]$. Then a consumer at an address x, who fails to obtain his ideal variant, faces a cost of tx when he buys from firm 1, and $t(1-x)$ when buys from firm 2. Therefore, $t > 0$ is just like a transport cost of travel per unit distance. We further assume that each consumer buys exactly one unit of the products and that the market is fully covered. He buys the product of the firm which brings him the largest net utility, that is, gross utility minus the costs of acquiring it. The costs comprise of the product price and the loss of utility (that is, travel cost) for not buying the ideal variant. Total number of consumers is normalized to be 1.

We assume that the net utility of consuming one unit of the product is additively separable in the vertical and horizontal dimensions, and this is given by:

$$u = \begin{cases} v + \theta_1 - tx - p_1 & \text{if to buy from firm 1} \\ v + \theta_2 - t(1-x) - p_2 & \text{if to buy from firm 2} \end{cases} \tag{1}$$

where $v > 0$ denotes the basic utility, same for all consumers, and p_i is the unit price charged by firm i.

Then for a consumer, $\bar{x}$, who is indifferent between firm 1 and firm 2's products, we have $u(\theta_1, p_1) = u(\theta_2, p_2)$. This gives

$$\bar{x} = \frac{1}{2t}\left[t + \theta_1 - \theta_2 + p_2 - p_1\right] \tag{2}$$

Therefore, demand for firm 1's product is $D_1(p_1, p_2) = \bar{x}$ and that for firm 2's product is $D_2(p_1, p_2) = 1 - \bar{x}$.

We assume that the unit cost of production is constant and independent of the quality level, and the cost associated with the quality is already sunk.[7]

Let c_i be firm i's unit production cost. This gives the profit function of firm i as:

$$\Pi_i\,(p_1, p_2) = (p_i - c_i)\; D_i(p_1, p_2) \quad i = 1, 2 \tag{3}$$

The corresponding two reaction functions in prices are:

$$\begin{aligned} 2p_1 - p_2 &= t + c_1 + \theta_1 - \theta_2 \\ -p_1 + 2p_2 &= t + c_2 + \theta_2 - \theta_1 \end{aligned}$$

We assume that these reaction functions intersect in the positive quadrant. Therefore, the pre-technology transfer prices are obtained by solving these reaction functions simultaneously[8] (second order conditions are also satisfied). These are

$$\begin{aligned} p_1^* &= \frac{1}{3}\left[3t + \theta_1 - \theta_2 + 2c_1 + c_2\right] \\ p_2^* &= \frac{1}{3}\left[3t + \theta_2 - \theta_1 + c_1 + 2c_2\right] \end{aligned} \tag{4}$$

The corresponding market shares and pre-transfer profit levels in equilibrium are:

$$\begin{aligned} D_1^* &= x^* = \frac{1}{6t}\left[3t + \theta_1 - \theta_2 + c_2 - c_1\right] \\ D_2^* &= 1 - x^* = \frac{1}{6t}\left[3t + \theta_2 - \theta_1 + c_1 - c_2\right] \end{aligned} \tag{5}$$

$$\begin{aligned} \Pi_1^* &= \frac{1}{18t}\left[3t + \theta_1 - \theta_2 + c_2 - c_1\right]^2 \\ \Pi_2^* &= \frac{1}{18t}\left[3t + \theta_2 - \theta_1 + c_1 - c_2\right]^2 \end{aligned} \tag{6}$$

It is assumed that under the given parameters both D_1^* and D_2^* are positive[9]. The profit expressions tell that each firm's profit is inversely related to its unit cost but directly related to the rival's unit cost. Therefore if technology transfer occurs from the low cost to the high cost firm, the payoff of the low cost firm will fall whereas that of the high cost

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[7] We have already discussed this in the introduction. If production of a higher quality product involves a larger unit cost, then our hypothesis is that there will be no technology transfer if the transferor and the transferee compete in the same market. Proposition 1 clearly proves the result.

[8] d'Aspremont et al. (1979) have shown the problem of non-existence of equilibrium in Hotelling model with linear transport cost when both prices and location of firms are variable.

[9] In particular, we assume $t > \max\{(1/3)(\theta_2 - \theta_1 + c_1 - c_2), (1/3)(\theta_1 - \theta_2 + c_2 - c_1)\}$.

firm will go up. Hence the question is: Can there be a profitable technology transfer agreement between the firms? In the next section we discuss the question under a fixed fee contract, that is, whether there exists a fee $L > 0$ such that a mutually profitable technology transfer deal can be signed. We shall also study the welfare implication of such a transfer.

2.1 Technology Transfer under the Fee Contract

Let us assume $c_1 \neq c_2$ and consider the possibility of technology transfer from the low cost firm to the high cost firm under a fee contract. The decisions of the firms are the following. First, the most efficient firm decides whether to transfer its technology to the less efficient firm, given the product qualities of the firms. Second, the firms compete in prices. Hence if technology transfer occurs, the market structure will remain to be duopoly with symmetric production technology (with each firm having low unit cost of production). Then the market-operated profits of the firms will be:

$$\begin{aligned} \tilde{\Pi}_1 &= \frac{1}{18t}\left[3t + \theta_1 - \theta_2\right]^2 \\ \tilde{\Pi}_2 &= \frac{1}{18t}\left[3t + \theta_2 - \theta_1\right]^2 \end{aligned} \tag{7}$$

Immediately, we have the following results.

Proposition 1:

(a) *There will be no technology transfer agreement under the fee contrtact if the most efficient firm also possesses the superior quality of the product. Formally, there does not exist* $L > 0$ *if simultaneously* $c_i < c_j$ and $\theta_i > \theta_j$ *hold.*

(b) *A technology transfer agreement is profitable under the fee contract if and only if their product quality differential is sufficiently larger than the technology differential. Formally, if* $c_j > c_i$, $\exists L > 0$ *iff* $2\,(\theta_j - \theta_i) > c_j - c_i$.

Proof: Part (a) is clearly proved if the condition underlying part (b) holds.

To prove part (b), without loss of generality assume $c_i < c_j$. Then technology transfer under the fixed fee contract is mutually profitable if and only if the following two conditions hold simultaneously, that is,

$$L + \tilde{\Pi}_i > \Pi_i^* \quad \text{and} \quad \tilde{\Pi}_j - L > \Pi_j^*$$

Therefore,

$$\exists L > 0 \;\; iff \;\; \tilde{\Pi}_i + \tilde{\Pi}_j > \Pi_i^* + \Pi_j^* \tag{8}$$

Given the payoffs, as defined in (6) and (7), the condition can be simplified to get

$$2\,(\theta_j - \theta_i) > c_j - c_i \,. \;\square \tag{9}$$

First note that the technology transfer agreement under the fixed fee contract is mutually profitable if and only if the post-transfer industry payoff is larger than the pre-transfer industry payoff (this is condition (8)). This is naturally required because otherwise the transferee will not be in a position to compensate the loss of the transferor. Then (9) tells that a technology transfer agreement with a fixed fee contract is never mutually profitable if the firm possessing superior technology also produces superior quality products. One implication of the result is the following. If a firm competes in a market with a superior quality product and at the same time possesses a superior production process, then it has no incentive to transfer its technology to its rival, because it already occupies a large market share. Thus our model provides a testable hypothesis: Will a firm, which competes with a superior quality product and possesses a better method of production, transfer its production technology to its rival? To explain the condition further, given the technological difference between the firms, technology transfer is mutually profitable if and only if $\theta_j - \theta_i$ is sufficiently large, that is, the products are sufficiently (vertically) differentiated. On the other hand, if the products are not sufficiently differentiated, the technology transfer deal is profitable if and only if the initial technological differences between the firms are not too large.

Therefore, what we really need is that the difference between qualities of products is sufficiently larger than the difference between technologies. Poddar and Sinha (2004) show that if the product differentiation is of Hotelling type, technology transfer under a fixed fee is never profitable. Note that Poddar and Sinha model is a special case of our model when both firms have the same quality products.[10] With both horizontal and vertical differentiations, our model shows that mutually profitable technology transfer with fixed fee can occur.

Intuition of the result is the following. If technology transfer occurs in a Cournot duopoly with homogeneous goods, the transferee gains from the use of superior production technology and the transferor suffers a loss due to increased competition. However, the extent of loss and gain depends on the pre-transfer market shares of the firms, which, in turn, depends on the asymmetry of technologies. If the technological asymmetry is too large, the efficient firm will have a larger market share compared to the inefficient firm. Then transfer of technology means that the transferor will have a greater amount of loss than the increased profit of the transferee. Under this situation transfer is not profitable under the fixed fee contract. But if the firms are close in terms of their technologies, the efficiency effect will dominate the competitive effect and the post-transfer industry payoff will go up making such a transfer mutually profitable. On the other hand, when the firms compete with differentiated products, competition becomes relaxed, and as a result technology transfer can be profitable even if their technologies are not close enough, provided that the degree of product differentiation is sufficiently large. Obviously, there will be no technology transfer under price competition with homogeneous goods.

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[10] The Poddar and Sinha model, like the present model, assumes uniform distribution of consumers over the length of the city. We may generalize the distribution assumption. Let $F(x)$ be the distribution over [0,1] interval. Then the profit functions of the firms are: $\pi_1 = (p_1 - c_1)F(\bar{x})$ and $\pi_2 = (p_2 - c_2)(1 - F(\bar{x}))$ where $\bar{x}$ is the indifferent consumer. Now if $c_2 < c_1$, then technology transfer from low cost firm to high cost firm will be profitable only if $\partial(\pi_1^* + \pi_2^*)/\partial c_1 < 0$. But $\partial(\pi_1^* + \pi_2^*)/\partial c_1 = -F(x^*) + (p_1^* - c_1) f(x^*) \underset{(+)}{(\partial x^* / \partial p_2)} \underset{(+)}{(\partial p_2^* / \partial c_1)} - (p_2^* - c_2) f(x^*) \underset{(-)}{(\partial x^* / \partial p_1)} \underset{(+)}{(\partial p_1^* / \partial c_1)}$.

In Hotelling model with uniform F, the last two terms dominate the first term and hence technology transfer is not profitable. However, with non-uniform distribution, there can be situations where the first term will dominate the last two terms, and the technology transfer can be profitable. In our model we have introduced vertical differentiation that increases x^* and hence $F(x^*)$, giving the possibility of technology transfer.

Now consider price competition with products horizontally differentiated in Hotelling sense (products are otherwise physically identical). In such a situation both the firms will have a positive profit even if they would have identical technologies. So initial asymmetry in technologies means that the superior technology owning firm will have a larger market share, given price competition. Now, if technology transfer would take place, both firms would compete on equal footing and price competition means that the transferor cannot extract a large enough profit from the transferee so as to overcompensate the loss of its payoff due to competition. Thus under spatial differentiation with price competition, technology transfer is not profitable. But if the high cost firm produces superior quality products, it can overcome to some extent the disadvantage of having an inefficient technology and thereby improve its market share. Then when technology transfer occurs, if the transferee has initially a sufficiently high product quality and so substantially a large market share, transferee's operated payoff goes up substantially in the post-transfer situation and hence the transferor can extract a larger payoff from the transferee by means of a fixed fee. Thus when the transferee produces sufficiently high quality relative to that of the transferor, technology transfer becomes mutually profitable.

2.2 Product Knowledge Transfer

In this paper the unit production cost and the quality of the product are independent. Moreover, each firm's profit is directly related to its own product quality and inversely related to the rival's product quality (see (6)). Therefore, we may think of the possibility of transferring the associated knowledge of producing the high quality from the high quality producing firm to the low quality producing firm. In the post-transfer situation, both the firms will operate with the high quality products. So when $\theta_1 \neq \theta_2$, our question is: Will such knowledge transfer be profitable to the firms under the fee contract? The post-transfer payoffs of the firms will be

$$\overline{\Pi}_1 = \frac{1}{18t}\left[3t + c_2 - c_1\right]^2$$
$$\overline{\Pi}_2 = \frac{1}{18t}\left[3t + c_1 - c_2\right]^2 \qquad (10)$$

We can easily show that $\overline{\Pi}_i + \overline{\Pi}_j > \Pi_i^* + \Pi_j^*$ if and only if

$$2\ (c_j - c_i) > \theta_j - \theta_i \qquad (11)$$

Therefore, for knowledge transfer to be profitable it is necessary that the superior quality producing firm has an inefficient method of production. And then we need that the technology differential must be sufficiently large compared to the product quality differential. Interpretation of the result is similar to the previous case. *The crucial requirement is that the potential transferee should have sufficiently large market share in the pre-transfer situation*. Further observe that conditions (9) and (11) may or may not hold simultaneously. Therefore it is possible to have a scenario where only knowledge transfer is profitable but technology transfer is not. This is the case when

$$2\ (c_j - c_i) > (1/2)\ (c_j - c_i) \geq \theta_j - \theta_i \qquad (12)$$

2.3 Cross-Licensing

In the last two subsections we have noted that for technology transfer or for product knowledge transfer it is necessary that if one firm has superiority in production technology, the other firm must produce a better quality. Therefore, given that each firm has some advantage over its rival (either in quality or in technology), we may then ask the question: Can the firms gain by combining their respective advantages, that is, by sharing their superior technology as well as knowledge of producing superior quality? The firms generally reap that benefit by cross-licensing their respective advantages. In our model, however, cross-licensing is not profitable to the firms. Let us write the result formally.

Proposition 2: *Given* $c_i < c_j$ *and* $\theta_i < \theta_j$, *cross-licensing technology and quality will never be profitable.*

Under cross-licensing both the firms become identical. Then the result follows because under cross-licensing the industry profit (derived using (6)) is $(1/18t)[3t]^2 < \pi_1^* + \pi_2^*$. The simple intuition of the result is that once the firms have the same quality of goods, the fierce price competition will drive their profits to a low level.

2.4 Welfare Implications

We now discuss welfare implications of technology transfer and product knowledge transfer in our model. First consider technology transfer. Let us assume

$$c_2 < c_1 \text{ and } 2\,(\theta_1 - \theta_2) > c_1 - c_2 \tag{13}$$

Under this condition, technology transfer from firm 2 to firm 1 is mutually profitable. This means, the industry profit is larger in the post transfer situation. Therefore, producers' surplus as a whole goes up. To see the effect on consumers' welfare, note that in the post-transfer situation the prices and market shares of the firms are:

$$\begin{aligned} \tilde{p}_1 &= \frac{1}{3}\left[3t + \theta_1 - \theta_2 + 3c_2\right] \\ \tilde{p}_2 &= \frac{1}{3}\left[3t + \theta_2 - \theta_1 + 3c_2\right] \end{aligned} \tag{14}$$

$$\begin{aligned} \tilde{D}_1 &= \tilde{x} = \frac{1}{6t}\left[3t + \theta_1 - \theta_2\right] \\ \tilde{D}_2 &= 1 - \tilde{x} = \frac{1}{6t}\left[3t + \theta_2 - \theta_1\right] \end{aligned} \tag{15}$$

Clearly, $\tilde{p}_i < p_i^* \;\; \forall i = 1, 2$, and $\tilde{x} > x^*$. The use of superior production technology (along with price competition) necessarily reduces prices charged by the firms, and in the new equilibrium some consumers shift from firm 2 to firm 1. Thus, all consumers in the interval $[0, x^*]$ and $[\tilde{x}, 1]$ retain their respective choices of firms and quality unchanged but buy at a lower price than before. But the consumers in the interval $[x^*, \tilde{x}]$ who were buying from firm 2 in the pre-transfer situation, has now option to buy from firm 2 at a lower price, but their optimal decision has been to switch to firm 1 and buy the high quality product. Hence they are also better off in the post-transfer situation.[11] Therefore, all consumers will be better off if technology transfer occurs, and under condition (13), technology transfer will occur.

Now consider product knowledge transfer. It is easy to see that in the post-transfer situation transferor's product price will fall and transferee's product price will go up, because after transfer, transferor faces more competition and transferee supplies a higher quality. Market share of the transferee will also go up. For example, if $\theta_1 > \theta_2$ along with $2\,(c_1 - c_2) > \theta_1 - \theta_2$ is satisfied, then product knowledge will be transferred from firm 1 to firm 2, and in the post-transfer situation, $\overline{p}_1 < p_1^*$, $\overline{p}_2 > p_2^*$ and $\overline{x} < x^*$. Then consumers in the interval $[0, \overline{x}]$ continue to buy the higher quality product from firm 1, but now at a lower price. Consumers in the interval $[\overline{x}, x^*]$ buy the higher quality product from firm 1 in the pre-transfer situation at price p_1^*, but in the post-transfer situation they buy the same quality product from firm 2 at price $\overline{p}_2$, which is lower than p_1^*, therefore, they are also better off. Finally, consumers in the interval $[x^*, 1]$ initially buy the low quality product from firm 2 at price p_2^*, but in the post-transfer situation they buy the high quality product from the same firm at a price $\overline{p}_2\ (> p_2^*)$. It can be easily shown that they are also getting higher utility.[12] Hence we have the following result.

Proposition 3: *Consumers' welfare must go up in the post-transfer situation.*

3. Technology Transfer across Countries

[11] Note that the consumers in the interval $[x^*, \tilde{x}]$ are paying a higher price $\tilde{p}_1 > p_2^*$ in the post-transfer situation, still they are better off because they are now buying a higher quality product.

[12] We have $\int_{x^*}^{1} [u(\theta_1, \overline{p}_2) - u(\theta_2, p_2^*)] dx > 0$.

In this section we extend the previous model to analyze the possibility of technology transfer between two firms across the border. So consider the situation where the firms belong to two different countries. Let us identify firm 1 as local firm and firm 2 as foreign firm. Initially both are competing in the local (or domestic) market. Further assume that there is a trading cost (τ) to be incurred by the consumers if to buy foreign firm's product. Obviously, if $\tau = 0$, the distinction between foreign and local firms becomes blurred, and in that case the present model is reduced to the previous model as far as the interaction between these firms is concerned. With $\tau > 0$ we rewrite the utility function as,

$$u = \begin{cases} v + \theta_1 - tx - p_1 & \text{if to buy from firm 1} \\ v + \theta_2 - t(1-x) - p_2 - \tau & \text{if to buy from firm 2} \end{cases} \tag{16}$$

The pre-transfer payoffs of the firms are

$$\begin{aligned} \Pi_1^{*\prime} &= \frac{1}{18t}\left[3t + \theta_1 - \theta_2 + \tau + c_2 - c_1\right]^2 \\ \Pi_2^{*\prime} &= \frac{1}{18t}\left[3t + \theta_2 - \theta_1 - \tau + c_1 - c_2\right]^2 \end{aligned} \tag{17}$$

and the post-transfer payoffs are:

$$\begin{aligned} \tilde{\Pi}_1^0 &= \frac{1}{18t}\left[3t + \theta_1 - \theta_2 + \tau\right]^2 \\ \tilde{\Pi}_2^0 &= \frac{1}{18t}\left[3t + \theta_2 - \theta_1 - \tau\right]^2 \end{aligned} \tag{18}$$

We examine whether τ is playing any distinct role in this model.

Let us assume $c_1 > c_2$ and consider the possibility of transfer of foreign technology to the local firm. It is then easy to get that such a transfer under the fee contract is mutually profitable if and only if

$$2(\theta_1 - \theta_2 + \tau) > c_1 - c_2 \tag{19}$$

The following proposition focuses on the importance of the existence of a trading cost in the context of technology transfer across borders.

Proposition 4: *Given a positive trading cost, even if the local firm produces no-better than foreign quality product, a profitable technology trade is possible if the trading cost is sufficiently large.*[13]

Given the trading cost, by means of transfer the foreign firm can save and therefore can capture as license fee a part of the trading cost, because a larger production will now take place in the local country. Obviously, the condition becomes relaxed if the local firm produces superior quality products and/or the firms are close in respect of their initial technologies.

In this context one may think of a scenario where the local firm possesses a superior technology, that is, $c_2 > c_1$. Is technology transfer from the local firm to the foreign firm profitable? The relevant condition is:

$$2(\theta_2 - \theta_1 - \tau) > c_2 - c_1 \qquad (20)$$

Clearly, for technology transfer to be profitable, it is now necessary that $\theta_2 > \theta_1 + \tau$. Therefore, a more stringent condition is needed to make the transfer profitable for the local firm. The reason is the following. The foreign firm which has a disadvantage due to existence of a tariff or trading cost, is now in a more competitive position in the post-transfer situation. But unless its product quality is sufficiently large, it will not be able to compensate, as license fee, the loss of payoff of the local firm.

4. Technology Transfer under Royalty Contracts

In this section we consider royalty equilibrium under the assumption of `full market coverage'. Let us assume $c_2 < c_1$, and consider technology transfer from firm 2 to firm 1 under a royalty contract. Since initially both firms have positive market shares, we have

$$t > \max\{(1/3)(\theta_2 - \theta_1 + c_1 - c_2), (1/3)(\theta_1 - \theta_2 + c_2 - c_1)\}$$

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[13] We shall get the similar result if we consider the possibility of product knowledge transfer in this case. If $\theta_2 > \theta_1$, the relevant condition for transfer is $2(\tau + c_2 - c_1) > \theta_2 - \theta_1$.

Now given $c_2 < c_1$, let us assume $c_1 - c_2 \geq \theta_1 - \theta_2$. Clearly, $\theta_2 \geq \theta_1$ is a sufficient, but not necessary, condition to satisfy the inequality. With this, having a positive market share of each firm implies

$$t > \frac{1}{3}(c_1 - c_2 + \theta_2 - \theta_1) \equiv \underline{t}$$

Then, given any royalty r, the equilibrium prices are[14]

$$\begin{aligned} \hat{p}_1(r) &= t + c_2 + r - \frac{\theta_2 - \theta_1}{3} \\ \hat{p}_2(r) &= t + c_2 + r + \frac{\theta_2 - \theta_1}{3} \end{aligned} \qquad (21)$$

The corresponding market shares and profit levels of the firms are respectively:

$$\begin{aligned} \hat{D}_1(r) &= \frac{1}{2t}\left[t - \frac{\theta_2 - \theta_1}{3}\right] \\ \hat{D}_2(r) &= \frac{1}{2t}\left[t + \frac{\theta_2 - \theta_1}{3}\right] \end{aligned} \qquad (22)$$

and

$$\begin{aligned} \hat{\Pi}_1(r) &= \frac{1}{2t}\left[t - \frac{\theta_2 - \theta_1}{3}\right]^2 \\ \hat{\Pi}_2(r) &= \frac{1}{2t}\left[t + \frac{\theta_2 - \theta_1}{3}\right]^2 + r \end{aligned} \qquad (23)$$

Note that any such royalty contract is acceptable to firm 1 because, given $t > \underline{t}$, we have $\hat{\Pi}_1(r) \geq \Pi_1^*$. Further note that $\hat{D}_1$, $\hat{D}_2$ and $\hat{\Pi}_1$ are independent of r, but $\hat{p}_1$, $\hat{p}_2$ and $\hat{\Pi}_2$ are linear and increasing function of r. Hence the patentee (firm 2) has an incentive to increase r as much as possible subject to the restriction of `full market coverage'; in response firm 1 will just raise its price linearly without losing its market share.

[14] The second stage problem of firm 1 is: $\max_{p_1}(p_1 - c_2 - r)D_1(p_1, p_2)$ and firm 2's problem is: $\max_{p_2}(p_2 - c_2)D_2(p_1, p_2) + rD_1(p_1, p_2)$.

Now, given $v > 0$ (see Eqn. (1)), the consumer located at x enjoys a surplus $v + \theta_1 - tx - p_1$ if he buys from firm 1, and $v + \theta_2 - t(1-x) - p_2$ if he buys from firm 2. That is, increase in r only extracts consumer surplus by increasing the prices of the goods. Therefore, under the assumption of `full market coverage', r can be increased as long as the $\hat{x}$-th consumer participates in consumption. We assume that a consumer participates in consumption if he enjoys a non-negative surplus (i.e., $u(\hat{x}) \geq 0$) from consumption. So the maximum possible royalty is determined corresponding to $u(\hat{x}) = 0$. This gives the royalty rate

$$\hat{r} = v - \frac{3}{2}t - c_2 + \frac{\theta_1 + \theta_2}{2} \tag{24}$$

Clearly,

$$\hat{r} > 0 \quad \text{iff } t < \frac{2}{3}(v - c_2) + \frac{\theta_1 + \theta_2}{3} \equiv \bar{t}\ .$$

We can further check that $\bar{t} > \underline{t}$ because we have $v + \theta_1 > \frac{c_1 + c_2}{2}$.

Now consider any $t \in (\underline{t}, \bar{t})$. Then the royalty contract on $\hat{r}$ can be signed if and only if $\hat{\Pi}_2(\hat{r}) \geq \Pi_2^*$. This means, using (6), (23) and (24),

$$v - \frac{3}{2}t - c_2 + \frac{\theta_1 + \theta_2}{2} > \frac{(c_1 - c_2)^2}{18t} + \frac{(c_1 - c_2)(\theta_2 - \theta_1)}{9t} + \frac{c_1 - c_2}{3} \tag{25}$$

The L.H.S. of (25) is linear and falling function of t, with positive intercepts, and the R.H.S. of (25) is convex and falling but never intersecting any axis. Further,

$$L.H.S.(\underline{t}) = v + \theta_1 - \frac{c_1 + c_2}{2} \quad \text{and} \quad R.H.S.(\underline{t}) = \frac{c_1 - c_2}{2} + \frac{(c_1 - c_2)(\theta_2 - \theta_1)}{6[c_1 - c_2 + \theta_2 - \theta_1]}$$

Then $L.H.S.(\underline{t}) > R.H.S.(\underline{t})$ if and only if

$$v - c_1 + \theta_1 > \frac{\theta_2 - \theta_1}{6\left[1 + \dfrac{\theta_2 - \theta_1}{c_1 - c_2}\right]} \tag{26}$$

Clearly, the inequality (26) is satisfied provided that θ_2 is not too large. This means, $\exists \hat{t}, \underline{t} < \hat{t} < \bar{t}$ such that $L.H.S.\ of\ (25) > R.H.S.\ of\ (25)\ \forall t \in (\underline{t}, \hat{t})$. Hence we can write the following proposition.

Proposition 5: *Assume* $t \in (\underline{t}, \hat{t})$ *and* θ_2 *is not large enough. Then under royalty contracts the optimal royalty rate is* $\hat{r}$.

Since $\hat{\Pi}_1(r) \geq \Pi_1^*$, the transferor can, in fact, enhance its profit by writing a fee plus royalty contract, $(\hat{L}, \hat{r})$, where $\hat{L} = \hat{\Pi}_1(\hat{r}) - \Pi_1^*$, and in this case the restriction on t is relaxed because now $\hat{t}$ will have to satisfy the inequality $\hat{\Pi}_2(\hat{r}) + \hat{L} \geq \Pi_2^*$.

Finally, if we relax the assumption of `full market coverage' (and therefore assume that each consumer buys at most one unit of the product), then clearly as r goes beyond the level of $\hat{r}$, the $\hat{x}$-th consumer drops out, and then there is a trade off between fall in demand and increase in royalty.

It may be observed that the existence of vertical product differentiation has no much role to play in the case of royalty equilibrium. For instance, assume $\theta_1 = \theta_2$ and thus restrict to the case of horizontal product differentiation only.[15] Then our results remain unchanged (to be more precise, become more sharp). On the other hand, transport cost which does not play any special role in the analysis of fee licensing, plays an important role in a royalty contract.

5. Conclusion

This paper analyzes technology transfer agreements between two asymmetric firms whose products are both vertically and horizontally differentiated. Horizontal differentiation is due to the firms' differing locations on the Hotelling line, and vertical

[15] Poddar and Sinha (2004) have tried to derive royalty equilibrium under spatial competition but their results seem to be incorrect (see Kabiraj and Lee (2008)).

differentiation is in the form of differing product qualities perfectly perceived by the consumers. At the outset both location and quality are given for each firm. The efficient firm first decides whether to transfer its superior technology to the less efficient firm. Then in the second stage they compete in price.

The main question discussed in the paper is whether and under what circumstances it is possible to have a transfer of technology between the firms when they have different production technologies and different product qualities. As far as royalty equilibrium is concerned, in our setting vertical differentiation has no special bite; of course, transport cost plays an important role. On the other hand, the degree of vertical product differentiation is crucial for transfer of technology under a fixed fee contract. In our model a high-quality low-cost firm has no incentive to share its technology with a low-quality high-cost firm. Indeed, for identical given prices, and taking into account that locations are also given, the high-quality firm has a higher demand as it gets more consumers. For given identical qualities, the low-cost firm can set a lower price and therefore has also a more demand. Thus there is no gain to share its technology for a firm that has a better technology as well as a high quality good. Hence, in this model, only a low-quality low-cost firm may want to share its technology with a high-quality high-cost firm.

One crucial assumption made in the paper is that the quality of the product is independent of the unit cost of production. This is not an absolutely unrealistic assumption. Quality of a product depends on an input-mix whereas the unit cost of production depends on the choice of a production process. Thus, given a quality of a product, the same quality can be produced by different methods of production and therefore has different unit costs of production. Of course, innovating a higher quality involves a larger R&D cost. But in the context of our paper the R&D cost is already sunk.

This permits us discuss the possibility of transferring knowledge associated with the superior product quality to the low-quality firm and inquire whether firms have an incentive to trade a better technology for a better quality. In our paper cross-licensing of the respective advantages under a fee contract is never profitable. Then we have provided a welfare analysis. We have shown that when technology transfer or knowledge transfer occurs, the welfare effect is positive. Consumers' welfare as well as global welfare always goes up.

We have extended the model to discuss the question of licensing in an open economy. In particular, we have focused on the importance of a tariff or trading cost in this context. The existence of such a tariff relaxes the condition of transfer. We have shown that if there is a sufficiently large trading cost, technology transfer between two firms will always be profitable, irrespective of the differences in qualities and technologies.

To conclude, note the following. In our paper the low-quality low-cost firm transfers its production technology to the high-quality high-cost firm provided that such a transfer is profitable. As an alternative, the efficient firm could possibly invest in improving its product quality. This is beyond the scope of this paper. In a model of vertical product differentiation firms have an incentive to increase the gap between qualities. But in our setting the low-quality firm has an incentive to have a better quality (and thus reduce the gap between qualities), whereas the high quality firm does not benefit from a reduction in the quality gap, and therefore, has no interest to see its competitor having a better quality.

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