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ABSTRACT

Knowledge Diffusion, Supplier's Technological Effort and Technology Transfer via Vertical Relationships*

This Paper studies the effect of knowledge diffusion on the incentives for developed countries' (DC) firms to undertake costly transfer of production knowledge of an input to their developing countries' (LDC) suppliers whose costs of production vary inversely with their technological effort. We distinguish between upstream knowledge diffusion, which occurs when the technology diffuses to other suppliers not directly engaged in the technology transfer process, and downstream knowledge diffusion, which occurs when other buyers learn from the incumbent DC firm to procure the same input from the trained LDC supplier(s). We show that when the cost of improving production efficiency is high, and hence where the incentive for technological effort is low, technology transfer is encouraged (discouraged) by upstream (downstream) knowledge diffusion. When, however, the cost of engaging in technological effort is low, and hence where technological effort has a significant impact on the input price, the opposite results obtain: upstream knowledge diffusion discourages technology transfer as increased competition reduces the incumbent supplier's incentive to undertake technological effort thus lowering the value of technology transfer for the DC firm. Downstream knowledge diffusion encourages technology transfer by increasing the demand for the supplier's product and hence the technological effort undertaken.

JEL Classification: F23, L13, O14, O19, O32 and O33
Keywords: buyer-supplier, developing countries, knowledge diffusion, technological effort and technology transfer

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Introduction

It is widely believed that the potential for developing countries to grow by using technology already developed by the industrialized countries is considerable. Some of these some knowledge spillovers are passive and can occur at relatively low costs through trade in intermediate goods embodying the technology[1] while the rest are active in the sense that agents from the developed countries need to incur resource costs to transfer the technology and agents from the developing countries need to engage in technological effort[2] to adapt and gain mastery over the technology received (see e.g., Pack and Westphal 1986, Teece 1977, Mansfield and Romeo 1980). Thus different countries can grow at very different rates depending on the institutional barriers and the incentives these countries provide for the transfer and mastery of technology through various channels like trade, licensing, foreign direct investment and subcontracting.[3]

In order to build the right incentive systems for encouraging greater transfer and mastery of foreign technology, policy makers need to have an understanding of the determinants of the incentives governing foreign firms' willingness to transfer technology and domestic firms' investment in technology mastery. Two factors that are widely cited as important in affecting the incentives for technology transfer are the ease of knowledge diffusion/imitation and the level of absorptive capacity in the recipient country, both of which can be influenced to some extent by policies.[4] Protection of intellectual property rights, labor market regulations, location of industries etc. will affect the ease of knowledge diffusion while absorptive capacity can be increased by education, subsidy for R&D, labor training etc. While there is unanimous agreement in the literature on appropriate policy as regard to absorptive capacity, policies with regard to knowledge diffusion are more controversial and deserve further study.

In the existing literature on the impact of knowledge diffusion on technology transfer via FDI or licensing, both theoretical papers and empirical evidence present contradictory findings. On the theoretical side, some argue that diffusion discourages technology transfer (e.g. Either and Markusen 1996) while others find the opposite (e.g. Glass and Saggi 1998, Wang and Blomstrom 1992).[5] On the empirical side, Lee and Mansfield (1996) presents survey evidence that the perceived degree of intellectual property rights protection provided by developing countries influences the willingness of multinationals to establish subsidiaries or undertakes joint ventures as well as the amount of technology transfer to such operations. On the other hand,

[1] The term "passive" is used by Kelller (2002) to describe this type of knowledge spillovers whereby the knowledge so obtained does not add to the domestic stock of knowledge available for use by domestic inventors (as opposed to "active" knowledge spillovers).

[2] The term technological effort is used by Pack and Westphal (1986) to represent explicit investment in technology mastery (e.g. effort used in acquiring technological information, in managing changes in products and processes, in creating new technology etc.) as opposed to passive learning by doing.

[3] See Parente and Prescott (2000) for empirical evidence.

[4] See Saggi (2002) for a recent survey of the literature.

[5] See also Van and Wan (1999) who argue that technology diffusion need not discourage technology transfer by multinationals because domestic agents acquire only partial knowledge and this knowledge is applied to products that do not compete with the multinationals.

Blomstrom et al. (1994) presents evidence that diffusion and local competition encourages more technology transfer.

In this paper we are interested in studying the impact of knowledge diffusion on technology transfer via buyer-supplier relationships. The reasons for doing so are twofold. First, several studies have documented that multinationals and developed country buyers are actively involved in transferring technology to their suppliers in developing countries. (See e.g. Radosevic (1999), Hobday (1995) and Egan and Mody (1992).[6] Furthermore, this channel of North-South technology transfer is gaining increasing importance given the trend towards international fragmentation of production (see Feenstra 1998 and Hummels et al. 2001) and the increased flow of FDI into developing countries. Second, it is not possible to apply directly the insights provided by the existing literature on horizontal technology transfer through FDI to analyze the impact of knowledge diffusion on vertical technology transfer. This is because in a vertical relationship we need to distinguish between two types of knowledge diffusion - upstream and downstream. Upstream diffusion is said to occur when the technology for producing the input diffuses to other potential suppliers of the input. Downstream diffusion occurs when new entrants in downstream production procure the input from suppliers already trained by other DC firms.[7] These two types of diffusion have very different implications for technology transfer and they also interact with each other in a way that is not present in the case of horizontal technology transfer. There is therefore a need to study separately the technology transfer process through buyer-supplier relationships.

The first (and, as far as we know, the only) theoretical paper that studies the effect of knowledge diffusion on the incentive for technology transfer in a vertical relationships is Pack and Saggi (2001). They show that upstream diffusion benefits the DC firm transferring the technology as it induces competition among suppliers. This gain from upstream diffusion can be high enough that even if it triggers entry into the downstream market, the DC firm will have incentives to engage in technology transfer.

We contribute to Pack and Saggi (2001) in two ways. First, we endogenize the technological effort of the firm receiving the technology. Empirical studies indeed show that the LDC suppliers are not passive recipient of technology but that successful long term buyer-seller relationships are built on the supplier undertaking technological effort to complement the knowledge received from the buyer.[8] Since there are important feedback effects between knowledge diffusion, suppliers' technological effort, and technology transfer, our understanding of the effects of knowledge diffusion is incomplete without studying jointly the incentives for technology transfer and for technological effort. The second contribution of this paper is to analyze the impact of downstream and upstream knowledge diffusion separately, while in Pack and Saggi (2001) downstream diffusion takes place only if there is

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[6] For example, multinationals/buyers often provide information on production technology and marketing, training of workers, quality and delivery standards to their suppliers.

[7] Evidence for downstream diffusion in the context of vertical relationship can be found in Egan and Mody (1992) who observed that some DC buyers obtain information about suppliers by "watching and imitating veteran buyers noted for finding good sources of supply" (p. 329).

[8] Egan and Mody (1992) cites the case of a footwear producer who upgraded his plant and sent his workers for training to complement the knowledge received from the buyer. See Radosevic (1999) and Hobday (1995) for other examples.

upstream knowledge diffusion. To this end, this paper provides a unified framework incorporating endogenous technology transfer and supplier's technological effort so as to analyze the effects of knowledge diffusion, both upstream and downstream, on the incentives for technology transfer in a vertical relationship.[9]

We construct a simple model in which a developed country (DC) multinational/buyer decides on the quality of an input to outsource to a less developed country (LDC) firm. The DC buyer has to incur a cost to transfer technology to the LDC firm so that the LDC supplier produces the input of the desired quality. Both the quality of the final product and the cost of technology transfer are increasing in the quality of the input. The technological effort of the LDC supplier is endogenized by allowing the supplier to invest in process R&D to reduce the unit cost of producing the input. After the transfer of technology and the investment in cost reduction, upstream knowledge diffusion can occur, whereby the knowledge of producing the input diffuses to other LDC firms who then compete with the incumbent supplier to supply the input. We also consider the possibility of downstream knowledge diffusion whereby other DC firms learn from the incumbent DC firm to procure the same input from the trained LDC supplier(s) without having to incur the cost of technology transfer. Our main result shows the importance of the cost of supplier's technological effort in determining the impact of knowledge diffusion on technology transfer. When the investment cost of achieving a given reduction in unit cost of production is high, upstream diffusion of knowledge increases technology transfer while downstream diffusion of knowledge discourages technology transfer. However, when technological effort is less costly, (downstream) knowledge diffusion *discourages (encourages)* technology transfer.

The basic intuition for the above results is as follows. First, both the incentives to invest in technology transfer and in cost reduction depend positively on the output that the incumbent firms can sell. The output of the incumbent DC firm in turn varies inversely with the input price and with the degree of downstream competition. Upstream knowledge diffusion increases upstream competition, which by itself reduces input price. However, competition also reduces the incentive of the incumbent LDC supplier to engage in technological effort (and hence raise the input price) by reducing the output of the incumbent LDC supplier. If improving efficiency is very costly, the first effect of competition on the input price dominates the second effect working through the reduced technological effort of the incumbent supplier and hence greater upstream knowledge diffusion encourages technology transfer. The converse is true when efficiency is less costly to achieve and thus stronger upstream knowledge diffusion discourages technology transfer. Similarly, entry in the downstream market increases the output of the incumbent supplier and raises its technological effort. If the cost of technological effort is low, the fall in input price is large enough to raise the output sold by the incumbent buyer despite the increased competition in the downstream market.

The rest of the paper is organized as follows. In section 2, we set out the basic model and analyze the impact of knowledge diffusion on the DC buyer's incentive to transfer technology and on the LDC supplier's incentive to invest in cost reduction. In

[9] In particular, we show that the results found by Pack and Saggi (2001) hold if the cost of technological effort is high but may be reversed if the cost of technological effort is low.

section 3 we discuss our model using specific functional forms for the demand the investment functions. Section 4 concludes.

2. The Model

Our basic model is a four stage game involving two incumbent firms, a DC buyer and a LDC supplier. The DC firm sells a consumer good whose production can be fragmented into two stages. Consumer demand is increasing in the quality of the final product that is in turn determined by the quality of the input from the upstream stage. The DC firm possesses the technology to produce both the downstream stage and the input in various qualities up to some maximum level $\bar{s}$. The downstream production stage requires a fixed cost M and one unit of the final product requires one unit of the input for production with no other variable costs.[10] The technology for producing the upstream stage can be transferred to a LDC firm who then becomes the supplier of the DC firm. Both the quality and the unit cost of production for the input of the LDC firm are endogenous and depend on the resources devoted to the transmission of knowledge by the DC buyer and on the technological effort of the LDC supplier. We assume that the effort used by the DC firm in the transmission of knowledge affects the quality of the input while the technological effort engaged by the LDC firm affects the unit cost of production.[11]

We make the following assumptions about the production and investment technologies.

<u>Assumption 1</u>
The unit cost of production of the input by the incumbent LDC firm is independent of quality and is given by $c^1 \leq \bar{c}$, where c^1 depends on the supplier's investment in process R&D and $\bar{c}$ is the level of unit cost at zero investment.[12]

<u>Assumption 2</u>
The incumbent supplier's cost of investment in process R&D is given by $H(\bar{c}-c^1)$ where $H'(.)>0$, $H''(.)>0$.

Assumptions 1 and 2 allow us to capture in a simple way the need for the LDC firm to undertake costly investment in order to gain greater mastery over the technology received and that the investment cost is increasing and convex in the extent of the improvement in efficiency.

[10] Since our interest is in technology transfer of the upstream stage, we simplify the technology of the downstream stage for ease of exposition. We could as well assume that the downstream stage required other factors in fixed proportion with the input outsourced to the LDC firm.
[11] Theoretically speaking, we could allow the effort used by both the DC buyer and the LDC supplier to have an impact on both the quality and the unit cost of production. However, Egan and Mody (1992) finds that in subcontracting relationships, the buyers are willing to transmit only the minimum information required to get the product out and that the product must follow strict specifications of quality before it can be accepted. It is therefore up to the supplier to try to manufacture the product of the quality specified by the buyer at the lowest cost possible. Hence our modeling strategy.
[12] Allowing the unit cost to vary with the quality does not change our main results but complicates the computations.

Assumption 3
The cost of technology transfer is given by *I(s)* where $s \leq \bar{s}$ is the desired quality of the input and *I'(.)>0, I''(.)>0*.

This assumption captures the fact that the transfer of technology is costly and that the cost is increasing and convex as the quality of the input increases.

The timing of the game is as follows: in the first stage of the game, the incumbent DC firm has to decide which quality of the input to outsource and hence on the amount of technology to transfer to the LDC supplier.[13] In the second stage, the LDC supplier chooses the amount of technological effort which determines the unit cost of production for the input.[14] What happen in the next two stages depends on whether or not there is knowledge diffusion. We consider two alternative scenarios: one where there is upstream knowledge diffusion only, and the other where there is downstream knowledge diffusion only. Under the first scenario, in the third stage of the game, a new supplier enters the input industry. The entrant and the incumbent supplier then compete in quantities to supply a homogenous input to the buyer. In the fourth stage of the game, the monopoly buyer takes the price of the input as given and chooses a price for the final output to maximize its profit. Under the second scenario where there is downstream knowledge diffusion only, in the third stage of the game, the monopoly supplier chooses a price to maximize its profit. In the fourth stage of the game, a firm enters the final product market and procures the same input from the trained supplier. The two firms then compete in quantities to supply a differentiated product to consumers. We assume that knowledge diffusion, if it occurs, is completely foreseen by the incumbent supplier and buyer and is taken into account when they make their investment decisions.

In what follows, we allow for general demand and investment cost functions and we make us of the envelope theorem to study the various channels through which upstream and downstream knowledge diffusion affect the incentives for technology transfer and technological effort. We compare the investment decisions of the buyer and supplier in the absence of knowledge diffusion with that in the presence of knowledge diffusion, first in the upstream only, and then in the downstream industry only. This will allow us to identify the role played by each type of knowledge diffusion on the incentives for technology transfer and technological effort. The objective is to show that in general, the effect of knowledge diffusion, either downstream or upstream, on the incentives for technology transfer is ambiguous, and that the results of Pack and Saggi (2001) apply only for some special cases.

2.1 Upstream knowledge diffusion

In this section, we allow for entry in the input market driven by knowledge diffusion among potential suppliers in the LDC. The downstream market remains

[13] The choice of different qualities can be motivated by supposing that the DC firm has various product lines differing in technological complexity or quality and that it chooses which of these product lines to outsource to the LDC supplier. For example, inexpensive leather, vinyl or plastic shoes (retailing for US$15 or less) versus man's leather dress shoes that must be perfect in terms of fit and finish and retailing over US$100 (Egan and Mody 1992).
[14] Our general results will not change even if we allow the decision on the transfer of technology to take place at the same time as the decision to invest in cost reduction in a simultaneous game.

monopolized. We consider the case where there is only one new entrant. Multiple entrants will be discussed in section 3. We assume that by incurring a given fixed cost, a LDC firm enters the input industry. The two suppliers compete in quantities to supply a homogenous input to the monopoly buyer. The objective of this section is to give a qualitative analysis of the various channels through which upstream knowledge diffusion affect the incentives for technology transfer and technological effort.

We make the following assumption about the unit cost of production of the entrant.

<u>Assumption 4</u>
The unit cost of the entrant is given by $c^2 = \bar{c} - \theta(\bar{c} - c^1)$, where $\theta \in [0,1]$ measures the degree of knowledge spillovers with θ=1 implying complete spillovers.[15]

By Assumption 4 we are allowing the possibility that the totality of the knowledge acquired by the incumbent LDC firm, including the new knowledge created by its own technological effort, diffuses to the entrant. The latter's unit cost is determined by both the degree of diffusion θ and the potential amount of knowledge that could be learned, which is in turn a function of the incumbent supplier's technological effort.

Under Cournot competition, the profit of the incumbent supplier is given by:

$$\Pi^{S_1}(c^1;s) = x^1(c^1;s)\left[w(x^1(c^1;s), x^2(c^1,c^2(c^1);s);s) - c^1\right] - H(\bar{c} - c^1) \qquad (1)$$

where x^1 and x^2 are respectively, the Nash equilibrium output of the incumbent and entrant, and w is the industry price for the input. By the envelope theorem we have:

$$\frac{\partial \Pi^{S_1}(c^1;s)}{\partial c^1} = x^1(c^1;s)\left[\frac{\partial w}{\partial x^2}\left(\frac{\partial x^2}{\partial c^1} + \theta \frac{\partial x^2}{\partial c^1}\right) - 1\right] + H'(\bar{c} - c^1) \qquad (2)$$

In order to see the effect of upstream knowledge diffusion on the incentive for technological effort, we compare equation (2) to the analogous equation that would characterize the investment decision of the incumbent supplier if there was no knowledge diffusion and that the input industry was monopolized. The latter is given by:

$$\frac{d\Pi^{S_1}(c^1;s)}{dc^1} = -x_m^1(c^1;s) + H'(\bar{c} - c^1) \qquad (3)$$

where x_m^1 is the optimal output of the monopoly LDC supplier.

Taking quality as given for the moment, we note that upstream diffusion affects the supplier's incentive to invest in cost reduction through two channels. First,

[15] Note that by restricting *$\theta \geq 0$*, we rule out the case where the entrant's unit cost is higher than $\bar{c}$. We do not gain any additional insights by including this case because all the results which hold for θ=0 apply equally to the case where the unit cost is higher.

at each level of unit cost, marginal benefit of investment is lower with diffusion since the output of the incumbent supplier decreases with competition and lower output reduces the total cost savings attainable for a given cost reduction. Second, diffusion gives rise to a *strategic effect* given by the first and second terms in the square bracket of equation (2). By reducing its unit cost the incumbent induces a change in the output of the entrant and hence in its own profit. There are however, two opposing forces of cost reduction on the entrant's output. On the one hand, reducing its unit cost allows the incumbent to steal market share from its rival (captured by the first term in the round bracket). On the other hand, since there is more knowledge to learn, the entrant's unit cost also falls, allowing it to increase its output (captured by the second term in the round bracket). Whether the change in the entrant's output is positive or negative depends on the extent of knowledge diffusion θ. If knowledge diffusion is strong, the strategic effect is negative. In this case, the incentive to invest in technological effort is unambiguously lower with knowledge diffusion. If knowledge diffusion is weak, then it is possible for diffusion to lead to greater technological investment because it allows the incumbent to steal market share from the entrant.

Note that so far we have analyzed the incentive to engage in technological effort at *a given level of quality*. Greater (smaller) technology transfer shifts up (down) the marginal benefit curve since higher quality increases the market demand for the final product and hence the input. Even if cost reduction effort is smaller with knowledge diffusion than without, if the DC firm has greater incentives to transfer technology with diffusion, the net incentive for cost reduction may be higher with diffusion. We turn therefore to a discussion of the effect of upstream competition on the incentive to transfer technology.

Let *p(s, q)* be the inverse demand curve for the final product where *q* is the output of the incumbent DC firm. The profit of the monopoly DC firm is given by:

$$\Pi_{B_1}(s) = \left[p(s, q_m(w)) - w(s, c^1(s))\right] q_m(w) - I(s) - M \tag{4}$$

where q_m is the optimal output of the monopoly buyer.

By the envelope theorem, we have,

$$\frac{d\Pi_{B_1}}{ds} = \left[\frac{\partial p}{\partial s} - \left(\frac{\partial w}{\partial s} + \frac{\partial w}{\partial c^1}\frac{dc^1}{ds}\right)\right] q_m(w) - I'(s) \tag{5}$$

Equation (5) says that the incentive for the monopoly buyer to transfer technology depends positively on its output and on the marginal increase in its profit margin arising from an increase in the quality of the input. The effect of upstream knowledge diffusion on technology transfer thus depends crucially on how increased upstream competition affects both the industry price for the input (which affects the output of the buyer) and the response of the input price to quality increment (which affects the marginal increase in the profit margin of the buyer). There are two opposing forces of upstream competition on the input price. First, competition directly lowers the price of input. However, the input price depends also on the technological effort of the incumbent LDC supplier which may decrease with upstream competition as discussed above. The same opposing forces also determine the net impact of competition on the adjustment of the input price to changes in quality. Competition reduces the direct effect of quality increment on the input price but it may also reduce the indirect effect through reducing the incentive for technological effort by the incumbent LDC firm.

In contrast to the result in Pack and Saggi (2001), we thus find that the effect of upstream knowledge diffusion on the incentives to transfer technology is in general ambiguous once we allow for endogenous technological effort of the supplier. We proceed to illustrate that the same ambiguity also holds for the impact of downstream knowledge diffusion on the incentives for technology transfer.

2.2 Downstream knowledge diffusion

In this section we consider the possibility that after the supplier has been trained by the incumbent buyer, another DC firm enters the industry and outsources the input to the same supplier.[16] We assume that the entrant has already an access to the downstream technology and that it is profitable for the new firm to enter the market only when a cheaper source of input becomes available. We assume that the two firms compete in quantities to supply a differentiated product to the consumers. As we shall see later the degree of product differentiation will be one of the key parameters determining the amount of technology transfer.

On the basis of equation (3) we note that downstream entry increases the monopoly supplier's incentive to invest in cost reduction since downstream competition increases the demand for the incumbent supplier's product. This effect by itself tends to lower input price and raises the incentive for technology transfer. On the other hand, competition directly lowers the demand for the incumbent buyer's product and hence reduces its incentive to transfer technology. In addition, there is now a strategic effect of diffusion. To see this more clearly, we note that the profit of the incumbent buyer is given by:

$$\Pi_{B_1} = \left[p_1(s, q_1, q_2(s, w(s, c^1(s)))) - w(s, c^1(s))\right] q_1 - I(s) \tag{6}$$

where $p_1(s, q_1, q_2), q_1, q_2$ are respectively, the inverse demand function of the incumbent DC firm and the Nash equilibrium outputs of the two DC firms.

By the envelope theorem we have:

$$\frac{d\Pi_{B_1}}{ds} = q_1\left[\frac{\partial p_1}{\partial s} - \left(\frac{\partial w}{\partial s} + \frac{\partial w}{\partial c^1}\frac{dc^1}{ds}\right)\right] + q_1\left\{\frac{\partial p_1}{\partial q_2}\left[\frac{\partial q_2}{\partial s} + \frac{\partial q_2}{\partial w}\left(\frac{\partial w}{\partial s} + \frac{\partial w}{\partial c^1}\frac{dc^1}{ds}\right)\right]\right\} - I'(s) \tag{7}$$

The strategic effect, captured by the terms in the curly bracket in above equation, reduces the incentive to transfer technology because any increase in technology transfer also increases the market demand for the entrant and induces the entrant to expand output thus hurting the profits of the incumbent DC firm. Given the different opposing forces at work, the net impact of downstream knowledge diffusion on the incentive to transfer technology is thus also ambiguous.

[16] We are assuming here that the supplier is engaged in open networks, that is, the subcontractor is not confined to dealing only with one buyer (see Wan, 2001, for examples of such networks in East Asia).

Given the general ambiguity of the effect of knowledge diffusion on technology transfer, we next introduce specific functional forms for the demand function and the investment cost functions into our model so as to obtain a better intuition and a clearer picture of the determinants of the magnitude of the various forces at work. This will allow us to characterize precisely the set of parameter values under which knowledge diffusion has a net positive/negative impact on technology transfer.

Section 3 Knowledge diffusion and technology transfer with linear demand and quadratic cost function

As discussed in section 2, knowledge diffusion affects the incentives for technology transfer and technological effort through several opposing forces. The objective of this section is to highlight the role of some parameters that are crucial for the sign of the net impact and to characterize the set of parameter values under which diffusion leads to greater technology transfer. In order to give the basic intuition with as simple a model as possible, we assume that the demand for the final product is linear and that the cost of investment in cost reduction is quadratic. We also impose the necessary conditions on parameter values so that the second order conditions hold. We first solve for the benchmark case with a monopoly buyer and supplier and then compare the solution to the case where there is one entrant in the upstream industry and to the case where there is one entrant in the downstream industry. We then check for the robustness of our results by allowing free entry in the upstream market. Finally, by allowing both entry upstream and downstream we study the interactions between upstream and downstream diffusion on the incentives for technology transfer.

3.1 Monopoly buyer and seller

We solve the model by backward induction beginning with the optimal price and quantity set by the buyer and the supplier and then proceed to solve for the investment decisions. Let the demand for the monopoly DC firm be given by:

$$p = as - q \tag{8}$$

where a is a positive constant.

One can show easily that the profit maximizing output of the DC firm is given by:

$$q_m = \frac{as - w}{2} \tag{9}$$

Given the output of the DC firm and hence the demand for the input we can show that the LDC firm maximizes profit by charging a price given by:

$$w = \frac{as + c^1}{2} \tag{10}$$

By routine computation one can show that the profits gross of investment costs are given by:

$$\pi^{S_1} = \frac{\left(as - c^1\right)^2}{8} \tag{11}$$

$$\pi_{B_1} = \frac{\left(as - c^1\right)^2}{16} \tag{12}$$

We proceed to solve for the investment decisions. Given the timing of the game, we solve first for optimal investment of the supplier taking as given the level of quality of the input. The incumbent supplier solves the following problem:

$$\underset{\Delta c^1}{Max}\, \Pi^{S_1} = \frac{\left(as - \bar{c} + \Delta c^1\right)^2}{8} - k\left(\Delta c^1\right)^2 \tag{13}$$

where $\Delta c^1(s) = \bar{c} - c^1$ and k is a positive constant which captures how costly it is for the supplier to engage in technological effort to improve efficiency.

Solving (13) we obtain the optimal cost reduction of the monopoly supplier:

$$\Delta c_m^1(s) = \frac{as - \bar{c}}{8k - 1} \tag{14}$$

The incumbent buyer takes into account the optimal investment by the supplier given by (14) and chooses a level of quality so as to maximize its profit:

$$\underset{s}{Max}\, \Pi_{B_1} = \frac{\left[as - \bar{c} + \Delta c_m^1(s)\right]^2}{16} - I(s) \tag{15}$$

The first order condition below implicitly defines the optimal quantity *s*, of the input demanded by the buyer:

$$\frac{8k^2 a\left(as - \bar{c}\right)}{\left(8k - 1\right)^2} = I'(s) \tag{16}$$

We proceed to introduce knowledge diffusion.

3.2 Upstream Diffusion

With entry driven by knowledge diffusion in the upstream industry, the two suppliers face a total industry demand curve given by (9). Solving the Cournot game between the two suppliers, it can be easily verified that the post investment profit of the incumbent supplier is given by:

$$\pi^{S_1} = \frac{\left(as + \bar{c} - \theta(\bar{c} - c^1) - 2c^1\right)^2}{18} \tag{17}$$

Optimal cost reduction of the incumbent supplier is given by:

$$\Delta c_1^1(s,\theta) = \frac{(as-\bar{c})(2-\theta)}{18k-(2-\theta)^2} \tag{18}$$

Equation (18) shows that the optimal cost reduction is decreasing in the cost of technological effort k and in the extent of knowledge diffusion θ. The latter is explained by the fact that more complete diffusion increases the intensity of competition, reduces the output of the incumbent and makes the strategic effect more negative.

We next solve for the technology transfer decision of the DC firm:

$$\underset{s}{Max}\, \Pi_{B_1} = \frac{\left[2as-2\bar{c}+(1+\theta)\Delta c^1(s)\right]^2}{36} - I(s) \tag{19}$$

The first order condition is given by:

$$\frac{a(as-\bar{c})}{18}\left[\frac{36k-2(2-\theta)^2+(1+\theta)(2-\theta)}{18k-(2-\theta)^2}\right]^2 = I'(s) \tag{20}$$

Comparing (20) to (16), we observe that technology transfer is greater with diffusion iff:

$$\frac{12k-2+3\theta-\theta^2}{18k-(2-\theta)^2} > \frac{4k}{8k-1} \tag{21}$$

In figure 1 below we illustrate the set of values in the parameter space *(θ, k)* for which the above inequality holds. In region A, technology transfer under monopoly supplier (s_m) is greater than that in the presence of upstream diffusion (s_c) while in region B, technology transfer is higher with diffusion. We observe that when the cost needed to achieve a given reduction in cost is high (k is large), knowledge diffusion and subsequent entry into the upstream industry always increases technology transfer regardless of the extent of knowledge diffusion. However, when investment in technological effort is less costly, the extent of knowledge diffusion determines whether technology transfer is higher or lower with diffusion.

The intuition for this result is as follows. Knowledge diffusion increases competition and reduces the input price and the greater the extent of diffusion the greater is the downward pressure on input price. This can be seen from equation (19) where the profit of the buyer is increasing in θ. This tend to encourage technology transfer. However, competition also reduces the incumbent supplier's incentive to engage in technological effort which raises the input price. When technological effort is costly, the incumbent supplier has little incentive to invest in cost reduction and hence the additional disincentive effect coming from competition has less impact. Thus, the competition effect dominates and technology transfer is higher with knowledge diffusion. However, as the cost of technological effort decreases, the disincentive effect becomes more important. Since the disincentive effect is increasing in the extent of knowledge spillovers, for high values of θ, the disincentive effect dominates the competition effect and technology transfer is higher without diffusion than with diffusion. For low values of θ, the competition effect dominates and technology diffusion is higher with diffusion.

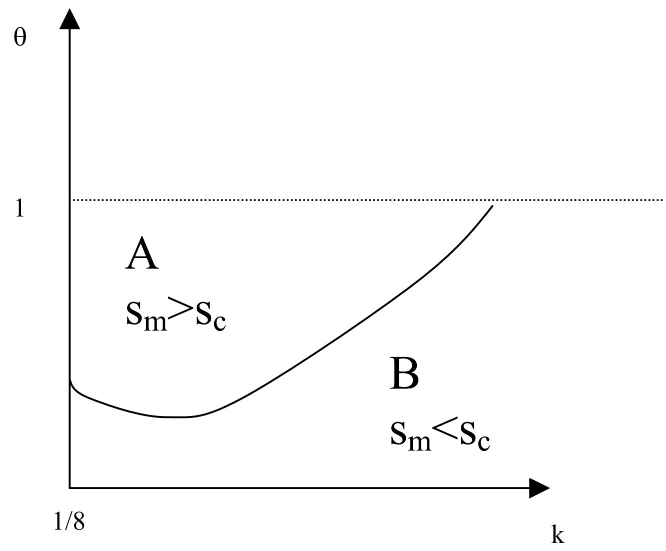

Figure 1 Upstream knowledge diffusion and technology transfer

To summarize our results so far, we have shown that upstream knowledge diffusion increases technology transfer in a vertical relationship if the recipient of the technology has little incentive to undertake technological effort due to the high cost of investment. However, if it is less costly for the supplier to undertake technological effort, upstream knowledge diffusion discourages investment in cost reduction which in turn discourages technology transfer.

Two policy implications follow naturally from the above results. First, when the cost of engaging in technological effort is high, due for example, to low human capital or lack of industrial experience, encouraging knowledge diffusion among local firms is desirable as a more competitive input industry helps to encourage greater technology transfer by foreign buyers. However, once the firms have move up the technological ladder and are capable to undertake significant technological effort to complement knowledge received from foreign buyers, encouraging technology diffusion may hinder rather than help to encourage technology transfer. Second, suppose that in the absence of government intervention, an industry is characterized by an absence of diffusion and by high cost of technological effort so that we are in region B. In this case, *either* encouraging technology investment through for example, subsidy for R&D, *or* encouraging knowledge diffusion increases technology transfer. However, surprisingly if both policies are employed together they do not necessary reinforce each other in encouraging greater technology transfer. In fact, if by employing both policies, the industry moves from region B into region A, where technology transfer is higher without diffusion, the two policies will actually be counter-productive. Indeed, the country will create greater incentives for technology transfer by pursuing just one of the policies rather than both at the same time.

3.3 Downstream knowledge diffusion

We now consider the possibility that entry in the downstream market occurs as the knowledge about the possibility of procuring the input from the trained supplier diffuses. We assume that the entrant sells a product which is differentiated from the incumbent DC firm. The demand functions for the two DC firms are given by:

$$p_1 = as - b\,q_2 - q_1 \tag{22}$$

$$p_2 = as - b\,q_1 - q_2 \tag{23}$$

The parameter $0 \le b \le 1$ captures the degree of product differentiation of the two final goods with a lower b implying a higher degree of differentiation.

Solving the Cournot game between the two buyers gives us the demand for the input as a function of the input price. We can then show easily that the post investment profit of the incumbent supplier is given by:

$$\pi^{S_1} = \frac{\left(as - c^1\right)^2}{2(2+b)} \tag{24}$$

Optimal cost reduction is given by:

$$\Delta c_1^1(s) = \frac{as - \bar{c}}{2(2+b)k - 1} \tag{25}$$

Comparing (25) with (14), we note that for the same quality s, cost reduction is higher in the presence of downstream diffusion. This is because downstream competition rises the industry output of the final product and hence increases the industry demand for the input. The higher demand for the input in turn increases the supplier's technological effort. Note that the smaller is b the larger is the expansion of market size and the greater the reduction in the unit cost of production of the input.

The incumbent buyer solves the following problem:

$$\underset{s}{Max}\,\Pi_{B_1} = \frac{\left[as - \bar{c} + \Delta c_1^1(s)\right]^2}{4(2+b)^2} - I(s) \tag{26}$$

The first order condition is given by:

$$\frac{2ak^2(as - \bar{c})}{\left[2(2+b)k - 1\right]^2} = I'(s) \tag{27}$$

By comparing (16) and (27), one can verify that diffusion downstream increases technology transfer if and only if the following inequality holds:

$$bk < 1/4 \tag{28}$$

Inequality (28) implies that higher technology transfer is favored by a lower degree of competition between the DC firms (smaller *b* implies lower degree of substitutability between their products) and a lower cost of achieving higher efficiency (smaller *k*). As discussed above, when technological effort is less costly, the supplier's incentive to reduce cost becomes an important factor in determining the price of the input. Upstream entry, by encouraging greater technological effort of the supplier, leads to a significant reduction in the input price. And the cost reduction effort is greater the smaller is *b*. This positive effect on the output of the incumbent DC firm has to be weighed against the negative effect of downstream competition. The negative effect of downstream competition is smaller the less substitutable are the products of the two DC firms.

Two policy implications follow from these results. First, when the cost of investment in technological effort is high, encouraging downstream diffusion is likely to reduce technology transfer, especially if the final products are not highly differentiated.[17] When the investment cost is low, downstream diffusion will encourage technology transfer even if the products of the two DC firms are perfect substitutes. Second, in contrast to the case for upstream diffusion, policies to encourage downstream diffusion and technological effort should go together since it is when the cost of technological effort is low that downstream diffusion will have a positive impact on technology transfer.

We have seen how downstream diffusion affects the incentive for technology transfer through its impact on the incentive for the supplier to engage in technological effort. There is however, another channel through which downstream diffusion can affect the incentive to transfer technology, namely, by changing upstream market structure. We have so far assumed that there is only one entrant in the upstream market. If there is free entry in the upstream market, downstream diffusion can affect the incentive to transfer technology through changing the number of entrants and hence, the degree of competition upstream. Therefore, we proceed to study the case where there is free entry in the upstream industry to study this interaction between downstream and upstream diffusion on the incentives for technology transfer.

3.4 Upstream free entry and downstream Cournot competition

In this section, we allow free entry in the input industry. Our objectives are first, to check for the robustness of our results to free entry upstream. But more importantly, we want to study the effect of downstream entry on the market structure of upstream industry and its consequent impact on the incentives for technology transfer.

We solve the model with knowledge diffusion and free entry in the upstream industry and Cournot competition in the downstream industry. The analogous results for the case without downstream diffusion is given in the appendix. We assume that each new LDC entrant needs to incur a fixed cost to enter into production. For ease of

[17] For example, LDC government can encourage downstream diffusion through trade fairs to showcase the products of suppliers and policies to attract multinationals in the same industry to locate close to each other.

exposition and without loss of generality, we assume that the fixed cost is $2F^2$, where F is a positive constant. The fixed cost determines endogenously the number of new entrants *n* into the input industry through the free entry condition. The total number of suppliers is thus *n+1*. Each entrant has the same unit cost as given in Assumption 4. The timing of the game is as follows: first, the incumbent DC firm transfers technology; second, the incumbent LDC firm invests in cost reduction; third, free entry takes place in the upstream industry and the various suppliers compete in quantities to supply a homogenous input; finally, entry takes place in the downstream market and the two buyers compete in quantities to sell a differentiated product to consumers.

We solve the model by backward induction beginning with solving the Cournot Nash equilibrium outputs of the two buyers taking the price and the quality of the input as given. We then solve the Cournot game among the *n+1* suppliers taking as given the unit cost of production. The post investment profit of the incumbent LDC firm and a typical entrant are given respectively by:

$$\pi^{S_1} = \frac{2\left[as + n[\bar{c} - \theta(\bar{c} - c^1)] - (n+1)c^1\right]^2}{(n+2)^2(2+b)} \tag{29}$$

$$\pi^{S_i} = \frac{2\left[as - 2[\bar{c} - \theta(\bar{c} - c^1)] + c^1\right]^2}{(n+2)^2(2+b)} \quad i=2, \ldots n+1 \tag{30}$$

The free entry condition requires that the profit of each new entrant is equal to the fixed cost of entry:

$$\frac{2\left[as - 2[\bar{c} - \theta(\bar{c} - c^1)] + c^1\right]^2}{(n+2)^2(2+b)} = 2F^2 \tag{31}$$

or:

$$\frac{as - 2[\bar{c} - \theta(\bar{c} - c^1)] + c^1}{(n+2)} = F(2+b)^{1/2} \tag{32}$$

The incumbent supplier solves the following problem:

$$\max_{\Delta c^1} \Pi^{s_1} = \frac{2\left[as - \bar{c} + [(n+1) - n\theta]\Delta c^1\right]^2}{(n+2)^2(2+b)} - k\left(\Delta c^1\right)^2 \tag{33}$$

Substituting the free entry condition (32) into (33) we have:

$$\max_{\Delta c^1} \Pi^{s_1} = \frac{2\left[F(2+b)^{1/2} + (1-\theta)\Delta c^1\right]^2}{(2+b)} - k\left(\Delta c^1\right)^2 \tag{34}$$

Optimal cost reduction is given by:

$$\Delta c_n^1 = \frac{2F(2+b)^{1/2}(1-\theta)}{(2+b)k - 2(1-\theta)^2} \tag{35}$$

We observe that the technological effort of the incumbent LDC firm increases with the fixed cost of entry. A lower fixed cost of entry and hence a larger number of entrants increases competition and reduces the output of the incumbent and its gains from investment in cost reduction. In contrast to the case where there is only one entrant, investment in cost reduction now has a entry deterrence effect instead of a strategic effect. This entry deterrence effect by itself tends to encourage technological effort provided that there is partial knowledge spillovers ($\theta < 1$). We note also that the technological effort of the incumbent supplier is greater when there is downstream entry even under free entry in the upstream industry (compare equation (35) with equation (A7) in the appendix). Even though downstream entry increases the number of entrants and hence the degree of competition in the input industry, there is still a net increase in the demand for the incumbent supplier's output. We also find that as in the case where there is only one entrant, the greater the degree of product differentiation (smaller b), the larger the optimal cost reduction.

We next solve for the technology transfer decision of the incumbent buyer. The incumbent buyer takes into account the optimal investment in cost reduction as given by (35) and chooses the level of quality to maximize its profits:

$$\max_s \Pi_{B_1} = \frac{\left[(n+1)(as-\bar{c}) + (n\theta+1)\Delta c_n^1)\right]^2}{(n+2)^2(2+b)^2} - I(s) \tag{36}$$

Substituting the free entry condition (32) into (36):

$$\max_s \Pi_{B_1} = \frac{\left[(as-\bar{c}) + \theta\Delta c_n^1 - F(2+b)^{1/2}\right]^2}{(2+b)^2} - I(s) \tag{37}$$

The first order condition is given by:

$$\frac{2a\left[(as-\bar{c}) + \theta\Delta c - F(2+b)^{1/2}\right]}{(2+b)^2} = I'(s) \tag{38}$$

With both knowledge diffusion upstream and downstream, the marginal benefits of undertaking technology transfer depend on the interplay between several forces. First, upstream knowledge diffusion affects the input price through the competition effect and the incentive effect for the supplier to invest in cost reduction. Both effects are in turn affected by downstream knowledge diffusion. Downstream entry increases the competition effect through inducing additional entry upstream. It also increases the incentive effect as discussed above. Both effects tend to increase the incentive for technology transfer. However, they have to be weighed against the negative effect of direct competition of the DC entrant on the output of the incumbent buyer.

In order to focus on the upstream competition enhancing role of downstream entry and to get an idea of when this effect is important, we shall analyze the special case when $\theta=0$. This shuts down the influence of technological effort of the supplier on the incentive for technology transfer and hence downstream entry will not affect technology transfer through this channel. We compare the marginal benefit of technology transfer with and without knowledge diffusion downstream. Comparing equation (38) and equation (A10) in the appendix, we observe that technology transfer is higher in the presence of downstream diffusion if the following inequality holds:

$$\frac{(as-\bar{c})-F(2+b)^{1/2}}{(2+b)} > \frac{(as-\bar{c})-F}{2} \tag{39}$$

or:

$$F > \frac{b(as-\bar{c})}{2\left[(2+b)-(2+b)^{1/2}\right]} \tag{40}$$

Inequality (40) says that for a given degree of product differentiation *b*, downstream entry increases technology transfer if the fixed cost of entry upstream is high. The intuition for this result is as follows. When fixed cost of entry is low, the number of entrants upstream is large and hence the additional entry encouraged by downstream entry will not have a significant impact on the input price. When fixed cost of entry is high, additional downstream entry will have a significant impact on upstream competition and hence on input price. When the fixed cost is high enough, this positive impact of lower input price on the output of the incumbent buyer outweighs the negative impact of downstream competition on the incentive for technology transfer. Since the R.H.S. of (40) is increasing in *b*, as the degree of product differentiation decreases, it is less likely that downstream entry will affect the degree of upstream competition by enough to compensate for the competition it poses for the downstream market.

To summarize our results so far, we have seen that the presence of a competitor does not necessary harm the incumbent buyer and reduce its incentive to transfer technology. The additional competition downstream driven by downstream entry increases the demand for the input and hence increases the technological effort of the incumbent supplier. It also leads to an increase in the degree of competition in the input industry when free entry is allowed. These positive effects of downstream entry on the buyer's incentive to transfer technology working through the upstream market can outweigh the direct negative effect on technology transfer due to the additional competition from the new entrant. In contrast, in the existing literature on horizontal technology transfer through FDI, entry of competitors driven by knowledge diffusion always hurts the incumbent firm engaging in technology transfer (see e.g. Ethier and Markusen, 1996).[18] Therefore, it is important to take into account the interactions between downstream and upstream markets as well as the complementarity between the technological efforts of the technology transferor and the recipient to have a more complete understanding of the effect of knowledge diffusion on the incentive for technology transfer.[19]

[18] However, it is not difficult to see by following the logic of our argument that even in the case of horizontal technology transfer through FDI, the incumbent firm may still have the interest to transfer technology even if the technology leaks out to competitors. This is so when competition leads to greater competition in the supplier market or greater incentive for workers to accumulate skills.

[19] See also Goh and Olivier (2002) who argues that the interactions between upstream and downstream markets are important in determining optimal patent protection.

4 Conclusion

The current trend towards international outsourcing provides an important opportunity for developing countries to obtain greater technology spillovers from developed countries. Understanding the economic incentives governing the willingness of multinationals/DC buyers to transfer technology to their suppliers should therefore be of concern to policy makers in developing countries. In this paper we focus on one such factor that affects the incentives to transfer technology, namely, knowledge diffusion. We argue that the effect of knowledge diffusion on the incentives for technology transfer depends crucially on the effect of knowledge diffusion on the incentives for the LDC suppliers to undertake costly technological effort.

Modeling the technological effort of the supplier as investment in cost reduction, we showed that when it is costly to improve production efficiency, technology transfer is best encouraged by widespread diffusion of technology among potential suppliers as competition creates price competitiveness for the input industry. However, downstream diffusion of knowledge discourages technology transfer as it creates competition for the incumbent buyer. On the other hand, if production efficiency is less costly to achieve, price competitiveness of the input industry is best achieved by maximizing the incentive for the incumbent supplier to reduce cost, which is in turn encouraged by weaker diffusion of knowledge upstream and more entry downstream. In addition, when free entry is allowed, downstream entry also increases the price competitiveness of the upstream industry through inducing more firms to enter in the upstream industry. Downstream knowledge diffusion thus may increase technology transfer even though it increases downstream competition.

In terms of policy implications, our analysis suggests that policy makers should encourage local firms to undertake technological effort as their technological efforts are complementary to that of the buyer and would encourage greater transfer of technology by the buyer. However, more caution should be exercised as far as encouragement of diffusion of technology among potential suppliers is concerned. The attractiveness of a country as a source of suppliers depends on both the degree of competition and the incentive of suppliers to exert technological effort. A trade-off between the two exists and whether or not diffusion is a more effective way to encourage technology transfer depends on the cost of technological effort. The same consideration governs the desirability of promoting local suppliers to potential buyers. We therefore conclude that helping local firms to improve their technological capability remains the best policy in terms of encouraging greater transfer of technology from the developed countries.

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Appendix 1

In this appendix, we solve for optimal technology transfer when there is upstream free entry while the downstream market remains monopolized. The objective is to check that our results in section 3.2 are robust to free entry upstream.

The post investment profit of the incumbent LDC firm and a typical entrant are given respectively by:

$$\pi^{S_1} = \frac{\left[as + n[\bar{c} - \theta(\bar{c} - c^1)] - (n+1)c^1\right]^2}{2(n+2)^2} \quad \text{(A1)}$$

$$\pi^{S_i} = \frac{\left[as - 2[\bar{c} - \theta(\bar{c} - c^1)] + c^1\right]^2}{2(n+2)^2} \quad i=2, \ldots n+1 \quad \text{(A2)}$$

The free entry condition requires that the profit of each new entrant is equal to the fixed cost of entry:

$$\frac{\left[as - 2[\bar{c} - \theta(\bar{c} - c^1)] + c^1\right]^2}{2(n+2)^2} = 2F^2 \quad \text{(A3)}$$

or:

$$\frac{as - 2[\bar{c} - \theta(\bar{c} - c^1)] + c^1}{(n+2)} = 2F \quad \text{(A4)}$$

The incumbent supplier solves the following problem:

$$\max_{\Delta c^1} \Pi^{s_1} = \frac{\left[as - \bar{c} + [(n+1) - n\theta]\Delta c^1\right]^2}{2(n+2)^2} - k\left(\Delta c^1\right)^2 \quad \text{(A5)}$$

Substituting the free entry condition (A4) into (A5) we have:

$$\max_{\Delta c^1} \Pi^{s_1} = \frac{\left[2F + (1-\theta)\Delta c^1\right]^2}{2} - k\left(\Delta c^1\right)^2 \quad \text{(A6)}$$

Optimal cost reduction is given by:

$$\Delta c_n^1 = \frac{2F(1-\theta)}{2k - (1-\theta)^2} \quad \text{(A7)}$$

We next solve for the technology transfer decision of the buyer:

$$\max_{s} \Pi_{B_1} = \frac{\left[(n+1)(as - \bar{c}) + (n\theta + 1)\Delta c_n^1)\right]^2}{4(n+2)^2} - I(s) \quad \text{(A8)}$$

Substituting the free entry condition (A4) into (A8):

$$\max_{s} \Pi_{B_1} = \frac{\left[(as - \bar{c}) + \theta\Delta c_n^1 - 2F\right]^2}{4} - I(s) \quad \text{(A9)}$$

First order condition is given by:

$$\frac{a\left[(as - \bar{c}) + \theta\Delta c_n^1 - 2F\right]}{2} = I'(s) \quad \text{(A10)}$$

Substituting (A7) into (A10) we have:

$$\frac{a\left[(as - \bar{c}) + \theta\frac{2F(1-\theta)}{2k - (1-\theta)^2} - 2F\right]}{2} = I'(s) \quad \text{(A11)}$$

We observe that more entry (lower F) into the upstream industry decreases (increases) technology transfer when:

$$\frac{\theta(1-\theta)}{2k-(1-\theta)^2} > 1 \qquad \text{(A12)}$$

or

$$k < \frac{1-\theta}{2} \qquad \text{(A13)}$$

Thus our previous result that greater competition upstream reduces technology transfer when the cost of technological effort is low continues to hold even when we allow for free entry.