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FOREIGN INVESTMENT AND TECHNOLOGY TRANSFER: A SIMPLE MODEL

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ABSTRACT

This paper develops a model in which international technology transfer through foreign direct investment emerges as an endogenized equilibrium phenomenon, resulting from the strategic interaction between subsidiaries of multinational corporations and host country firms. The model explicitly recognizes two types of costs -- the costs to the multinational of transferring technology to its subsidiaries and the learning costs of domestic firms -- and treats technology transfer in a game theoretic context. The model points to the importance of the learning efforts of host-country firms in increasing the rate at which MNCs transfer technology. The paper also explores some of the reasons why learning investment in host country firms may be suboptimal.

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Foreign Investment and Technology Transfer

A Simple Model

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I. Introduction

What policy measures should a country hosting multinational corporations (MNCs) adopt to get these firms to transfer more technology? This question needs little defense at a time when multinationals have become the most important actors in the generation, application, and international transfer of modern technology, and when it is generally agreed that technology is a key determinant of economic growth, international competitiveness, and trade performance.

The theoretical literature on technology transfer through international capital movements is mostly confined to an ad hoc modelling of externalities (see e.g. Findlay, 1978a, Koizumi and Kopecky, 1977, Das, 1987, and Wang, 1988; also see Cheng, 1984b for a survey). In these models, host country production efficiency is formulated as an increasing function of the presence of foreign capital. The foreign firms are supposed to possess superior technological knowledge and the technologies transferred are "public goods" in nature.

The analytical convenience of these technology transfer models is, however, purchased at the expense of abstracting from the costs and characteristics of the transfer process itself, and the purpose of this paper is to try to fill in this theoretical gap. We suggest that a theory of technology transfer via multinational firms should be able to explain at least the following: (a) In the presence of MNCs, competing host country firms may become more efficient because of technological "spillovers" from foreign direct investment (Blomström and Persson, 1983); (b) The average age of technologies transferred by multinationals to their subsidiaries in developed countries is considerably lower than the age of those transferred to developing countries (Mansfield and Romeo, 1980); (c) A large presence of foreign capital may coexist with slow technology transfer and transfer of relatively "old" technologies, something which is common in many Latin American countries today.

This paper develops a model in which international technology transfer through multinational firms emerges as an endogenized equilibrium phenomenon, resulting from the strategic interaction between foreign subsidiaries of MNCs and host country firms. The model explicitly recognizes the costs of transferring technology within MNCs and the learning costs of the host country firms, and treats technology transfer in a game theoretic context.

Modelling technology transfer in a strategic environment is relatively new in the trade literature, and mostly has been concerned with product technology transfer. For instance, Jensen and Thursby (1986), along the lines of Vernon's (1966) product life cycle, study transfer of product technology in a dynamic game framework. New goods are invented in the North and the production of them shifts eventually to the developing South as the goods become "old". Another growing game theoretical literature tries to combine the insights of industrial organization and trade theories in analyses of international R & D or export rivalry (Cheng, 1984a, Spencer and Brander, 1983, and Brander and Spencer, 1985). The work most relevant to our model is that by Cheng and by Spencer and Brander, because there the firms' market interaction is explicitly treated.

The paper is organized as follows. In Section 2 we set up our basic duopoly, noncooperative differential game model, and establish the steady state open-loop Nash equilibrium.[1] The next section analyses the comparative steady states of the basic model, and generates our main propositions. Section 4 extends the model from a host country monopoly to n host country firms. This enables us to examine the effects of positive externalities of the host country's learning investment. Section 5 discusses some policy implications of our analysis, and, finally, section 6 concludes the paper.

2. The Basic Model

Consider two firms, a subsidiary of a multinational corporation and a host country firm, producing differentiated products for the host country market. The products provide certain common Lancasterian characteristics and are not traded internationally.[2] The main difference between the foreign

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[1]A more realistic solution concept would be the close-loop Nash equilibrium, in which the players' decision variables can be revised in the light of new information embodied in current state variables. Following Cheng (1984a) and Jensen and Thursby (1986), we adopt the open-loop solution simply for the analytic tractability.

[2]The assumption of no foreign trade is useful, but not indispensable for

affiliate and the domestic, host country firm lies in their accessibility to advanced production technology. The innovative research and development (R & D) is assumed to take place in the parent company of the multinational, and is accessible only to the MNC's subsidiary, but not to the rival host country firm.[3] Thus, as Das (1987) has described, multinationals transfer new technology from the parent headquarters to the overseas subsidiaries, and the host country firms learn from the subsidiaries. For simplicity, we abstract from the decision taken by the parent firm to invest in R & D.

The parent company, thus, provides the foreign affiliate with technology, but the transfer of such technological knowledge is not free. Teece (1976) convincingly shows that technology transfer activities within multinationals are not too different from the R & D process itself, and involve a substantial commitment of real resources and a sequence of overlapping stages of activities. Furthermore, Teece's study suggests that there exists "learning by doing" in international technology transfers, i.e. the transfer cost decreases with the frequency of transfers. This invokes the following assumptions:

(A1) For $a \in R_{++}$, let $I_f: R_{++} \rightarrow R_+$. I_f is monotonically decreasing in a, with

$$\lim_{a \to 0} I_f(a) = \infty, \quad \lim_{a \to \infty} I_f(a) = 0$$

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our main analytic results. It can be justified by the argument that the MNC has already made the decision to serve the host country market by local production, rather than by exporting there, perhaps because of tariffs. (See Smith, 1987). This assumption also implies that locally produced products are not exportable.

[3]Since the innovative R & D is considered strategic to the MNCs, it is generally carried out under the direct control of the parent firms. R & D

where a denotes the age of the technology transferred, and I_f the resources devoted to transfer activities by the foreign (or multinational) firm.

(A2) For $I_f \in R_+$, let C_f: $R_+ \rightarrow R_+$. C_f, i.e. the foreign firm's costs of transferring technology, is strictly convex in I_f.

Assumptions (A1) and (A2) together imply that the "learning by doing" effect makes its relatively cheaper to transfer old technologies and that the transfer costs of the latest technology are forbiddenly high.

Although there is generally some degree of technology spillover between firms, there is almost no free copying of technologies in the world. Searching for information, reversed engineering, personnel training for the new production methods, et cetera, make learning costly and time consuming. How much resources should be devoted to learning is, therefore, essentially an investment decision.[4]

(A3) For $I_d \in R_+$, let C_d: $R_+ \rightarrow R_+$. C_d is strictly convex in I_d. I_d denotes the domestic firm's investment in learning and C_d its cost of learning.

Quasi-Profit Functions

The interdependence of two firms in a differentiated product duopoly model is usually specified through price effects of their respective output. However, we have one more complication here, viz the "technology

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investment in affiliates is mainly undertaken to adapt production processes and characteristics of products to local market conditions and regulations. See Zejan (1988) for affirmative evidence.

[4]Findlay (1978b) addresses to the costs of generating "intermediate" technology, which could be understood in the light of learning process.

effect" on the profit margin. There are several ways to incorporate technology into the model. One can specify the unit cost as a decreasing function of the technological level K_i, i=f,d, or postulate the market demand as an increasing function of K_i, or both.[5] Assume that each firm faces a downward sloping demand curve for its product. An increase in one firm's market share will lower the market clearing price for the rival firm. Analytically we can decompose each firm's decision into two steps. At every moment each firm chooses its output to maximize its momentary profit, given the status quo of both firms' technology levels and its competitor's current output. Intertemporally each firm chooses its technology investment to maximize the present value of its profit stream. Let k be the technological gap between the foreign and the domestic firm[6]:

$$k(t) = K_f(t) - K_d(t) \qquad (1)$$

where the subscripts f and d represent the foreign and the domestic firm, respectively. In the following definition we suppress the argument t in each variable, since no ambiguity would arise. The quasi-profit functions at time

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[5]Similar formulations can be found in the oligopoly theory, where K_i is termed capital or good will (see Friedman, 1986, Chapter 4).

[6]In order to simplify the presentation and the mathematical expressions, we define k in absolute terms in (1). One can show that all the qualitative results in the paper hold if we instead specify k in relative terms, i.e. $k=K_f(t)/K_d(t)$. After a suitable modification of (4) and (5a), we get:

$$DK_f(t) = I_f(t)K_f(t) \qquad (4')$$
$$DK_d(t) = \phi(I_d(t))K_f(t) \qquad (6a')$$

which in turn gives:

$$Dk/k = I_f - \phi(I_d)k \qquad (7')$$

What is important for our model is the existence of a technology gap between the foreign and the domestic firm, and the effects of this on the profitability of both firms.

t are defined as[7]

$$R_i(k) = \underset{y_i}{\text{Max}} \{p_i(y)y_i - D_i(y_i, K_i) \mid y_i \text{ is feasible}\} \quad i = f,d \qquad (2)$$

where y_i and $D(\cdot)$ are the output and the production cost of firm i, respectively, and $y = (y_f, y_d)$. The quasi-profit functions are assumed to be continuously differentiable, bounded from above by some arbitrary number $M > 0$, and having the following properties:

$$R_f' > 0, \; R_f'' < 0 \qquad (3a)$$

$$R_d' < 0, \; R_d'' < 0 \qquad (3b)$$

(3a) states that the foreign firm's quasi-profit function $R_f(k)$ is an increasing function of k. The larger the multinational's technological lead, which results in either lower marginal cost or higher market demand or both, the higher its quasi-profits. $R_f(k)$ is assumed to be strictly concave in (3b); the narrower the technology gap, the more competitive the domestic, host country firm becomes, and hence the higher its quasi-profits.

The Model

The technology transfer process is quite simple. The MNC's technological capability K_f is augmented by devoting resources to transfer activities.

$$DK_f(t) = I_f(t) \qquad (4)$$

where the operator D denotes the time derivative of the variable. The speed of the technology transfer is proportional to the MNC's commitment to

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[7]An alternative way of defining quasi-profit functions, which, more explicitly, brings out the trade off between the current output and the

the transferring activity, and, for simplicity, the constant marginal productivity of I_f is assumed to be 1.

The domestic firm's technology level is an increasing function of its learning investment and diminishing returns occur as the learning effort scales up in each period. The hypothesis from Findlay (1978a), viz. that the rate of technological progress in a relatively 'backward' country is an increasing function of the gap between its own level of technology and that of the 'advanced' country, is also incorporated into the learning process:

$$DK_d(t) = \phi(I_d(t))[K_f(t) - K_d(t)] \quad (5a)$$

$$\phi'>0, \quad \phi''<0, \quad \phi(0)=v>0 \quad (5b)$$

where the constant v is the rate of costless technology spillovers. Equations (1), (4) and (5) together imply that the whole transfer-absorption process can be collapsed into the following differential equation:

$$Dk = I_f - \phi(I_d)k \quad (6)$$

The foreign firm's objective is to choose $I_f(t)$ for $t \geq 0$ to maximize the discounted value of its profit stream V^f subject to the transfer-absorption process (6), given the learning efforts of the domestic firm:

$$V^f = \int_0^\infty e^{-rt}[R_f(k) - C_f(I_f)]dt \quad (7)$$

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future market share each firm faces, is to assume that the investment rate enters each firm's static production function with a negative and decreasing marginal productivity (Lucas, 1967). Assuming that each firm faces a fixed factor price, this formulation yields the same analytical results as (2).

where r is the discount rate used by the foreign firm. The investment cost function $C_f(\cdot)$ is defined in (A2).

The domestic firm's objective function is:

$$V^d = \int_0^\infty e^{-\rho t} \; [R_d(k) - C_d(I_d)]dt \qquad (8)$$

where ρ is the discount rate used by the domestic firm, which may or may not be equal to r for reasons we shall explain in the next section. The properties of $C_d(\cdot)$ are described in (A3). The domestic firm's problem is to choose $I_d(t)$ for $t \geqslant 0$ to maximize V^d subject to (6).

Thus, we have laid out the entire basic differential game model and may now solve it by first characterizing the steady equilibrium conditions for each player's optimal control problem, given the decision of the other player, and then seek the steady state Nash equilibrium of the game.

<u>Solving The Model</u>

Begin by looking at the foreign firm's problem. The current value Hamiltonian is

$$H^f(I_f, I_d, k, t) = R_f(k) - C_f(I_f) + \mu_f[I_f - \phi(I_d)k] \qquad (9)$$

where μ_f is the cost variable for the foreign firm associated with the dynamic equation (6). μ_f may be interpreted as the shadow value of a marginal increase in resources to the transfer activities. The standard optimal control procedure yields the following first order necessary conditions:

$$\mu_f = C_f'(I_f) \qquad (10)$$

$$D\mu_f = [r + \phi(I_d)]\mu_f - R_f' \qquad (11)$$

and equation (6) as well as the usual transversality conditions.

The interpretation of (10) is that the multinational firm deploys resources to technology transfers up to the point where the marginal revenue equals the marginal cost. In the steady state we must have $Dk = D\mu_f = 0$, which yields the steady state values of μ_f and k conditional on I_d: $\tilde{\mu}_f = R_f'(\tilde{k})/[r+\phi(I_d)]$ and $\tilde{k} = I_f/\phi(I_d)$. Substituting these into (10), we arrive at the following expression, which depends on t only through I_f and I_d:

$$T_f(I_f, I_d; r) = \frac{R_f'[I_f/\phi(I_d)]}{r + \phi(I_d)} - C_f'(I_f) = 0 \qquad (12)$$

A similar method applies to the domestic firm's maximization problem:

$$T_d(I_d, I_f; \rho) = \frac{-R_d'[I_f/\phi(I_d)]}{\rho + \phi(I_d)} - \frac{C_d'(I_d)\phi(I_d)}{\phi'(I_d)\; I_f} = 0 \qquad (13)$$

(12) and (13) together then enables us to establish the steady state Nash equilibrium of this dynamic game.

<u>Proposition 1</u>. Under the assumptions (A2), (A3), and (3), there exist a unique, locally stable steady state Nash equilibrium, characterized by a pair of positive constants I_f^* and I_d^*, such that $T_f(I_f^*, I_d^*; r) = 0$ and $T_d(I_d^*, I_f^*; \rho) = 0$, whenever

$$I_f > \frac{R'_f\, \phi^2}{-R''_f(r+\phi)} \qquad (14)$$

$$\phi'(0) > \frac{C'(0)(\rho + v)v}{-R_d'(I_f/v)I_f} \qquad (15)$$

and $$\left(\frac{dT_f}{dI_f} * \frac{dT_d}{dI_d}\right) > \left(\frac{dT_f}{dI_d} * \frac{dT_d}{dI_f}\right) \tag{16}$$

Proof. See Appendix 1.

It is interesting to note that a steady state Nash equilibrium exists even when (15) does not hold. In this case, the domestic firm's maximization problem attains a corner solution $I_d^* = 0$. Since $\phi(0) = v>0$, despite of the complete passiveness of the domestic firm, the MNC's technological lead would still be eroded over time. The equilibrium strategy of the MNC is thus $I_f^* = u>0$, which is derived from $T_f(I_f^*, 0) = 0$.[8] The constant u gives the minimum level of equilibrium technology transfer.

In spite of the obvious economic implications of this Nash equilibrium, we are more interested in the comparative steady states of the interior equilibrium, for which we assume (15). The domestic firm will not invest in learning unless the marginal benefit of its first unit of resource spent on such activities exceeds the loss in current profits. This lower bound is specified in (15), which increases as the costless rate of technology absorption, v, increases. If v is very high, i.e. technology learning is mostly free, the domestic firm will not invest in learning at all. Condition (14) is needed for an upward sloping reaction function of the MNC. Finally, inequality (16) insures uniqueness and local stability of the equilibrium.

3. Steady State Technology Transfers and The Behavior of The Firms

From Proposition 1, we know that the steady state equilibrium

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[8]Das (1987) shows that under similar circumstances, if I_f=0, then the market share and the profit of the MNC's subsidiary will decline over time, while that of the domestic firm will increase.

technology transfer investment I_f* and the domestic firm's learning efforts I_d*, are jointly determined by (12) and (13), with the discount rates r and ρ as parameters. In other words, the equilibrium (I_f*, I_d*) is conditional on the firms' behavior. Given this, we will now try to add some more reality into the discussion.

From the empirical literature we know that multinationals not only enjoy technological advantages that allow them to compete successfully with domestic firms on the latter's own turfs, but also that MNCs generally have advantages over domestic firms in access to international capital markets (see e.g. Mason, 1973). This is particularly true when the host country is a developing country, and we, thus, have $r \leq \rho$, in general. Then, imagine a multinational corporation having two foreign subsidiaries in two different countries, with one country being more politically stable and enjoying higher predictable economic growth. In that situation we expect the subsidiary in the more risky country, say country 1, to discount its future profits more heavily, i.e. $r_1 \geq r_2$, and the consequences of this is readily seen in the first order conditions (10), (11), and (6), or in Figure 1, which shows the familiar phase diagram for the dynamic system (6) and (11). The system exhibits saddle path stability (see Appendix 2). The AA ($D\mu_f$=0) schedule is downward sloping. For the foreign firm, the higher the equilibrium technology gap, the smaller the shadow value of increasing investment in transfer activity.

INSERT

Figure 1

An increase in r shifts the AA schedule down to A'A', leaving Dk=0 locus unchanged, given the level of I_d. The new steady state is then $\mu_f' < \mu_f^*$ for r'>r. From (10) we know that $I_f' < I_f^*$, since $C_f'' > 0$. This implies, that for the same steady state technology gap, the higher the operation risks for a multinational firm, the more reluctant it appears to transfer technology. This finding can be stated in the following proposition:

Proposition 2. Given the learning efforts of host country firms, a multinational firm's incentive to transfer technology is negatively related to its perceived country (industry) specific operation uncertainty.

The Nash equilibrium established in Proposition 1 can be seen and analyzed more intuitively by using the concept of best reply mapping. Equations (12) and (13) implicitly define the two steady state best reply mappings:

$$I_f = \psi_f(I_d, r), \quad \psi_f(0, r) = u, \quad u>0. \tag{17a}$$

$$\psi_f' > 0 \tag{17b}$$

$$I_d = \psi_d(I_f, \rho) \tag{18a}$$

$$\psi_d' > 0 \tag{18b}$$

The derivation of (17b) and (18b) is relegated to Appendix 3. Intuitively, given the paramater r, the higher the domestic host country firm's investment in learning, the narrower the future technology gap, since investment in learning by the domestic firm squeezes the foreign affiliate's profits. In anticipating this, the MNC allocates more resources to transfer more advanced technologies in order to keep its business profitable. In the case I_d=0, I_f=u, since $\phi(0)$=v. The same interpretation holds for $\psi_d(\cdot)$. The Nash equilibrium of the game is determined by the intersection of these best reply mappings (Figure 2).

INSERT

Figure 2

Suppose that ρ=r at the equilibrium point A. The MNC's reaction function $\psi_f(\cdot)$ then turns clockwise (for r'>r) as a consequence of Proposition 2. Hence, the resulting new Nash equilibrium level of I_f is below that at point A.

By further investigating the two best reply mappings, we found that both the speed of the technology transfer and the vintage of the technologies transferred via foreign direct investment were dependent on the actions taken by the domestic, host country firms.

Proposition 3. Technologies will be transferred more rapidly and the more modern ones will be transferred, (a) the lower the domestic firms' discount rate, or time preference rate, (b) the more efficient the learning activities are, and (c) the higher degree of substitution between the competing products. In general, technology transfer via foreign direct investment is positively related to the level of host country firms' learning investment.

Proof. Higher equilibrium I_f* represents faster technology transfer and transfer of newer (more modern) technologies by virtue of (4) and (A1). $\psi_d(\cdot)$ can be written in an implicit form as

$$\frac{|R_d'|}{\rho+\phi(I_d)} = \frac{C_d'(I_d)\phi(I_d)}{\phi'(I_d)I_f} \tag{19}$$

which is simply the reproduction of (13). The left hand side is the steady state marginal revenue of learning investment and the right hand side represents the marginal costs. Holding I_d constant, an increase in ρ entails a rise in I_f for the equality to be held. This is equivalent to turning $\psi_d(\cdot)$ counter-clockwise in Figure 2 above, where the new Nash equilibrium was depicted as point B. This lends a proof to Proposition 3(a). We use an example to prove statement (b). Let $\phi(\cdot)$ take an exponential form and let the two learning technologies be $\phi_1 = I_d^{\alpha}$ and $\phi_2 = I_d^{\beta}$. Clearly $(\phi_1'/\phi_1) > (\phi_2'/\phi_2)$ implies $\alpha>\beta$, which in turn implies $\phi_1 > \phi_2$, for all $I_d > 0$. The higher the ϕ'/ϕ, for given I_d, the smaller the value of I_f for (19) to hold. These comparative steady states are shown in Figure 3, which proves (b). The degree of substitution of the two goods is captured by $|R_i'|$, i = f,d, which appears both in (12) and (19). The higher the value of $|R_i'|$, the larger the magnitude of the shifts in both the reaction functions. At the new equilibrium point B in Figure 4, $I_f' > I_f^*$. This completes the proof of Proposition 3.

INSERT <u>Figure 3</u>

INSERT <u>Figure 4</u>

Before leaving this section, we can state one more comparative steady state result.

<u>Proposition 4</u>. The more costless technology spillovers from foreign to domestic firms, the faster the technology transfer.

Proof. Let $\phi(0)=v$ and $\phi(0)' = v'$, $v'>v$. Recall equation (12), we have $I_f = \psi_f(0|v) = u$, $I_f' = \psi_f(0|v') = u'$, and $u'>u$. This amounts to lifting the $\psi_f(\cdot)$ locus vertically upwards in Figure 2. Thus, the new Nash equilibrium level of I_f is higher.

4. Learning Externalities and Aggregate Learning Investment

There are many factors that may contribute to below optimal levels of investment in learning in a host country. While high real rates of interests may be important, especially for less developed countries, another possible reason is externalities in learning investment. Once a domestic firm has adapted or modified foreign technologies to fit domestic conditions, it is generally easier and cheaper for other firms to do the same. The phenomenon of learning by someone else's doing has long been observed by economists (see e.g. Bhagwati, 1968), and Arrow's famous learning-by-doing paper (Arrow, 1962) provides a theoretical exploration of the divergence between social and private rate of returns associated with investment activities. In this section we extend our basic model to allow for such possibilities.

Suppose that there are n identical host country firms in the same industry. Each of them applies reversed engineering I_i, i=1,2,...n. Assume that there is no collusion among the firms. Their respective learning processes are interrelated by an unavoidable transmission of information, i.e. there exist positive externalities in learning. Let E_i be the effective learning investment in firm i.

$$E_i(t) = I_i(t) + \sum_{j\neq i}^{n} \beta\, I_j(t), \qquad \beta \in (0, 1) \tag{20}$$

The magnitude of the externalities is captured by β. The larger the β, the higher the effective learning actually attained by firm i, given the other firms' learning efforts. The technology transfer-absorption process for firm i, thus, becomes:

$$Dk_i = I_f - \phi(E_i)k_i \tag{21}$$

where $k_i = K_f - K_i$ is the technology gap between the foreign affiliate and the domestic firm i. The functional form of $\phi(\cdot)$ is the same for all the domestic firms, and the assumptions in (5b) still apply. By choosing the path of its investment I_i, firm i maximizes the present value of its profits V^i:

$$V^i = \int_0^\infty e^{-\rho t}[R_i(k_i) - C_i(I_i)]dt \tag{22}$$

subject to (21). The resulting first order necessary conditions imply the private shadow value of investment in learning in the steady state

$$-\mu_i = \frac{C_i'(I_i)\phi(E_i)}{\phi'(E_i)\ I_f} \tag{23}$$

The constant variable μ_i is negative, because the larger the technology gap k_i, the less the quasi-profit $R^i(k_i)$ for firm i, given the level of investment I_i.

Let us then superimpose a social planner who is able to internalize the domestic firms' learning externalities. In order to attain social optimality he has to maximize the aggregate discounted stream of future profits of all the n firms, to determine each firm's investment level. Therefore, his problem is

$$\underset{I_i}{\text{Max}}\ V^S = \sum_{i=1}^{n} V_i = \int_0^\infty e^{-\rho t}\left\{\sum_{i=1}^{n}[R^i(k_i) - C_i(I_i)]\right\}dt \qquad (24)$$

subject to $\dot{k}_i = I_f - \phi(E_i)k_i$, $\qquad i = 1,2,\ldots.n.$

where the superscript S denotes "social". The planner's current value Hamiltonian is

$$H^S = \sum_{i=1}^{n}[R^i(k_i) - C_i\ (I_i)] + \sum_{i=1}^{n}\mu_i[I_f-\phi(E_i)k_i] \qquad (25)$$

where μ_i has the same interpretation as before, i.e. the shadow value of an increasing investment perceived by firm i. Note by the symmetry assumption we made before, that μ_i is identical for all i, i=1,2,...n. By applying the standard technique, we then obtain the following expression for the Pareto-optimal (social) valuation of the investment of firm i:

$$-\mu^S_i = -[1+b(n-1)]\mu_i = \frac{C'(I_i^S)]\phi(E_i^S)}{\phi'(E_i^S)\ I_f} \qquad (26)$$

It is obvious that $-\mu^S_i \geqslant -\mu_i$, since $\beta \geqslant 0$ and $n \geqslant 1$. In other words, the social benefit of firm i's investment is higher than the private benefit perceived by firm i itself, due to the existence of positive externalities. When n=1, the model collapses into the monopolist's model in Section 2 above. We also notice, that if $\beta=0$, i.e. if there is no external economies in learning investments, the present model essentially behaves like the basic model.

Since the social value of firm i's investment is higher than the private value, it is desirable from the host country social welfare point of view to increase firm i's investment to the socially optimal level. More precisely, we have:

Proposition 5. If $\beta>0$ and $n>1$, there exists positive externalities in the domestic firms' learning investments, and the individual firm i's steady state investment $I_i < I^s_i$ under laissez-faire, where I^s_i is the social optimal level of firm i's investment in learning.

Proof. Compare (26) with (23). Given the value of I_f, $-\mu_i<-\mu^s_i$ iff $I_i<I^s_i$, since $\phi'>0$, $\phi''<0$, $C_i' > 0$, $C_i'' > 0$, and $dE_i/dI_i = 1 > 0$ for all i.

Proposition 5 shows, that even when the domestic firms' discount rate is equal to that of the MNC, the aggregate level of investment in learning may stil be suboptimal, because each firm's investment is suboptimal and $I_d = \sum_{i=1}^{n} I_i$. This result effectively turns the host country's aggregate best reply mapping locus in Figure 2 towards the vertical axis without resorting to the condition of $\rho>r$. Hence, we know that the steady state Nash equilibrium level of technology transfers is slower. The insights we obtained from Proposition 3 are reinforced. This leaves room for appropriate policy interventions.

5. Policy Implications

The most important policy implication of our model emerges from Proposition 3. A host country is often, particularly in the development literature, thought to be sure of achieving benefits from an MNC project after a successful outcome to negotiations between its government and the foreign firm (see e.g. Vaitsos, 1974, pp. 311-315). However, rather than focusing on such negotiations and stipulating performance requirements for the multinationals, our model suggests that if countries hosting multinational corporations want to increase the rate at which MNCs transfer technology, they should concentrate on supporting their domestic firms in their efforts to learn from the foreigners.[9] This is not only because individual host countries have limited possibilities to influence the multinationals in their choice of production location, but also because technology transfer via MNCs depends, to a large extent, on the performance of the host country firms.

We also believe that Proposition 3 might be more general than it appears to be. As long as foreign firms mainly serve host country markets, and foreign and domestic goods are substitutes, Proposition 3 would hold even if we allow for foreign trade. It may, in fact, be valid even when the MNCs are purely export oriented. The market interaction between the firms will then take place in some third country.

The implications of Proposition 3 become more important if the domestic firms' ability to learn is related to their stock of technical knowledge K_d. One may rewrite (5) in the following way:

$$DK_d = \phi(I_d, K_d)(K_f - K_d), \qquad d^2\phi/dI_d dK_d > 0$$

The accumulation of K_d increases the domestic firms' ability to learn. Active learners will, thus, get modern technology faster than others, which, of course, increases their possibilities to catch up with the more advanced

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[9]We do not say that all performance requirements on MNCs are undesirable. For a welfare analysis of export-performance requirements on foreign investors in a second-best environment, see Rodrik (1987).

countries. Passive watchers, on the other hand, will be left further and further behind in a changing world.

While the general policy message is a kind of "cautious activism" (Krugman, 1987), coinciding with the literature on "new" trade theory and strategic trade policy, the policy prescription is more in the spirit of the "general theory of distortions", i.e. to target the source of distortion directly. Proposition 3 and Proposition 5 justify the need for incentives to learning investment in host countries. Domestic firms competing in products that are close substitutes to the products of the foreign affiliates need most support. Proposition 3 also reveals the vital role of efficiency in learning, but it is beyond the scope of this paper to analyze that more in detail.[10]

6. Concluding Remarks

In this paper we have developed a model of international technology transfer via foreign direct investment. Our primary contribution lies in highlighting the essential role played by the competing host country firms in increasing the rate at which MNCs transfer technology. Thus, our model goes beyond earlier ad hoc modelling of technological spillovers (e.g. Findlay, 1978a). Furthermore, our model is able to explain some features, mentioned in the beginning of the paper, that we believe are crucial in understanding the technology transfer process. It we interpret one of the key differences between developed and developing countries, from the point

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[10]It should be pointed out that all the general equilibrium and political economy caveats against the "new" trade interventionism (see e.g. Krugman, 1987) apply to our discussion.

of view of the multinationals, as differences in operational uncertainty, Proposition 2 may explain why the average age of technologies transferred by MNCs to their subsidiaries in developed countries is lower than the age of those transferred to developing countries. Proposition 3, coupled with Proposition 2 and 5 can also explain why large foreign participation in an economy can coexist with slow technology transfer. While "learning-by-watching" is proportional to the presence of foreign firms, technology transfer via foreign direct investment is also conditional on the competitive pressure in the host country. The latter effect may, in fact, dominate the former.

Models of the product cycle emphasize the transfer of product (embodied) technology. Dynamic analyses of the product cycle, however, usually result in a persistent technology gap between the two trading regions, and it is not in the interest of latecomers to narrow that gap (see e.g. Jensen and Thursby, 1986). Our model sheds light on process technology transfer. Although there is a steady state technology gap between MNC subsidiaries and host country firms, there are possibilities for the initially backward country to catch up. When the growth rate of the MNC's R & D falls short of the rate at which the host country imitators erode the MNC's technological advantage, the technology gap will eventually be closed. However, whether this will happen or not depends, as our model suggests, on the actions taken by the latecomer's own firms.

Appendix

A.1 Proof of Proposition 1

The profit function of firm i at time t, π_t^i is

$$\pi_t^i = R_i(k(t)) - C_i(I_i(t)), \qquad i = f,d. \tag{P1}$$

The dynamic equation (6) in a discrete time version can be written as:

$$k(t) - k(t-1) = I_f(t-1) - \phi(I_d(t-1))k(t-1). \tag{P2}$$

It is straightforward to show that π_t^i is strictly concave in both $I_i(t)$ and $I_i(t-1)$, given the assumptions (A2), (A3), and (3).

$$\frac{d^2\pi_t^i}{dI_i^2(t)} = -C_i'' < 0, \qquad i = f,d. \tag{P3}$$

$$\frac{d^2\pi_t^f}{dI_f^2(t-1)} = R_f'' < 0 \tag{P4}$$

$$\frac{d^2\pi_t^d}{dI_d^2(t-1)} = R_d'' \phi'^2 - R_d' \phi'' < 0 \tag{P5}$$

π_t^i is also continuous and bounded, since both $R_i(\cdot)$ and $C_i(\cdot)$ are continuous. Finally, because $R_i(\cdot)$ is bounded from above by M and $\pi_t^i \geqslant 0$, each player's strategy set $[0, C_i^{-1}(M)]$, hence, is evidently compact and convex. The existence of an open-loop, steady state equilibria of our time-dependent supergame follows directly from a Theorem in Friedman (1986), pp. 118.

Condition (14) guarantees that the best reply mapping of the foreign firm is upward sloping, as our intuition leads us to expect.

Condition (15) is introduced to ensure an interior equilibrium

(I_f^*, I_d^*). If (15) does not hold, the Nash equilibrium would be $(\hat{I}_f, 0)$, where $\hat{I}_f$ is determined by $T_f(\hat{I}_f, 0) = 0$

Both dT_f/dI_f and dT_d/dI_d are negative, and dT_f/dI_d and dT_d/dI_f are positive (Appendix 3). (16) insures that the Jacobian of system (12) and (13) is negative quasi-definite, which in turn insures the uniqueness and domestic stability of (I_f^*, I_d^*).

A.2. Stability of System (6) and (11)

Let $a_{11} = dDk/dk$, $a_{12} = dDk/d\mu_f$, $a_{21} = dD\mu_f/dk$, and $a_{22} = dD\mu_f/d\mu_f$, all the partial derivatives are evaluated at the steady state, $Dk = 0$ and $D\mu_f = 0$. One can show that the determinant of the Jacobian,

$$\det |J| = \begin{vmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{vmatrix} = \begin{vmatrix} - & 0 \\ + & + \end{vmatrix} < 0.$$

Hence, the system exhibits a saddle path stability. The slopes of the two schedules, $Dk = 0$ and $D\mu_f = 0$ are $-(a_{11}/a_{12}) = \infty$ and $-(a_{21}/a_{22}) < 0$, respectively.

A.3. Slopes of the Best Reply Mappings

Differentiating (12) and (13) totally, using the facts that $T_i(I_f^*, I_d^*) = 0$, $i = f,d$ and $k^* = I_f^*/\phi(I_d^*)$ in equilibrium, we have the following partial derivatives:

$$\frac{dT_f}{dI_f} = \frac{R_f''}{(r+\phi)\phi} - C_f'' < 0 \qquad \text{(P6)}$$

$$\frac{dT_f}{dI_d} = \frac{\phi'[-(r+\phi)I_f R_f'' - R_f'\phi^2]}{[(r+\phi)\phi]^2} > 0 \qquad \text{(P7)}$$

given the condition (14).

$$\frac{dT_d}{dI_f} = [\frac{C_d{'}}{\phi'\tilde{k}^2} - \frac{R''_d}{(\rho + \phi)}] / \phi > 0 \qquad (P8)$$

$$\frac{dT_d}{dI_d} = \frac{\phi'[(\rho+\phi)I_f\ R''_d + R'_d\ \phi^2]}{[(r+\phi)\phi]^{\ 2}} - D < 0 \qquad (P9)$$

$$\text{where } D = \frac{\phi' C_d'' - C'_d\ (\phi'' - \phi'^2/\phi)}{\phi'^2\ \tilde{k}} > 0$$

(P6) and (P7) together imply that $\psi'_f > 0$, and (P8) and (P9) imply that $\psi'_d > 0$.

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Figure 1.

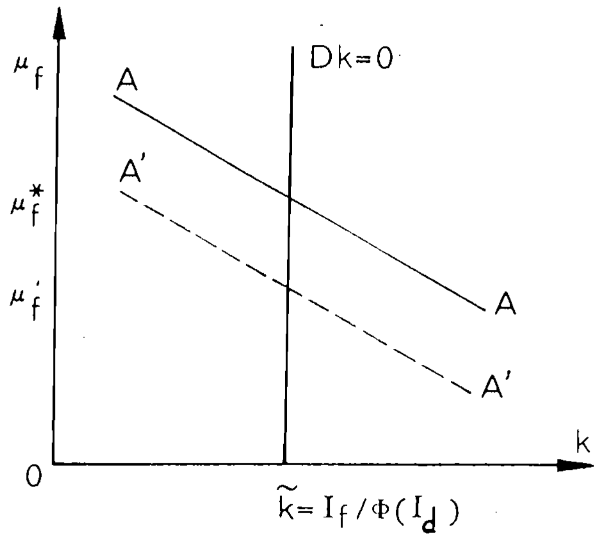

Figure 2.

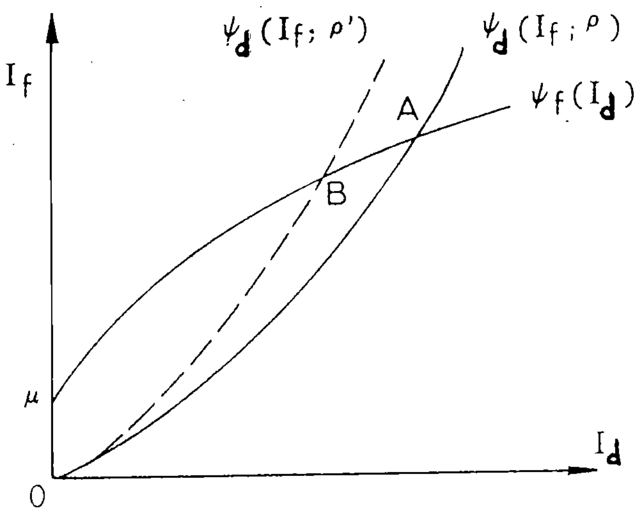

Figure 3.

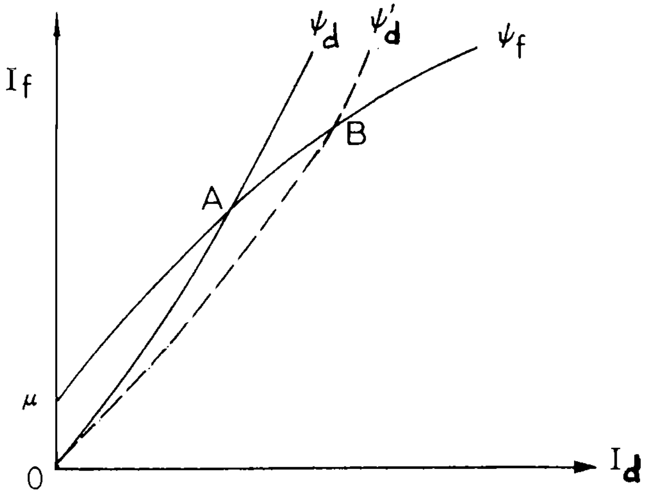

Figure 4.