Discussion Paper #622

MARKET STRUCTURE AND INTERNATIONAL TECHNOLOGY TRANSFER

by

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1. INTRODUCTION

One of the main questions in the field of economics of technical change concerns "market structure and innovation." A bulk of the research in this field deals with the impact of market structure upon innovation. A typical question in this literature is, "what is the optimal number of firms in an industry which leads to the most rapid rate of innovation?" An extensive survey of this literature, empirical and theoretical, can be found in Kamien and Schwartz (1982).

A similar question can be asked in a developing country which heavily depends on foreign sources for most of the new technologies it needs. In this developing country, the rate of technical advance depends on the technologies produced outside of the country through international technology transfer. The relevant question for the country is "what is the optimal number of firms in an industry, if any, which leads to the most rapid rate of technical change through international technology transfer?"

As in the previous paper, Lee(1984), we treat a technology as an economic commodity, so that we can consider international technology transfer as a pure economic phenomenon in which buyers and sellers are maximizing their expected profits arising from the trade of the technology.

Because the demand for a technology is single-unit demand, i.e., a firm doesn't want to buy more than one unit of the same technology, the buyer's (buying country or firm) problem is again a timing problem. They are more concerned about when to buy rather than how many to buy. ($t = \infty$ if there is no transfer).

Whereas Lee(1984) deals with the timing problem of technology trade between monopolist seller and monopsonist buyer, this chapter deals with the problem of several prospective buyers in the buying country.

In Section 2, we will discuss the problem of timing equilibrium when the technology buying industry is not monopolistic. More specifically, we will set up a model of "Nash timing equilibrium" in a duopolistic market structure in the buying industry for a given new advanced technology available from a foreign source.

The two firms are assumed to be operating using the current best technology. They are Cournot output competitors with each other, given market demand. When a cost reducing foreign new technology is available to the firms, each firm can be the international transferee of the technology, paying a higher transfer cost and expecting a higher future profit stream. Or, the firm can be the domestic adopter of the technology, paying a lower cost and expecting a lower future profit stream. Of course, domestic adoption by a firm can occur only after another firm buys the technology at some earler time.

We will follow Reinganum (1980), and Flaherty (1980), in describing the Nash timing equilibrium. Whereas, in their technology adoption studies, they assumed two firms face the same adoption cost function for the acquisition of the technology no matter which firm moves first, we assume the international transferee and the domestic adopter of the technology may have different cost schedules which are functions of time. Reinganum and Flaherty's model can be considered as a special case of our model. The difference in the cost for the international transfer and the domestic adoption is essential in the study of the international technology transfer.

Differing from Reinganum and Flaherty's results, our analysis discloses that when the intra-industry technology diffusion effect is strong enough, there can be a case of non-existence of a Nash timing equilibrium. This is because the domestic adopter follows the international tranferee too soon, lessening the profit opportunity to be a first mover (international transferee of the technology). That is, even though moving first gives some positive benefit for a firm, moving second gives more benefits for the firm, so, each firm wants the other firm to move first, resulting in a socially inefficient "waiting game problem" in the technology adoption game.

In Section 3 we will investigate the relationship between the market structure and the timing of the technology transfer. In particular, we will study the case in which the buying industry is composed of n indentical firms with constant marginal cost.

Our analysis discloses that an intermediate market structure, one that is neither monopolistic nor perfectly competitive, is most conducive to rapid technical advance. The exact number of firms depends on the size of cost reduction by the new technology relative to the market demand.

We also found that the socially optimal time of the transfer is earlier than the private optimal time. Furthermore, the transfer time with collusion is later than the transfer time without collusion.

2. NASH TIMING EQUILIBRIUM

2.1 Model

Consider an industry composed of two identical firms in a technology buying country. Each of these two firms is assumed to be a Cournot-competitor with each other, facing given market demand. Initially these two firms are using the current best technology available, the old technology 0. At time $t = 0$, a cost reducing advanced technology, the new technology N, is available to both firms. Each firm has two alternative actions regarding the new technology:

(1) buying the technology from a foreign seller, paying the international transfer cost $c(t)$, which is the function of the transfer time (the time at which the firm purchases the technology from the foreign seller),

(2) waiting until the other firm buys the technology and adopting it at some later time, paying the domestic adoption cost $d(s,t)$, where t is the transfer time and s is the time elapsed between the adoption and the transfer. So the actual adoption time is $s + t$.

At time $t = 0$, each firm must determine when to buy or adopt the technology, maximizing the expected discounted net profit. This profit is a function of the other firm's choice and each firm is assumed to be a Nash competitor with the other.

We will make the following assumptions regarding the transfer cost and the adoption cost.

(A1) $c(t) > 0. \quad c'(t) < 0. \quad c''(t) > 0 \quad \text{for all } t \mp [0,\infty].$

(A2) $d(s,t) > 0,\ d_s(s,t) < 0,\ d_{s,s}(s,t) > 0,$

$d_t < 0,\ d_{t,t} > 0,\ d_{t,s} > 0 \quad \text{for all } t \geq 0 \text{ and } s \geq 0 .$

(A3) $d(s,t) < c(t+s) \quad \text{for all } t \geq 0 \text{ and } s > 0,$

$\text{and } d(0,t) = c(t) \text{ for all } t.$

A1 states that the transfer cost function is a positive and strictly decreasing convex function of the transfer time. This transfer cost is considered to include the price of the technology. For the negative monotonicity of the price of a technology with one buyer and one seller, refer to Lee(1984). An example of such a cost function is $c(t) = \alpha e^{-kt}$. Another example is $c(t) = k/t$.

A2 states that the domestic adoption cost function is a decreasing convex function of the time elapsed between the adoption and the transfer and also a decreasing convex function of the transfer time.

A3 states that once the technology has been transferred to a firm from the foreign seller, then the cost for the other firm to acquire the technology by domestic adoption is less than the international transfer cost. This is equivalent to saying that the adopting firm has a choice between domestic adoption and international transfer for acquiring the technology.

An example of such an adoption cost function satisfying A2 is $d(s,t) = \alpha e^{-(kt+hs)}$. Together with $c(t) = \alpha e^{-kt}$, Assumption A3 is also satisfied.

There are four possible states for the industry regarding the technology each firm uses,

$$(0,0),\ (N,0),\ (0,N),\ (N,N),$$

where the first coordinate is for firm 1's technology and the second coordinate is for firm 2's technology. So, (0,0) represents that both firms use the old technology, and (N,0) represents that firm 1 uses the new technology, and firm 2 uses the old technology, and so on.

Assuming that the market demand is stationary over time the profit allocation generated by Cournot competition is constant over time in each of above four states, i.e.,

state	(0,0)	(N,0)	(0,N)	(N,N)
profit per period	(π_o,π_o)	(π_1,π_2)	(π_2,π_1)	(π_3,π_3)

Representing this relationship in the time, profit space,

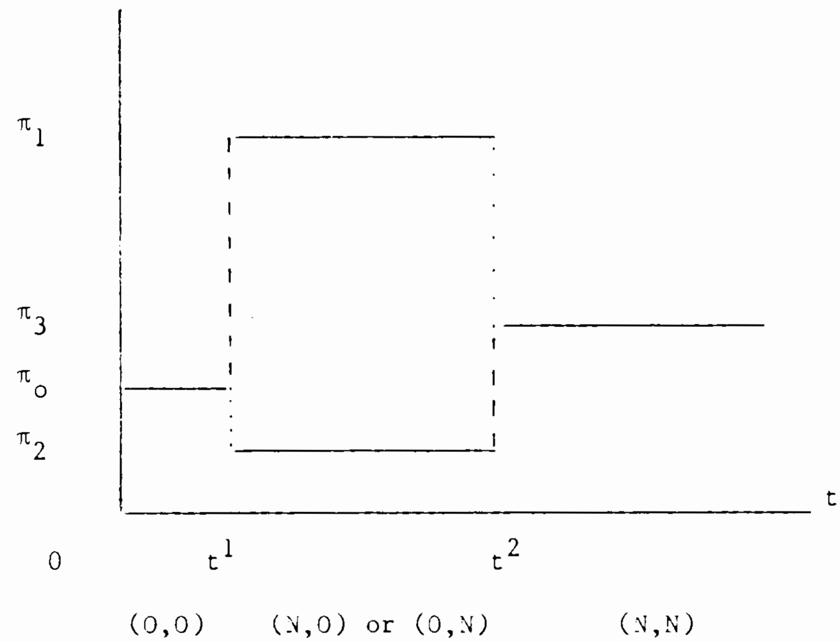

Figure 1

where, t^1 is the international transfer time and t^2 is the domestic adoption time

Furthermore, we will make a following assumption regarding the profit.

(A4) $\pi_1 > \pi_3 > \pi_o > \pi_2 > 0$, and $\pi_1 - \pi_o > \pi_3 - \pi_2$.

This assumption states that profit increase for the technology transferee is greater than the profit increase for the adopting firm. This assumption can be shown to be satisfied when the production cost function is of constant marginal cost and the market demand is linear.

function is of constant marginal cost and the market demand is linear.

Let t_1 and t_2 represent the time of action (buying or adopting) by firm 1 and firm 2 respectively, and r represent the interest rate. Then the firm 1's discounted net profit of moving at time $t = t_1$, given firm 2's move at $t = t_2$, is

$$
(1) \quad V_1(t_1,t_2) = \begin{cases} \int_{t_1}^{t_2} e^{-rt}(\pi_1 - \pi_o)dt + \int_{t_2}^{\infty} e^{-rt}(\pi_3 - \pi_o)dt - e^{-rt_1}c(t_1) & \text{if } t_1 \leq t_2, \\ \int_{t_2}^{t_1} e^{-rt}(\pi_2 - \pi_o)dt + \int_{t_1}^{\infty} e^{-rt}(\pi_3 - \pi_o)dt - e^{-rt_1}d(t_1-t_2,t_2) & \text{if } t_1 \geq t_2 . \end{cases}
$$

Similarly, firm 2's discounted net profit of moving at time $t = t_2$, given firm 1's move at $t = t_1$, is

$$
(2) \quad V_2(t_1,t_2) = \begin{cases} \int_{t_1}^{t_2} e^{-rt}(\pi_2 - \pi_o)dt + \int_{t_2}^{\infty} e^{-rt}(\pi_3 - \pi_o)dt - e^{-rt_2}d(t_2-t_1,t_1) & \text{if } t_1 \leq t_2, \\ \int_{t_2}^{t_1} e^{-rt}(\pi_1 - \pi_o)dt + \int_{t_1}^{\infty} e^{-rt}(\pi_3 - \pi_o) - e^{-rt_2}c(t_2) & \text{if } t_1 \geq t_2 . \end{cases}
$$

Notice that $V_i(t_1,t_2)$ are continuous at $t_1 = t_2$ since $d(0,t) = c(t)$ for all t. But they are not differentiable at such a point.

For an analytical simplicity we will exclude the possibility that a firm will not adopt the technology at all. This can occur if the transfer cost or the adoption cost is too high to guarantee the firm a positive value from the technology transfer or adoption. Formally this can be stated as in the following assumption.

(A5) Given t_j, there exists some t_i such that $V_i(t_1,t_2) > 0$,

where $i = 1, 2$ and $j = 2, 1$.

2.2 Equilibrium

The problem can be modeled and solved as a game theoretic framework: The game is represented by

$$\Gamma = \{(1,2),\ S,\ V\} ,$$

where;

1) There are two <u>players</u>, firm 1 and firm 2.
2) The <u>strategy space</u> is $S = S_1 \times S_2$,

   where $S_i = [0, \infty)$ for $i = 1, 2$.

   The pure strategy for player i is $t_i \in S_i$.
3) <u>Payoff functions</u> V_1, V_2 are given by

   (1), and (2) respectively.

DEFINTION 1. The <u>best response</u> for firm i to t_j is

$$r_i(t_j) = \text{Inf}\{t_i \in S_i : V_i(t_i, t_j) \geq V_i(t_i', t_j) \text{ for all } t_i' \in S_i\}$$

The mapping $r_i; S_j \to S_i$ is i's best response function.

DEFINITION 2. A strategy pair (t_1^*, t_2^*) is a Nash Equilibrium for the game Γ if

a. $t_i^* \in S_i$, $\quad i = 1, 2$,

b. $V_1(t_1^*, t_2^*) \geq V_1(t_1, t_2^*)$, $\quad$ for all $t_1 \varepsilon S_1$,

c. $V_2(t_1^*, t_2^*) \geq V_2(t_1^*, t_2)$ $\quad$ for all $t_2 \varepsilon S_2$.

That is (t_1^*, t_2^*) is a Nash Equilibrium if $t_1^* = r_1(t_2^*)$ and $t_2^* = r_2(t_1^*)$.

Now, the best response function for firm 1 is

$$(3) \quad r_1(t_2) = \text{Inf}\{\arg \underset{t_1}{\text{Max}}\, V_1(t_1, t_2)\}$$

$$= \text{Min}\{\arg \underset{t_1}{\text{Max}}[\underset{t_1 \in [0, t_2]}{\text{Max}} V_1(t_1, t_2), \underset{t_1 \in [t_2, \infty)}{\text{Max}} V_1(t_1, t_2)]\}$$

Similarly the best response function for firm 2 is

$$(4) \quad r_2(t_1) = \text{Min}\{\arg \underset{t_2}{\text{Max}}[\underset{t_2 \in [0, t_1]}{\text{Max}} V_2(t_1, t_2), \underset{t_2 \in [t_1, \infty)}{\text{Max}} V_2(t_1, t_2)]\}$$

LEMMA 1 If a firm moves first (buys the technology), then the firm's optimal transfer time is either 0 or $\hat{t}$, independent of the other firm's adoption time, where $\hat{t}$ is such that

(5) $$\pi_1 - \pi_o = rc(\hat{t}) - c'(\hat{t}) \ .$$

PROOF Without loss of generality, consider the case in which firm 1 moves first, that is $t_1 < t_2$. Suppose we found such a $\hat{t}$. Because firm 1 is predetermined to be the first mover, $\hat{t} < t_2$. So, firm 1's problem is

(6) $$\max_{t_1 \varepsilon [0,t_2]} V_1(t_1, t_2) = \int_{t_1}^{t_2} e^{-rt}(\pi_1 - \pi_o)dt + \int_{t_2}^{\infty} e^{-rt}(\pi_3 - \pi_o)dt - e^{-rt_1}c(t).$$

The first order condition is given by

(7) $$\frac{dV_1}{dt_1} = - e^{-rt_1}\{(\pi_1 - \pi_o) - [rc(t_1) - c'(t_1)]\} \ .$$

The second order condition for maximum can be shown to be satisfied using the assumption A1. Since $\hat{t}_1 < t_2$, the solution is not binding by t_2. So, by Equation (7) the optimal trasnfer time is

$$(8) \qquad t_1^* = \begin{cases} \hat{t} \text{ such that } (\pi_1 - \pi_o) = rc(\hat{t}) - c'(\hat{t}) & \text{if } (\pi_1 - \pi_o) < r\, c(0) - c'(0), \\ 0 & \text{otherwise.} \end{cases}$$

So $\hat{t}$ is independent of t_2, and uniquely determined since the RHS of (5) is strictly decreasing in t_1.

Q.E.D.

Notice that the LHS of Equation (5) represents the marginal loss of delaying one more period, and the RHS represents the marginal gain of the delay.

LEMMA 2 If a firm moves second, i.e., it is the domestic adopter of the technology, then the optimal adoption lag for the firm is either 0 or $\hat{s}(t)$, where $\hat{s}(t)$ is the function of the transfer time, t, such that

$$(9) \qquad \pi_3 - \pi_2 = rd(\hat{s}(t), t) - d_s(\hat{s}(t), t).$$

Furthermore the adoption lag will be shortened as the transfer time is delayed, i.e.,

$$\frac{d}{dt}\hat{s}(t) < 0.$$

PROOF Without loss of generality, consider the case where firm 1 moves second, i.e., $t_1 = t_2 + s$ where $s \geq 0$. . The firm's problem is

$$\underset{s\in[0,\infty)}{\text{Max}} \quad V_1(t_2 + s,\ t_2)$$

$$= \int_{t_2}^{t_2+s} e^{-rt}(\pi_2 - \pi_o)dt + \int_{t_2+s}^{\infty} e^{-rt}(\pi_3 - \pi_o)dt - e^{-r(t_2+s)} d(s,t_2).$$

The first order condition is given by;

$$\text{(10)} \qquad \frac{\partial V_1}{\partial s} = - e^{-r(t_2 + s)} \{(\pi_3 - \pi_2) - [rd(s,t_2) - d_s(s,t_2)]\}.$$

The second order condition for a maximum is also satisfied by assumption A2. Therefore the optimal adoption lag, given the transfer time, t, is;

$$\text{(11)} \qquad s^*(t) = \begin{cases} \hat{s}(t) \ \text{ such that } (\pi_3 - \pi_2) = rd\ (\hat{s}(t),\ t) - d_s(\hat{s}(t),\ t) \\ \qquad\qquad \text{if } \pi_3 - \pi_2 < r\ d(0,t) - d_s(0,t) \\ 0 \qquad\qquad \text{otherwise.} \end{cases}$$

Since the RHS of Equation (9) is decreasing in s, $\hat{s}(t)$ is uniquely determined given t.

Now, using the implicit function theorem and assumption A2 on Equation (9), we get $\frac{d}{dt}\hat{s}(t) < 0$ for all t.

Q.E.D.

By Lemma 1 and Lemma 2 we established the set of possible Nash timing equilibria in pure strategies as follows:

$$\{(0,0),\ (0,\ \hat{S}(0)),\ (\hat{S}(0),0),\ (\hat{t},\hat{t}),\ (\hat{t},\ \hat{s}(\hat{t}) + \hat{t}),\ (\hat{s}(\hat{t}) + \hat{t},\ \hat{t})\}$$

Now regarding the non-zero symmetric equilibrium $(\hat{t},\hat{t})$, we state the following lemma:

LEMMA 3 There is no non-zero symmetric Nash equilibrium in pure strategies, i.e., $(\hat{t},\hat{t})$ is not an equilibrium.

PROOF: It suffices to show that $\hat{s}(\hat{t}) > 0$. Suppose $\hat{s}(\hat{t}) = 0$, then

$$\begin{aligned} \pi_3 - \pi_2 &\geq rd(0,\hat{t}) - d_s(0,\hat{t}), && \text{by (11)} \\ &> rc(\hat{t}) - c'(\hat{t}), && \text{by A3} \\ &= \pi_1 - \pi_0 \end{aligned}$$

Therefore $\pi_3 - \pi_2 > \pi_1 - \pi_0$, which contradicts to A4.

The second inequality holds because $c(t) = d(0,t)$, and $c(t+s) > d(s,t)$ for all $s > 0$ implies $c'(t) > d_s(0,t)$ for all t.

Q.E.D.

So we have excluded the non-zero symmetric equilibrium $(\hat{t},\hat{t})$ from the set of possible Nash equilibria.

LEMMA 4 There exists a unique $\tilde{t}$ and $\tilde{t}_o$ such that

1) $V_1(\hat{t},t) \lesseqgtr V_1(t + \hat{s}(t),\ t)$ as $t \lesseqgtr \tilde{t}$,

2) $V_1(0,t) \lesseqgtr V_1(t + \hat{s}(t),\ t)$ as $t \lesseqgtr \tilde{t}_o$.

PROOF: Suppose firm 2 moves at time t. Then the difference between

PROOF: Suppose firm 2 moves at time t. Then the difference between moving first and moving second for firm 1 is given by

$$\Delta(t) \equiv V_1(\hat{t},t) - V_1(t + \hat{s}(t),\ t).$$

By Lemma 3, $\Delta(\hat{t}) < 0$.

Also notice that

$$\lim_{t\to\infty} \Delta(t) = \int_{\hat{t}}^{\infty} (\pi_1 - \pi_o)e^{-ru}du - e^{-r\hat{t}}c(\hat{t})$$

$$- [\lim_{t\to\infty} \{\int_t^{t+\hat{s}(t)} (\pi_2 - \pi_0)e^{-ru}du + \int_{t+\hat{s}(t)}^{\infty} (\pi_3 - \pi_0)e^{-ru}du$$

$$- e^{-r(\hat{s}(t) + t)} d(\hat{s}(t),\ t)\}]$$

$$> 0.$$

Therefore there exists some sufficiently large number T such that $\Delta(T) > 0$. Since $\Delta(t)$ is a continuous function in t, we can use the intermediate value theorem to conclude that there exists a $\tilde{t}$, such that, $T > \tilde{t} > \hat{t}$ which satisfies $\Delta(\tilde{t}) = 0$.

Notice that $\Delta(t)$ is a strictly increasing function of t, since

$$\text{(12)} \qquad \frac{d}{dt}\Delta(t) = \frac{d}{dt} V_1(\hat{t},t) - \frac{d}{dt} V_1(t + \hat{s}(t),\ t)$$

$$= V_{1,2}(\hat{t},t) - V_{1,2}(t + \hat{s}(t),t)$$

$$> 0,$$

where the first subscript denotes firm 1, and the second subscript denotes partial derivative. The second equality holds using the envelope theorem.

Therefore $\tilde{t}$ is uniquely determined and

$$V_1(\hat{t},t) \lesseqgtr V_1(t + \hat{s}(t),\ t) \text{ as } t \lesseqgtr \tilde{t}.$$

Similarly we can show that there is a unique $\tilde{t}_o > 0$ such that

$$V_1(0,t) \lesseqgtr V_1(t + \hat{s}(t),\ 0) \text{ as } t \lesseqgtr \tilde{t}_0.$$

Q.E.D.

The above lemma states that a firm prefers moving first, that is, buying the technology from the foreign seller at time $\hat{t}$, if and only if the other firm adopts it later than $\tilde{t}$.

Now we can describe the firm i's best response function as follows: First note that

$rc(0) - c'(0) > \pi_1 - \pi_o$ implies $rd(0,0) - d_s(0,0) > \pi_3 - \pi_2$, which can be shown easily using conditions A3 and A4. Therefore, we need to consider only three cases listed as below.

CASE 1: If $(\pi_1 - \pi_o) < rc(0) - c'(0)$,

then

$$r_i(t_j) = \begin{cases} \hat{t} & \text{if } t_j \geqslant \tilde{t} \\ \hat{s}(t_j) + t_j & \text{if } t_j < \tilde{t}, \end{cases}$$

for i = 1, 2, and j = 2, 1.

CASE 2: If $(\pi_1 - \pi_o) \geqslant rc(0) - c'(0)$

and $(\pi_3 - \pi_2) < rd(0,0) - d_s(0,0)$,

then

$$r_i(t_j) = \begin{cases} 0 & \text{if } t_j \geq \tilde{t}_o \\ s(0) & \text{if } t_j < \tilde{t}_o . \end{cases}$$

CASE 3: If $(\pi_1 - \pi_o) \geq rc(0) - c'(0)$,

and $(\pi_3 - \pi_2) \geq rd(0,0) - d_s(0,0)$,

then

$$r_i(t_j) = 0 \qquad \text{for all } t_j > 0.$$

Firm 2's reaction function for case 1 is shown in Figure 1.

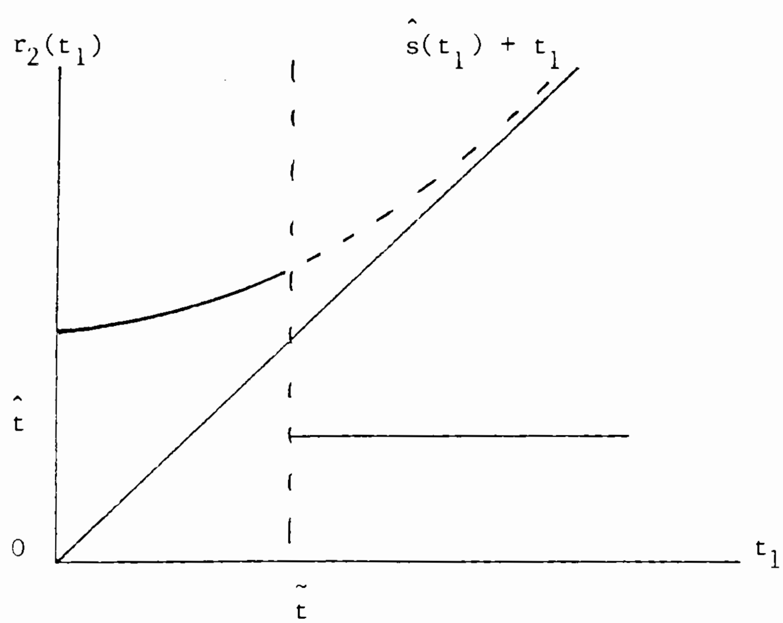

Figure 2

This Figure illustrates that firm 2's optimal time is along $\hat{s}(t_1)$ curve as t_1 moves from 0 to $\tilde{t}$, at that point jump down to $\hat{t}$ and stays there as t_1 increases starting from $\tilde{t}$.

PROPOSITION 1

a) When $rc(0) - c'(0) > \pi_1 - \pi_o$, there are Nash equilibria in pure strategies if and only if $\hat{s}(\hat{t}) + \hat{t} \geq \tilde{t}$. If they exist, the set of Nash equilibria is $\{(\hat{t}, \hat{s}(\hat{t})+\hat{t}), (\hat{s}(\hat{t})+\hat{t}, \hat{t})\}$.

b) When $rc(0) - c'(0) \leq \pi_1 - \pi_o$ and $rd(0,0) - d_s(0,0) > \pi_3 - \pi_2$, there are Nash equilibria in pure strategies if and only if $\hat{s}(0) \geq \tilde{t}_o$. If they exist, the set of Nash equilibria is $\{(0,\hat{s}(0)), (\hat{s}(0),0)\}$.

c) When $rc(0) - c'(0) \leq \pi_1 - \pi_o$ and $rd(0,0) - d_s(0,0) \leq \pi_3 - \pi_2$, (0,0) is the only Nash equilibrium.

PROOF:

a) When $rc(0) - c'(0) > \pi_1 - \pi_o$, by Lemma 1, the first mover's optimal transfer time is $\hat{t}$ which is independent of the second mover's adoption time. Since $rc(0) - c'(0) > \pi_1 - \pi_o$ implies $rd(0,0) - d_s(0,0) > \pi_3 - \pi_2$, the second mover's optimal adoption time, given the transfer time, $\hat{t}$, is $\hat{s}(\hat{t}) + \hat{t}$ which is greater than $\hat{t}$. Therefore, by Lemma 3, only candidates for Nash will move first if and only if the other firm moves later than $\tilde{t}$. So, the equilibria will occur if and only if $\hat{s}(\hat{t}) + \hat{t} \geq \tilde{t}$.

b) When $rc(0) - c'(0) \leq \pi_1 - \pi_o$, by Lemma 1, the first mover's optimal transfer time is $t = 0$, that represents the immediate transfer. Given this immediate transfer, since $rd(0,0) - d\ (0,0) > \pi_3 - \pi_2$, the second mover will adopt the technology at $\hat{s}(0)$. So, $(0, \hat{s}(0))$ and $(\hat{s}(0), 0)$ will be the only candidates for Nash equilibria. By Lemma 4, the equilibria will occur if and only if $\hat{s}(0) > \tilde{t}_o$.

c) If $rc(0) - c'(0) \leq \pi_1 - \pi_o$ and $rd(0,0) - d_s(0,0) \leq \pi_3 - \pi_2$, then it is clear from Lemma 1 and Lemma 2 that immediate transfer is the optimal choice for the transferee and immediate adoption is the optimal choice for the domestic adopter.

Q.E.D.

The case a) is illustrated in Figure 3 and Figure 4 below. In Figure 3, where $\hat{s}(\hat{t}) + \hat{t} \geq \tilde{t}$, best response functions intersect at $(\hat{t}, (\hat{t})+\hat{t})$ and $(\hat{s}(\hat{t})+\hat{t}, \hat{t})$, which are Nash equilibria. But in Figure 4, where $\hat{s}(\hat{t}) + \hat{t} < \tilde{t}$, the best response functions do not intersect, therefore there is no Nash equilibrium.

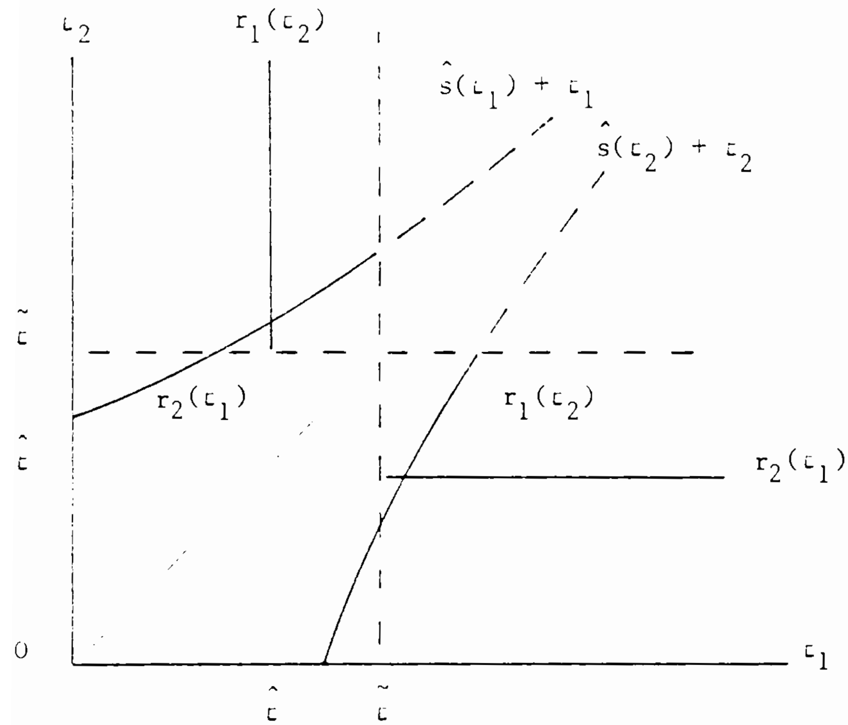

Figure 3

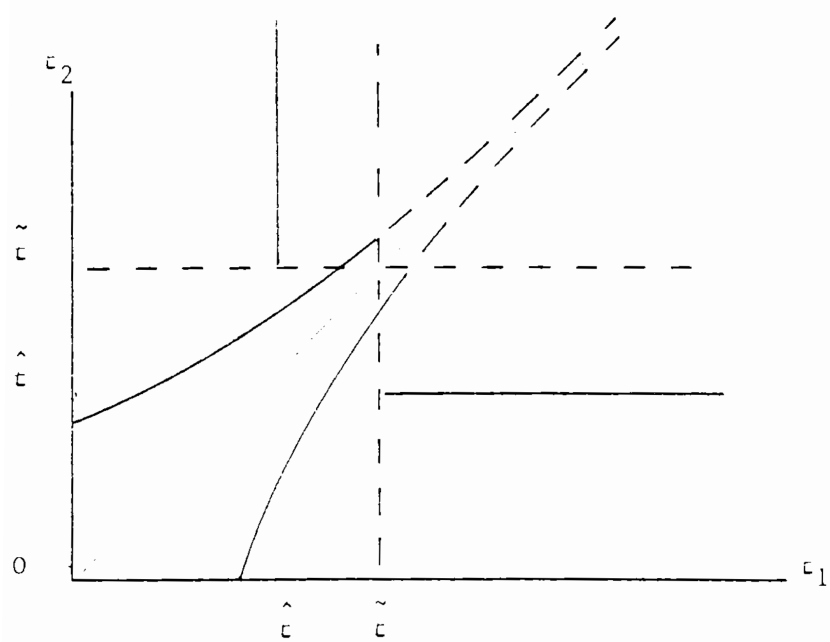

Figure 4

2.3 Waiting Game Problem

In order to better understand the situation in which there is no equilibrium, let us go back to Figure 4. Suppose a firm moves first. Then it will choose $\hat{t}$, and the other firm will follow at $\hat{s}(\hat{t}) + \hat{t}$. Now because $\hat{s}(\hat{t}) + \hat{t}$ is less than $\tilde{t}$, the first firm is better off to choose $\hat{s}[\hat{s}(\hat{t}) + \hat{t}] + [\hat{s}(\hat{t}) + \hat{t}]$. Therefore no firm moves first, resulting in no equilibrium.

This "waiting game" problem can arise if the domestic diffusion of the technology is too fast, resulting in an adoption lag that is too short. In section 2.4, we will use a specific form of adoption cost function to study the relationship between the diffusion speed and the existence of equilibrium.

The shortened adoption lag will raise the follower's net profit and lower the leader's net profit. Even though the net benefit of the leading is positive, the net benefit of the following is greater than that of the leading so every firm would rather be a follower than a leader. In this case there will not be any leader; no firm can be a follower either.

This "waiting game" problem will obviously lead to social inefficiency for the technology buying country. One way to correct the problem by the government, as can be observed in developing countries, is to lengthen the adoption lag by protection of the leader for a certain period of time. But this policy will lead to another kind of inefficiency, which is the suppression of otherwise beneficial technology diffusion in the industry.

Another policy measure for the government is to designate a specific firm to be the leader. This can be done by alternating leader designation for different technologies, or by compensating the designated firm with some subsidy plans. But notice that even without any subsidy the leader may have positive benefit, even though it is less than that of the follower.

2.4 Diffusion Speed and Equilibrium

In this subsection we will use a specific form of a transfer cost function and an adoption cost function to study the timing equilibrium discussed previously.

1) <u>Transfer cost function</u>

(13) $$c(t) = \alpha e^{-kt}, \quad \text{where} \quad \alpha > 0 \quad \text{and} \quad k > 0.$$

The transfer cost function is assumed to be an exponentially decreasing function of the transfer time with exponential coefficient k, and $c(0) = \alpha$. This is illustrated in Figure 5.

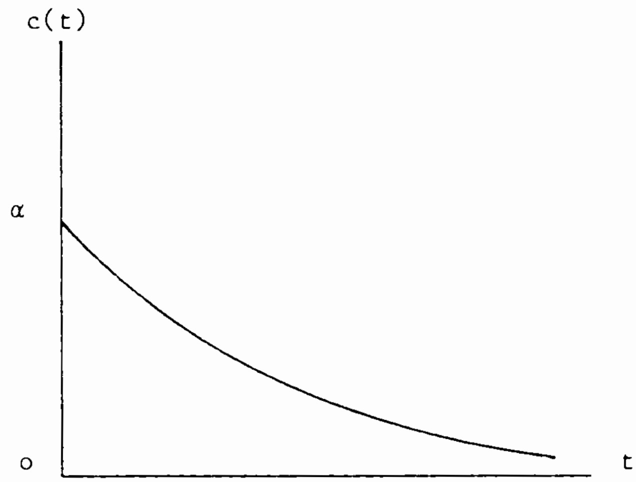

Figure 5

Notice that $c'(t) < 0$ and $c''(t) > 0$ for all t, satisfying the assumption A1.

2) Adoption cost function

(14) $$d(s,t) = \alpha e^{-kt} e^{-hs}, \quad \text{where} \quad h > k.$$

The adoption cost function is assumed to be an exponentially decreasing function of the time elapsed between the adoption time and the transfer time, with the exponential coefficient h. It can be considered that the coefficient (h - k) represents the degree of the domestic diffusion speed of the technology. The greater h, given k, the faster domestic diffusion, and the lower the adoption cost. This adoption cost function is illustrated in Figure 6.

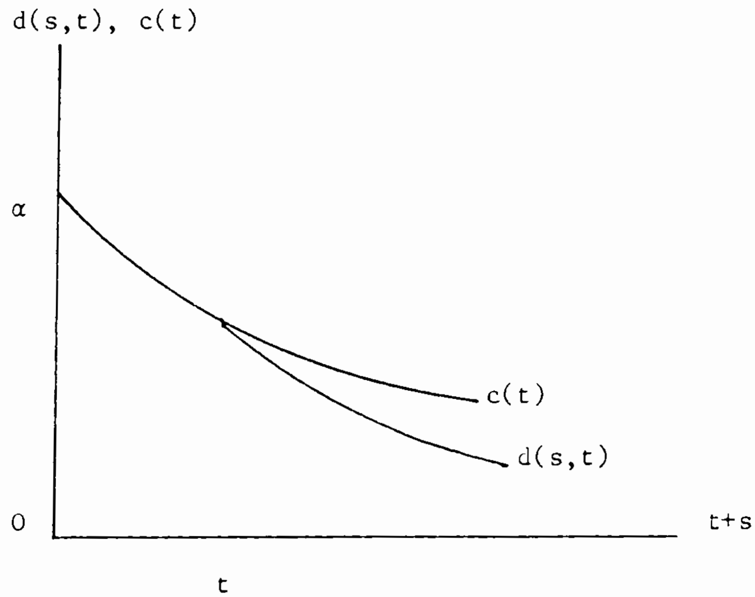

Figure 6

Notice that first order partial derivatives of the adoption cost function are negative with respect to t and s, and the second order partial derivatives are positive with respect to t and s including the cross partial derivative. This satisfies assumption A2. Together with the transfer cost function, $c(t) = \alpha e^{-kt}$, the adoption cost function satisfies assumption A3.

In order to check this, notice that

$$\alpha e^{-kt} e^{-hs} < \alpha e^{-k(t+s)} \quad \text{for all } h > k,$$

Therefore,

(15) $$d(s,t) < c(s+t). \qquad \text{for all } s > 0,\ t \geq 0.$$

When $s = 0$,

(16) $$d(0,t) = c(t) \qquad \text{for all } t \geq 0.$$

Notice that inequality (15) states that domestic adoption is always less costly than international transfer. Equality (16) states that an immediate adoption doesn't lead to any positive cost saving for domestic adoption compared to the international transfer. Actually the adoption cost function employed here can be considered to include the opportunity to buy the technology directly from the foreign seller by paying the transfer cost.

3) <u>Optimal transfer time</u>

Firm 1's problem as a first mover is

(17) $$\max_{t_1 \in [0,t_2]} V_1(t_1,t_2) = \int_{t_1}^{t_2} e^{-rt}(\pi_1 - \pi_o)dt + \int_{t_2}^{\infty} e^{-rt}(\pi_3 - \pi_o)dt - \alpha e^{-(k+r)t_1}$$

The first order condition gives

(18) $$(\pi_1 - \pi_0) - \alpha(k + r)e^{-kt_1} = 0.$$

Therefore the optimal transfer time is

$$(19) \qquad t_1^* = \begin{cases} \hat{t} = -\frac{1}{k} \ln \frac{(\pi_1 - \pi_o)}{\alpha(k + r)} & \text{if} \quad k + r > (\pi_1 - \pi_o)/\alpha \\ 0 & \text{if} \quad k + r \leq (\pi_1 - \pi_o)/\alpha . \end{cases}$$

Notice that the optimal transfer time is independent of the other firm's adoption time. It is decreasing in $(\pi_1 - \pi_o)$ and increasing in α, r, and k. And for a sufficiently large profit increase, $(\pi_1 - \pi_o)$, or for a sufficiently small initial cost (α), the optimal decision for the transferee is the immediate purchase of the technology.

4) <u>Optimal adoption time</u>

The firm 1's problem as a domestic adopter is

$$(20) \qquad \underset{s\in(0,\infty)}{\text{Max}} \; V_1(s + t_2, t_2)$$

$$= \int_{t_2}^{s+t_2} e^{-rt}(\pi_2 - \pi_o)dt + \int_{s+t_2}^{\infty} e^{-rt}(\pi_3 - \pi_o)dt$$

$$- \alpha e^{-[(k+r)t_2 + (h+r)s]} .$$

The first order condition is

$$(21) \qquad (\pi_3 - \pi_2) - \alpha(h + r)e^{-(kt_2 + hs)} = 0 .$$

Therefore the optimal adoption lag, given the transfer time t, is

$$(22) \quad s^*(t) = \begin{cases} \hat{s}(t) = -\frac{1}{h}\left(\ell n \frac{\pi_3 - \pi_2}{\alpha(h+r)} + kt\right) & \text{if } h+r > (\pi_3 - \pi_2)e^{kt}/\alpha \\ 0 & \text{otherwise,} \end{cases}$$

where, for the sake of simplicity, we eliminated subscript 2 for transfer time.

The optimal adoption lag is a decreasing function of the transfer time. Specifically,

$$(23) \qquad -1 < \frac{d\hat{s}(t)}{dt} < 0.$$

Inequality (23) states that the adoption lag will be shortened as the transfer is delayed but the size of the reduction will be less than the transfer delay.

Again, notice that the adoption will be hastened, the greater the $(\pi_3 - \pi_2)$, the smaller the interest rate (r), or the smaller the degree of diffusion speed (h).

5) Nash timing equilibria

Using Equation (19) and Equation (22), the possible Nash timing equilibria can be shown to be as follows. When $k + r \leq (\pi_1 - \pi_o)/\alpha$, the optimal transfer time is $t = 0$. Given $t = 0$, the optimal adoption lag is

(24)

$$s^*(0) = \begin{cases} \hat{s}(0) = -\frac{1}{h}\,\ell n[(\pi_3 - \pi_2)/\alpha(h+r)] & \text{if } (h+r) > (\pi_3 - \pi_2)/\alpha \\ 0 & \text{if } (h+r) \leqslant (\pi_3 - \pi_2)/\alpha . \end{cases}$$

When $k + r > (\pi_1 - \pi_o)/\alpha$, the optimal transfer time is $\hat{t}$. Given $t = \hat{t}$, the optimal adoption lag is

(25)

$$s^*(\hat{t}) = \begin{cases} \hat{s}(\hat{t}) = -\frac{1}{h}\,\ell n \frac{(\pi_3 - \pi_2)}{(\pi_1 - \pi_o)} \frac{(k + r)}{(h + r)} & \text{if } (k+r) < \frac{\pi_1 - \pi_0}{\pi_3 - \pi_2}(h+r) \\ 0 & \text{otherwise.} \end{cases}$$

See Figure 7 for the relationship between the magnitude of k and h, and the possible realization of equilibria. Notice that we employed $(k + r) \times (h + r)$ space instead of $k \times h$ space for diagrammatic simplicity.

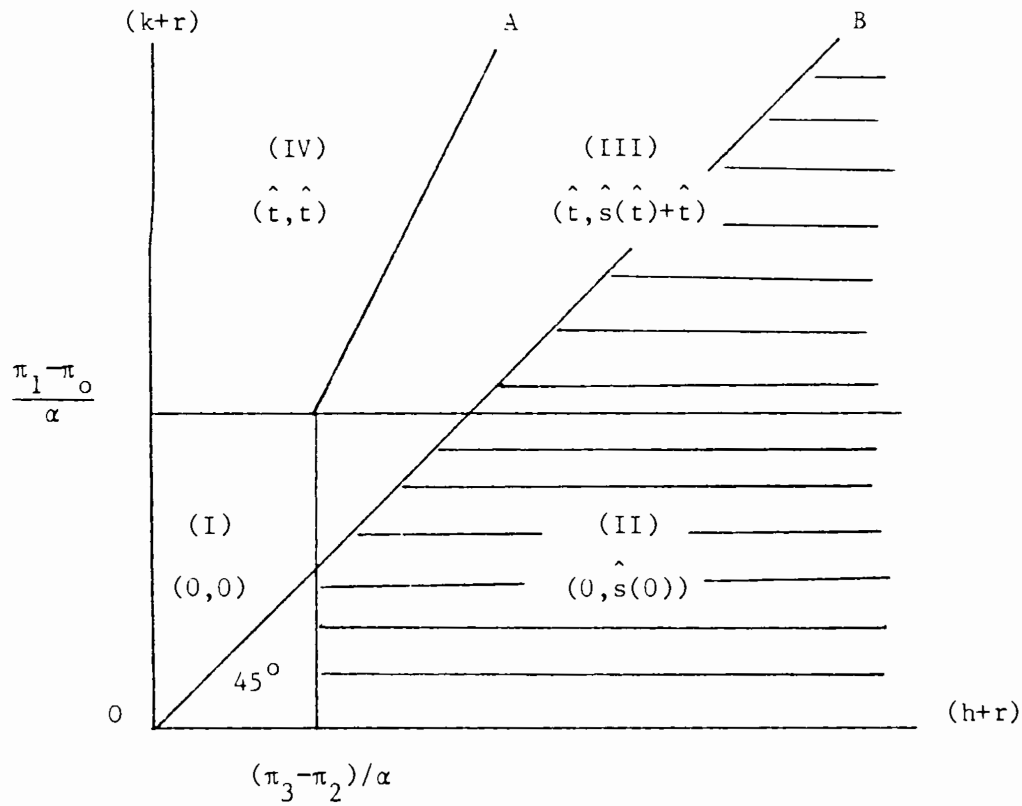

Figure 7

The slope of line OA is $(\pi_1 - \pi_0)/(\pi_3 - \pi_2)$ and that of OB is unity.

In region I, where both the cost reduction rate (k) and the domestic diffusion speed (h) are low, the transfer and the adoption will occur immediately, resulting in an equilibrium at (0,0).

In region II, where k is small and h is large, the transfer will occur immediately and the adoption will occur at some time later, resulting in a possible equilibrium at $(0, \hat{s}(0))$.

In region III, where both k and h are large, the transfer will occur at some positive time $\hat{t}$, and the adoption will occur at some later time, resulting in a possible equilibrium at $(\hat{t}, s(\hat{t})+\hat{t})$.

Finally in region IV, where k is large and h is small, the transfer will occur at $\hat{t}$, and the adoption follows it immediately, resulting in a possible symmetric equilibrium at $(\hat{t}, \hat{t})$.

But with the condition $h > k$ as we assumed in (14), together with the assumption A4, line OA lies above line OB. Therefore region IV is excluded and the relevant area becomes the shaded one which is below line OB. So the possibility of non-zero symmetric equilibrium is eliminated.

6) Waiting game problem

In Proposition 1, we have shown that if $\tilde{t} > \hat{s}(\hat{t}) + \hat{t}$ then there is no Nash timing equilibrium. That is, no firm wants to move first, resulting in the "waiting game" problem.

Since we cannot explicitly compare the size of $\tilde{t}$ and $\hat{s}(\hat{t}) + \hat{t}$ (because $\tilde{t}$ is not explicitly determined), we will compare the change of $\tilde{t}$ and $\hat{s}(\hat{t})$ with respect to the domestic diffusion speed h, to see the relationship between the size of h and the equilibrium outcome.

We will write the equation (24) and (25) here again, for convenience.

(24)
$$s^*(0) = \begin{cases} \hat{s}(0) = -\frac{1}{h}\,\ell n[(\pi_3 - \pi_2)/\alpha(h + r)] & \text{if } (h + r) > (\pi_3 - \pi_2)/\alpha, \\ 0 & \text{otherwise.} \end{cases}$$

$$(25)\quad s^*(\hat{t}) = \begin{cases} \hat{s}(\hat{t}) = -\frac{1}{h}\, \ell n \frac{(\pi_3 - \pi_2)}{(\pi_1 - \pi_o)} \frac{(k + r)}{(h + r)} & \text{if } (k + r) < \frac{\pi_1 - \pi_o}{\pi_3 - \pi_2}(h + r), \\ 0 & \text{otherwise.} \end{cases}$$

And $\tilde{t}$ is such that $\Delta(t) = 0$,

where

$$(26)\quad \Delta(t) = \begin{cases} \alpha e^{-(k+r)t}(e^{-(h+r)\hat{s}(t)} - 1) + \int_{\hat{t}}^{t} e^{-ru}(\pi_1 - \pi_o)du \\ \quad + \int_t^{t+\hat{s}(t)} e^{-ru}(\pi_3 - \pi_2)du & \text{if } (k + r) > (\pi_1 - \pi_o)/\alpha, \\ \alpha(e^{-[(k+r)t + (h + r)\hat{s}(t)]} - 1) + \int_0^t e^{-ru}(\pi_1 - \pi_o)du \\ \quad + \int_t^{t + \hat{s}(t)} e^{-ru}(\pi_3 - \pi_2)\, du & \text{if } k + r \leq (\pi_1 - \pi_o)/\alpha. \end{cases}$$

CASE 1: Region III, k and h are large.

The possible equilibrium is at $(\hat{t}, (\hat{s}(\hat{t})))$. Partially differentiating (25) with respect to h,

$$(27)\quad \frac{\partial \hat{s}(\hat{t})}{\partial h} = \frac{1}{h} \left\{ \frac{1}{h}\, \ell n \frac{(\pi_3 - \pi_2)}{(\pi_1 - \pi_0)} \frac{(k + r)}{(h + r)} + \frac{1}{h+r} \right\} < 0,$$

if and only if

$$(28)\qquad (k + r) < (\pi_1 - \pi_o)/(\pi_3 - \pi_2)e^{[-h/(h + r)]}\ (h + r).$$

Using the implicit function theorem for equation (26), we get

$$(29)\qquad \frac{d(\tilde{t})}{dh} > 0 \quad \text{for all } h,$$

which can be derived with the condition A4, (23) and using Leibnitz's Rule for differentiating an integral with respect to a parameter. (See Kamien and Schwartz (1981: p254)).

CASE 2: Region II; k is small, h is large.

$$(30)\qquad \frac{\partial \hat{s}(0)}{\partial h} = \frac{1}{h}\ [\ \frac{1}{h}\ \ell n\ (\pi_3 - \pi_2)/\alpha(h + r) + 1/(h + r)]$$
$$< 0,$$

if and only if

$$(31)\qquad e^{[-h/(h + r)]}(h + r) > (\pi_3 - \pi_2)/\alpha.$$

Similarly, as in deriving (29), we get

$$\frac{d\tilde{t}}{dh} > 0 \qquad \text{for all } h.$$

In both cases we have shown that $\partial\tilde{t}/\partial h > 0$. And the sign of $\partial\hat{s}(\hat{t})/\partial h$ depends on the size of h relative to k.

In Figure 8, the shaded area R represents the set of points where the sign of $\partial\hat{s}(\hat{t})/\partial h$ is negative. In the figure, line OA, OB are the same as those in Figure 8. $\bar{h}$ is such that

$$\frac{1}{h}\{\ell n(\pi_3 - \pi_2)/\alpha(h + r) + 1/(h + r)\} = 0$$

where

$$\frac{\partial \hat{s}(0)}{\partial h} = 0 \quad \text{holds.}$$

Notice that $(\pi_3 - \pi_2) < \alpha(\bar{h} + r) < (\pi_1 - \pi_0)$.

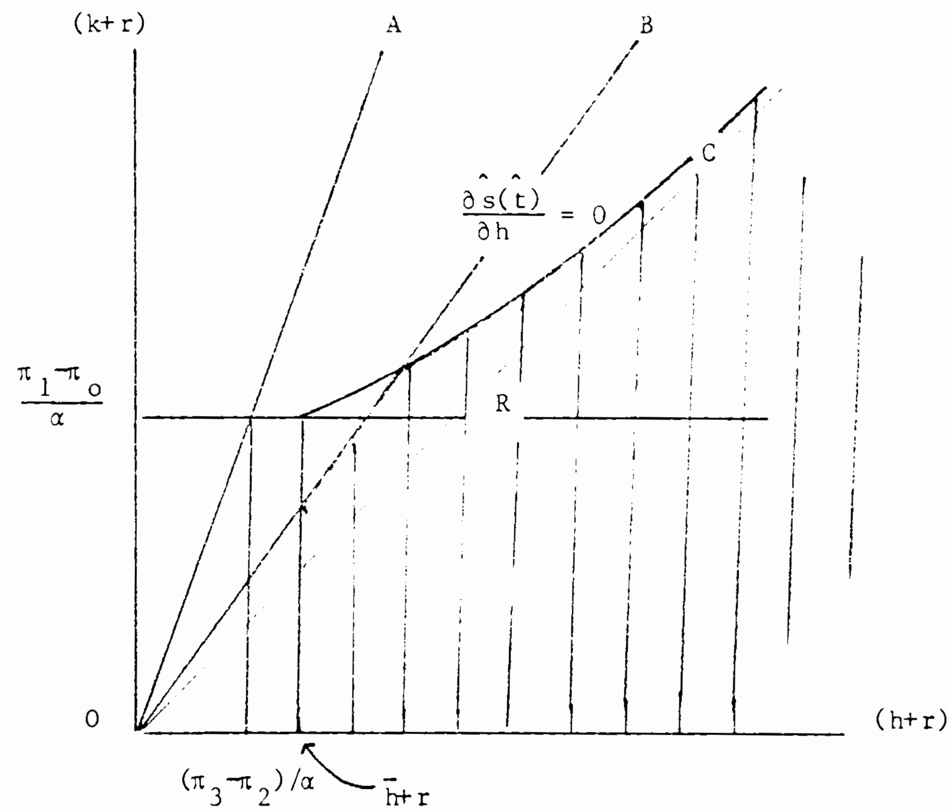

Figure 8

The slope of line OC is $(\pi_1 - \pi_o)/(\pi_3 - \pi_2)e$, to which line the boundary curve for $\partial \hat{s}(\hat{t})/\partial h = 0$ is asymptotic as h increases.

In the shaded area R, as h increases, the adoption lag is shortened, whereas $\tilde{t}$ is increased.

Therefore when the degree of the domestic diffusion speed (h) is high enough relative to the rate of cost reduction for the international transfer (k), the gap between $\tilde{t}$ and $\hat{s}(\hat{t}) + \hat{t}$ is getting wider as the diffusion speed becomes higher. So the waiting game problem can be caused by a relatively high domestic diffusion speed.

3. MARKET STRUCTURE AND THE TRANSFER TIME

In this section we will investigate the relationship between the market structure and the time of the technology transfer. In particular our question will be "what is the optimal number of firms, if any, which leads to the earliest technology transfer?"

In order to answer this question we will assume that the firms in the technology buying industry are Cournot-oligopoly firms, of which there are $n \geq 1$ firms. Initially, the firms in the Cournot oligopoly have identical linear cost functions that pass through the origin. So each firm has the same constant marginal cost.

The industry as a whole faces a linear demand function.

$$(32) \qquad P(Q) = b - aQ, \qquad a > 0, \quad b > 0,$$

where P is the market price, and Q is the industry's total output.

First, we begin by stating the formulas for the Cournot equilibrium quantities, price, and firm profits in an industry with different technologies.

LEMMA 5 If the n-firms use the cost function $f_1, \ldots, f_n$ respectively where

$$(33) \qquad f_i(q_i) = c_i q_i, \qquad c_i > 0,$$

then the Cournot equilibrium quantity, price and profits are given by;

$$q_i^* = \begin{cases} \frac{1}{(k+1)a} [b - (k+1) c_i + \sum_{j \in A} c_j] & \text{for } i \in A \\ 0 & \text{for } i \notin A \end{cases},$$

$$Q^* = \frac{1}{(k+1)a} [kb - \sum_{j \in A} c_j],$$

$$P^* = \frac{1}{(k+1)} [b + \sum_{j \in A} c_j),$$

$$\pi_i^* = \begin{cases} \frac{1}{(k+1)^2 a} [b - (k+1) c_i + \sum_{j \in A} c_j]^2 & \text{for } i \in A \\ 0 & \text{for } i \notin A, \end{cases}$$

where the superscript * denotes the Cournot equilibrium level and will be omitted later if obvious in the context. The set A is defined to be the set of firms who actually participate, with a positive output level, in this Cournot oligopoly game. And k represents the number of firms in the set A.

The proof of the lemma can be easily verified.

Remark A simple way to construct the set A is as follows.

1) Rearrange the firms with their constant marginal cost increasing in order, i.e.,

$$c_1 \leq c_2 \leq \dots \leq c_n$$

2) Check whether $q_1^* > 0$, with firm 1 as a monopolist.

If $q_1^* \leqslant 0$, then the set A is a null set.

If $q_1^* > 0$, then proceed to the next step.

3) Check whether $q_2^* > 0$ as $\{1,2\}$ forms a duopoly game.

If $q_2^* \leqslant 0$ then $A = \{1\}$.

If $q_2^* > 0$, then proceed to the next step.

4) Continue this process until $q_i^* \leqslant 0$ with $1,2,\ldots,i$, participating in the game, but $q_{i-1}^* > 0$ with $1,2,\ldots, i-1$, participating in the game, concluding that $A = \{ 1,\ldots,i-1 \}$.

Suppose initially each firm in the industry is using the current best technology characterized by the marginal cost c. At time $t = 0$, a cost reducing new technology, characterized by the size of the marginal cost reduction ε , becomes available for the firms. Throughout this section the cost structure and the market demand are assumed to be stationary over time except when there is a technical change through the adoption of the new technology, in which case only the cost function of the adopting firm will change.

By proposition 1 only one firm will be the transferee of the technology. Therefore, without loss of generality, suppose firm 1 is the transferee. Then each firm's cost function is

$$(34) \qquad f_i(q_i) = \begin{cases} (c - \varepsilon)q_i & \text{if} \quad i = 1, \\ cq_i & \text{if} \quad i \neq 1. \end{cases}$$

Then immediately from Lemma 5, we get the following lemma.

LEMMA 6

If the cost functions are given by (34) and the market demand is given by (32), then the Cournot equilibrium levels are;

$$q_i^*(n,\varepsilon) = \begin{cases} \frac{1}{(n+1)a}[b - c + n\,\varepsilon] & i = 1, \quad \varepsilon < b - c, \\ \frac{1}{2a}[b - c + \varepsilon] & i = 1, \quad \varepsilon \geqslant b - c, \\ \frac{1}{(n+1)a}[b - c - \varepsilon] & i \neq 1, \quad \varepsilon < b - c, \\ 0 & i \neq 1, \quad \varepsilon \geqslant b - c, \end{cases}$$

$$Q^*(n,\varepsilon) = \begin{cases} \frac{1}{(n+1)a}[n(b - c) + \varepsilon] & \varepsilon < b - c, \\ \frac{1}{2a}[b - c + \varepsilon] & \varepsilon \geqslant b - c, \end{cases}$$

$$P^*(n,\varepsilon) = \begin{cases} \frac{1}{(n+1)}[b + nc - \varepsilon], & \varepsilon < b - c, \\ \frac{1}{2}[b + c - \varepsilon] & \varepsilon \geqslant b - c, \end{cases}$$

$$\pi_i^*(n,\varepsilon) = \begin{cases} \frac{1}{(n+1)^2 a}[b - c + n \cdot \varepsilon]^2 & i = 1, \quad \varepsilon < b - c, \\ \frac{1}{4a}[b - c + \varepsilon]^2 & i = 1, \quad \varepsilon \geqslant b - c, \\ \frac{1}{(n+1)^2 a}[b - c - \varepsilon]^2 & i \neq 1, \quad \varepsilon < b - c, \\ 0 & i \neq 1, \quad \varepsilon \geqslant b - c, \end{cases}$$

$$\Pi^*(n,\varepsilon) = \begin{cases} \dfrac{1}{(n+1)^2\, a}\,[n(b-c)^2 + 2\varepsilon\,(b-c) + (n^2+n-1)\varepsilon^2] & \text{if} \quad \varepsilon < b-c, \\ \dfrac{1}{4a}\,[b-c+\varepsilon]^2 & \text{if} \quad \varepsilon \geq b-c, \end{cases}$$

$$S^*(n,\varepsilon) = \begin{cases} \dfrac{1}{2(n+1)^2 a}\,[n(b-c)+\varepsilon]^2 & \varepsilon < b-c, \\ \dfrac{1}{8a}\,[b-c+\varepsilon]^2 & \varepsilon \geq b-c, \end{cases}$$

where 1) $q_i^*(n,\varepsilon)$ denotes the Cournot equilibrium output level of firm i when the industry is composed of n firms and the new technology is characterized by the cost reduction size ε,

2) $\Pi^*(n,\varepsilon)$ denotes the total industry profit, i.e.,

$$\Pi^*(n,\varepsilon) = \sum_{i=1}^{n} \pi_i^*(n,\varepsilon),$$

3) $S^*(n,\varepsilon)$ denotes the consumer surplus.

Following Arrow (1962), we will call an innovation with $\varepsilon \geq b - c$ a drastic innovation, and one with $\varepsilon < b - c$ a nondrastic innovation.

Now, to compare the post-transfer equilibrium levels with pre-transfer levels, set $\varepsilon = 0$. The pre-transfer equilibrium levels are:

$$q_i^*(n,0) = \frac{1}{(n+1)a}[b - c] \quad \text{for all } i,$$

$$Q^*(n,0) = \frac{n}{(n+1)a}[b - c] ,$$

$$P^*(n,0) = \frac{1}{(n+1)}[b + nc] ,$$

$$\pi_i^*(n,0) = \frac{1}{(n+1)^2 a}[b - c]^2 \quad \text{for all } i,$$

$$\Pi^*(n,0) = \frac{n}{(n+1)^2 a}[b - c]^2 ,$$

$$S^*(n,0) = \frac{n^2}{2(n+1)^2 a}[b - c]^2 .$$

Remark We can compare the pre-transfer and the post-transfer equilibrium levels as follows;

For all n and $\varepsilon > 0$,

1) $q_1^*(n,\varepsilon) > q_1^*(n,0)$,

2) $q_i^*(n,\varepsilon) < q_i^*(n,0)$ for all $i \neq 1$,

3) $Q^*(n,\varepsilon) > Q^*(n,0)$,

4) $P^*(n,\varepsilon) < P^*(n,0)$,

5) $\pi_1^*(n,\varepsilon) > \pi_1^*(n,0)$,

6) $\pi_i^*(n,\varepsilon) < \pi_i^*(n,0)$ for all $i \neq 1$,

7) $\Pi^*(n,\varepsilon) > \Pi^*(n,0)$,

8) $S^*(n,\varepsilon) > S^*(n,0)$.

Therefore,

$$W^*(n,\varepsilon) > W^*(n,0),$$

where $W^*(n,\varepsilon)$ represents the society's total welfare gain from the production of the goods, when the industry is composed of n firms and the maginal cost of production is $c - \varepsilon$. That is

$$W^*(n,\varepsilon) = \Pi^*(n,\varepsilon) + S^*(n,\varepsilon).$$

LEMMA 7 Given a value function $V(n,\alpha)$ defined on the set of integer N, with a parameter $\alpha \in R$, if the following condition holds for some strictly increasing function g(n);

(35) $$V(n,\alpha) > V(n+1, \alpha) \quad \text{iff } \alpha < g(n),$$

then for all $\alpha \in (g(0), \lim_{n\to\infty} g(n))$, there exists a positive finite integer $n^*(\alpha)$ which maximizes $V(n,\alpha)$ over $n \in N$.

PROOF: Since $g(n)$ is strictly increasing in n, for all $\alpha \varepsilon (g(0), \lim_{n\to\infty} g(n))$, there exists a unique $k \in N$, such that

$$g(k - i) \leq \alpha < g(k-1 + j) \tag{36}$$

for all $i \in N$,such that, $i \leq k$,and for all $j \in N$.

For such k, by condition (35) and using mathematical induction, it can be shown that

$$V(k,\alpha) \geq V(k-i,\alpha) \qquad \text{for all } i \leq k$$

and

$$V(k,\alpha) > V(k-1+j,\alpha) \qquad \text{for all } j \in N.$$

Therefore $V(k, \alpha) \geq V(n,\alpha)$ for all $n \in N$. By the strict monotonicity of $g(n)$, the condition (36) is equivalent to $g(k-1) \leq \alpha < g(k)$. Therefore $n^*(\alpha)$ is such that

$$g(n^*(\alpha) - 1) \leq \alpha < g(n^*(\alpha)). \tag{37}$$

Q.E.D.

PROPOSITION 2

Given a cost reducing technology characterized by the reduction size $\varepsilon > 0$, there is an optimal number of firms $n^*(\varepsilon)$ which leads to the most rapid rate of technical change. That is, for all $\varepsilon > 0$, there exists $n^*(\varepsilon)$, such that

$$t^*(n^*(\varepsilon), \varepsilon) \leq t^*(n,\varepsilon) \quad \text{for all positive integer } n.$$

Furthermore,

1) $$n^*(\varepsilon) = \begin{cases} \infty & \text{if} \quad b - c \leq \varepsilon \\ k \text{ such that } 1 \leq k < \infty & \text{if} \quad 2/7 \leq \varepsilon/(b-c) < 1 \\ 1 & \text{if} \quad \varepsilon/(b-c) < 2/7 \end{cases}$$

2) $n^*(\varepsilon)$ is nondecreasing in ε.

PROOF

CASE A: Nondrastic innovation ($\varepsilon < b - c$).

Suppose firm 1 is the transferee of the technology. The firm expects to have per period profit after the transfer,

(38) $$\pi_1(n,\varepsilon) = \frac{1}{(n+1)^2 a} (b - c + n\,\varepsilon)^2 \quad \text{(by Lemma 6)}.$$

The difference between the profit after the transfer and the profit before the transfer is

(39) $$\Delta\pi_1(n,\varepsilon) \equiv \pi_1(n,\varepsilon) - \pi_1(n,o)$$

$$= \frac{1}{(n+1)^2\, a} [\varepsilon^2 n^2 + 2\varepsilon(b-c)n]$$

From this we get

(40) $\Delta\pi_1(n,\varepsilon) > \Delta\ \pi_1(n+1,\ \varepsilon)$,

if and only if,

$$\varepsilon/(b-c) < (2n^2 + 2n - 2)/(2n^2 + 4n + 1).$$

Define $g(n) \equiv (2n^2 + 2n - 2)/(2n^2 + 4n + 1)$, and notice that $g(n)$ is strictly increasing in n. Now we can use Lemma 7 to conclude that for all $0 < \varepsilon < b - c$, there is a unique finite number $n^*(\varepsilon)$ which maximizes $\Delta\pi_1(n,\varepsilon)$ over n.

Therefore we can conclude that there is a finite number of firms in the industry given by $n^*(\varepsilon)$, which leads to the earliest technology transfer.

Actual $n^*(\varepsilon)$ is determined by the inequality

(41) $$g(n^*(\varepsilon) - 1)) \leq \varepsilon/(b - c) < g(n^*(\varepsilon)).$$

CASE B: Drastic innovation ($\varepsilon \geq b - c$);

By Lemma 6, per period profit for the firm after the transfer is given by

(42) $$\pi_1(n,\varepsilon) = \frac{1}{4a}\ [b-c + \varepsilon]\ ,$$

which is independent of n, since the firm will become the monopolist after the transfer. Before the transfer the firm has profit given by

$$(43) \qquad \pi_1(n,0) = \frac{1}{(n+1)^2 a} [b-c]^2$$

which is strictly decreasing in n. Therefore $\Delta\pi_1(n,\varepsilon)$ is strictly increasing in n. So the time of the transfer will be earlier when the market is more competitive.

Q.E.D.

So far we have discussed the technology transfer time, when firms are non-cooperative Cournot competitors. We will compare this with the cooperative outcome where firms collude by making a cartel. And we will also compare these with the socially optimal time of the transfer where the consumer surplus should be also included in the consideration.

We need the following notations.

t^*_P : the transfer time determined by non-cooperative firms.

t^*_c : the transfer time when firms collude.

t^*_s : the socially optimal transfer time.

PROPOSITION 3. When firms collude the transfer will be delayed and the socially optimal time of transfer will be earlier than the one determined by either collusive or non-collusive firms, i.e.,

$$t_s^* < t_p^* < t_c^*.$$

PROOF: We will show only the nondrastic innovation case, since the proof of the drastic innovation case is just similar to that of nondrastic innovation case except for the fact that after the transfer of the drastic innovation the transferee of the technology will become the monopolist in the industry.

From Lemma 6, firm 1, which we assumed to be the transferee of the technology, will have a profit increase given by

$$(44) \qquad \Delta\pi_1(n,\varepsilon) = \frac{1}{(n+1)^2 a} [2n(b-c)\varepsilon + n^2\varepsilon^2].$$

The industry's total profit increase due to the transfer is

$$(45) \qquad \Delta\Pi(n,\varepsilon) = \frac{1}{(n+1)^2 a} [2(b - c)\varepsilon + (n^2 + n-1)\varepsilon^2].$$

Therefore, we have

$$(46) \qquad \Delta\pi_1(n,\varepsilon) > \Delta\Pi(n,\varepsilon) \text{ for all } n > 1.$$

The increase in consumers' surplus due to the transfer is

$$(47) \qquad \Delta S(n,\varepsilon) = \frac{1}{2(n+1)^2 a} \{2n(b-c)\varepsilon + \varepsilon^2\}.$$

The social welfare increase due to the transfer is

$$(48)\qquad \Delta W(n,\varepsilon) \equiv \Delta\Pi(n,\varepsilon) + \Delta\, S(n,\varepsilon)$$

$$= \frac{1}{2(n+1)^2 a}[\, 2(n + 2)(b - c)\, \varepsilon + (2n^2 + 2n - 1)\varepsilon^2].$$

So we have

$$(49)\qquad \Delta W(n,\varepsilon) > \Delta\pi_1(n,\varepsilon). \qquad \text{for all } n.$$

Combining (48) and (49) we get

$$\Delta\Pi(n,\varepsilon) < \Delta\pi_1(W,\varepsilon) < \Delta W(n,\varepsilon) \text{ for all } n.$$

Therefore we have

$$t_s^* < t_p^* < t_c^*.$$

Q.E.D.

VI. CONCLUDING REMARKS

A firm in a technology receiving country has alternative choices regarding the adoption of a new advanced technology. One is buying the technology from a foreign seller, paying a higher international technology transfer cost and expecting a higher profit stream until the other firms adopts it some time later. The other choice for the firm is to wait until some other firm buys the technology and then adopt the technology domestically, paying lower domestic adoption cost and expecting lower profit stream.

In our two-firm Nash competition model, our analysis discloses that, in some situations, such as the intra-industry diffusion effect being strong enough, there may not exist an equilibrium.

A necessary condition for a firm being able to be a domestic adopter is some other firm's buying the technology from a foreign seller at some earlier time. If the domestic diffusion speed is high enough, the domestic adoption follows the international technology transfer too soon to allow a sufficient profit opportunity for the international transfer to occur. Therefore each firm prefers being a domestic adopter to being the international transferee of the technology, resulting in a socially inefficient "waiting game problem".

In order to correct the problem, the government can lengthen the adoption lag by protection of the leader for a specified period of time. But this policy will lead to another kind of inefficiency, which is the supression of otherwise beneficial technology diffusion in the industry.

Another policy measure for the government is to designate a specific firm to be the leader. This can be done by alternating leader designation for different technologies, or by compensating the designated firm with some subsidy plans.

In the last section we investigated the relationship between the market structure and the timing of the technology transfer. In our n-firms Cournot output competition model, our analysis discloses that an intermediate market structure, one that is neither monopolistic nor perfectly competitive, is most conducive to rapid technical advance. The exact number of firms depends on the size of cost reduction by the new technology relative to the market demand.

We also found that the socially optimal time of the transfer is earlier than the private optimal time. Furthermore, the transfer time with collusion is later than the transfer time without collusion.

Changing or relaxing some of the assumptions on the profit stream, technology transfer cost, adoption cost, commodity production cost and market demand will make the models richer. One could also consider the case in which there are more than two firms or more than two technologies available.

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