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INTERNATIONAL TECHNOLOGY TRANSFER AND TECHNOLOGY DIFFUSION EFFECTS

by

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I. INTRODUCTION

This paper studies the technology buyer's decision problem in the field of international technology transfer. The buyer's problem is formalized as a timing decision problem.

International technology transfer has emerged as an important issue both in developing countries as well as in industrialized countries. A large body of literature on this issue comes from various sources; international business studies, studies of international organizations such as the United Nations, and government policy studies from individual countries including advanced and developing countries.

Most of these studies lack a rigorous analytical framework; many of them are descriptive case studies such as country studies and industry studies. An extensive review can be found in Contractor and Sagafi-Nejad (1981).

Compared to the bulk of the literature from other sources such as those mentioned above, theoretical studies by economists are relatively few. The complicated nature of the technology makes it somewhat difficult for economists to incorporate the phenomenon of international technology transfer into formal models.* Recent studies by international trade theorists include those of Carlos Rodriguez (1975), Ronald Findlay (1978), Paul Krugman (1979), G. W. Irwin (1982), Richard Brecher (1982), MuCulloch and Yellen (1982), Feenstra and Judd (1982).

In the field of economics of technical change, most theoretical

*This point was raised in Jones and Neary (1982) p. 48.

studies are concerned with the production of technology; they have asked, "What is the optimal market structure which leads to the optimal level of R & D activities over time?" A thorough survey of the literature on the market structure and innovation, theoretical and empirical, is found in Kamien and Schwartz (1982).

In another branch of studies, Kamien and Schwartz, (1972), Jensen (1980), Reinganum (1980), Balcer and Lippman (1981)* deal with the problem of a firm's behavior in adopting newly innovated technologies.

None of these studies, however, attempt to analyze technology buying firms' or countries' decision problem regarding the international technology transfer.

For a developing country, which heavily depends on foreign sources for most of the major technologies needed for its economic development and growth, the issue of international technology transfer is of great importance. In the process of decision making regarding the international transfer of technology, the buying country should take technology diffusion effects into serious consideration.

As Mansfield (1969) has convincingly argued, the diffusion of an innovation is essentially a learning process. The technology diffusion effect can be considered as a kind of economic externality in the form of imitation or learning by the adopter of the technology.

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*Balcer and Lippman (1981) analyzed a firm's behavior in adopting existing technology. Extending the work of Kamien and Schwartz (1972), they formulated a model of a technology adopting firm's optimization problem in the presence of a stochastic evolution process of technological knowledge.

An important aspect of technology diffusion is found in the concept of diffusion speed or diffusion distance; again, this can be considered to be learning speed or learning distance. Diffusion of a technology takes place among agents; in the case of major industrial technologies, the agents are mostly firms. The diffusion runs from the supplier of the technology to the receiver of the technology, or from the seller to the buyer. The diffusion speed of a technology from one agent to the other agent depends on the nature of the technology itself and the various characteristics of the agents involved.

Conceptually, the degree of differences in the characteristics of the agents can be considered as the diffusion distance. The relevant characteristics of an agent influencing technology diffusion include:

1) The level of scientific knowledge and technical skill which is closely related to the general technological base in the country to which the agent belongs; the smaller the difference of the level between the agents, the shorter the diffusion distance.

2) The method of communication such as language; the closer the method of communication between agents the shorter the distance.

3) The labor mobility between agents; the higher the mobility, the shorter the distance.

Besides these, various aspects of socio-economic structure, the legal system, and cultural environment will also be important determinants of the diffusion distance between agents, which consequently influence the diffusion speed.

All of the factors described above are considerably more homogeneous within a country than across the countries. Because of this, it should be clear why the phenomenon of international technology transfer should be studied separately from the adoption of a technology in broad terms. Given the relative homogeneity of agents within a country compared to the agents across the national boundary, the diffusion distance between agents in a country is substantially shorter than the diffusion distance between agents in different countries. Therefore, technology diffusion effects are considerably more influential in a domestic adoption than in an international transfer of the technology.

In this study, we will make a clear distinction between the adoption of a technology from a foreign source and the adoption of technology from a domestic source. The former is international technology transfer and the latter is domestic technology adoption. One important fact necessary to note here is that, for a technology importing developing country, the domestic adoption of a technology cannot be realized unless the international transfer of the technology occurred in the first place.

In this paper, we will study the technology buyer's timing decision problem in the presence of three forms of technology diffusion effects. One is the inter-sectoral technology diffusion effect which will be treated in Chapter 2. Another is the inter-technology diffusion effect which will be treated in Chapter 3. The last form of technology diffusion effect is the intra-industry technology diffusion effect, and we will study this in the seperate paper, Lee (1984).

In Chapter 2, a formal model of international technology trade, with a monopolist buyer and a monopsonist seller, is developed. In this model a technology is defined to be an economic commodity. We identify some special characteristics of this "technology-commodity," distinct from other conventional commodities, such as the limited nature of the life of the technology, single-unit demand, and zero marginal cost of reproduction. With these special characteristics of the technology-commodity, we formulate the buyer's and seller's problems as timing problems.

The timing of the trade is determined through the tradeoff between the cost of delay due to forgone profits and the benefit of delay due to the reduced transfer cost. The technology transfer cost is generally assumed to be a decreasing function of time.

In this chapter, we investigate the technology transfer timing problem when there is a technology diffusion effect among sectors in the buying country. Using a two-sector model, which includes a technology buying sector and another sector, we examine three categories: the market outcome, the social optimum, and government policies.

Some of the results in Chapter 2 are as follows:

1) fast technical change will delay the time of the transfer.

2) the higher the comparative advantage of the buying country with respect to the selling country, the earlier the transfer time.

3) a higher interest rate will delay the transfer.

4) the private optimal time of technology transfer is later than the social optimal transfer time.

5) government policy instruments to achieve the social optimum include the special interest rate subsidy as well as the lump-sum subsidy, which is a function of time.

In Chapter 3, the technology choice problem is analyzed in the case of a buyer who has more than one technology available from foreign sources. The buyer's problem is which technologies to buy and in what order to buy them. We set up a model in which the buyer faces two different technologies for the production of the same good; one is a more advanced technology and the other is a less advanced technology.

In this setting, there is a kind of externality problem between technology adoption arising from an inter-technology diffusion effect, even though the externality exists inside of the buying firm. Once a technology has been adopted and used for a while by the firm, it will be less costly for the firm to adopt another more advanced technology than it would be if they did not have the experience of using the less advanced technology at all.

The experience of using the less advanced technology can make the firm use the resources more efficiently or make it less costly to adopt the more advanced technology. This is because some of the experience with the first adopted technology, such as modification of capital equipment and engineers' or technicians' learning in the form of know-how, can be used when adopting the other technology later.

Some of the results disclosed in this chapter are as follows:

1) The buyer has a choice between adopting only the more advanced technology or adopting both technologies—the less advanced one earlier and the more advanced one later.

2) The stronger the inter-technology diffusion effect, the earlier the adoption time of the less advanced technology, but the later the adoption time of the more advanced technology.

3) The stronger the inter-technology diffusion effect, the more likely the firm will choose step-by-step adoption (the less advanced technology first and the more advanced technology later) rather than one-shot adoption (only the more advanced technology).

The last chapter concludes the paper with some final remarks. Included are a brief summary of the main results and a discussion of some potentially interesting extensions.

It is important to emphasize that the question of selling firms' or selling countries' behavior in supplying new technologies will not be addressed, except in the beginning model of Chapter 2. Rather the focus of attention here will be on the behavior of firms who are potential transferees of technologies which are supplied by foreign sources.

II. INTERNATIONAL TECHNOLOGY TRADE AND INTERSECTORAL EXTERNALITY

1. INTRODUCTION

The purpose of this chapter is to develop a formal model of the international technology trade, by treating a technology as an economic commodity and finding the value of the technology for each market participant. We will not be concerned with what determines the level of technology or how the market structure of technology evolves. Instead, the main focus in this study will be on the decisions to buy and sell a technology made by firms in the market, and how this market outcome compares with the social optimality.

Technology as an economic commodity has special characteristics distinct from other commodities. These include:

1) The demand for a technology is a single-unit demand; a firm doesn't want more than one unit of the same technology.
2) Once a technology has been produced in a market, the marginal cost of reproducing the technology in another market is near zero, ignoring the technology transfer cost.
3) Once a technology has been bought by a firm, there exist, through a diffusion process, some external benefits to other parts of the economy, which cannot be appropriated by the buyer.
4) A technology market is highly concentrated in both the selling

and the buying sides. Technology is occasionally monopolized in the market by the protection of a legal patent system and/or by successfully keeping it secret from the use of others.

5) The life of a technology is not permanent because there will be a new arrival of a more advanced technology in the future.

Because of the single-unit demand property, the buyer's problem is a timing problem, i.e.,when to buy, rather than how many to buy. ($t = \infty$ if there is no transfer) The timing of the transfer is determined through the tradeoff between the cost of delay due to forgone profits and the benefit of delay due to reduced transfer cost. The technology transfer cost is generally assumed to be a decreasing function of time.

In the following sections, we shall examine three categories: the market outcome, the social optimum, and government policy. The market outcome is not efficient because there is an externality problem arising from technology diffusion. In order to include the external benefits from technology diffusion into our analysis , we use a two-sector model for the technology buying country: the buying sector, and the other sector.

'The other sector' does not compete with the 'buying sector' in the market, but enjoys external benefits from the technology purchased by the buying sector. The other sector's problem is to choose the optimal time of adoption, taking into account adoption cost. The adoption cost function is assumed to be decreasing over adoption time and is increasing over the time of purchase by the buying sector (i.e., the transfer time). So the optimal adoption time is a function of the transfer time.

The Government's problem is to make the buying sector choose the socially optimal transfer time.

Some of the results are as follows:

1) Fast technical change will delay the time of the transfer.

2) The higher the comparative advantage of the buying country with respect to the selling country, the earlier the transfer.

3) Higher transfer cost will delay the transfer.

4) The social optimal transfer time is earlier than the private optimal transfer time.

4) Government policy instruments to achieve the social optimum include the special interest rate subsidy as well as a lump-sum subsidy, which is a function of time.

2. MODEL

A. Technology as a commodity

We consider a technology as an economic commodity which renders a stream of future services in the form of profits. This stream of profits depends on the demand in a certain market for the products produced using the technology. So we define the technology commodity to be the title of the technology in a certain market.

DEFINITION 1: A technology commodity N^m is the exclusive right of using the technology, N, of which the use is restricted for the production of final products to be sold in the market, m.

B. Assumptions

There are two countries, country 1 and country 2. Firm 1 in country 1 has the new technology N. Firm 2 in country 2 does not have the technology, but it is the only prospective buyer of the technology in country 2. From now on we will call country (firm) 1 the selling country (firm), and country (firm) 2 the buying country (firm). In this study our interest will be restricted to the technology commodity N^2, which is the exclusive right to use the technology in the market of the buying country. The two countries differ only by wage levels; the wage level in country 1 is higher than that of country 2, i.e., $w_1 > w_2$.*

The demand for the final products is assumed to be stationary over time in the buying country. Therefore, the selling firm expects to receive a profit $\pi(w_1)$ per period, by not selling the technology, N^2 but using it to produce products for export to the buying country. Similarly the buying firm expects to get a profit $\pi(w_2)$ per period, by using the technology to produce products in its own country to meet its country's market demand.

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* Actually, this wage differential is representative of the comparative advantage of the buying country with respect to the selling country. Other comparative advantages arise from, for example, relatively smaller stock of old-vintage capital equipment which should be replaced by the new technology.

The technology will become obsolete when there is a more advanced technology which supersedes the existing technology. The probability that the technology N becomes obsolete by time t is $G(t)$.

There is a technology transfer cost* which is assumed to be a decreasing convex function of time, i.e., $c'(t) < 0$, $c''(t) > 0$. This cost is a one-shot fixed cost and will be borne by the buying firm.**

C. Seller's and Buyer's Problem

The selling firm will sell the technology only if the price of the technology is higher than the expected discounted future profits from the exports of its products to the buying country. So the selling reservation price of the technology for the selling firm is,

$$(1) \qquad R_1(\hat{t}) = [1 - G(\hat{t})] \int_{\hat{t}}^{\infty} G'(\bar{t}|\hat{t}) \left\{ \int_{\hat{t}}^{\bar{t}} e^{-rt} \pi(w_1) dt \right\} d\bar{t},$$

where $\hat{t}$; time of transfer,

r ; interest rate, and

$G'(\bar{t}|\hat{t}) = G'(\bar{t}) / [1 - G(\hat{t})]$; the probability that the technology will become obsolete at time $\bar{t}$,

* The technology transfer cost is specific to the technology and the countries involved. The larger the gap between the selling country and the buying country in general science and technological bases, the higher the transfer cost. See Teece (1976) and Mansfield et al. (1982), p214-216.

** The assumption about who bears the cost is not essential in our model. The time of transfer is not affected, but only the income distribution between the buyer and the seller is affected.

given that it has not yet become obsolete by the time $\hat{t}$. (hazard rate*)

Similarly, the buying firm will buy the technology only if the price of the technology is lower than the expected net discounted future profits from the technology. So the buying reservation price of the technology is,

$$(2) \qquad R_2(\hat{t}) = [1 - G(\hat{t})]\left\{\int_{\hat{t}}^{\infty} G'(\bar{t}|\hat{t})\left(\int_{\hat{t}}^{\bar{t}} e^{-rt}\pi(w_2)dt\right)d\bar{t} - e^{-r\hat{t}}c(\hat{t})\right\},$$

where the last term in the parenthesis is the discounted transfer cost, which is assumed to be born by the buyer.

The technology transfer can take place if

$$(3) \qquad R_2(\hat{t}) \geqslant R_1(\hat{t}), \qquad \text{for some} \quad \hat{t} \in [0,\infty),$$

and the price of the technology will be such that

$$(4) \qquad P(\hat{t}) \in [R_1(\hat{t}), R_2(\hat{t})].$$

The selling firm's problem is

$$(5) \qquad \underset{\hat{t}}{\text{Max}}\ V_1(\hat{t}) = P(\hat{t}) - R_1(\hat{t}),$$

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* For an explanation and application to innovation games, see Kamien and Schwartz (1982; p114 - 119).

and the buying firm's problem is

(6) $$\underset{\hat{t}}{\text{Max}}\ V_2(\hat{t}) = R_2(\hat{t}) - P(\hat{t}).$$

So the problem is a monopoly-monopsony price bargaining problem.

DEFINITION 2: In this monopoly-monopsony price bargaining problem, a <u>convex-combination pricing rule</u>, $P(\hat{t})$, is defined to be a function which satisfies

$$P(\hat{t}) = \sigma R_1(\hat{t}) + (1-\sigma)R_2(\hat{t}) \ , \quad \text{where} \quad \sigma \in [0,1].$$

In this definition, σ represents the degree of the bargaining power of the buying firm. Notice that $\sigma/(1 - \sigma)$ represents the relative bargaining power of the buying firm with respect to the selling firm. This convex-combination pricing rule is general enough to include the Stackleberg solution and the Nash Bargaining solution as special cases, i.e., $\sigma = 0$ (or $\sigma = 1$) represents the selling firm's (or the buying firm's) Stakleberg leadership, and $\sigma = 1/2$ represents the Nash bargaining solution.

LEMMA 1 If the price of the technology is determined by the convex-combination pricing rule, then the buyer's problem and the seller's problem are equivalent, i.e.,

$$\arg \underset{\hat{t}}{\text{Max}}\ V_1(\hat{t}) = \arg \underset{\hat{t}}{\text{Max}}\ V_2(\hat{t}).$$

And furthermore,

$$\arg \underset{\hat{t}}{\text{Max}}\ V_2(\hat{t}) = \arg \underset{\hat{t}}{\text{Max}}\ V(\hat{t}), \quad \text{where } V(\hat{t}) = R_2(\hat{t}) - R_1(\hat{t}).$$

PROOF:

$$\begin{aligned} V_1(\hat{t}) &= P(\hat{t}) - R_1(\hat{t}) \\ &= \sigma R_1(\hat{t}) + (1 - \sigma)R_2(\hat{t}) - R_1(\hat{t}) \\ &= (1 - \sigma)\ [R_2(\hat{t}) - R_1(\hat{t})]. \end{aligned}$$

Similarly,

$$\begin{aligned} V_2(\hat{t}) &= R_2(\hat{t}) - P(\hat{t}) \\ &= \sigma[R_2(\hat{t}) - R_1(\hat{t})]. \end{aligned}$$

Therefore,

$$V_1(\hat{t}) = (1 - \sigma)V(\hat{t}) = \frac{(1 - \sigma)}{\sigma} V_2(\hat{t}).$$

Q.E.D.

3. THE MARKET OUTCOME

By Lemma 1, and using Equations (1) and (2), the technology selling firm's and the buying firm's optimization problems become

$$(7) \qquad \underset{\hat{t}}{\text{Max}}\ V(\hat{t}) = [1-G(\hat{t})]\{\int_{\hat{t}}^{\infty} G'(\bar{t}|\hat{t}) \int_{\hat{t}}^{\infty} e^{-rt}[\pi(w_2)-\pi(w_1)]dt\ d\bar{t} - e^{-rt}c(\hat{t})\},$$

where, $V(\hat{t})$ represents the expected discounted value of the total surplus arising from the technology transfer at time $\hat{t}$.

Now, we assume that the arrival of more advanced technology is a poisson process, so the probability of the obsolescence of the technology is exponentially distributed over time, i.e.,

$$(8) \qquad G(t) = 1 - e^{-\lambda t}, \quad \text{so that, } G(0) = 0, \text{ and } \lim_{t\to\infty} G(t) = 1.$$

Notice that a higher λ represents faster technical change, and a lower λ represents slower technical change.

We will state the following result about the determination of the technology transfer time through the seller's and the buyer's optimazation in the technology market.

PROPOSITION 1 The international transfer of technology N^2 will take place at the time $\hat{t} = t_p^*$, where

$$(9) \qquad t_p^* = \begin{cases} 0 & \text{if } V(0) > 0 \text{ and } \pi(w_2) - \pi(w_1) > (\lambda+r)c(0) - c'(0). \\ \hat{t}, & \text{such that, } \pi(w_2) - \pi(w_1) = (\lambda+r)c(\hat{t}) - c'(\hat{t}), \\ & \text{if } V(t) > 0 \text{ for some } t \in (0,\infty), \text{ and} \\ & \lim_{t\to\infty}(\lambda+r)c(t) - c'(t) < \pi(w_2) - \pi(w_1) < (\lambda+r)c(0) - c'(0). \\ \infty & \text{if } V(\hat{t}) < 0 \text{ for all } \hat{t} \in [0,\infty), \\ & \text{or } \pi(w_2) - \pi(w_1) \leq \lim_{t\to\infty} (\lambda + r)c(t) - c'(t). \end{cases}$$

PROOF: Substituting Equation (8) into Equation (7), and rearranging it gives

$$(10)\qquad V(\hat{t}) = e^{-(\lambda+r)\hat{t}}\{[\pi(w_2) - \pi(w_1)]/(\lambda+r) - c(\hat{t})\} .$$

Differentiating Equation (10) with respect to $\hat{t}$, we have

$$(11)\qquad V'(\hat{t}) = e^{-(\lambda+r)\hat{t}}\{ - [\pi(w_2) - \pi(w_1)] + \{(\lambda+r)c(\hat{t}) - c'(\hat{t})\}\} .$$

The second order condition for maximum is satisfied since at the optimal time,

$$V''(\hat{t}) = e^{-(\lambda+r)\hat{t}}\{(\lambda+r)c'(\hat{t}) - c''(\hat{t})\} < 0 ,$$

where the inequality follows from the negative monotonicity and the convexity of the transfer cost function, $c(t)$.

If $V(\hat{t}) < 0$ for all nonnegative $\hat{t}$, then the transfer will not take place.

If $\pi(w_2) - \pi(w_1) > (\lambda + r)c(0) - c'(0)$ and $V(0) \geq 0$, then the transfer will take place immediately.

If $\pi(w_2) - \pi(w_1) \leq \lim_{t\to\infty} (\lambda + r)c(t) - c'(t)$, then the firms will delay the transfer indefinitely.

By Equation (11), the interior solution for the private optimal time of technology transfer is given by

$$(12)\qquad \pi(w_2) - \pi(w_1) = (\lambda + r)c(t_p^*) - c'(t_p^*) .$$

Therefore the result (9) follows.

Q.E.D.

Notice that the LHS of equation (12), $\pi(w_2) - \pi(w_1)$, represents the forgone profit due to the delay of the transfer by one period, and RHS of (12) represents the sum of the saved service flow of the transfer cost and the cost reduction due to waiting one more period. Related to capital investment theory, the first term on the RHS corresponds to the capital gain of not spending earlier. At the optimum the marginal cost and the marginal benefit should be the same.

Now, recall that higher λ represents faster technical change. Then we have the following result.

COROLLARY 1 Assuming an interior solution, faster (slower) technical change will delay (hasten) technology transfer and decrease the resulting value to the firms.

PROOF: From Equation (12), and using the implicit function theorem, we get

$$\frac{\partial t_p^*}{\partial \lambda} > 0 .$$

Therefore the first result follows.

For the latter, using the envelope theorem, we have

$$\frac{dV_p^*}{d\lambda} = \frac{dV_p(t_p^*,\lambda)}{d\lambda} = \frac{\partial V_p(t_p^*,\lambda)}{\partial\lambda}$$

$$= e^{-(\lambda+r)t_p^*}\{[\pi/(\lambda+r) - c(t_p^*)](-t_p^*) - \pi/(\lambda+r)^2\} < 0 ,$$

where $\pi \equiv \pi(w_2) - \pi(w_1)$.

The inequality holds because for an interior solution,

$$V(t_p^*) = e^{-(\lambda+r)t_p^*}\{\pi/(\lambda+r) - c(t_p^*)\} \geq 0 .$$

Q.E.D.

To see the effect of technology transfer cost on the timing of the transfer, let's assume the transfer cost function to be a simple inverse function of time, i.e., $c(t) = k/t$, where $k > 0$. Notice that higher k represents a larger transfer cost for all t.

Now, we get the following results:

COROLLARY 2. Higher (lower) transfer cost will delay (hasten) technology transfer and decrease (increase) the resulting value to the firms, i.e.,

$$\frac{\partial t_p^*}{\partial k} > 0, \text{ and } \frac{\partial V_p^*}{\partial k} < 0.$$

The proof can be easily verified and will be omitted here.

This result has been supported by empirical works. For example, Teece (1976) compared transfer times for different countries and reported that the transfer cost is positively related to the transfer time.

COROLLARY 3. The higher (lower) the wage differential between the selling country and the buying country, the earlier (later) the technology transfer and the larger (smaller) the resulting benefits to the firms, i.e.,

$$\frac{\partial t_p^*}{\partial(w_1 - w_2)} < 0, \text{ and } \frac{\partial V_p^*}{\partial(w_1 - w_2)} > 0.$$

The proof is similar to the proof of proposition 1, and will be omitted.

Recall that the wage differential, $w_1 - w_2$ is representative of the comparative advantage of the buying country with respect to the selling country in this one input-factor production model. The above result can be interpreted to indicate that the higher the comparative advantage of the buying country with respect to the selling country, the earlier the technology transfer will take place.

Even if we extend our model to include the fixed capital equipment as another input-factor of production (see Kamien and Schwartz (1972)), the result will not be changed. This result will explain, at least partially, why some underdeveloped countries will adopt a very recent advanced technology earlier than some more advanced countries.

4. INTERSECTORAL EXTERNALITY

A. Externality

In this section we will consider that there is some external benefits to the other part of the economy arising from the technology purchased by the buying firm. That is, the other part of the country (or other industries) will take advantage of the now domestically possessed technology by applying it for their own benefit.

We will assume that there are two sectors in the buying country: sector 1 and sector 2. Sector 1 is the technology buying sector which is the same as the buying firm in previous sections, and sector 2 is the other part of the country which enjoys the external benefits arising from the technology when they adopt it, which requires some adoption cost.

The amount of external benefits is assumed to be stationary over time as before. The adoption cost is assumed to be an increasing function of the buying sector's purchase time, and decreasing function of their own adoption time. Specifically, the adoption cost function, $d(t_p, t_a)$ is such that,

$$\frac{\partial d(t_p,t_a)}{\partial t_p} > 0, \qquad \frac{\partial d(t_p,t_a)}{\partial t_a} < 0,$$

$$\frac{\partial^2 d(t_p,t_a)}{\partial t_p^2} < 0, \qquad \frac{\partial^2 d(t_p,t_a)}{\partial t_a^2} > 0. \qquad \frac{\partial^2 d(t_p,t_a)}{\partial t_p\, \partial t_a} < 0.$$

where t_p; the buying sector's purchase time which is the transfer time in the previous section, and

t_a; the sector 2's adoption time.

The sector 2's problem in adopting the technology is

$$\max_{t_a} E(t_p,t_a) = e^{-\lambda t_a} \int_{t_a}^{\infty} \lambda e^{-\lambda(\bar{t}-t_a)} \left(\int_{t_a}^{\bar{t}} e^{-rt}\, b\,dt \right) d\bar{t} - e^{-(\lambda+r)t_a}\, d(t_p,t_a)$$

$$= e^{-(\lambda+r)t_a}\{b/(\lambda+r) - d(t_p,t_a)\} ,$$

where b is the amount of external benefits per period.

The first order condition is given by,

$$\text{(13)} \qquad \frac{\partial E(t_p,t_a)}{\partial t_a} = e^{-(\lambda+r)t_a}\{-b + \{(\lambda+r)d(t_p,t_a) - \frac{\partial d(t_p,t_a)}{\partial t_a}\}\}$$

$$= 0.$$

The second order condition for maximization is also satisfied locally. So, the optimal time of adoption t_a^* , given the purchase time by the buying sector t_p , is,

$$t_a^*(t_p) = t_p \text{ if } E(t_p,t_p) \geq 0 \text{ and } b \geq (\lambda+r)d(t_p,t_a) - \frac{\partial d(t_p,t_a)}{\partial t_a} \text{ at } t_a = t_p,$$

$$t_a^*(t_p) = \infty \text{ if } E(t_p,t_a) < 0 \text{ for all } t_a \in [t_p,\infty), \text{ or}$$

$$b \leq \lim_{t_a \to \infty}(\lambda + r)d(t_p,t_a) - \frac{\partial d(t_p,t_a)}{\partial t_a} ,$$

$$\text{(14)} \quad t_a^*(t_p) \in (t_p,\infty), \text{ such that, } b = (\lambda+r)d(t_p,t_a^*(t_p)) - \frac{\partial d(t_p,t_a^*)}{\partial t_a} ,$$

$$\text{if } E(t_p,t_a) \geq 0 \text{ for some } t_a \in (t_p,\infty), \text{and}$$

$$\lim_{t_p \to \infty}(\lambda+r)d(t_p,t_a) - \frac{\partial d(t_p,t_a)}{\partial t_a} < b < (\lambda+r)d(t_p,t_a) - \frac{\partial d(t_p,t_a)}{\partial t_a} .$$

So the resulting external benefit is a function of t_p , which is given by

$$(15) \qquad E^*(t_p) = e^{-(\lambda+r)t_a^*(t_p)}\{b/(\lambda+r) - d(t_p, t_a^*(t_p))\},$$

where $\quad E^*(t_p) = E(t_p, t_a^*(t_p)).$

PROPOSITION 2 A delay in the time of technology transfer , t_p , will delay the time of adoption (t_a) by sector 2, and lower the resulting external benefit, i.e.,

$$\frac{dt_a^*(t_p)}{dt_p} > 0 \text{ and } \frac{dE^*(t_p)}{dt_p} < 0 .$$

However, the effect on the time elapsed between the technology transfer and the sector 2's adoption is not determined.

PROOF: From Equation (14), and using the implicit function theorem,

$$(16) \qquad \frac{dt_a^*}{dt_p} = - \frac{\{(\lambda+r)\frac{\partial d}{\partial t_p} - \frac{\partial^2 d}{\partial t_p \partial t_a}\}}{\{(\lambda+r)\frac{\partial d}{\partial t_a} - \frac{\partial^2 d}{\partial t_a^2}\}} > 0.$$

By Equation (15),

$$(17) \qquad \frac{dE^*(t_p)}{dt_p} = e^{-(\lambda+r)t_a^*} \frac{dt_a^*}{dt_p} \{-b + \{(\lambda+r)d - \frac{\partial d}{\partial t_a}\}\} - e^{-(\lambda+r)t_a^*} \frac{\partial d}{\partial t_p}$$

$$= - e^{-(\lambda+r)t_a^*} \frac{\partial d}{\partial t_p} < 0 .$$

To see the effect on the adoption lag, notice that

$$(18) \qquad \frac{d\left(t_a^*(t_p) - t_p\right)}{dt_p} = \frac{dt_a^*}{dt_p} - 1 .$$

By substituting Equation (16) into Equation (18), we get

$$\frac{d[t_a^*(t_p) - t_p]}{dt_p} \lesseqgtr 0 \text{ iff } (\lambda+r) \lesseqgtr \frac{\dfrac{\partial^2 d(t_p,t_a^*)}{\partial t_a^2} + \dfrac{\partial^2 d(t_p,t_a^*)}{\partial t_p \partial t_a}}{\dfrac{\partial d(t_p,t_a^*)}{\partial t_p} + \dfrac{\partial d(t_p,t_a^*)}{\partial t_a}} .$$

Q.E.D.

Notice that $dE^*(t_p) / dt_p$ represents the "marginal externality gain" by delaying the transfer one period, which is negative.

B. Social Optimum

The Society's problem is to maximize the social value arising from the technology transfer including the external benefits, so the value function for the society becomes

$$(19) \qquad V_s(\hat{t}) = e^{-(\lambda+r)\hat{t}}\{\pi/(\lambda+r) - c(\hat{t})\} + E^*(\hat{t}) ,$$

where $\pi \equiv \pi(w_2) - \pi(w_1)$.

Using Equation (11) and Equation (17), the first order condition becomes

$$(20)\quad V_s'(\hat{t}) = e^{-(\lambda+r)\hat{t}}\{ -\pi + \{(\lambda+r)c(\hat{t}) - c'(\hat{t}) - e^{-(\lambda+r)(t_a^*-\hat{t})}\frac{\partial d}{\partial t_p}\}\}$$
$$= 0,$$

and the second order condition for maximum is also satisfied.

So the social optimal time of the technology transfer t_s^* is given by,

$t_s^* = 0$, if $V_s(0) \geq 0$ and

$$\pi \geq (\lambda+r)c(0) - c'(0) - e^{-(\lambda+r)t_a^*(0)} \frac{\partial d}{\partial t_p}.$$

$t_s^* = \infty$, if $V_s(\hat{t}) < 0$ for all $\hat{t} \in [0,\infty)$,

$$\text{or } \pi \leq \lim_{t_p\to\infty}(\lambda+r)c(t_p) - c'(t_p) - e^{-(\lambda+r)[t_a^*(t_p)-t_p]}\frac{\partial d}{\partial t_p}.$$

$t_s^* \in (0,\infty)$, such that,

$$(21)\quad \pi = (\lambda+r)c(t_s^*) - c'(t_s^*) - e^{-(\lambda+r)(t_a^*-t_s^*)}\frac{\partial d}{\partial t_p},$$

if $V_s(\hat{t}) \geq 0$ for some $\hat{t} \in (0,\infty)$, and

$$\lim_{t_p\to\infty}(\lambda+r)c(t_p) - c'(t_p) - e^{-(\lambda+r)[t_a^*(t_p)-t_p]}\frac{\partial d}{\partial t_p}$$
$$< \pi < (\lambda+r)c(0) - c'(0) - e^{-(\lambda+r)t_a^*(0)}\frac{\partial d}{\partial d_p}.$$

PROPOSITION 3 Assuming an interior solution, the social optimal time of technology transfer is earlier than the private optimal time of technology transfer, i.e., $t_s^* < t_p^*$.

PROOF: By equation (12),

$$\pi = (\lambda+r)c(t_p^*) - c'(t_p^*),$$

and by equation (21),

$$\pi = (\lambda+r)c(t_s^*) - c'(t_s^*) - e^{-(\lambda+r)(t_a^*-t_s^*)} \frac{\partial d}{\partial t_s}.$$

Also, notice that

$$\frac{d}{dt}\{(\lambda+r)c(t) - c'(t)\} < 0 .$$

Therefore, $t_s^* < t_p^*$

Q.E.D.

C. Subsidy Plans

The government's problem is to induce the buying sector to choose the socially optimal time of technology transfer. One way is a direct lump-sum subsidy plan as a function of time of the transfer. The simplest one is $S(t) = E^*(t)$, where, $E^*(t)$ is defined by equation (15).

Notice that this subsidy plan is not unique, since any vertical transformation of $E^*(t)$ will serve the government's objective provided that the resulting benefit to the buying sector is positive, i.e., $S(t) = E^*(t) + K$, where K is such that, the value of $\max_t V_p(t) + E^*(t) + K$ is positive.

An alternative for the government's policy variable is interest rate, as shown below.

PROPOSITION 4 There exists a special interest rate r^* which induces the buying sector to choose the socially optimal time of technology transfer, and the interest rate is given by,

$$r^{*} = r - e^{-(\lambda+r)(t_a^{*} - t_s^{*})} \frac{\partial d}{\partial t_s} / c(t_s^{*}). \tag{22}$$

And the special interest rate is lower than the market interest rate.

PROOF: Such an r^{*} should satisfy

$$t_s^{*} = \arg \max_{t} V_s(t\ ,r)$$

$$= \arg \max_{t} V_p(t\ ,r^{*}).$$

By equation (12) and (19),

$$(\lambda+r)c(t_s^{*}) - c'(t_s^{*}) - e^{-(\lambda+r)(t_a^{*}-t_s^{*})} \frac{\partial d}{\partial t_s}$$

$$= (\lambda+r^{*})c(t_s^{*}) - c'(t_s^{*}).$$

Therefore, $$r^{*} = r - e^{-(\lambda+r)(t_a^{*}-t_s^{*})} \frac{\partial d}{\partial t_p} / c(t_s^{*}) .$$

Because $\frac{\partial d}{\partial t_p} > 0$, we get $r^{*} < r$.

Q.E.D.

Actually, in some developing countries, the government charges different interest rates to different industries or firms for various purposes.

5. Concluding remarks

A technology is considered as an economic commodity which is traded in the international market. This technology commodity is defined to be the exclusive right of using the technology in a certain limited market. With this definition of technology commodity, the value of the technology is well defined.

Because of the single unit-demand characteristic of a technology, the decision problem is a timing problem, rather than a quantity problem. In our monopoly-monopsony technology trade setting, we found that a convex-combination price bargaining rule makes the buyer's and the seller's problem equivalent.

Our analysis discloses that the transfer time of the technology is negatively related to the comparative advantage of the buying country with respect to the selling country, and positively related to the technology transfer cost. The comparative advantage we employed in our analysis is the wage differential between countries, but it can be extended to other cases such as the difference in the stock of old-vintage capital equipment between countries. These results seem to be consistent with some observed phenomena in the international technology market.

Another not so obvious result we found in our analysis is that rapid technical change will delay the technology transfer rather than hasten it. It is interesting because when we consider a dynamic problem of technology evolution over a longer period, rapid technical change in the current generation will delay adoption of current technologies, which will in turn have a negative effect on the speed of technical progress in the next generation.

The market outcome of international technology transfer is not efficient, considering the external benefits arising from the domestic technology diffusion in the buying country. Technology diffusion is more active after the technology is domestically possessed than before. In our two-sector model, we found that the transfer time of the technology is positively related to the adoption time of the technology, and negatively related to the resulting external benefits. And also, the private optimal time of the transfer is later than the socially optimal time.

One way the government can make a private firm buy the technology at the socially optimal time is to offer a lump-sum subsidy plan which is a function of the transfer time. We found that an alternative for the government is to offer a special interest rate to the firm which is lower than the market rate.

III. APPROPRIATE TECHNOLOGY

1. Introduction

In the previous chapter, we have studied the optimal timing problem of a technology buyer when the buyer has only one advanced technology available from foreign sources. In this chapter we will investigate the technology buyer's problem when he has more than one technology available to buy at the time of decision making.* The problem is choosing some "appropriate technology"** from the "menu of technologies" available.

Traditional Theory and its Weakness

Traditionally, the "appropriate technology" theory in the development literature asks, "What is the most appropriate technology to adopt, for a technology receiving developing country, given a menu of different technologies available?" Here, a technology is characterized in terms of the labor-capital ratio in the production process.

In the neoclassical production theory, the menu of technologies can

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*In this chapter we will restrict our analysis to the production technologies for a homogeneous good. So each of the different technologies which will be studied in this chapter is the technology for the production of the same good.

**The term "appropriate technology" is somewhat misleading. From an economist's point of view, where there is a clearly defined set of objectives in choosing a technology, it should be understood as the optimal technology.

be represented by a production function, as a function of labor and capital inputs. Such a production function is illustrated in Figure 1, where the menu of available technologies is represented by the set of points along the isoquant curve QQ. Any point along QQ represents a candidate technology for adoption.

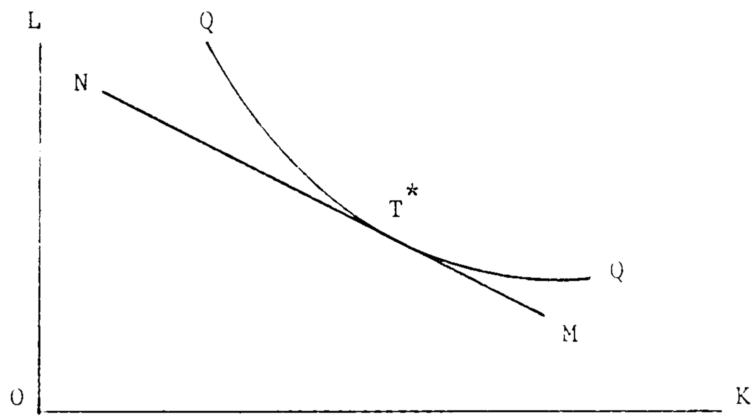

Figure 1

Given the country's labor and capital endowment, the wage-rental ratio will be determined, which is represented in the figure by the slope of the line NM. A simple static analysis indicates that the optimal choice of a technology is the one represented by the point T^* at which the isoquant curve, QQ, and the wage-rental ratio line, MN, are tangent. But the developing country, in many instances, cannot base its technology choice decision making on this argument, for it has a weakness.

The developing country may not actually have a wide range of choices among technologies in terms of the capital-labor ratio. At the initial stage, an innovator of the technology may have some freedom of choices among different levels of capital-labor ratio in the design of the production process. However, once the technology is localized at a certain capital labor ratio in the originating advanced country, the developing country's choice may only be in some small neighborhood of the already localized technology. Or in some extreme cases, only the localized technology will be available for the technology adopter.

This is because in order to develop a technology fully useful for acutal production, there should be a lengthy and costly development stage. For a developing country to adopt a technology other than the one already developed by the advanced country, they must pay the cost of another development process. This development cost includes capital equipment modification cost or redesign cost, which may sometimes be almost as costly as the inital development cost in the advanced country. Furthermore, the development of a technology with a different capital-labor ratio calls for different human-capital imbedded know-how which may be significantly different from that of currently available know-how from the developed country or accumulated experience of the advanced country.

Another Approach

Recognizing the weakness of the traditional theory discussed above, we will approach the choice of technology problem in a different setting. In this study technologies are not characterized by the capital-labor ratio but by the degree of the advanceness.

Different technologies have different performances in terms of the size of cost reduction for a cost reducing innovation, or in terms of the size of the profit for a product innovation. Also, different technologies have different transfer costs which should be borne by the transferee of the technology. This technology transfer cost includes the price of the technology to be paid to the seller and the pure transfer cost such as modification costs and learning cost for the actual use of the technology by the transferee.

Generally, higher performing technologies will have higher transfer costs. In this situation, the technology buying firm's or buying country's problems are, which technologies they should adopt among the set of available ones, and in what order they should adopt them.

An important factor for a technology buyer to take into consideration is the diffusion effect between technologies. Once a technology has been used for a while, it will be less costly for the firm to adopt another, more advanced technology than it would be if they did not have the experience of adopting and using the first technology at all. The experience of using the less advanced technology can make the firm spend the resources more efficiently or less costly in adopting the more advanced technology because some part of the experience, such as in modification of capital equipment or human-capital imbedded know-how, are common in both technologies. This diffusion effect between technologies can be called the "inter-technology diffusion effect."*

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*As far as I know, the concept of "inter-technology diffusion effect" has not been identified clearly and treated formally by economists. But in developing countries, government policy planners and firm managers have well recognized this effect and take this into consideration, either implicitly or explicitly, in their technology choice decision

In this chapter we restrict our analysis to the case in which there are only two technologies available to choose from; one is the more advanced technology and the other is the less advanced technology.

Some of the results disclosed in this chapter are as follows.

1) The buyer has a choice between adopting only one technology and adopting both technologies with some positive time lag between the two adoptions.
2) If the buyer adopts only one technology, then the technology will be the more advanced technology.
3) If the buyer adopts both technologies, then the less advanced one will be adopted first and the more advanced one later.
4) The adoption time of the less advanced technology with a diffusion effect will be earlier than the one without a diffusion effect. The adoption time of the more advanced technology, however, will be later with a diffusion effect than the one without a diffusion effect.
5) Related to the above result, the stronger the diffusion effect (or the higher the learning speed), the earlier the adoption time of the less advanced technology, whereas the stronger the diffusion effect, the later the adoption time of the more advanced technology.

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making. An example of such a consideration can be found in the Korean government's planning of a national telephone network renovation to replace the mechanical telephone switching system which has become obsolete by the time of planning. They had a choice between the less advanced semi-automatic switching system and the more advanced fully automatic system, which they could purchase from foreign sellers including AT&T in the United States.

6) The stronger the inter-technology diffusion effect, the more likely the firm will choose step-by-step adoption (the less advanced technology adopted earlier and the more advanced technology adopted later) rather than one-shot adoption (only the more advanced technology adopted).

The last result is interesting because it indicates that if a country learns fast, then the rate of the technological change in terms of the adoption time of the more advanced technology will be lower than that of a country with slower learning.

In the next section we will formulate our problem formally with some simplifying assumptions. In Section 3 we will begin with the case in which there is no diffusion effect. And in Section 4 the case with inter-technology diffusion effect will be studied, and Section 5 will conclude the chapter.

2. Model

Consider a monopolist firm in a developing country whose current profit is π_0 per period using the current technology T_0. At time $t = 0$ there are two advanced technologies available to the firm to buy from abroad. One of the technologies, denoted by T_1, is less advanced than the other technology, denoted by T_2.

The firm can earn per period profit π_1 by using T_1, and π_2 by using T_2. We assume that $\pi_2 > \pi_1$. So, T_2 can be called the advanced technology and T_1 the intermediate technology.

In order to adopt the technology T_1, the firm should pay the transfer cost $C_1(t_1,t_2)$, which is a function of the transfer time of T_1, t_1, and the transfer time of T_2, t_2. That is, there is some positive external effect from the use of T_2 to the cost of transferring T_1. Similarly, the transfer cost function of T_2, $C_2(t_1,t_2)$ is a function of the transfer time of T_2, and also a function of the transfer time of T_1.

This can be summarized as follows:

	Technology	Transfer time	Profit per period	Transfer cost
advanced*	T_2	t_2	π_2	$C_2(t_1,t_2)$
intermediate*	T_1	t_1	π_1	$C_1(t_1,t_2)$
current	T_o		π_o	

Now we will list every conceivable choice pattern for the firm regarding the order of the technology transfer as follows, of which some cases will be eliminated later:

1) $t_1 = t_2 = \infty$; there will be no techology transfer at all.

*An alternative interpretation of T_1 and T_2 is as follows. T_1 is the only advanced technology available to the firm to adpot at the time of the decision making. And T_2 is the more advanced technology, which is not available at the time of the decision making but will be available at some time in the future. The analysis will be the same except that the stochastic arrival time of the future technology should be incorporated into the model.

2) $t_1 < t_2 = \infty$; only the intermediate technology will be transferred.

3) $t_2 < t_1 = \infty$; only the advanced technology will be transfered.

4) $t_1 < t_2 < \infty$; both technologies will be transferred; the intermediate one first and the advanced one at some time later.

5) $t_2 < t_1 < \infty$; both technologies will be transferred; the advanced one earlier and the intermediate one later.

6) $t_1 = t_2 < \infty$; Two technologies will be transferred at the same time.

7) $t_1 = t_2 = \infty$; Neither technology will be transfered.

The firm maximizes the discounted sum of profits from both of the technologies less the transfer costs over time. So the firm's objective function is

$$(1)\quad V(t_1,t_2)=\begin{cases}\int_{t_1}^{\infty}(\pi_1-\pi_o)e^{-rt}dt + \int_{t_2}^{\infty}(\pi_2-\pi_1)e^{-rt}dt - C_1(t_1,t_2) - C_2(t_1,t_2) & \text{if } t_1 \leq t_2, \\ \int_{t_1}^{\infty}(\pi_1-\pi_2)e^{-rt}dt + \int_{t_2}^{\infty}(\pi_2-\pi_o)e^{-rt}dt - C_1(t_1,t_2) - C_2(t_1,t_2) & \text{if } t_1 > t_2.\end{cases}$$

Notice that $V(t_1,t_2)$ is not continuous at $t_1 = t_2$.

We will restate the assumption about profits formally as follows;

(A1) $0 < \pi_o < \pi_1 < \pi_2.$

And following are assumptions about the technology transfer cost function for each technology.

$$(A2)\quad C_1(t_1,t_2)\begin{cases} > 0 & \text{if } t_1 \in [0,\infty) \quad \text{for all } t_2 \in R_+, \\ = 0 & \text{if } t_1 = \infty \quad \text{for all } t_2 \in R_+.\end{cases}$$

$$C_2(t_1,t_2)\begin{cases} > 0 & \text{if } t_2 \in [0,\infty) \quad \text{for all } t_1 \in R_+, \\ = 0 & \text{if } t_2 = \infty \quad \text{for all } t_1 \in R_+.\end{cases}$$

(A3) $C_i\ (t_1,t_2)$ is continuous and twice differentiable in t_i over $[0, \infty)$,

and $\dfrac{\partial^2 C_i}{\partial t_i^2} > 0$, $\dfrac{\partial^2 C_i}{\partial t_1 t_2} > 0$, for $i = 1, 2$.

3. OPTIMAL CHOICE IN THE ABSENCE OF DIFFUSION EFFECT

In this section we will begin with the case in which there is no diffusion effect from one technology to the other technology. That is, the transfer cost function of a technology is only the function of the transfer time of the technology, not a function of the transfer time of the other technology. In this case the transfer cost functions for technologies T_1 and T_2 are $c_1(t_1)$ and $c_2(t_2)$ respectively. So we can modify the assumptions A_2 and A_3 as follows:

(A2') $$c_i(t_i)\begin{cases} > 0 & \text{for all } t_i \in [0, \infty) \\ = 0 & \text{if } t_i = \infty, \end{cases}$$

where $i = 1, 2$.

(A3') $c_i(t_i)$ is continuous and convex in t_i over $(0, \infty)$, i. e., $c_i''(t_i) > 0$.

The firm's objective function becomes,

$$\text{(2)} \quad V(t_1,t_2) = \begin{cases} e^{-rt_1}(\pi_1 - \pi_o)/r + e^{-rt_2}(\pi_2 - \pi_1)/r - c_1(t_1) - c_2(t_2) & \text{if } t_1 \leqslant t_2, \\ e^{-rt_1}(\pi_1 - \pi_2)/r + e^{-rt_2}(\pi_2 - \pi_o)/r - c_1(t_1) - c_2(t_2) & \text{if } t_1 > t_2. \end{cases}$$

Notice that $V(t_1, t_2)$ is a separable function with respect to t_1 and t_2, i.e.,

$$V(t_1, t_2) = V_1(t_1) + V_2(t_2)$$

where

$$V_1(t_1) = \begin{cases} e^{-rt_1}(\pi_1 - \pi_o)/r - c_1(t_1) & \text{if } t_1 \leqslant t_2, \\ e^{-rt_1}(\pi_1 - \pi_2)/r - c_1(t_1) & \text{if } t_1 > t_2, \end{cases}$$

and

$$V_2(t_2) = \begin{cases} e^{-rt_2}(\pi_2 - \pi_1)/r - c_2(t_2) & \text{if } t_1 \leqslant t_2, \\ e^{-rt_2}(\pi_2 - \pi_o)/r - c_2(t_2) & \text{if } t_1 > t_2. \end{cases}$$

By the following lemma we will exclude the possibility of case 5) and case 6) listed in the last section; that is the firm will neither buy both technologies at the same time, nor buy advanced technology earlier and the intermediate technology later.

LEMMA 1: If $t_2 \leqslant t_1 < \infty$, then (t_1, t_2) cannot be an optimal choice.

PROOF: We will consider the case $t_1 = t_2$ and $t_1 > t_2$ separately.

1) Suppose $t_1 = t_2 = t < \infty$. Then, by (2), we get

$$V(t,t) = e^{-rt}(\pi_2 - \pi_o)/r - c_1(t) - c_2(t).$$

Since $c_1(t) = 0$ when $t = \infty$,

$$V(\infty,t) = e^{-rt}(\pi_2 - \pi_o)/r - c_2(t) .$$

Since $c_1(t_1) > 0$ for all $t < \infty$,

$$V(\infty,t) > V(t,t) \text{ for all } t < \infty.$$

Therefore (t,t) is not an optimal choice for every $t < \infty$.

2) Suppose $t_2 < t_1 < \infty$. Then, by (2), we get

$$V(t_1,t_2) = e^{-rt_1}(\pi_1 - \pi_2)/r + e^{-rt_2}(\pi_2 - \pi_o)/r$$

$$- c_1(t_1) - c_2(t_2).$$

Since $\pi_1 < \pi_2$, and $c_1(t_1) > 0$ for all $t_1 < \infty$,

$$V(t_1,t_2) < e^{-rt_2}(\pi_2 - \pi_o)/r - c_2(t_2)$$
$$= V(\infty,t_2)$$

Therefore, (t_1, t_2) is not an optimal choice for every $t_2 < t_1 < \infty$.

Q.E.D.

Now let's define $\bar{t}_1$, $\bar{t}_2$, $\bar{\bar{t}}_2$ as follows:

(3)
$$\bar{t}_1 = \begin{cases} t_1, \text{ such that, } e^{-rt_1}(\pi_1 - \pi_o) = - c_1'(t_1) & \text{if } (\pi_1 - \pi_o) < - c_1'(0), \\ 0\ , & \text{if } (\pi_1 - \pi_o) \geqslant - c_1'(0). \end{cases}$$

(4)
$$\bar{t}_2 = \begin{cases} t_2, \text{ such that, } e^{-rt_2}(\pi_2 - \pi_1) = - c_2'(t_2), & \text{if } (\pi_2 - \pi_1) < - c_2'(0), \\ 0 & \text{if } (\pi_2 - \pi_1) \geqslant - c_2'(0). \end{cases}$$

(5)
$$\bar{\bar{t}}_2 = \begin{cases} t_2, \text{ such that, } e^{-rt_2}(\pi_2 - \pi_o) = - c_2'(t_2) & \text{if } (\pi_2 - \pi_o) < - c_2'(0) \\ 0 & \text{if } (\pi_2 - \pi_o) \geqslant - c_2'(0). \end{cases}$$

It can be easily shown that if the firm should buy the advanced techology earlier, then the firm will buy the advanced technology at $t = \bar{\bar{t}}_2$ but will not buy the intermediate technology at all. Formally, we will state the following lemma.

LEMMA 2. If $t_1 > t_2$ and $t_2 < \infty$, then the optimal choice is $(\infty, \bar{\bar{t}}_2)$.

LEMMA 3.

1) If $\bar{t}_1 \geq \bar{t}_2$, then for all $t_1 < \infty$ and $t_2 < \infty$,

$$V(\infty, \bar{\bar{t}}_2) > V(t_1, t_2).$$

2) If $\bar{t}_1 < \bar{t}_2$, then for all $t_1 < t_2 < \infty$,

$$V(\bar{t}_1, \bar{t}_2) > V(t_1, t_2).$$

PROOF.

1) By Lemma 2, it suffices to show that

$$t_1 < t_2 < \infty \quad \text{implies} \quad V(t_1, t_2) < V(\infty, \bar{\bar{t}}_2).$$

<u>CASE A</u>; If $t_2 \geq \bar{t}_1$,

$$V(t_1, t_2) \leq V(\bar{t}_1, t_2) \leq V(\bar{t}_1, \bar{t}_1) < V(\infty, \bar{\bar{t}}_2).$$

where the first inequality holds because $\bar{t}_1 < t_2$, and the second inequality holds because $t_2 > \bar{t}_1 > \bar{t}_2$, and the third inequality holds by Lemma 1 and Lemma 2.

<u>CASE B</u>; If $t_1 \leq \bar{t}_2$,

$$V(t_1,t_2) \leq V(t_1, \bar{t}_2) \leq V(\bar{t}_2, \bar{t}_2) < V(\infty,\bar{\bar{t}}_2),$$

where the first inequality holds because $t_1 \leq \bar{t}_2$, and the second inequality holds because $t_1 \leq \bar{t}_2 \leq \bar{t}_1$, and the third inequality holds by Lemma 1 and Lemma 2.

<u>CASE C</u>; If $t_2 < \bar{t}_1$ and $t_1 > \bar{t}_2$, since $t_1 < t_2$, we have

$$\bar{t}_2 < t_1 < t_2 < \bar{t}_1.$$

Therefore,

$$V(t_1,t_2) \leq V(t_2,t_2) \leq V(\infty,\bar{\bar{t}}_2)$$

where the first inequality holds because $t_1 < t_2 < \bar{t}_1$, and the second inequality holds by Lemma 1 and Lemma 2.

The three cases will exhaust all the possibilities when $\bar{t}_1 \geq \bar{t}_2$ and $t_1 < t_2 < \infty$; therefore the result 1) follows.

2) We have $V(\bar{t}_1,\bar{t}_2) = V_1(\bar{t}_1) + V_2(\bar{t}_2)$, for all $t_1 < t_2 < \infty$.

Since $V_1(\bar{t}_1) > V_1(t_1)$ for all $t_1 < t_2$,
and $V_2(\bar{t}_2) > V_2(t_2)$ for all $t_2 \varepsilon (t_1, \infty)$,

$$V(\bar{t}_1, \bar{t}_2) > V(t_1, t_2) \text{ for all } t_1 < t_2 < \infty.$$

Q.E.D.

Now, using the results of above lemmas we can summarize the firm's optimal timing choices in the following proposition. Notice that the transfer cost function for T_1 and T_2 can be discontinuous at $t_1 = \infty$ and $t_2 = \infty$ respectively. Therefore the firm should consider the possibility of not buying T_1 or T_2 separately and compare the outcome with other choices.

PROPOSITION 1.

The optimal pair of transfer times (t_1^*, t_2^*) is given by,

$$(6) \quad (t_1^*, t_2^*) = \begin{cases} \arg\ \text{Max}\ \{V(\bar{t}_1, \bar{t}_2),\ V(\bar{t}_1, \infty),\ V(\infty, \bar{\bar{t}}_2), V(\infty, \infty)\} & \text{if } \bar{t}_1 < \bar{t}_2, \\ \arg\ \text{Max}\ \{V(\infty, \bar{\bar{t}}_2),\ V(\infty, \infty)\} & \text{if } \bar{t}_1 \geq \bar{t}_2. \end{cases}$$

PROOF: If $\bar{t}_1 < \bar{t}_2$, then by Lemma 3, $(\bar{t}_1, \bar{t}_2)$ is the maximizer of $V(t_1, t_2)$ over $t_1 < t_2 < \infty$. And, by Lemma 2, $(\infty, \bar{\bar{t}}_2)$ is the maximizer of $V(t_1, t_2)$ over $t_2 \leq t_1 < \infty$. Allowing the possibility of $t_1 = \infty$ and $t_2 = \infty$, the overall maximizer is as stated above.

If $\bar{t}_1 \geq \bar{t}_2$, then by the first part of Lemma 3, $(\infty, \bar{\bar{t}}_2)$ is the maximizer of $V(t_1, t_2)$ over $t_1 \leq \infty$ and $t_2 < \infty$. Again, allowing the possibility of $t_2 = \infty$, the overall maximizer of $V(t_1,$

t_2) is as stated above.

Q.E.D.

Notice that $V(\infty,\infty) = 0$. That is, the firm may choose neither the intermediate technology nor the advanced technology at all, and receiving the zero value from the choice.

The above results can be illustrated in the following figures, Figure 2 and Figure 3. In the figures we drew imaginary lines representing $t_1 = \infty$ and $t_2 = \infty$ with broken lines. If $\bar{t}_1 < \bar{t}_2$ the firm will compare four points,

$$(\bar{t}_1, \bar{t}_2),\ (\bar{t}_1, \infty),\ (\infty, \bar{\bar{t}}_2),\ (\infty, \infty)$$

as in Figure 2. Whereas, if $\bar{t}_1 \geqslant \bar{t}_2$ the firm will compare only two points,

$$(\infty, \bar{\bar{t}}_2),\ (\infty, \infty)$$

as in Figure 3.

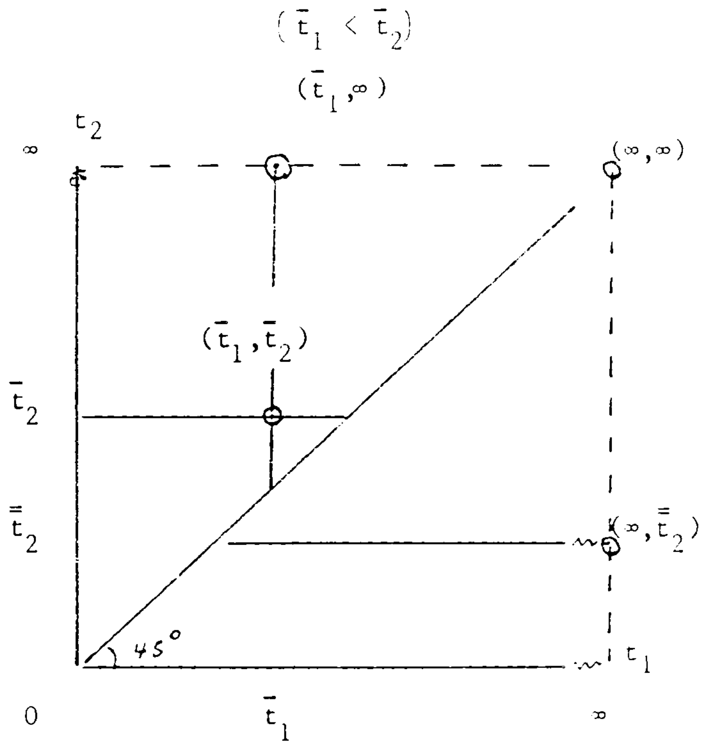

Figure 2

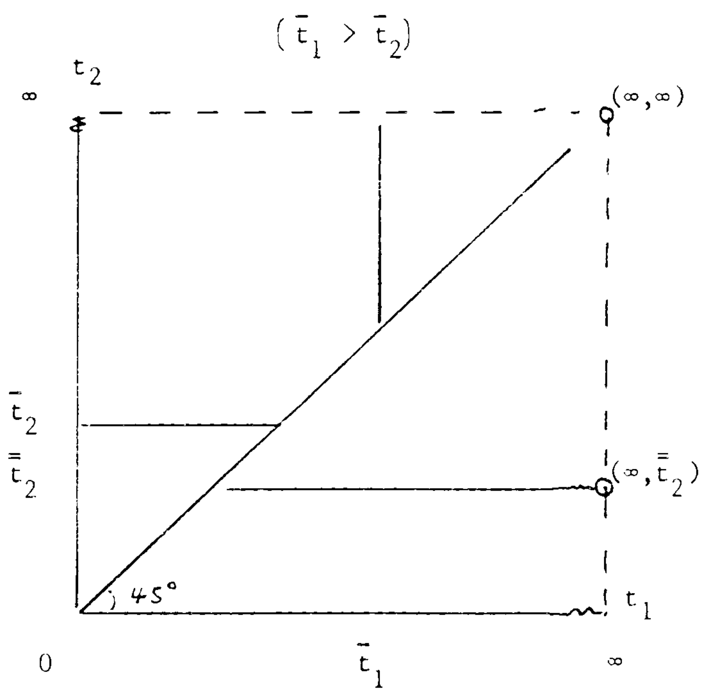

Figure 3

4. OPTIMAL CHOICE WHEN THE INTER-TECHNOLOGY DIFFUSION EFFECT IS PRESENT

In this section we will discuss the case in which there is diffusion effect between the intermediate technology (T_1) and the advanced technology (T_2). We will restrict our analysis to the case where only a "one-way diffusion effect" exists from T_1 to T_2; diffusion effect in terms of cost reduction in the technology transfer cost of T_2 by the firm's adoption of T_1 at some earlier time.

The transfer cost function can be modified as follows.

$$
(7)\qquad
\begin{aligned}
C_1(t_1,t_2) &= c_1(t_1) && \text{for all } t_1,\ t_2, \\
C_2(t_1,t_2) &\begin{cases} = c_2(t_2) & \text{if } t_2 \leqslant t_1, \\ < c_2(t_2) & \text{if } t_2 > t_1 . \end{cases}
\end{aligned}
$$

where $c_1(t_1)$ and $c_2(t_2)$ are the same functions as those in Section 3.

We will make an additional assumption about $C_2(t_1, t_2)$:

$$
\text{A4.}\quad \frac{\partial C_2(t_1,t_2)}{\partial t_2} < c_2'(t_2) \qquad \text{for all } t_2 \geqslant t_1 .
$$

This assumption states that an earlier adoption of T_1 will expedite the speed of the cost reduction in technology transfer of T_2 at any later time.

Accordingly, the firm's objective function is modified as follows:

$$(8)\quad V(t_1,t_2) = \begin{cases} e^{-rt_1}(\pi_1 - \pi_o)/r + e^{-rt_2}(\pi_2-\pi_1)/r - c_1(t_1) - C_2(t_1,t_2) & \text{if } t_1 \leqslant t_2, \\ e^{-rt_1}(\pi_1 - \pi_2)/r + e^{-rt_2}(\pi_2 - \pi_o)/r - c_1(t_1) - c_2(t_2) & \text{if } t_1 > t_2. \end{cases}$$

We can easily check that Lemma 1 and Lemma 2 in the previous section are still valid in this section.

Now, let's define $t_1(t_2)$, $t_2(t_1)$ and $\hat{\hat{t}}_2$ as follows:

$$(9)\quad t_1(t_2) \equiv \begin{cases} t_1 \text{ such that } e^{-rt_1}(\pi_1 - \pi_o) = - c_1'(t_1) - \dfrac{\partial C_2(t_1,t_2)}{\partial t_1} \\ \qquad \text{if} \quad (\pi_1 - \pi_o) < - c_1'(0) - \dfrac{\partial C_2(0,t_2)}{\partial t_1}, \\ 0 \qquad \text{otherwise.} \end{cases}$$

$$(10)\quad t_2(t_1) \equiv \begin{cases} t_2 \text{ such that } e^{-rt_2}(\pi_2 - \pi_1) = - \dfrac{\partial C_2(t_1,t_2)}{\partial t_2} \\ \qquad \text{if} \quad (\pi_2 - \pi_1) < - \dfrac{\partial C_2(t_1,0)}{\partial t_2}, \\ 0 \qquad \text{otherwise.} \end{cases}$$

$$(11)\quad \hat{\hat{t}}_2 \equiv \begin{cases} t_2 \text{ such that } e^{-rt_2}(\pi_2 - \pi_o) = - c_2'(t_2) \\ \qquad \text{if } (\pi_2 - \pi_o) < - c_2'(0), \\ 0 \qquad \text{otherwise.} \end{cases}$$

Furthermore, we will define $\hat{t}_1$ and $\hat{t}_2$ as the solution of the two simultaneous equations, $t_1 = t_1(t_2)$ and $t_2 = t_2(t_1)$.

Now we can show that Lemma 3 in the previous section is also valid in this section, when we replace $\bar{t}_1$ and $\bar{t}_2$ by $\hat{t}_1$ and $\hat{t}_2$ respectively. In the following Lemma we will compare the transfer time of T_1 and T_2 with the diffusion effect to those without the diffusion effect.

LEMMA 4.

1) The transfer time of T_1 with a diffusion effect is earlier than that without a diffusion effect, i.e., $\bar{t}_1 > \hat{t}_1$.

2) The transfer time of T_2 with a diffusion effect is later than that without a diffusion effect, i.e., $\bar{t}_2 < \hat{t}_2$.

PROOF: First notice that non-zero $\hat{t}_1$, and $\bar{t}_1$ are determined by

1)
$$\begin{cases} e^{-r\hat{t}_1}(\pi_1 - \pi_o) = -c_1'(\hat{t}_1) - \dfrac{\partial C_2(\hat{t}_1,\hat{t}_2)}{\partial t_1}, \\ e^{-r\bar{t}_1}(\pi_1 - \pi_o) = -c_1'(\bar{t}_1) . \end{cases}$$

Suppose $\bar{t}_1 \leq \hat{t}_1$.

In order to be a maximizer, it is necessary for $\hat{t}_1$ to satisfy

$$e^{-rt_1}(\pi_1 - \pi_o) \leq -c_1'(t_1) - \frac{\partial C_2(t_1,\hat{t}_2)}{\partial t_1} \quad \text{for all } t_1 \leq \hat{t}_1 \quad ,$$

which implies

$$e^{-rt_1}(\pi_1 - \pi_o) < - c_1'(t_1) \quad \text{for all } t_1 < \hat{t}_1 \quad ,$$

since $\dfrac{\partial C_2(t_1,\hat{t}_2)}{\partial t_1} > 0 \qquad$ for all $t_1 < \hat{t}_2$.

Therefore, $e^{-r\bar{t}_1}(\pi_1 - \pi_o) < - c_1'(\bar{t}_1)$, which is a contradiction.

So we have $\bar{t}_1 > \hat{t}_1$.

2) $$\begin{cases} e^{-r\hat{t}_2}(\pi_2 - \pi_1) = - \dfrac{\partial}{\partial t_2} C_2(\hat{t}_1,\hat{t}_2) \\ e^{-r\bar{t}_2}(\pi_2 - \pi_1) = - c_2'(\bar{t}_2) \end{cases}$$

Suppose $\bar{t}_2 \geqslant \hat{t}_2$.

In order to be a maximizer, it is necessary for $\bar{t}_2$ to satisfy

$$e^{-rt_2}(\pi_2 - \pi_1) \lesseqgtr - c_2'(t_2) \quad \text{for all } t_2 \leqslant \bar{t}_2 \ .$$

But since $\dfrac{\partial C_2(t_1,t_2)}{\partial t_2} < c_2'(t_2)$ for all $t_1 < t_2 < \infty$,

$$e^{-r\hat{t}_2}(\pi_2 - \pi_1) = - \frac{\partial C_2(\hat{t}_1, \hat{t}_2)}{\partial t_2} > - c_2'(\hat{t}_2) \ ,$$

which is a contradiction.

Therefore $\bar{t}_2 < \hat{t}_2$.

Q.E.D.

To find the relationship between diffusion speed and the choice of technology, let's use a specific form of transfer cost function; $c_1(t_1)$ and $C_2(t_1, t_2; \ell)$ are defined by

$$(12) \quad c_1(t_1) = a_1(t_1 - b_1)^2 + m_1.$$

$$(13) \quad C_2(t_1, t_2, \ell) = \begin{cases} (a_2 + \ell)(t_2 - b_2)^2 + m_2 - \ell(t_1 - b_2)^2 & \text{if } t_1 \leq t_2 \\ a_2(t_2 - b_2)^2 + m_2 & \text{if } t_1 \geq t_2, \end{cases}$$

where, the parameter ℓ represents the degree of the diffusion effect or learning speed, which is assumed to be non-negative.

These cost functions are illustrated in Figure 2 and Figure 3.

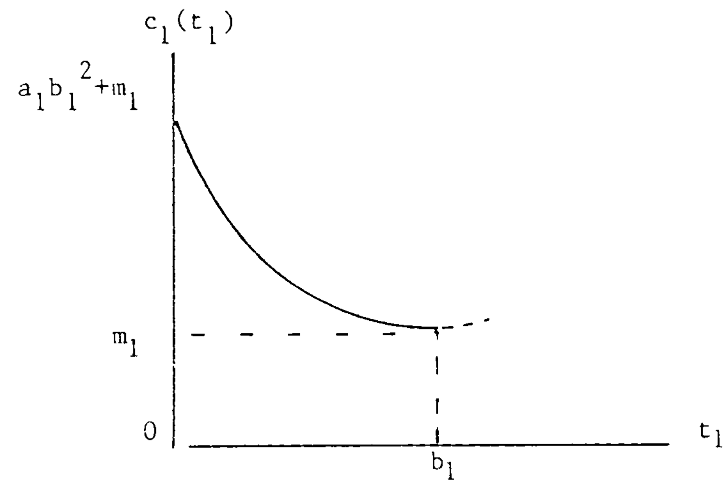

Figure 4

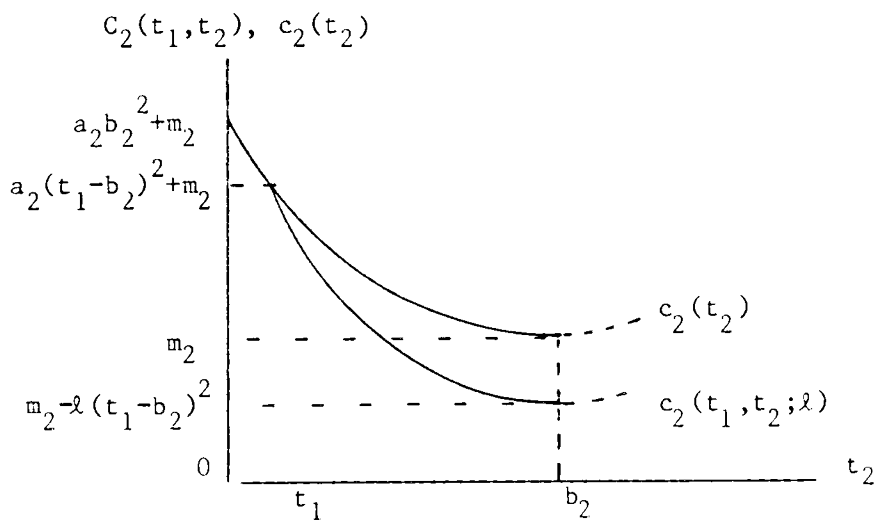

Figure 5

Accordingly, the objective function for the firm is modified as follows;

$$(14)\qquad V(t_1,t_2) = \begin{cases} e^{-rt_1}(\pi_1 - \pi_o)/r + e^{-rt_2}(\pi_2 - \pi_1)/r - [a_1(t_1 - b_1)^2 + m_1] \\ \quad - [(a_2 + \ell)(t_2 - b_2)^2 + m^2 - \ell(t_1 - b_2)^2] & \text{if } t_1 \leqslant t_2, \\ e^{-rt_1}(\pi_1 - \pi_2)/r + e^{-rt_2}(\pi_2 - \pi_o)/r - [a_1(t_1 - b_1)^2 + m_1] \\ \quad - [a_2(t_2 - b_2)^2 + m_2] & \text{if } t_1 > t_2. \end{cases}$$

Now, $\hat{t}_1$ and $\bar{t}_1$ are determined by

$$(15)\qquad \begin{cases} e^{-r\hat{t}_1}(\pi_1 - \pi_o) = -2(a_1 + \ell)\left[\hat{t}_1 - \dfrac{a_1b_1 - \ell b_2}{a_1 + \ell}\right] \\ e^{-r\bar{t}_1}(\pi_1 - \pi_o) = -2a_1[\bar{t}_1 - b_1]\ . \end{cases}$$

And $\hat{t}_2$ and $\bar{t}_2$ are determined by

$$(16)\qquad \begin{cases} e^{-r\hat{t}_2}(\pi_2 - \pi_1) = -2(a_2 + \ell)(\hat{t}_2 - b_2) \\ e^{-rt_2}(\pi_2 - \pi_1) = -2\,a_2(\bar{t}_2 - b_2)\ . \end{cases}$$

Using (15) and (16) it is easy to verify that

(17) $\hat{t}_1 < \bar{t}_1$ and $\bar{t}_2 < \hat{t}_2$ for all $\ell > 0$.

and

(18) $\dfrac{\partial \hat{t}_1(\ell)}{\partial \ell} < 0$ and $\dfrac{\partial \hat{t}_2(\ell)}{\partial \ell} > 0$.

Now we can state the following proposition about the degree of the inter-technology diffusion effect and the firm's pattern of technology choice.

PROPOSITION 3.

The stronger the diffusion effect, which is represented by ℓ , the more likely the firm will choose step-by-step adoption, $(T_o \rightarrow T_1 \rightarrow T_2)$, than one-shot adoption $(T_o \rightarrow T_2)$.

PROOF: Since $\dfrac{\partial \hat{t}_1}{\partial \ell} < 0$ and $\dfrac{\partial \hat{t}_2}{\partial \ell} > 0$ (from Equation (18)), for all $\ell_1 < \ell_2$ we have

$$\hat{t}_1(\ell_2) < \hat{t}_1(\ell_1) \quad \text{and} \quad \hat{t}_2(\ell_2) > \hat{t}_2(\ell_1) .$$

Suppose $V(\hat{t}_1(\ell_1), \hat{t}_2(\ell_1)) > V(\infty, \hat{\hat{t}}_2)$, that is, when the diffusion effect was given by ℓ_1 the firm chose step-by-step adoption. Then

$$V(\hat{t}_1(\ell_2),\hat{t}_2(\ell_2);\ \ell_2)$$

$$= \max_{t_1,t_2} \{e^{-rt_1}(\pi_1 - \pi_o)/r + e^{-rt_2}(\pi_2-\pi_1)/r - [a_1(t_1-b_1)^2 + m_1]$$
$$-[(a_2 + \ell_2)(t_2 - b_2)^2 + m_2 - \ell_2(t_1 - b_2)^2]\}$$

$$\geq V(\hat{t}_1(\ell_1),\ \hat{t}_2(\ell_1);\ \ell_2) \qquad \text{[Revealed Preference]}$$

$$= V(\hat{t}_1(\ell_1),\ \hat{t}_2(\ell_1);\ \ell_1) + (\ell_2 - \ell_1)\ [(\bar{t}_2 - b_2)^2 - (\bar{t}_1 - b_2)^2]$$

$$> V(\hat{t}_1(\ell_1),\ \hat{t}_2(\ell_1);\ \ell_1).$$

Since $V(\infty,\ \hat{\hat{t}}_2(\ell)) = V(\infty,\ \hat{\hat{t}}_2)$ for all ℓ ,

$$V[\hat{t}_1(\ell_1),\ \hat{t}_2(\ell_1)] > V[\infty,\ \hat{\hat{t}}_2(\ell_1)]$$

implies

$$V[\hat{t}_1(\ell_2),\ \hat{t}_2(\ell_2)] > V[\infty,\ \hat{\hat{t}}_2(\ell_2)]\ ,$$

that is, the firm will choose step-by-step adoption.

Q.E.D.

5. CONCLUDING REMARKS

In this chapter we have investigated a firm's problem in choosing technologies from the set of different technologies. In line with the traditional "appropriate technology argument," our question was also focused on which technology they should adopt from the set of available technologies.

But our approach is different from the traditional approach in allowing sequential adoption of different technologies. This is made possible by using the model of a transfer timing decision, which has been employed in the previous chapter. By choosing the optimal transfer time for each of the available technologies, the order of the adoptions is also simultaneously determined.

Also, our model takes into consideration the inter-technology diffusion effect, which is regarded as essential in developing countrys' decision making on the choice of technology.

Using the one-firm and two-technology model we found the following results:

1) The buyer has a choice between adopting only one technology and adopting both technologies with some positive time lag between the two adoptions.
2) If the buyer adopts only one technology, then the technology will be the more advanced technology.
3) If the buyer adopts both technologies, then the less advanced one will be adopted first and the more advanced one later.
4) The adoption time of the less advanced technology with a diffusion effect will be earlier than the one without a diffusion effect. The adoption time of the more advanced technology, however, will be later with a diffusion effect than the one without a diffusion effect.
5) Related to the above result, the stronger the diffusion effect (or

the higher the learning speed), the earlier the adoption time of the less advanced technology, whereas the stronger the diffusion effect, the later the adoption time of the more advanced technology.

6) The stronger the inter-technology diffusion effect, the more likely the firm will choose step-by-step adoption rather than one-shot adoption.

IV. CONCLUSION

This study formalized the technology buyer's optimal transfer timing problem in the presence of various forms of domestic diffusion effects. In this study we made a distinction between domestic adoption of a technology and the international transfer of the technology. Due to the relative homogeneity of agents within a country compared to agents across countries, technology diffusion effects are considerably more influential in a domestic adoption than in an international transfer. We identified three forms of technology diffusion effects, and each of them were treated separately.

In Chapter 2, a formal model of international technology transfer is developed, by treating a technology as an economic commodity. With the model of one buyer and one seller, we investigated the technology timing decision problem when there is an inter-sectoral diffusion effect.

Main results in this chapter are: 1) fast technical change will delay the transfer; 2) the higher the comparative advantage of the buying country, the earlier the transfer time; 3) the private optimal transfer time is later than the social optimal time, and the social optimum can be achieved by government policies such as special interest subsidy or the lump-sum subsidy as a function of time.

In Chapter 3, a model of technology choice was analyzed, in which there are two technologies available to the buyer. In this chapter we incorporated the inter-technology diffusion effect into the model.

Main results in this chapter are: 1) the buyer has a choice between step-by-step adoption (the intermediate technology adopted earlier and the advanced technology adopted later) and one-shot adoption (only the advanced technology adopted); 2) the stronger the inter-technology diffusion effect, the more likely the choice of the step-by-step adoption.

Although the models employed in this study involved some restrictive assumptions, the results generated from them seem broadly applicable and interesting for the understanding of the buyers' behavior regarding international technology transfer.

Furthermore, considering the scarcity of analytical studies on this issue, especially in light of the importance given to the issue by governments, international organizations, and the international business world, this study will be of a significant base from which to set out.

Nevertheless, since this was an initial effort at a formal analysis, there are various possible extensions which could yield interesting results. 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.

A most valuable extension would be to incorporate the problem of the seller of the technology (including the selling country) with that of the potential buyers. This should then be completed by thoroughly linking the relationships among innovation, international trade, and international technology transfer.

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