

## LEARNING BY DOING AND INTERNATIONAL TRADE IN A SUCCESSIVELY MONOPOLISTIC MARKET WITH MULTISTAGE PRODUCTION

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*This paper develops a dynamic model where there is an opportunity for learning by doing in a vertically related market with successive monopolies, an upstream firm in a technologically advanced country and a downstream firm in a technically lagging country. Under this framework, learning by doing promotes import substitution in the technically lagging country unless the downstream firm pays higher wages than the upstream firm does. If the downstream firm pays lower wages than the upstream firm does, learning by doing also affects each firm's cumulative profit: the upstream firm's profit always increases, but the downstream firm's profit would either increase or decrease depending on the cost structure and the shape of the learning curve. In particular, the downstream firm's cumulative profit is more likely to decrease if the wage gap between two countries is very big and/or if the downstream firm is a very fast learner.*

JEL Classification: F12, L13

Keywords: Learning By doing, Multistage Production, Successive Monopolies

### I. INTRODUCTION

There is no doubt that technological change plays a major role to determine the pattern of trade as well as the distribution of income in the world economy. To understand international trade in the real world, therefore, it is necessary to delve deeply into causes and consequences of technological change. Until quite recently, however, the extensive literature on trade theory has focused mainly on the effects of technological differences across countries under the static frameworks where technology is invariable.

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*Received for publication: Apr. 20, 1998. Revision accepted: Aug. 5, 1998.*

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A firm acquires technological advantage by inventing a new product or a new process, and the advantage generated by innovation is usually rewarded by the creation of a monopoly position in the market. But, such a technological advantage lasts only for a short time if a competitor catches up with the technology. When there is a possibility of technology catch-up, therefore, the monopoly power created by the technological advantage decays over time. In this context, the relationship between technological change and trade should be treated as a dynamic event, not a static one. What we cannot disregard in this respect is that technological innovation is more likely to occur in the intermediate good sector than in the final product sector. It is not hard to find such an example as semiconductors and personal computers. Thus it is also essential to take a closer look into the intermediate good sector in order to grasp a deep insight into technological change and trade.

Let us consider a country which produces a final product by importing a key input from the foreign country because of a lack of technology in the intermediate good sector. This is a fairly common phenomenon taken place during the development process in most developing countries. For instance, Korea has relied heavily on Japan for supplies of key parts and components. But, if the country has an opportunity to catch up with the technology, it starts producing the intermediate good that used to be imported. There are a lot of ways for a country to make its technological progress, but the role of learning by doing in the technical advancement is extremely important in many developing countries, particularly at the earlier stage of the development.

The purpose of this paper is to study the effects of the technological progress caused by learning by doing on international trade of intermediate goods in order to understand the development process of many developing countries which have the experience illustrated above. To that end, this paper develops a simple dynamic model where there is an opportunity for learning by doing in the intermediate good sector that has the multistage production structure. In particular, this paper considers a vertically related market with successive monopolies to analyze strategic interactions between a technological leader in the upstream industry and a technically lagging firm in the downstream industry.

Since Arrow(1962) introduced learning by doing in a formal model, there have been numerous studies in this field under the closed economic models. But, only recently has learning by doing been incorporated into trade theory. Among others, Krugman (1987) and Lucas (1988) build the models in which learning by doing plays a role to enhance the sectoral productivity in the case where the learning curve is sector-specific completely external to firms. Grossman and Helpman (1990) study inter-industry spillover effects in learning by doing when there is unbounded opportunities for learning, while Young (1991) and Stokey (1991) examines similar issues when learning process is bounded.

All the models above are concerned only with final product markets. Recently, Ishikawa (1992) studies the effects of learning by doing in the intermediate good

sector (which produces producer services) on the industrial structure and trade patterns when trade of intermediate goods is not allowed. Chang and Park (1995) analyze a vertically integrated monopolist's optimal decision on vertical supply in a model where a potential entrant in the downstream industry has an opportunity for technology catch-up after using the intermediate input supplied from the monopolist for a required learning time that is exogenously given. As for import substitution in the intermediate good sector, Bhattacharya(1985) constructs a stochastic dynamic model in which a firm adopts an R & D program for development of intermediate goods that are substitutable for tied inputs under the technology licensing contract.

The multistage production model used in this paper is originally developed by Dixit and Grossman(1982), who study trade of intermediate goods in a static framework in which each stage in the production process differs in its factor intensity and the pattern of production specialization across countries is governed by the usual comparative advantage. Among the static models concerning trade of intermediate goods in a vertically realted market, Rodrik and Yoon(1989), and Spencer and Jones(1992) are specially relevant to this paper.

The rest of the paper is organized as follows. The structure of the model is described in Section II. Section III discusses an equilibrium in a single period problem in which the level of learning is given. In Section IV, we consider a two-period problem to examine the effect of learning by doing on trade of intermediate goods at intertemporal equilibrium. Concluding remarks follow in Section V.

## II. THE MODEL

We consider a production process that consists of a succession of vertical stages where each stage adds some value to an intermediate good to produce another intermediate good ready for the next stage. Each stage differs in the technology required for its production activities. For analytical tractability, a continuum of stages is allowed. Let the stages of production processes be indexed by  $\theta$ , ranging over the interval  $[0, 1]$ . The production process starts at  $\theta=0$  which represents the upstream end. The intermediate good at stage  $\theta + d\theta$  is produced using one unit of stage  $\theta$  output and labor, and all goods with index  $\theta < 1$  are treated as pure intermediate goods in that they require further processes in order to be sold to consumers. Any intermediate good at stage  $\theta < 1$  can be traded internationally at no transport cost, and it makes no difference who completes the rest of the stages. The production process ends at  $\theta=1$  where the entire continuum of stages is completed, and thus the goods with index  $\theta=1$  are final products ready to be sold for consumption. For a final product to be produced, then, all we need is that it should pass once through each stage. Thus the ordering of the stages is immaterial, and we can

choose the order so that the level of technology becomes higher as  $\theta$  gets close to 0. It is quite usual in many industries that the production processes close to the upstream end require a higher level of technology than those close to the downstream end.

To investigate the effects of learning by doing on international trade of the intermediate good, we now develop a two-period model with two countries (country A and country B) and two firms (firm A in country A and firm B in country B). All the stages  $0 \leq \theta \leq 1$  are accessible to firm B which is a technological leader. In the first period, however, firm A lacks technology to pass through all the stages  $0 \leq \theta < 1$ , and operates only at stage 1 in the downstream end by using the intermediate good imported from firm B. Only after accumulating its technical knowledge through learning by doing in the first period, firm A can enter the lower stages in the second period. Let  $y_t$ ,  $t=1, 2$ , be output of the final product produced by firm A in period  $t$ . Then, the lowest accessible stage by firm A in period 2 can be expressed as  $\theta(y_1)$ , where

$\theta(0) = 1$ ,  $0 \leq \theta(y_1) \leq 1$  for  $y_1 > 0$ , and  $\theta'(y_1) < 0$ . Firm A can participate in all the production stages from 1 to  $\theta(y_1)$  in period 2, and hence  $1 - \theta(y_1)$  shows the highest level of import substitution in the intermediate good sector that can be achieved by country A in period 2. As firm A expands its production stages, firm B's monopoly position in the upstream industry decays in the sense that firm B has to compete with firm A for the production range of the intermediate good. It is thus in the interest of firm B to control the price and the volume of the intermediate good exported to firm A.

In this paper, we consider the case where the opportunity for learning is bounded, that is,  $0 < \theta(y_1) \leq 1$  for all  $y_1$ .<sup>1</sup> In many industries, it is true that the production stage near the upstream end requires sophisticated technology that is hard to learn solely from experience. The important feature of this assumption is that firm A has no choice but to import the intermediate good, whatever its stage might be, as long as it produces the final product. If this is the case, a vertically integrated firm has an incentive not to export the intermediate good but to monopolize the final product market. As shown in Rodrik and Yoon (1989) and Spencer and Jones (1992), such vertical market foreclosure is commonly observed at equilibrium under free trade. In this paper, we rule out the possibility of vertical market foreclosure by assuming that country A imposes a prohibitive tariff on imports of the final product. This allows us to focus on the intermediate good sector.

Now, let  $w$  and  $w^*$  be the wage rates in country A and B, respectively. The

<sup>1</sup> When  $\theta(y_1) = 0$ , the cumulative profit function of each firm becomes discontinuous. Although it is also possible to deal with such a discontinuity problem in this model, we ignore such a case that is beyond the scope of this paper.

intermediate good at stage  $\theta(y_1) + d\theta$  is produced with one unit of stage  $\theta(y_1)$  output, and labor at a cost of  $k(w, \theta(y_1))d\theta$  in country A and  $k(w^*, \theta(y_1))d\theta$  in country B, respectively, where  $k(w, \theta(y_1))$  is an increasing function of  $w$ . We assume that stage 1 in the downstream end incurs no production cost. Let

$$c(w^*, \theta(y_1)) = \int_0^{\theta(y_1)} k(w^*, \theta) d\theta \text{ and } c(w, \theta(y_1)) = \int_{\theta(y_1)}^1 k(w, \theta) d\theta$$

where  $c(w^*, \theta(y_1))$  and  $c(w, \theta(y_1))$  are all the incremental unit costs incurred during all the stages  $0 \leq \theta \leq \theta(y_1)$  undertaken by firm B and during all the stages  $\theta(y_1) < \theta \leq 1$  undertaken by firm A, respectively. Then, when firm A imports the intermediate good at stage  $\theta(y_1)$ , its production cost per unit of the final product can be written as

$$E(w, w^*, \theta(y_1)) = q(\theta(y_1)) + c(w, \theta(y_1)),$$

where  $q(\theta(y_1)) = q(w, w^*, \theta(y_1))$  is the import price of the intermediate good at stage  $\theta(y_1)$ .

Let  $p = p(y)$  be the inverse demand function for the final product, where  $p(y)$  has all the usual properties of the demand function. Assuming there is no discount for the future profits, the cumulative profit of firm A during two periods can be written as

$$V = \max_{y_1, y_2} [p(y_1) - q_1]y_1 + [p(y_2) - q_2(\theta_2) - c(w, \theta_2)]y_2 \quad (1)$$

where  $q_t$ ,  $t=1, 2$ , is the price of the intermediate good in period  $t$ , and  $\theta_2 \in [\theta(y_1), 1]$  is the production stage such that

$$q_2(\theta_2) + c(w, \theta_2) \leq q_2(\theta) + c(w, \theta) \text{ for all } \theta(y_1) \leq \theta \leq 1.$$

The firm B's cumulative profit can be also expressed as

$$V^* = \max_{q_1, q_2} [q_1 - c(w^*, 1)]y_1 + [q_2(\theta_2) - c(w^*, \theta_2)]y_2 \quad (2)$$

To find a solution to the dynamic maximization problem described above, we will look for the Stackelberg equilibrium. Firm B, a Stackelberg leader, chooses a schedule of  $q_t(\theta)$ , after full consideration of its effects on  $y_t$  and on the state variable  $\theta(y_1)$ .<sup>2)</sup> Then, firm A, a follower, chooses  $y_t$  to maximize its cumulative profit, taking  $q_t(\theta)$  as given.

### III. EQUILIBRIUM IN A SINGLE PERIOD PROBLEM

Before we consider the two-period problem given by (1) and (2), it is useful to analyze the equilibrium in a single-period problem where  $\theta$ ,  $0 < \theta \leq 1$ , is given. Then, the firm A's profit maximization problem becomes

$$\pi = \max_y [p(y) - q(\theta) - c(w, \theta)]y,$$

where  $q(\theta)$  is given, and its first order condition is

$$g(y) = q(\theta) + c(w, \theta), \text{ where } g(y) = p(y) + yp'(y). \quad (3)$$

The firm B's maximization problem is

$$\pi^* = \max_{q(\theta)} [q(\theta) - c(w^*, \theta)]y.$$

Since  $q(\theta) = g(y) - c(w, \theta)$  from (3), the firm B's problem can be rewritten as

$$\pi^* = \max_y [g(y) - c(w, \theta) - c(w^*, \theta)]y.$$

Thus the first order condition for the firm B's problem becomes

$$h(\bar{y}) = c(w, \theta) + c(w^*, \theta), \text{ where } h(\bar{y}) = \bar{g}(\bar{y}) - y\bar{g}'(\bar{y}). \quad (4)$$

Assuming that  $h'(\bar{y}) < 0$  and  $\bar{g}'(\bar{y}) < 0$ , which are the second order conditions for each firm's profit maximization problem, (4) determines  $\bar{y} = \bar{y}(\theta)$ , and (3) can be used to find  $\bar{q}(\theta)$ , where "—" denotes the values at equilibrium.

Now, let us investigate various effects of learning by doing. From (4) and the definition of  $c(w, \theta)$  and  $c(w^*, \theta)$ ,

$$\frac{d\bar{y}}{d\theta} = \frac{1}{h'(\bar{y})} [k(w^*, \theta) - k(w, \theta)]. \quad (5)$$

Since  $k(w, \theta)$  is increasing in  $w$ ,  $d\bar{y}/d\theta < 0$  if  $w^* > w$ , and  $d\bar{y}/d\theta > 0$  if  $w^* < w$ . If  $w^* = w$ ,  $\bar{y}$  is invariant to  $\theta$ . From (3) and (5), it can be also found that

<sup>2</sup> The operational level of  $\theta$  in period 2,  $\theta_2$ , is actually chosen by firm B. Firm B chooses  $\theta_2$  by announcing a schedule of  $q_i$  which are prohibitively high everywhere except at  $\theta_2$ .

$$\frac{d\bar{q}(\theta)}{d\theta} = \frac{g'(\bar{y})}{h'(\bar{y})} [k(w^*, \theta) - k(w, \theta)] + k(w, \theta). \quad (6)$$

Then, using the definition of  $E(w, w^*, \theta)$  and (6),

$$\frac{dE(w, w^*, \theta)}{d\theta} = \frac{g'(\bar{y})}{h'(\bar{y})} [k(w^*, \theta) - k(w, \theta)]. \quad (7)$$

If  $w < w^*$ , the firm A's production cost in the final product sector decreases as its range of production processes expands. If  $w < w^*$ , therefore, firm A can minimize its production cost by expanding its range of production up to  $\theta$ . If  $w > w^*$ , firm A must operate only at stage 1 in the downstream end in order to minimize its production cost. If  $w = w^*$ , firm A's production cost is independent of the value of  $\theta$ , and it can choose any stage from the interval  $[\theta, 1]$  without affecting its production cost.

Next, let us examine the effects of import substitution in the intermediate good sector on each firm's profit. For firm A,

$$\frac{d\bar{\pi}}{d\theta} = \frac{-g'(\bar{y})}{h'(\bar{y})} [k(w^*, \theta) - k(w, \theta)]\bar{y} \quad (8)$$

by (3) and (6), and for firm B,

$$\frac{d\bar{\pi}^*}{d\theta} = -[k(w^*, \theta) - k(w, \theta)]\bar{y} \quad (9)$$

by (4). If  $w < w^*$ , therefore, the expansion of the range of production by firm A will increase both firms' profits at equilibrium. If  $w \geq w^*$ , however, both firms' profits remain the same as those when all the production stages except  $\theta = 1$  are completed by firm B. This is because the firm A's production cost of the final product does not vary with its range of production if  $w = w^*$  while firm A operates only at stage 1 in the downstream end if  $w > w^*$ .

#### IV. INTERTEMPORAL EQUILIBRIUM

To characterize the equilibrium in the two-period model described in Section II, it is convenient to consider three cases separately depending on whether the wage rate in country A is less than, equal to, or greater than that in country B.

##### 4.1. The Case Where $w = w^*$

If  $w = w^*$ , the firm A's production cost and output of the final product as

well as each firm's instantaneous profit are independent of  $\theta(y_1)$ , as explained in Section III. In period 2, therefore, firm A can choose any stage  $\theta_2$  such that  $\theta(y_1) \leq \theta_2 \leq 1$  without affecting its production cost and profit. Then, since  $c(w, 1) = 0$  by the assumption,  $g(\bar{y}_t) = q_2(1) + c(w, 1) = \bar{q}(1)$ ,  $t = 1, 2$ , where  $\bar{q}(1)$  is the price of the intermediate good when all the production stages except  $\theta = 1$  are completed by firm B. Let  $\tilde{q}$  and  $\tilde{y}$  denote the price of the intermediate good and output of the final product, respectively, when there is no opportunity for learning by doing in the downstream industry. Then, since  $g(\tilde{y}) = \tilde{q} = \bar{q}(1)$ ,  $y_t = \tilde{y}$  for all  $t = 1, 2$ .

The main reason for the result above lies in the firm B's strategic pricing policy in the intermediate good market. To see this point, we have

$$\bar{q}_2(\theta_2) = g(\bar{y}_2) - c(w, \theta_2) = \bar{q}(1) - c(w, \theta_2),$$

for any  $\theta(y_1) \leq \theta_2 \leq 1$ . Firm B lowers the price of the intermediate good at stage  $\theta_2$  exactly by  $c(w, \theta_2)$ , which is the total cost incurred during all the stages from  $\theta_2$  to 1 that are undertaken by firm A in period 2. Accordingly, firm B maintains the same level of mark-up in the intermediate good market no matter what stage firm A starts its production process.

In summary, if wages are identical in the two countries, the production cost and output of the final product in each period are independent of the ranges of production undertaken by firm A, and they are constant at the levels when all the stages of production are completed by firm B. Both firms' profits also remain at the same levels as those when there is no opportunity for learning by doing in the downstream industry. In particular, firm B can keep its cumulative profit constant because it maintains the same level of mark-up in the intermediate good market by lowering the price of the intermediate good as much as the total cost incurred during all the production stages undertaken by firm A. From the perspective of country A, however, learning by doing has a positive effect in terms of import substitution in that it is now possible for firm A to import the lower-stage intermediate good at a lower price.

#### 4.2. The Case Where $w < w^*$

If  $w < w^*$ , firm A's production cost of the final product decreases and each firm's instantaneous profit increases as firm A expands its range of the production, as explained in Section III. In period 2, therefore, firm A undertakes all the stages up to  $\theta(y_1)$  which is the lowest accessible stage in period 2.

First, let us consider the second period problem in which  $\theta(y_1)$  is given. From the result in Section III, each firm's instantaneous profit at equilibrium in period 2 can be written as



$$\bar{\pi}_2 = [p(\bar{y}_2) - \bar{q}_2 - c(w, \theta(y_1))] \bar{y}_2, \text{ and} \quad (10)$$

$$\bar{\pi}_2^* = [g(\bar{y}_2) - c(w, \theta(y_1)) - c(w^*, \theta(y_1))] \bar{y}_2, \quad (11)$$

where  $\bar{y}_2$  and  $\bar{q}_2$  satisfy the following conditions:

$$\bar{q}_2 = g(\bar{y}_2) - c(w, \theta(y_1)), \quad g(\bar{y}_2) = p(\bar{y}_2) + \bar{y}_2 p'(\bar{y}_2), \quad (12)$$

$$h(\bar{y}_2) = c(w, \theta(y_1)) + c(w^*, \theta(y_1)), \text{ and } h(\bar{y}_2) = g(\bar{y}_2) + \bar{y}_2 g'(\bar{y}_2). \quad (13)$$

When  $w < w^*$ , (5) implies that  $\bar{y}_2$  increases as  $\bar{y}_1$  increases since  $\theta'(y_1) < 0$ . Then,  $\bar{y}_2 > \hat{y}$  since  $\hat{y}$  in period 2 is independent of  $y_1$ . (6) also implies that  $q_2$  falls as  $\bar{y}_1$  increases, and  $\bar{q}_2 < \hat{q}$  since

$$\bar{q}_2 = g(\bar{y}_2) - c(w, \theta(y_1)) < g(\hat{y}) - c(w, \theta(y_1)) < g(\hat{y}) = \hat{q}.$$

The price of the intermediate good falls because the total cost incurred during all the stages undertaken by firm A is reflected in the price, as shown in (12).

In period 2, therefore, learning by doing in the downstream sector brings about an increase in output of the final product and a decrease in the price of the intermediate good. In addition, learning by doing has a positive effect on import substitution in the intermediate good sector in that firm A expands its production process up to the lowest accessible stage. But, the quantity of the intermediate good imported in period 2 increases because of a rise in output of the final product.

Next, let us consider the first period. Each firm's profit maximization problem in period 1 can be written as

$$V = \max_{y_1} [p(y_1) - q_1] y_1 + \bar{\pi}_2, \text{ and } V^* = \max_{q_1} [q_1 - c(w^*, 1)] y_1 + \bar{\pi}_2^*,$$

where  $\bar{\pi}_2$  and  $\bar{\pi}_2^*$  are given by (10) and (11), respectively. Using (6) and (12), then, the first order condition for firm A's problem becomes

$$q_1 = g(y_1) - \beta(y_1) \bar{y}_2, \quad (14)$$

where  $g(y_1) = p(y_1) + y_1 p'(y_1)$ , and

$$\beta(y_1) = \frac{g'(\bar{y}_2)}{h'(\bar{y}_2)} [k(w^*, \theta(y_1)) - k(w, \theta(y_1))] \theta'(y_1) < 0. \quad (15)$$

Since  $\beta(y_1) = dE(w, w^*, \theta(y_1))/dy_1$  by (7), an increase in the final product by one unit in period 1 lowers the production cost per unit of the final product by  $\beta(y_1)$  in period 2.

Using (14), then, firm B's problem can be rewritten as

$$V^* = \max_{y_1} [g(y_1) - \beta(y_1)\bar{y}_2 - c(w^*, 1)]y_1 + \bar{\pi}_2^*,$$

and its first order condition can be expressed as

$$[h(\bar{y}_1) - c(w^*, 1) + \delta(\bar{y}_1)] + \sigma(\bar{y}_1) = 0, \quad (16)$$

where  $h(\bar{y}_1) = g(\bar{y}_1) + g'(\bar{y}_1)\bar{y}_1$ ,

$$\delta(\bar{y}_1) = -\left[\beta(\bar{y}_1)\bar{y}_2 + \frac{d\beta(\bar{y}_1)}{dy_1}\bar{y}_1\bar{y}_2 + \beta(\bar{y}_1)\frac{d\bar{y}_2}{dy_1}\bar{y}_1\right], \text{ and}$$

$$\sigma(\bar{y}_1) = \frac{\bar{\pi}_2^*}{dy_1} = -[k(w^*, \theta(\bar{y}_1)) - k(w, \theta(\bar{y}_1))]\theta'(\bar{y}_1)\bar{y}_2$$

by (13). In (16),  $[h(\bar{y}_1) - c(w^*, 1) + \delta(\bar{y}_1)]$  and  $\sigma(\bar{y}_1)$  shows the marginal effect of  $y_1$  on firm B's instantaneous profits in period 1 and in period 2, respectively. (16) also implies that  $\sigma(\bar{y}_1) > 0$  and  $[h(\bar{y}_1) - c(w^*, 1) + \delta(\bar{y}_1)] < 0$  when  $w < w^*$ . It follows that an increase in the final product by one unit in period 1 reduces firm B's first period profit by  $[h(\bar{y}_1) - c(w^*, 1) + \delta(\bar{y}_1)]$  (in absolute value) and raises its second period profit by  $\sigma(\bar{y}_1)$ . To maximize its cumulative profit, therefore, firm B has to balance the effects of the output in period 1, that is, the loss in the first period profit and the gains in the second period profit.

Now, let us compare  $\bar{y}_1$  with  $\hat{y}$  to examine a change in output of the final product in period 1 caused by learning by doing. Since  $h(\hat{y}) = c(w^*, 1)$ ,

$$h(\hat{y}) - h(\bar{y}_1) = \delta(\bar{y}_1) + \sigma(\bar{y}_1)$$

by (16). Therefore,  $\bar{y}_1 < \hat{y}$  if  $\delta(\bar{y}_1) + \sigma(\bar{y}_1) < 0$ ,  $\bar{y}_1 = \hat{y}$  if  $\delta(\bar{y}_1) + \sigma(\bar{y}_1) = 0$ , and  $\bar{y}_1 > \hat{y}$  if  $\delta(\bar{y}_1) + \sigma(\bar{y}_1) > 0$ . Now, by the definition of  $\delta(y)$  and  $\sigma(y)$ ,

$$\sigma(\bar{y}_1) + \delta(\bar{y}_1) = \left[ \sigma(\bar{y}_1) - \beta(\bar{y}_1)\bar{y}_2 - \beta(\bar{y}_1)\frac{d\bar{y}_2}{dy_1}\bar{y}_1 \right] - \frac{d\beta(\bar{y}_1)}{dy_1}\bar{y}_1\bar{y}_2. \quad (17)$$

In the right-hand side of (17), the value of the bracket is always positive. But, the sign and the magnitude of  $-[d\beta(\hat{y})/dy_1]\hat{y}_1\hat{y}_2$  is undeterminable, since the value of this expression depends on various factors of the model such as the

demand structure, the cost structure, and the shape of the learning curve. As a result,  $\bar{y}_1$  can be smaller than, equal to, or greater than  $\hat{y}$  depending on the specification of the model.<sup>3</sup>

To explore the effect of learning by doing on the price of the intermediate good in period 1, (14) can be rewritten as

$$\bar{q}_1 = g(\bar{y}_1) - \beta(\bar{y}_1)\bar{y}_2, \quad (18)$$

where  $-\beta(\bar{y}_1)\bar{y}_2 = d\bar{\pi}_2/dy_1$  by (8) and (15). Thus firm B charges the price for the intermediate good in period 1 so that all the incremental profits of firm A in period 2 can be transferred to firm B. Now, with a given  $y_1$  and  $y_2$ ,  $\beta(y_1)$  becomes larger (in absolute value) as the value of  $k(w^*, \theta(y_1)) - k(w, \theta(y_1))$  increases and/or as the value of  $\theta'(y_1)$  increases (in absolute value). Thus  $\bar{q}_1$  increases as the wage gap between the two countries becomes larger and/or as the learning process of firm A becomes faster. It follows that firm B charges a higher price in period 1 to the firm paying lower wages than the firm paying higher wages, and to a fast learner than a slow learner.

Now, if  $\bar{q}_1 < \hat{q}$ , then  $\bar{y}_1 > \hat{y}$  since  $g(\bar{y}_1) - \beta(\bar{y}_1)y_2 < g(\hat{y})$  by (18). On the other hand, if  $\bar{q}_1 > \hat{q}$ , then it is more likely that  $\bar{y}_1 < \hat{y}$  although it is still possible that  $\bar{y}_1 > \hat{y}$ . By combining this result with the earlier discussion about  $q_1$ , we can draw some conclusions about the relationship between  $\bar{y}_1$  and  $\hat{y}$ . If the difference in wages between the two countries is substantial and/or firm A is a fast learner, then it is more likely that  $\bar{y}_1$  is less than  $\hat{y}$ . By contrast, if the difference in wages between the two countries is small and/or firm A is a slow learner, then it is likely that  $\bar{y}_1$  is larger than  $\hat{y}$ .

Next, let us consider the effect of learning by doing on each firm's cumulative profit. Let  $\bar{V}(\bar{V}^*)$  be firm A's (firm B's) cumulative profit when there is an opportunity for learning by doing, and  $\hat{V}(\hat{V}^*)$  be the firm A's (firm B's) cumulative profit in the absence of learning effect. Then, for firm B,

$$\begin{aligned} \hat{V}^* &= 2[g(\hat{y}) - c(w^*, 1)]\hat{y}, \text{ and} \\ \bar{V}^* &= [g(\bar{y}_1) - \beta(\bar{y}_1)\bar{y}_2 - c(w^*, 1)]\bar{y}_1 \\ &\quad + [g(\bar{y}_2) - c(w, \theta(\bar{y}_1)) - c(w^*, \theta(\bar{y}_1))]\bar{y}_2. \end{aligned}$$

Now, since  $\bar{V}^*$  is maximized at  $y_1 = \bar{y}_1$  and  $y_2 = \bar{y}_2$ ,

$$\bar{V}^* > [g(\hat{y}) - \beta(\hat{y})\hat{y} - c(w^*, 1)]\hat{y} + [g(\hat{y}) - c(w, \theta(\hat{y})) - c(w^*, \theta(\hat{y}))]\hat{y}.$$

<sup>3</sup> If both demand curve and learning curve are linear, and if  $k(w, \theta)$  is invariant to  $\theta$ , then  $d\beta(\bar{y}_1)/dy_1 = 0$ . In this case,  $\delta(\hat{y}) + \sigma(\hat{y}) > 0$ , and thus  $\bar{y}_1 > \hat{y}$ .

Hence,

$$\bar{V}^* - \tilde{V}^* > [-\beta(\tilde{y})\tilde{y} - c(w, \theta(\tilde{y})) - c(w^*, \theta(\tilde{y})) + c(w^*, 1)]\tilde{y} > 0,$$

since  $\beta(\tilde{y}) < 0$  and  $c(w, \theta(\tilde{y})) + c(w^*, \theta(\tilde{y})) < c(w^*, 1)$ . Therefore, firm B's cumulative profit increases in spite of the fact that firm B gives up some production stages to firm A. This is because firm B captures most of the gains from a shift in some production stages from the high-cost firm B to the low-cost firm A, as discussed above in this section.

To explore how firm A's cumulative profit would be affected by its own learning by doing, we can use (18) to derive

$$\bar{V} = [p(\bar{y}_1) - \bar{q}_1]\bar{y}_1 + \bar{\pi}_2 = [-p'(\bar{y}_1)\bar{y}_1 + \beta(\bar{y}_1)\bar{y}_2]\bar{y}_1 + \bar{\pi}_2,$$

where  $\bar{\pi}_2 = \bar{\pi}_2(\bar{y}_1, \bar{y}_2)$ . We also have

$$\tilde{V} = 2\tilde{\pi} = 2[p(\tilde{y}) - \tilde{q}]\tilde{y} = -2p'(\tilde{y})\tilde{y}^2,$$

where  $\tilde{\pi}$  is firm A's profit in each period in the absence of learning effect. Then

$$\bar{V} - \tilde{V} = [-p'(\bar{y}_1)\bar{y}_1^2 + p'(\tilde{y})\tilde{y}^2] + \beta(\bar{y}_1)\bar{y}_2\bar{y}_1 + [\bar{\pi}_2 - \tilde{\pi}].$$

Now, since  $d\bar{\pi}_2/dy_1 = -\beta(\bar{y}_1)\bar{y}_2$ , and since  $\tilde{\pi}$  in period 2 is independent of  $y_1$ ,  $\bar{\pi}_2 - \tilde{\pi}$  can be approximated as

$$\bar{\pi}_2 - \tilde{\pi} \approx -\beta(\bar{y}_1)\bar{y}_2\Delta y_1 = -\beta(\bar{y}_1)\bar{y}_2\bar{y}_1.$$

With some qualifications, then, whether  $\bar{V}$  is less than, equal to, or greater than  $\tilde{V}$  depends largely on the sign of  $[-p'(\bar{y}_1)\bar{y}_1^2 + p'(\tilde{y})\tilde{y}^2]$ , the value of which would be either positive or negative depending on the specification of the model. For instance, if the demand curve is linear,  $p'(y)$  has a constant value. In this case, therefore, if  $\bar{y}_1 > \tilde{y}$  ( $\bar{y}_1 < \tilde{y}$ ), it is more likely that  $\bar{V} > \tilde{V}$  ( $\bar{V} < \tilde{V}$ ). As discussed earlier in this section, then, it is more likely that learning by doing causes firm A's cumulative profit to increase if the wage gap between two countries is small and/or firm A is a very slow learner. However, it is also possible that firm A's cumulative profit decreases if the wage gap between two countries is very big and/or firm A is a very fast learner. As a result, learning by doing causes firm A's cumulative profit either to increase or to decrease depending on the demand structure, the cost structure, and the shape of the

learning curve.<sup>4)</sup>

In summary, if country A has a lower wage rate than country B, firm A expands its production process up to the lowest accessible stage, and thus learning by doing in a downstream industry has a positive effect on import substitution in the intermediate good sector. The quantity of the intermediate good imported always increases in period 2, but it would either increase or decrease in period 1. Learning by doing also affects each firm's profit. The cumulative profit of firm B always increases, but that of firm A would either increase or decrease. The reason is that firm B captures most of the gains from a shift in some production stages from the high-cost firm B to the low-cost firm A. Accordingly, firm A not only has to split the gains from its learning by doing with firm B but should undergo a decrease in its profit in some circumstance due to its own learning by doing.

#### 4.3. The Case Where $w > w^*$

If  $w > w^*$ , the firm A's production cost of the final product is minimized when all the production stages are completed by firm B, according to the result in section III. In this case, therefore, firm A participates only at stage 1 in the downstream end and would not operate at any stage  $0 \leq \theta < 1$ , although it is able to have access to the lower production stages. Thus the problem in this case is the same as the one in the absence of opportunities for learning by doing. As a result, if country A has no advantage in the wage rate over country B, learning by doing would affect neither trade of the intermediate good nor each firm's cumulative profit.

### V. CONCLUSION

This paper has developed a simple dynamic model where there is an opportunity for learning by doing in the intermediate good sector that has the multistage production structure. In particular, this paper considers a vertically related market with successive monopolies, an upstream firm in a technologically advanced country, called firm B in country B, and a downstream firm in a technically lagging country, called firm A in country A. Under this framework, this paper has demonstrated that learning by doing has different effects on trade of the intermediate good and each firm's profit depending on the wage rates, the cost of labor used in producing the intermediate good, in the two countries.

If firm A faces lower wages than firm B, then firm A expands its production

<sup>4</sup> If both demand curve and learning curve are linear, and if  $k(w, \theta)$  is invariant to  $\theta$ , then  $\beta(y_1)$  has a constant value. In this case, then,  $\bar{\pi}_2 - \tilde{\pi} = -\beta(\bar{y}_1) \bar{y}_1 \bar{y}_2$  and  $\bar{V} - \tilde{V} = -p'(\bar{y}_1) \bar{y}_1^2 + p'(\tilde{y}) \tilde{y}^2$ . It follows that  $\bar{V} > \tilde{V}$  since  $\bar{y}_1 > \tilde{y}$  in this case.

process up to the lowest accessible stage. From the perspective of country A, therefore, learning by doing in a downstream industry has a positive effect on import substitution in the intermediate good sector. As the production stages shift from high-cost firm B to low-cost firm A, firm B's cumulative profit always increases, but firm A's cumulative profit would either increase or decrease depending on the demand structure, the cost structure, and the shape of the learning curve. In particular, firm A's cumulative profit is more likely to decrease if the wage gap between the two countries is very big and/or firm A is a very fast learner.

If wages are identical in the two countries, both firm A's production cost and output of the final product in each period are independent of its range of production, and they are constant at the levels when all the production stages are completed by firm B. Each firm's profit also remains at the same levels as those when there is no opportunity for learning by doing in the downstream industry. The reason is that firm B maintains the constant mark-up regardless of the stage of the intermediate good exported. However, since it is now possible for firm A to import the lower-stage intermediate good at a lower price, learning by doing has a positive effect in terms of import substitution in country A.

If firm A pays higher wages than firm B, there is no benefit for firm A to expand its range of production. Thus in this case, firm A participates only in the downstream end in every period, although it is able to have access to lower stages of production. Neither trade of the intermediate good nor each firm's profit would be affected by learning by doing.

The important implications of this paper is that the downstream firm's technological progress brought about entirely by learning by doing would not guarantee beneficial effects on the cumulative profit of the downstream firm, even though it would stimulate import substitution in the key input sector. The downstream firm not only has to split the gains from learning by doing with the upstream firm but has to undergo a decrease in its profit in some circumstances due to its own learning by doing. On the contrary, the upstream firm's monopoly power as a technological leader would not vanish due to learning by doing in the downstream industry, as long as the opportunity of learning by doing is bounded. This outcome provides some clues to understand what is happening in the development process of many developing countries which depend highly on the advanced countries for supplies of technology-embodied intermediate goods.

The result in this paper has been derived under the assumption of bounded learning. To get full insight into the problem, however, it is necessary to pursue further studies which consider unbounded opportunities for learning by doing. This paper also considers the case in which there is no vertical market foreclosure by a technological leader. But, since the technological leader has an incentive to integrate the downstream sector vertically, particularly if it faces

higher wages than the technically lagging downstream firm, the research along this line is also required to complete the model in this paper.

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