

## ENDOGENOUS TECHNOLOGY GAP WITH NORTH-SOUTH TRADE

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*This paper examines a simple unbounded endogenous growth model of bounded trade-induced learning by doing to illustrate the long-run effects of North-South trade on economic growth. The concept of specialization in both innovative and imitative processes is incorporated into learning by doing model with North-South trade. In this model, international trade results in a dynamic feedback effect between Southern imitation and Northern innovation yielding a higher steady-state growth rate. In a wide-gap equilibrium, the effect of Southern imitation is greater than that of Northern innovation. However, the effect of Northern innovation is greater than that of Southern imitation under a narrow-gap equilibrium. The model reveals that North-South trade generates steady endogenous technology gap in the long-run equilibrium.*

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### I. INTRODUCTION

In the theory of international trade, the static gains from international trade are well established. However, the dynamic effects of trade on growth, technical progress and welfare have not been thoroughly developed. In neoclassical exogenous growth models, international trade has only a level effect without

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growth effect. With the development during the 1980s of models endogenizing long-run growth, economists provide rationales for the long-run growth effects of international trade.<sup>1</sup> The newly industrialized economies (NIEs) such as South Korea and Taiwan that have adopted the outward-oriented policies have experienced high rate of GDP growth and technical progress greater than those of advanced economies (AEs) from 1960s to mid-1990s. As the NIEs close in on the AEs, in contrast, their rates of GDP growth and technical progress tend to slow relatively. Consequently, technology gap between trade partner (e.g., the NIEs and AEs) seemed to play an important role in their economic development. In this paper we develop a model in which endogenous growth is generated by trade-induced learning by doing to investigate the long-run effects of international trade on economic growth.

Theoretically, we put forth an argument that North-South trade is beneficial to both countries. Such trade leads to Northern specialization in innovative processes as well as Southern specialization in imitative processes. Free trade with the South leads the North to specialize in innovative process, while free trade with the North leads the South to specialize in imitative process. In particular, this paper focuses on an argument that North-South trade is beneficial to the North as well as the South, since such trade leads to Northern specialization in innovative processes. Enlarged markets (i.e., scale effects) with North-South trade induce the diversification and specialization, which accelerates technical progress. In fact, international trade is a mechanism by which newly expanded foreign demand can be used to the advantage of a developed country to boost domestic innovation. Northern firms create new processes and products, whereas Southern firms target Northern goods for imitation; each activity is increasing the technology level of goods produced domestically. Thus the North as well as the South experiences rates of technical progress greater than or equal to those enjoyed under autarky. When considering the effects of North-South trade on the Northern innovation, the North has the benefit from a high-end specialization while the South has the benefit from relatively a low-end specialization.<sup>2</sup>

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<sup>1</sup> For example, Romer (1987), Lucas (1988), Rivera-Batiz and Romer (1991a, 1991b), Grossman and Helpman (1991), Stokey (1991), Young (1991, 1993), etc.

<sup>2</sup> Fagerberg (2000) remarked that "Countries specializing in technologically progressive ('high-tech') activities will enjoy high rates of productivity growth compared to other countries. Countries specializing in 'low-tech' activities, on the other hand, should be expected to have relatively slow productivity growth."

This paper presents a simple unbounded growth model of bounded trade-induced learning by doing to illustrate the long-run effects of North-South trade on economic growth.<sup>3</sup> The concept of specialization in both innovative and imitative processes is incorporated into the learning by doing model with North-South trade. There exist an innovative specialization in the North and an imitative specialization in the South, which depend on technology gap between North-South as well as each economy's degree of openness. In the model of this paper, international trade results in a positive feedback effect between Southern imitation and Northern innovation yielding a higher steady-state growth rate in the long-run equilibrium.

The model developed in this paper relates closely to Grossman and Helpman (1991) and Chuang (1998). Our model is similar to Grossman and Helpman (1991) in that both consider a steady-state equilibrium where the North innovates and the South imitates. Grossman and Helpman (1991) developed a quality ladder model in which utility is an increasing function of the quality of goods consumed. In this paper, however, we examine a model of trade-induced learning by doing in which trade results in a positive feedback effect between Southern imitation and Northern innovation. Our model is closely related to Chuang (1998) in that both present a growth theory of trade-induced learning by doing. Chuang (1998) focused only on a trade-induced Southern specialization in imitative processes. In contrast, this paper provides a trade-induced Northern specialization as well as a trade-induced Southern specialization, and reveals a steady-state endogenous technology gap between the North and the South. This paper adds a major contribution to the existing theoretical literature on a model of learning by doing with North-South trade. The first is that this paper explicitly incorporates a trade-induced Northern specialization in innovative processes within the learning by doing model. The second is that the paper investigates the existence of the steady-state endogenous technology gap between the North and the South.

The paper proceeds as follows. Section 2 introduces the basic model of this paper, as in Young (1991), illustrating how bounded learning by doing with spillovers across goods can result in unbounded endogenous growth in an autarkic economy. Section 3 provides a specific functional form of this model to

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<sup>3</sup> As in Chuang (1998), both exports and imports are important sources and are mutually reinforced in intensifying the specializing process. The trade partner also is a key factor in determining trade-induced specialization.

examine the trade equilibrium between the North and the South. Section 4 investigates a unique and persistent technology gap such that the North and the South grow at the same rate. Section 5 provides some concluding remarks.

## II. THE BASIC MODEL

Consider an economy that has many identical consumers and many identical firms, and all markets are perfectly competitive. Goods indexed by  $x$  along  $[F, \infty)$  are ordered according to the sophistication of the technical processes used in their production. Thus the production of higher numbered goods is involving more advanced technologies. Labor is the sole factor of production and there exists a lower bound on potential unit labor requirements,  $\bar{a}(x)$  for each good  $x$ . As in Young (1991), the economy exhibits bounded learning by doing with spillovers across goods. In particular, if  $a(x, t) > \bar{a}(x)$ , then

$$\frac{\partial a(x, t)/\partial t}{a(x, t)} = - \int_F^\infty \varphi l(v, t) dv, \quad (1)$$

where  $l(v, t)$  is the amount of labor devoted to the production of good  $v$  at time  $t$  and  $\varphi$  denotes the rate at which each worker learns.<sup>4</sup>

### 2.1. Demand

The representative consumer seeks to maximize the intertemporal utility function:

$$U = \int_t^\infty e^{-\rho(s-t)} V(s) ds, \quad (2)$$

where  $V(s)$  denotes the same instantaneous utility function which is logarithmic as

$$V(s) = \int_F^\infty \log(C^i(x, t) + 1) dx, \quad (3)$$

<sup>4</sup> As in the typical learning by doing model, there is a constant rate of learning,  $\varphi$ , but only until the industry has exhausted its potential stock of knowledge.

where  $C^i(x, t)$  denotes the consumption of good  $x$  at time  $t$  and  $F$ , a large negative number, denotes the first good produced by mankind. At each time  $t$ , all consumers who inelastically supply one unit of labor for wage  $w$  maximize (3) subject to the budget constraint:

$$\int_0^\infty p(x, t) C(x, t) dx \leq w, \quad (4)$$

where  $p(x, t)$  is the price of good  $x$ . The usual first-order condition to this problem holds:

$$\frac{C(x, t) + 1}{C(y, t) + 1} = \frac{p(y, t)}{p(x, t)} \quad \text{for } x > 0, y > 0. \quad (5)$$

Thus, the demand function for good  $x$  is

$$C(x, t) = d_x(p, w). \quad (6)$$

The number of varieties that are potentially available can be infinitely large. However, the budget constraint sets the upper and lower bound on the spectrum of goods consumed.

## 2.2. Supply

Goods are produced using labor as the sole factor of production as follows:

$$q(x, t) = \frac{l(x, t)}{a(x, t)}, \quad (7)$$

where  $q(x, t)$ ,  $l(x, t)$ ,  $a(x, t)$  are the output, labor input and unit labor requirement of economy to produce good  $x$  at time  $t$ , respectively. In particular, technology at any time  $t$  generalized by the actual unit labor requirement curve  $a(x, t)$  has the property given by

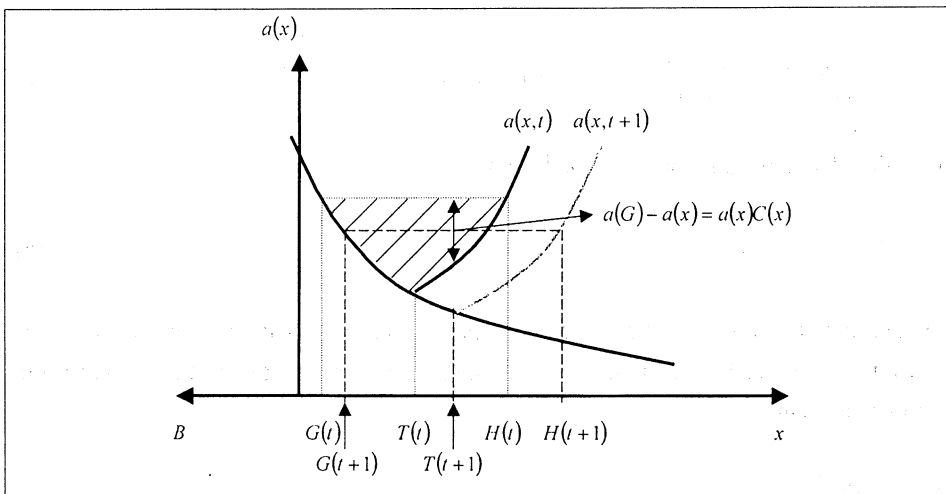
$$\begin{aligned} a(x, t) &= \bar{a}(x) = \bar{a} e^{-x} & x \leq T(t), \\ a(x, t) &= \bar{a} e^{x-2T} & x \geq T(t), \end{aligned} \quad (8)$$

where  $T(t)$  is the level of technology in this economy at time  $t$ . With  $T(t)$  evolving according to the learning by doing equation

$$\frac{dT(t)}{dt} = \int_{T(t)}^{\infty} l(x, t) dx = \frac{1}{2} L(t), \quad (9)$$

where  $l(x, t)$  denotes the labor allocated to the production of good  $x$  at time  $t$ .

[Figure 1] Autarky equilibrium



This economy experiences bounded learning by doing with symmetric spillovers across goods. As Figure 1 reveals, at any time  $t$ , there is a U-shaped actual unit labor requirement curve. In this economy, the technical sophistication level,  $T$ , corresponding to the lowest point of the U-shaped curve of the unit labor requirement, is defined as the current level of technology. At any given time, there are two sets of goods in this economy. Low-technology goods are those of index smaller than  $T$  that have already exhausted their learning, and hence reach their learning bounds. However, high-technology goods are those of an index greater than  $T$  that still enjoy learning. As property (8) reveals, for those low-technology goods, the greater the technology index of the good implies the lower its learning bound,  $\bar{a}(x)$ . For those high-technology goods, the greater the technology index of the good implies the greater the unit labor required for its production. In particular, technology change shifts the unit labor

requirement curve downward over time.

On the supply side, taking  $p(x, t)$  and  $w$  given with each country allocating labor competitively among sectors, the profit maximization problem under simple linear technology becomes

$$\begin{aligned} \text{Max } & \int_0^{\infty} [p(x, t)q(x, t) - wl(x, t)]dx, \\ \text{s.t. } & q(x, t) - \frac{l(x, t)}{a(x, t)}. \end{aligned} \quad (10)$$

The supply rules of the problem are

$$\begin{aligned} q(x, t) &= 0 & \text{if } p(x, t) > wa(x, t), \\ q(x, t) &\in [F, \infty) & \text{if } p(x, t) = wa(x, t), \\ q(x, t) &= \infty & \text{if } p(x, t) < wa(x, t). \end{aligned} \quad (11)$$

### 2.3. Autarky equilibrium

Under perfect competition, prices  $p(x) = wa(x)$ , and then the real price of goods in units of labor is  $a(x)$ . There exists a good  $G$  such that for all goods  $x$  such that  $a(x) < a(G)$ , consumption is positive, while for all goods  $x$  such that  $a(x) \geq a(G)$ , consumption is zero at each time  $t$ . As  $a(x)$  goes to  $a(G)$  from below, consumption of good  $x$  goes to zero. Using the first order condition (5), we get that for all goods  $x$  which are consumed in positive quantities:

$$a(x)C(x) = a(G) - a(x), \quad (12)$$

where  $G$  is determined by the requirement that the consumer exhaust her budget constraint.

As in the autarky equilibrium illustrated in Figure 1, the difference between the dashed horizontal line of height  $a(G)$  and the unit labor requirements curve  $a(x, t)$  is equal to the consumer's expenditure on each good  $x$ . As  $a(x)$  is symmetric around  $T$ , to each  $G$  there corresponds an  $H$  such that  $a(G) = a(H)$ , with  $G$  and  $H$  located equidistant from  $T$ . The consumer consumes all goods in  $(G, H)$ . As the consumer's budget is exhausted, the shaded area denotes total expenditure that equals one. If we let  $\kappa(t) = T(t) -$

$G(t) = H(t) - T(t)$ , that is, the range of goods on each side of  $T$  that are consumed, then using the binding budget constraint, we have

$$\begin{aligned}
 \int_G^H a(x)C(x)dx &= \int_G^H (a(G) - a(x))dx \\
 &= a(G)(H - G) - 2 \int_G^T ae^{-x}dx \\
 &= \bar{a}e^{-G}(2\kappa) + 2\bar{a}(e^{-T} - e^{-G}) \\
 &= (2\kappa - 2)\bar{a}e^{-G} + 2\bar{a}e^{-T} = 1.
 \end{aligned} \tag{13}$$

Using  $0 < d\kappa/dT < 1$  and  $\kappa(t) = T(t) - G(t) = H(t) - T(t)$ , we have  $\frac{d\kappa}{dT} = 1 - \frac{dG}{dT} = \frac{dH}{dT} - 1$ .<sup>5</sup> Therefore,  $0 < \frac{dG}{dT} < 1$  and  $1 < \frac{dH}{dT} < 2$ . Hence, as  $T$  increases from  $T(t)$  to  $T(t+1)$  at time  $t+1$ , the spectrum of goods produced and consumed in this economy expands by adding more technically sophisticated goods and dropping off less technically sophisticated goods over time. Furthermore, the range of new goods introduced is greater than the range of old goods dropped. That is, the variety and quantity of goods produced and consumed with respect to the current technology level in this economy increase over time.

#### 2.4. Autarky growth rate of technological progress

Autarky growth rate of real GDP per capita can be defined the proportional change in value of output minus the rate of population growth as follows:

$$\eta(t) = \frac{\int_0^\infty p(x, t)(\partial X(x, t)/\partial t)dx}{\int_0^\infty p(x, t)X(x, t)dx} - \frac{dL(t)/dt}{L(t)}, \tag{14}$$

where  $\eta(t)$  denotes the growth rate of real GDP per capita and  $X(x, t)$  is aggregate output of good  $x$  at time  $t$ . By using the zero-profit condition  $p(x, t) = w \cdot a(x, t)$ , labor supply conditions

$$L(t) = \int_0^\infty a(x, t)X(x, t)dx$$

<sup>5</sup>  $dG/dT = 1 - d\kappa/dT > 0$ .



and

$$\frac{dL(t)}{dt} = \int_0^\infty a(x, t) \frac{\partial X(x, t)}{\partial t} dx + \int_0^\infty \frac{\partial a(x, t)}{\partial t} X(x, t) dx,$$

and then substituting into equation (14) gives

$$\begin{aligned} \eta(t) &= \frac{- \int_0^\infty (\partial a(x, t) / \partial t) \cdot X(x, t) dx}{L^i(t)} \\ &= \frac{2 \frac{dT(t)}{dt} \int_{T(t)}^{H(t)} a(x, t) X(x, t) dx}{L(t)} \\ &= \frac{2 \frac{dT(t)}{dt} \left( \frac{1}{2} L(t) \right)}{L(t)} = \frac{dT(t)}{dt} = \frac{L(t)}{2}. \end{aligned} \quad (15)$$

In autarky, thus, the growth rate of real GDP per capita is equal to the rate of technological progress, which leads to one half of the labor force being allocated to goods in which learning by doing has to be exhausted.

### III. TRADE EQUILIBRIUM BETWEEN THE NORTH AND THE SOUTH

Consider two economies in which economy  $N$  denotes the North and economy  $S$  denotes the South. The technology level indexed by  $T$  is greater in economy  $N$  than in economy  $S$ . That is,  $T^N > T^S$ . Thus,  $a^N(x) \leq a^S(x)$  with strict inequality for all  $x > T$ . Labor in economy  $N$  has a comparative advantage in producing more technically sophisticated goods and trade leads to complete specialization in which  $w^N/w^S > 1$ . We define  $\theta = T^N - T^S$  as the difference in the levels of technical knowledge. Let  $w^S$  be the numeraire,  $w^S = 1$ , then we have

$$\omega = w^N/w^S \text{ and } p(x) = P(x)/w^S, \quad (16)$$

where  $\omega$  is the relative wage and  $p(x)$  is the goods price in terms of units of the South labor.

Learning in each economy proceeds independently according to the learning by doing equation (9) with no spillovers of knowledge between the two economies.

However, free trade intensifies the process of learning in both the North and the South and thus shifts the right hand part of the unit labor requirement curve downward. Therefore,  $T(t)$  evolving according to trade-induced learning by doing is formulated as follows:

$$\frac{dT^i}{dt} = \Psi^i(\phi_{ji}, \theta) \int_{T^i(t)}^{\infty} l^i(x, t) dx, \text{ for } i, j = N, S, \quad (17)$$

where the  $\int_{T^i(t)}^{\infty} l^i(x, t) dx$  represents the notion of bounded learning by doing and the  $\Psi^i(\phi_{ji}, \theta)$  is the trade-induced specialization coefficient. First, in the integral part on the right hand side of equation (17), goods with indices below  $T^i(t)$  have already exhausted their learning, whereas economy-wide learning by doing occurs among those goods with indices above  $T^i(t)$ . Therefore, in the wide-gap equilibrium, one half of total labor in the each economy is employed in producing economy-wide learning by doing goods.<sup>6</sup> However, in the narrow-gap equilibrium, more than one half of total labor in economy  $N$  is employed in producing economy-wide learning by doing goods, while less than one half of total labor in economy  $S$  is employed in producing economy-wide learning by doing goods. As a result, there exist asymmetric trade-induced learning effects between the two trading economies. Next, when considering the effects of the trade-induced specialization with North-South trade, in general, the effect of Southern specialization in imitative processes is greater than that of Northern specialization in innovative processes. Thus, we let  $\lambda$  denote the discount factor and assume that  $0 < \lambda < 1$ . The trade-induced specialization effects captured by the coefficient,  $\Psi(\phi_{ji}, \theta)$ , are assumed as follows:

$$\begin{aligned} \Psi^N(\phi_{ji}, \theta) &= \lambda \cdot \phi_{ji}(t) \cdot \theta(t) + 1, \text{ for } 0 < \lambda < 1, \text{ if } T^j(t) - T^i(t) < 0, \\ \Psi^S(\phi_{ji}, \theta) &= \phi_{ji}(t) \cdot \theta(t) + 1, \text{ if } T^j(t) - T^i(t) > 0, \end{aligned} \quad (18)$$

in which  $\phi_{ji}(t)$  is the degree of openness of economy  $i$  with respect to the trading partner  $j$  on taking both exports and imports, and  $\theta$  represents the technology gap between two economies at time  $t$ . The trade-induced imitation coefficient of the South is larger than the trade-induced innovation coefficient of

<sup>6</sup> In wide-gap equilibrium, the production sets of the two economies are disjointed. However, the production sets of the two economies are jointed in narrow-gap equilibrium.

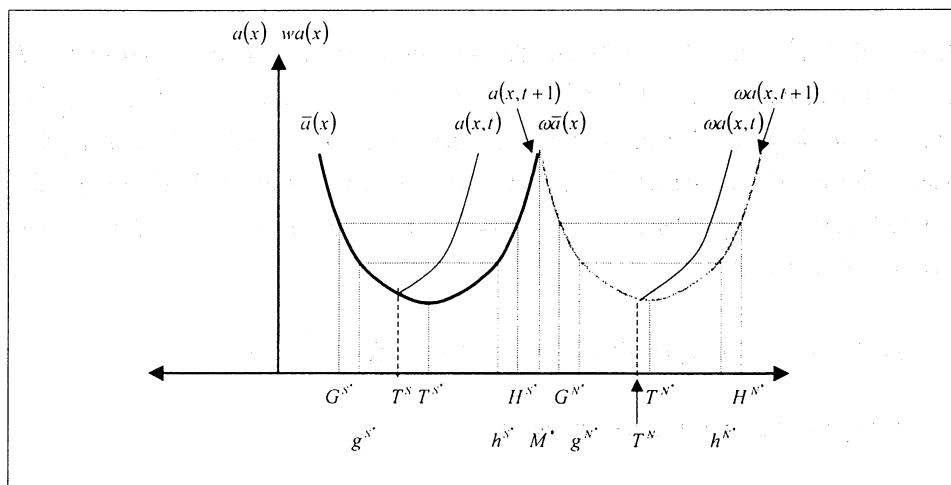
the North by assuming that  $0 < \lambda < 1$ , that is,  $\Psi^S(\phi_{ji}, \theta) > \Psi^N(\phi_{ji}, \theta)$ .<sup>7</sup>

Under the free trade between the North and the South, two types of equilibrium (wide-gap and narrow-gap equilibrium depending on the relative technology gap) may emerge.

### 3.1. Wide-gap equilibrium

In wide-gap equilibrium in which some goods with indices between  $T^N$  and  $T^S$  is not produced by both economies, the production sets of the two economies are disjoint. There is a spectrum of goods not produced in either economy. As all goods enter the utility function symmetrically according to equations (3) and (5), the representative consumer in both economies consumes goods symmetrically about  $T^N(t)$  and  $T^S(t)$ , the lowest point of unit cost curve  $\omega \cdot a(x, T^N)$  and  $a(x, T^S)$  respectively, until the budget is exhausted as Figure 2 depicts.

[Figure 2] Wide-gap equilibrium



<sup>7</sup> In case of  $\lambda > 1$ , the effect of Northern specialization is greater than that of Southern specialization with North-South trade. As a result, the trade-induced innovation coefficient of the North is larger than the trade-induced imitation coefficient of the South, that is,  $\Psi^N(\phi_{ji}, \theta) > \Psi^S(\phi_{ji}, \theta)$ . Only if  $\lambda = 1$ , the effect of Northern innovation is equal to that of Southern imitation with North-South trade. In this case, there exist symmetric trade-induced specialization effects between the North and the South. Thus, the trade-induced innovation coefficient of the North is equal to the trade-induced imitation coefficient of the South, that is,  $\Psi^N(\phi_{ji}, \theta) = \Psi^S(\phi_{ji}, \theta)$ .

Each economy will specialize in a distinct set of goods according to the principle of comparative advantage. For the North and the South respectively, it follows that

$$\begin{aligned} q^N(x, t) &\in [F, \infty) \text{ when } p(x) = w^N a^N(x, t) < w^S a^S(x, t), \\ q^S(x', t) &\in [F, \infty) \text{ when } p(x') = w^S a^S(x', t) < w^N a^N(x', t), \end{aligned} \quad (19)$$

where  $x$  and  $x'$  belong to the potential set of goods technically producible for economy  $N$  and  $S$ , respectively.

From equations (5) and (19), we have

$$\frac{C^i(x, t) + 1}{C^i(y, t) + 1} = \frac{a^i(y, t)}{a^i(x, t)}, \text{ for } x, y \in (G^i, H^i), \quad i = N, S$$

and

$$\frac{C^N(x, t) + 1}{C^S(x', t) + 1} = \frac{a^S(x', t)}{\omega a^N(x, t)}, \text{ for } x \in (G^N, H^N), \quad x' \in (G^N, H^N), \quad (20)$$

where  $(G^N, H^N)$  and  $(G^S, H^S)$  are the sets of goods produced in economy  $N$  and  $S$  respectively, and  $H^S < G^N$ . For economy  $i$  at time  $t$ ,  $T^i(t)$  is the current technology level corresponding to the lowest cost.  $G^i(t)(H^i(t))$  is the greatest lower (least upper) bound of technical sophistication level of goods produced domestically. Thus,  $C(G^i, t) = 0$  and  $C(H^i, t) = 0$ ,  $i = N, S$ . From equation (20), we get

$$a^i(G^i, t) = a^i(H^i, t) = a^i(x, t)(C^i(x, t) + 1), \text{ for } i = N, S.$$

By rearranging the above equation, we have

$$a^i(x, t)C^i(x, t) = a^i(G^i, t) - a^i(x, t), \text{ for } i = N, S. \quad (21)$$

The budget constraint of economy  $N$  is

$$\int_{G^N}^{H^N} p(x)C^N(x)dx + \int_{G^S}^{H^S} p(x')C^N(x')dx' \leq \omega,$$

and the zero-profit condition under competitive markets requires

$$p(x) = \omega a(x, t), \text{ for } x \in (G^i, H^i), \quad i = N, S.$$

Therefore, the budget constraint can be written as

$$\int_{G^N}^{H^N} \omega a^N(x, t) C^N(x) dx + \int_{G^S}^{H^S} a^S(x', t) C^N(x') dx' \leq \omega. \quad (22)$$

By substituting equation (21) into equation (22), we obtain

$$\int_{G^N}^{H^N} \omega [a^N(G^N, t) - a^N(x, t)] dx + \int_{G^S}^{H^S} [a^S(G^N, t) - a^S(x', t)] dx' \leq \omega. \quad (23)$$

This means that the area between  $\omega \cdot a^N(G^N, t)$  and  $\omega \cdot a^N(x, t)$  plus the area between  $a^S(G^S, t)$  and  $a^S(x', t)$  are equal to the relative wage  $\omega$ . Under wide-gap equilibrium, the spectra of goods produced at time  $t$  in both economies bounded intervals of  $(G^N(t), H^N(t))$  and  $(G^S(t), H^S(t))$  are fully determined by the consumer's budget constraint in economy  $N$ . The spectra of goods consumed in economy  $N$  will therefore consist of  $(G^N(t), H^N(t))$  of domestic goods and  $(G^S(t), H^S(t))$  of imported goods.

Similarly the budget constraint of economy  $S$  can be written as

$$\begin{aligned} \int_{g^N}^{h^N} \omega a^N(x, t) C^S(x) dx + \int_{g^S}^{h^S} a^S(x', t) C^S(x') dx' &\leq 1, \\ \int_{g^N}^{h^N} \omega [a^S(m^S, t) - a^S(x, t)] dx + \int_{g^S}^{h^S} [a^S(m^S, t) - a^S(x', t)] dx' &\leq 1, \end{aligned} \quad (24)$$

where  $(g^S(t), h^S(t))$  and  $(g^N(t), h^N(t))$  are the set of domestically produced goods and imported goods consumed by economy  $S$  respectively. Since the relative wage  $\omega > 1$ ,  $(g^S(t), h^S(t))$  will be smaller than  $(G^S(t), H^S(t))$  and  $(g^N(t), h^N(t))$  will be smaller than  $(G^N(t), H^N(t))$ . Therefore, economy  $S$  will export some low- and high-end goods which are not consumed domestically, and will consume some imported goods with most efficient production but not the state-of-art technology of economy  $N$ . The relative wage  $\omega$  by the trade balance condition given by

$$\int_{g^N}^{h^N} \omega a^N(x, t) C^S(x) dx = \int_{G^S}^{H^S} a^S(x', t) C^N(x') dx'. \quad (25)$$

The trade-induced learning by doing and the rate of technical progress in economy  $N$  is given by

$$\begin{aligned} \frac{dT^N(t)}{dt} &= \int_{T^N(t)}^{H^N(t)} [\lambda \cdot \phi_{SN}(t) \cdot \theta(t) + 1] l^N(x, t) dx \\ &= \int_{T^N(t)}^{H^N(t)} [\lambda \cdot \phi_{SN}(t) \cdot \theta(t)] l^N(x, t) dx + \frac{1}{2} L^N(t) > \frac{1}{2} L^N(t). \end{aligned} \quad (26)$$

On the right hand side of the second equality sign, the first term is the trade-induced innovative effect which depends on the degree of openness and the technology gap. The second term is the usual learning effect. On the other hand, the trade-induced learning by doing and the rate of technical progress in economy  $S$  is given by

$$\begin{aligned} \frac{dT^S(t)}{dt} &= \int_{T^S(t)}^{H^S(t)} [\phi_{NS}(t) \cdot \theta(t) + 1] l^S(x, t) dx \\ &= \int_{T^S(t)}^{H^S(t)} [\phi_{NS}(t) \cdot \theta(t)] l^S(x, t) dx + \frac{1}{2} L^S(t) > \frac{1}{2} L^S(t). \end{aligned} \quad (27)$$

On the right hand side of the second equality sign, the first term is the trade-induced imitative effects that depend on the degree of openness and the technology gap. The second term is the usual learning effects.

This tells us that with trade-induced specialization, the North as well as the South can actually grow more rapidly than autarky equilibrium. However, the South can grow more rapidly than the North. In the presence of trade-induced specialization, the further downward shift of  $\omega a(x, T^N)$  and  $a(x, T^S)$  may drastically alter the spectrum of production and consumption in both economies compared with the circumstance without trade. The technology level in economy  $N$  (economy  $S$ ) advances from  $T^N(T^S)$  to  $T^{N'}(T^{S'})$  as Figure 2 shows. The magnitude of the downward shift of the  $\omega a(x, T^N)$  curve, as the Northern innovation decreases further the unit labor requirement for goods maintaining learning by doing, depends on how openly economy  $N$  trades with economy  $S$ ,  $\phi_{SN}$ , and on the current technology gap between two economies,  $\theta$ . Similarly, the magnitude of the downward shift of the  $a(x, T^S)$  curve, as the Southern

imitation decreases further the unit labor requirement for goods maintaining learning by doing, depends on how openly economy  $S$  trades with economy  $N$ ,  $\phi_{NS}$ , and on the current technology gap between two economies,  $\theta$ .

As a result of trade-induced specialization, the consumption pattern in both economies becomes altered.<sup>8</sup> Economy  $N$  as well as economy  $S$  tends to consume more varieties of goods locally produced and may consume a greater spectrum of goods produced abroad. In terms of production, through international technology specialization, the North as well as the South accelerates technology by producing more technically sophisticated goods. The learning by doing and the trade-induced specialization plays a prominent role in fostering the production set of the North as well as the South. Consequently, each economy can produce and export goods it could not do so before. In the presence of trade-induced specialization and technical progress, the properties of economic development of the North as well as the South are characterized by production, consumption and trade patterns all being upgraded along the technology ladder.

### 3.2. Narrow-gap equilibrium

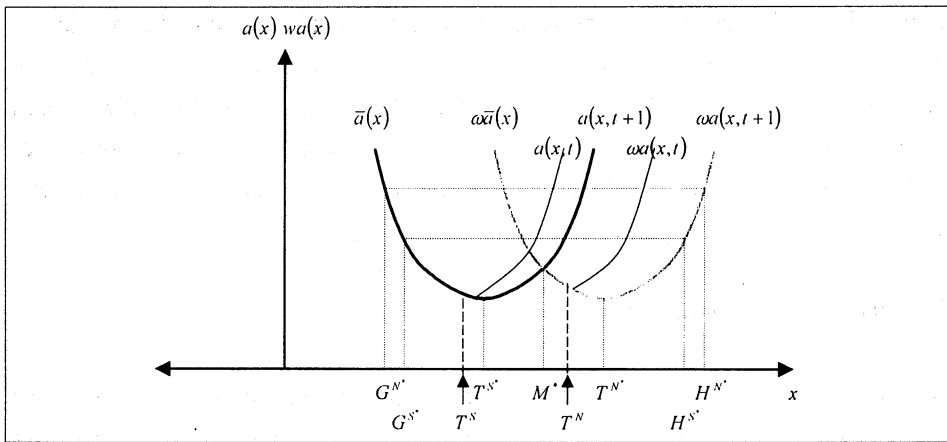
In the narrow-gap equilibrium, some goods with indices between  $T^N$  and  $T^S$  are produced by both economies. Thus the production sets of the two economies are jointed. In particular, the sets of goods produced by both economies are still determined by the relative wage  $\omega$ , and the least upper (greatest lower) bound  $M$  of production set of economy  $S(N)$  depends on the intersection of two unit cost curves,  $a(x, T^S)$  and  $\omega \bar{a}(x)$ , of the two economies. According to the principle of comparative advantages, more than one half of total labor in economy  $N$  is employed in producing high-technology goods, while more than one half of total labor in economy  $S$  is employed in producing low-technology goods.

Let sets  $(G^S, M)$  and  $(M, H^N)$  be the two production sets of economy  $S$  and  $N$ , respectively. For goods indexed at technology level  $M$ ,  $p(M, t) = a(M, T^S) = \omega \cdot \bar{a}(M)$ , with  $\omega = w^N/w^S$ . Hence,  $\bar{a}e^{M-2T^S} = \omega \bar{a}e^{-M}$ , or  $M - T^S$

<sup>8</sup> As in Figure 2, the spectra of goods consumed in economy  $N$  at time  $t+1$  will consist of  $(G^N, H^N)$  of domestic goods and  $(G^{S'}, H^{S'})$  of imported goods. The spectra of goods consumed in economy  $S$  at time  $t+1$  will consist of  $(g^{S'}, h^{S'})$  of domestic goods and  $(g^{N'}, h^{N'})$  of imported goods.

$= \frac{1}{2} \ln \omega$ . Taking the derivative yields  $\frac{dM}{dt} - \frac{dT^S}{dt} = \frac{1}{2\omega} \frac{d\omega}{dt}$ . Thus the spectra of goods still enjoying learning in economy  $S$  depends on the variation of relative wages between the two economies. If over time the wage of economy  $S$  increases relative to the wage of economy  $N$ , then the spectrum of sophisticated goods in economy  $S$  is expected to contract. That is,  $\frac{dM}{dt} - \frac{dT^S}{dt} \leq 0$ , if  $\frac{d\omega}{dt} \leq 0$ .

[Figure 3] Narrow-gap equilibrium



In this equilibrium, the rate of technical progress and the trade-induced learning by doing in the two economies follows that

$$\frac{dT^N(t)}{dt} = \int_{T^N(t)}^{H^N(t)} \lambda \phi_{SN} \theta \cdot l^N(x, t) dx + \frac{TH}{MH}(\theta) L^N(t) > \frac{1}{2} L^N(t). \quad (28)$$

$$\frac{dT^S(t)}{dt} = \int_{T^S(t)}^{M(t)} \phi_{NS} \theta \cdot l^S(x, t) dx + \frac{TM}{GH}(\theta) L^S(t) < \frac{1}{2} L^S(t). \quad (29)$$

The growth rate of per capita GDP in economy  $N$  exceeds  $\frac{1}{2} L^N(t)$ , because with North-South trade, labor force allocated from a low-technology industry to high-technology industry increases. In economy  $N$ , thus, more than one half of total labor force is employed in producing goods that are still enjoying trade-induced learning. With trade-induced specialization, the unit cost curve of economy  $S$ ,  $a(x, T^S)$ , shifts further down. The production set of goods still



enjoying trade-induced learning by doing upgrades along the technology ladder and captures the market of goods originally produced by economy  $N$ . However, the spectra of these goods are confined by the unit cost curve of goods that have already exhausted learning in economy  $N$ , i.e.,  $\omega \cdot \bar{a}(x)$ . Although trade-induced specialization effects upgrade the technology level, the production of refined goods in the less technology-endowed economy likely contracts under the circumstance of a small technology gap, and increasing relative wages of economy  $S$  which shifts downwards  $\omega \cdot \bar{a}(x)$  curve over time. As in equation (29), the second term is less than  $\frac{1}{2} L^S(t)$ . With trade under the narrow-gap situation, labor force reallocated from a high-technology industry to low-technology industry increases. Thus, less than  $\frac{1}{2} L^S(t)$  is employed in producing high-technology goods.

When the gap is narrowed, the range between  $T^S$  and  $M$  can be contracted. Thus the trade-induced specialization effect on the first term of equation (29) becomes less significant. Therefore, even in the presence of specialization effect, the rate of technology change in economy  $S$  can be less than  $\frac{1}{2} L^S(t)$ . As in Figure 3, the technology level in economy  $N$  (economy  $S$ ) advances from  $T^N(T^S)$  to  $T^{N'}(T^{S'})$ . As a result, the consumption pattern in both economies becomes altered. The spectra of goods consumed in economy  $N$  at time  $t+1$  will consist of  $(M^*, H^{N'})$  of domestic goods and  $(G^{N'}, M^*)$  of imported goods. The spectra of goods consumed in economy  $S$  at time  $t+1$  will consist of  $(G^{S'}, M^*)$  of domestic goods and  $(M^*, H^{S'})$  of imported goods.

In the narrow-gap situation, therefore, the more advanced economy may actually grow rapidly at the expense of the less advanced economy. This result confirms the belief that a narrow-gap situation is a sufficient condition to ensure that trade-induced specialization enables the North to grow more rapidly than the South.

#### IV. ENDOGENOUS TECHNOLOGY GAP WITH NORTH-SOUTH TRADE

Given the above specification, we investigate the existence of the steady-state endogenous technology gap between the North and the South in the dynamic long-run trade equilibrium. In a wide-gap equilibrium, the effect of Southern imitation is greater than that of Northern innovation. In a narrow-gap equilibrium, in contrast, the effect of Northern innovation is greater than that of

Southern imitation. Since the growth patterns due to technology gap situations are different between the North and the South, there exists a unique and persistent technology gap such that both economies grow at the same rate.

#### 4.1. Endogenous technology gap

In this subsection we examine the long-run dynamic effect of technology gap on growth rate with North-South trade. From equations (26) and (28), we can establish the following relationships between  $\eta^N$  and  $\theta$ :

$$\begin{aligned}\eta^N &= (\lambda\phi\theta + 1) \frac{TH}{MH}(\theta) L^N, \text{ if } \eta^N > (\lambda\phi\theta + 1) \frac{1}{2} L^N, \\ \eta^N &= (\lambda\phi\theta + 1) \frac{1}{2} L^N, \text{ if } \eta^N \leq (\lambda\phi\theta + 1) \frac{1}{2} L^N.\end{aligned}\quad (30)$$

In Figure 4, this relationship is depicted as the  $NN$  curve. The slope of the curve and its direction of shift are given by the following partial derivatives:

$$\left. \frac{\partial \eta^N}{\partial \theta} \right|_{NN} < 0, \quad \left. \frac{\partial \eta^N}{\partial \phi} \right|_{NN} > 0, \quad \left. \frac{\partial \eta^N}{\partial L^N} \right|_{NN} > 0.$$

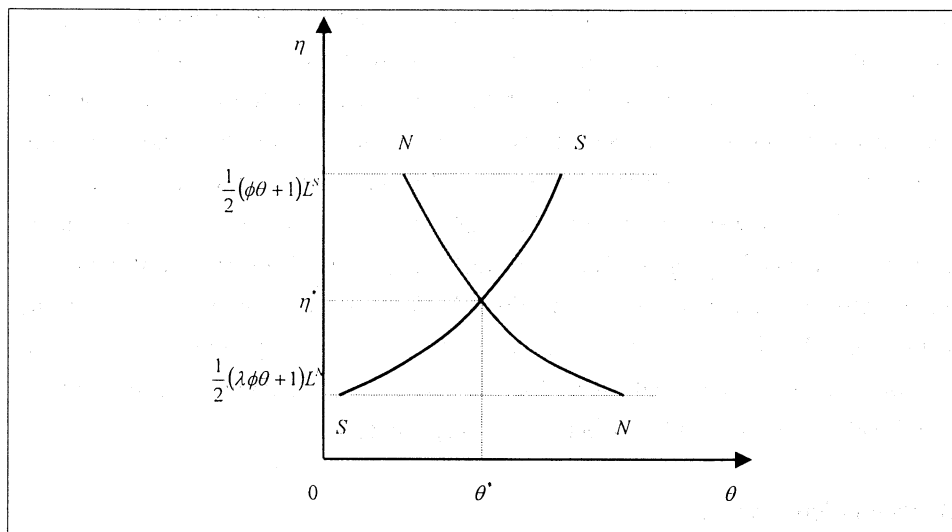
From equations (27) and (29), we can establish the following relationships between  $\eta^S$  and  $\theta$ :

$$\begin{aligned}\eta^S &= (\phi\theta + 1) \frac{TH}{GM}(\theta) L^S, \text{ if } \eta^S < (\phi\theta + 1) \frac{1}{2} L^S, \\ \eta^S &= (\phi\theta + 1) \frac{1}{2} L^S, \text{ if } \eta^S \geq (\phi\theta + 1) \frac{1}{2} L^S.\end{aligned}\quad (31)$$

In Figure 4, this relationship is depicted as the  $SS$  curve. The slope of the curve and its direction of shift are given by the following partial derivatives:

$$\left. \frac{\partial \eta^S}{\partial \theta} \right|_{SS} > 0, \quad \left. \frac{\partial \eta^S}{\partial \phi} \right|_{SS} > 0, \quad \left. \frac{\partial \eta^S}{\partial L^S} \right|_{SS} > 0.$$

We can now illustrate the equilibrium in a simple diagram. Figure 4 shows the equilibrium at the intersection of the  $NN$  and  $SS$  curves where  $\theta^*$  and  $\eta^*$  are simultaneously determined.

**[Figure 4]** Steady-state technology gap with North-South trade

In the long-run, free trade between the North and the South naturally move technology gap toward the equilibrium of these two curves. To see why, consider what happens when the technology gap is not equal to the equilibrium. Suppose first that the technology gap is above the equilibrium, in which the growth rate of the South exceeds the growth rate of the North,  $\eta^S > \eta^N$ . Then there is a convergence between the South and the North: When there is a prevailing Southern imitation effect, the technology gap between the North and the South continues to fall until the gap reaches the equilibrium. Suppose now that technology gap is below the equilibrium, in which the growth rate of the North exceeds the growth rate of the South,  $\eta^N > \eta^S$ . There is a divergence between the North and the South: When there is a prevailing Northern innovation effect, technology gap between the North and the South continues to rise until the gap reaches the equilibrium. Therefore, the growth paths of the North and the South automatically push the technology gap toward the equilibrium,  $\theta^*$ . Once the growth path reaches its equilibrium, both the North and the South are satisfied. In the long run equilibrium, thus, there is no upward or downward pressure on endogenous technology gap under free trade.

#### 4.2. Degree of openness

Consider the case in which the degree of openness increases between two

economies. According to equation (30), an increase in  $\phi$  shifts up the  $NN$  curve and a decrease in  $\phi$  shifts it down. According to equation (31), an increase in  $\phi$  shifts up the  $SS$  curve and a decrease in  $\phi$  shifts it down. These shifts due to the North-South trade show that the North as well as the South can experience the greater rates of economic growth than those enjoyed under autarky. As  $\phi$  increases, hence, the  $NN$  line shifts upward and the  $SS$  line also shifts upward. However, the  $SS$  line shifts by proportionately more under wide technology gap. Thus the technology gap between North-South is further narrowed under wide-gap situation. Under narrow technology gap, on the contrary, the North enjoys the higher rate of technological progress than that of the South due to high-end specialization. Thus the technology gap between North-South is further widen under narrow-gap situation.

### 4.3. Population growth

In this subsection, we analyze an unambiguous effect of population growth on endogenous technology gap,  $\theta$ . Consider first the case in which the Northern population increases at the same rate as the number of effective labor units. According to equation (30), an increase in  $L^N$  shifts up the  $NN$  curve and a decrease in  $L^N$  shifts it down. Next, consider an increase in the Southern population proportionately more than the Northern population. According to equation (31), a decrease in  $L^S$  shifts down the  $SS$  curve and an increase in  $L^S$  shifts it up. These shifts establish:

$$\frac{d\theta}{dL^N} > 0, \quad \frac{d\theta}{dL^S} < 0.$$

It is important to point out that a change in  $\theta$  implies a change in  $\eta$ . If  $L^N$  increases, the endogenous technology gap,  $\theta^*$ , is increased, and thus the equilibrium growth rate is increased. If  $L^S$  increases, the endogenous technology gap,  $\theta^*$ , is decreased, and thus the equilibrium growth rate,  $\eta^*$ , is increased. In cases of both  $\hat{L}^N < 0$  and  $\hat{L}^S < 0$ , by the same token, the equilibrium growth rate decreases, i.e.,  $\hat{\eta}^* < 0$ .<sup>9</sup>

<sup>9</sup> The hat notation denotes the rate of change.

## V. CONCLUSION

Using an endogenous growth model of trade-induced learning by doing, this paper investigates the long-run effects of North-South trade on economic growth and technical progress. The concepts of trade-induced specialization are incorporated into the learning by doing model with North-South trade. There is an innovative specialization in the North as well as an imitative specialization in the South, which depend on the technology gap as well as the degree of openness. In particular, the model of this paper explicitly incorporates a trade-induced Northern specialization in innovative processes within the learning by doing model.

Through trade-induced learning by doing with North-South trade, the North specializing in 'high-tech' activities enjoy innovative progress and the South specializing in 'low-tech' activities enjoy imitative progress. In a relatively narrow-gap equilibrium, international trade causes the North to specialize in producing the goods that generate the most learning, while the South finds itself specializing in goods where learning opportunities are fewer. Thus the effects of Northern innovation as the pattern of specialization are greater than that of Southern imitation. In a wide-gap equilibrium, however, the possible impacts of Southern imitation are greater than that of Northern innovation. These results reveal that North-South trade generates a steady endogenous technology gap in the long-run equilibrium.

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