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Learning-Driven Product Cycles, New Product Adoption and North-South Inequality

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This paper examines how key product-cycle parameters, such as the ease of new product adoption and the pace of product obsolescence, influence North-South wage inequality and the trade pattern. An innovative feature of the paper is in modeling the interaction between endogenous Northern product innovation and endogenous production transfers to South with industry specific learning, cross-industry learning spillovers, and product obsolescence. Greater difficulty in adopting new products raises wage inequality while lowering Northern innovation and Southern learning rates. Slowing the pace of product obsolescence reduces wage inequality in the short run, but does the opposite in the long run.

I. Introduction

Product-cycle based transfers of production from the developed countries of the North to the less developed countries of the South have become a dynamic force in the world economy. A country's ability to gain access to and successfully deploy a subset of world production is, in general, strongly dependent on its historic industrial experience (Vernon (1966)). With the preponderance of innovations being adopted first in developed countries, most less developed countries have become increasingly reliant on the subsequent acquisition of older products from the North. Newer production techniques often require significantly higher learning costs in the South, whereas older less sophisticated processes tend to be less costly to adopt. This has resulted in the agglomeration of advanced industries in the North leaving the South to concentrate in less sophisticated goods (Stiglitz (1989) and Stewart (1984)).

This paper introduces a simple dynamic model of North-South trade that incorporates a learning-driven product cycle and it explores how changes in key product-cycle parameters affect North-South wage inequality and the rate of new product adoption over time. Learning-based product cycles have strong implications for North-South wage inequality especially in the long run. The innovative feature of the paper is that we model the interaction between product innovation in the North and product transfers to the South in the presence of direct learning (learning specific to the industry), cross-industry learning spillovers, and product obsolescence. To this end the paper examines the impact of changes

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in key product-cycle parameters related to the difficulty of learning and the pace at which goods become obsolete. With new goods being developed and old goods becoming obsolete over time, the model focuses on the product-cycle positions of goods rather than specific goods *per se*. This allows us to identify the distribution of products across product cycle positions within each country and the corresponding demand for a good at any point in time.

By coupling learning to production experience the model allows us to formalize the crucial linkage between the "acquisition of knowledge" and "learning by doing" identified by Westphal *et al*. (1985). This enhances our understanding of learning by doing (see Arrow (1962)) in two important respects. First, the cost of acquiring the production capability for a new good is endogenous, costly, and occurs gradually over time. Initial diseconomies for producing a good depend on the degree of inexperience in producing that good and the degree of difficulty in the learning process. It is more costly for South to adopt newly innovated goods given that North is more experienced. Second, there is a general as well as product-specific element to learning. Production exhibits external economies of experience such that a country can learn how to produce new goods more readily as it fully masters older technologies and gains experience. There are, however, diminishing returns to the learning process and the benefits from learning are bounded. Together these features provide a compelling new dynamic foundation for differences in productivity that give rise to the conventional static Ricardian trade model. The context in which we model bounded learning and industry spillovers is similar to Young (1991) and the process by which goods become obsolete is similar to Stokey (1988). The introduction of a gradual and costly learning process in the current model, however, leads to a gradual transition, rather than immediate movement, towards the steady state after a perturbation. The adjustment path is strongly affected by the difficulty of learning, the extent of the learning externalities, the bounded nature of the learning, and pace at which goods become obsolete.

Past history gives rise to production experience that acts as the key determinant of relative wages and the trade pattern. A country's initial stock of experience determines the long-run pattern of trade. Given North is initially more experienced it has an absolute advantage in producing all goods. Innovations are thus, naturally taken up in North because the learning costs associated with inexperience are smaller than in the South. Since we do not consider endogenous investment in R&D, our model is distinct from but complementary to endogenous growth models such as those of Romer (1986), Lucas (1988), and Grossman and Helpman (1991b). In equilibrium, North produces the most advanced goods and the North-South wage differential reflects differences in learning embodied in a countries labour force. While similar wage differentials and trade patterns arise in Romer (1986), Lucas (1988), Stiglitz (1989) and Grossman and Helpman (1991b) the source of these differences in the current paper is due to the South's lack of accumulated learning in production. Period-by-period mutual gains from trade arise on the basis of Ricardian comparative advantage.

Given that South begins to produce goods in which North has already obtained economies associated with learning, South must pay a wage less than that of North to be competitive. In a steady-state equilibrium, the relative Southern wage depends on the point in the product cycle where the South commences production (the borderline of Southern production). At positions later in the product cycle, there is lower demand and thus, production of a good. This implies that it will take longer to attain the cumulative output required to complete the learning process. To compensate for the slower pace of learning, and in order for the South to keep pace with Northern innovation in a steady state, South must simultaneously learn and produce a wider set of goods. Learning and Southern production are however, more costly in this case so that a lower relative Southern wage is required to maintain the South's competitiveness. In any equilibrium, of course, Southern production must ultimately commence at a point that will balance trade at the going relative wage.

As learning becomes more difficult for both North and South or it becomes harder to adopt new products, the labour costs of learning new products rise and the length of the South's learning phase within the product cycle expands.[1] This in turn lowers both the rate of Northern product innovation and rate of transfer to the South. Since products that are transferred to South occupy later positions in the product cycle, they are relatively older goods with lower demand. South thus, produces a narrower set of older goods, and learns relatively less, causing the degree of wage inequality between North and South to rise.

Changing the rate at which goods become obsolete also affects steady-state wage inequality. When the length of the product cycle expands and it takes longer for goods to become obsolete, North-South wage inequality initially falls as South retains goods at the end of their product cycle for a longer period of time. Both the range of goods produced in South relative to North and the relative Southern wage rise in the short run. With a higher Southern relative wage, Southern production costs increase lowering the rate of production transfers from the North. This in turn, lowers the pace of learning in South since it now learns products that face weaker demand. In the long-run or steady-state equilibrium, the gap in learning between North and South rises so that both the South's relative labour productivity and its relative wage rate fall. Ultimately, the initial convergence in wages is more than fully reversed.

An increase in the Southern labour supply raises the South-to-North relative wage over the long term. This however, is not a result of transfers of capital as in Dollar (1986) or a higher rate of imitation in South as in Grossman and Helpman (1991a). Rather it is due to a closing of the North-South learning gap and a rise in Southern labour productivity as South produces newer goods. In the short run however, the Southern relative wage declines, which increases the rate of production transfer from the North. As South occupies earlier positions in the product cycle, where products are subject to greater demand, it begins to learn at a faster rate raising both Southern labour productivity and relative Southern wage.

The remainder of the paper is organized as follows. Sections II outlines the product cycle and Section III examines production technologies and relative costs. Demand and the trade balance are examined in Section IV. Short-run and steady-state equilibria are determined in Sections V and VI. Sections VII through IX examine the product cycle dynamics of learning, alternative learning regimes, and changes in obsolescence. The paper

1. Parente and Prescott (1994) discuss and model the effects of greater barriers to technology transfers. They find a positive link between weaker barriers to technology transfers and economic development. They do not however, model the interaction between barriers to technology adoption and innovation in the North.

concludes with Section X.

II. Products and Product-Cycle Positions

We adapt the Ricardian continuum-of-goods analysis of Dornbusch *et al*. (1977) to form a simple learning-based model of a North-South product cycle. To facilitate the analysis of long-run or steady-state equilibria later in the paper, we focus primarily on the *economic positions* of technologies and goods within the product lifecycle rather than the technologies and goods *per se*. Product cycle positions are indexed by x on the interval $[0, \boldsymbol{z}(t)]$, where $\boldsymbol{z}(t)$ represents the total number of goods ever produced at time t. The demand and supply sides of the model are such that there is always new learning and the total number of goods rises continuously over time, $\dot{z}(t) \equiv dz(t)/dt > 0$.

The position, denoted by x, represents the economic age of a product. A larger x denotes later or older positions within the product cycle. The economic age of a particular good or its position in the product cycle however, changes over time. When a good is first introduced or born, it occupies the *adoption point*, zero, but as newer products come on stream the good progressively comes to occupy less advanced or older positions over time, higher values of x. At the end of its useful economic life, a good eventually occupies the *obsolescence point*, $\boldsymbol{x}(t)$. For simplicity, we take the number of non-obsolete technologies and goods to be parametric so that $\boldsymbol{x}(t) = \boldsymbol{x}$. Obsolete goods occupy positions beyond $\boldsymbol{x}$ on the product-cycle continuum. In other words, goods in positions on the interval $[\boldsymbol{x}, \boldsymbol{z}(t)]$ are obsolete, while those on the interval $[0, \boldsymbol{x})$ are currently being produced and consumed.

With exactly $\boldsymbol{x}$ goods being consumed and produced at each point in time, a less advanced good becomes obsolete for each new good that is introduced. A similar process is used in Stokey (1988). This allows for a useful but simple caricature of how goods cycle from the leading edge of technology to the end of their practical usage. Since the duration of time required for a complete cycle may vary over time, there is no invariant correspondence between a product’ s economic age and its chronological age. Figure 1, previews the simple continuum of North-South product-cycle positions that will be generated by the model, and shows the key positions and developmental stages or ranges pertaining to specialization and learning.

III. Technology, Production and Relative Costs

We assume Ricardian technologies where the output of the good in position x at time t in country j, $q_j(x,t)$, depends on the number of efficiency units of labour applied to production, $\ell_j(x,t)$.

$$q_j(x,t) = f_j(x,t) g_j(x,t) \ell_j(x,t). \tag{1}$$

While there are constant returns to scale at any point in time, there is learning over time.

Figure 1 Product-Cycle Overview

Labour productivity for the good in position x at time t in country j depends on a direct learning coefficient, $f_j(x,t)$, and a learning spillover coefficient, $g_j(x,t)$. We will postulate a specific functional form for these learning coefficients, and later for the utility function, so as to permit parameter changes that give rise to simple comparative dynamic analyses of product cycles.

The direct learning coefficient is dependent on standard learning by doing and represents economies that are internal to the industry:

$$f_j(x,t)=\begin{cases}\boldsymbol{d}+(1-\boldsymbol{d})\dfrac{Q_j(x,t)}{\boldsymbol{q}} & \text{if} \quad Q_j(x,t)\le\boldsymbol{q}, \\ 1 & \text{if} \quad Q_j(x,t)\ge\boldsymbol{q}, \end{cases} \qquad (2)$$

where: $0\le\boldsymbol{d}<1$.

Here $Q_j(x,t)$ denotes the cumulative industry output for the good occupying position x at time t in country j, q is an experience threshold parameter, and d is an ease of learning-by-doing parameter. Alternatively, $(1-d)$ represents the sensitivity of the direct learning coefficient to changes in cumulative output. The larger is the ease of learning-by-doing parameter, d, the smaller is the amount of direct learning associated with any increase in cumulative output. Higher cumulative output, up to the experience threshold, generates a larger value for the direct learning coefficient and more productive labour. The experience threshold parameter places an upper bound on the amount of industry specific learning that can occur. When all industry-specific learning possibilities are exhausted $f_j(x,t)=1$.

The learning spillover coefficient takes account of the fact that additional experience within a country makes it easier to learn new products. These economies spillover from one sector to the next [2]

$$g_j(x,t)=\begin{cases} 0 & \text{if } \bar{x}_j(t)-x \geq g, \\ 1-\dfrac{\bar{x}_j(t)-x}{g} & \text{if } g \geq \bar{x}_j(t)-x \geq 0, \\ 1 & \text{if } 0 \geq \bar{x}_j(t)-x. \end{cases} \tag{3}$$

Here, $\bar{x}_j(t)$ represents the *borderline of experience* for country j at time t, and g is an ease of product adoption parameter. We define the borderline of experience for country j at time t, $\bar{x}_j(t)$, to be the position of the newest good for which cumulative output exceeds the experience threshold parameter (i.e., the smallest value of x such that $Q(x,t) \geq q$), or the newest good for which the industry specific learning opportunities have been exhausted. The structure of the learning spillover coefficient is such that a country cannot produce goods that fall more than g goods earlier in the product cycle than its borderline of experience (i.e., $x \leq \bar{x}_j(t)-g$). That is, it cannot produce more than g goods for which it is accumulating experience. For all products falling later in the cycle than a country's borderline of experience, $x \geq \bar{x}_j(t)$, the learning spillover coefficient is equal to unity. Given the definition of the borderline of experience, this implies that if the learning spillover coefficient is equal to unity, so too is the direct learning coefficient. On the open interval $(\bar{x}_j(t)-g, \bar{x}_j(t))$ learning becomes progressively easier and the spillover coefficient becomes larger as products age and cumulative output expands.[3]

2. Shi and Yang (1995) also allow for cross industry spillovers from expanded variety of production. The benefits in their paper derive from increased specialization of the labour force.

3. We have assumed that there is a definite end point for the economies of direct learning by doing (i.e., once $Q(x,t)$ reaches q), and that learning spillovers from experience only benefit newer rather than older products (i.e., positions such that x is less than $\bar{x}_j(t)$). The essential results of the model, however, would be unaffected by allowing the economies associated with learning to continue indefinitely and/or permitting learning spillovers that also enhance the production of older goods.

Given that, by historic accident, North is initially experienced in newer goods, the nature of the model is such that North will typically remain more experienced (i.e., $\bar{x}_N(t) < \bar{x}_S(t) \quad \forall t \geq 0$). North will be first to develop and adopt each good, but later, as still newer goods are developed and adopted, the technology and production of each good will eventually be transferred to the South. We assume that the initial experience gap, $\bar{x}_S(0) - \bar{x}_N(0)$, is less than x so that it is feasible for South to produce some goods that are still demanded by the North. Otherwise, trade would not arise. While each country's borderline of experience can potentially vary over time, it should be emphasized that the borderline of experience is predetermined in the short-run or momentary equilibrium that exists at any point in time.

The *borderline of production* for country j at time t, $\tilde{x}_j(t)$, is the newest or youngest good that it is currently producing (i.e., the smallest x). The North, being more experienced than the South, will always produce the good occupying the adoption point.

$$\tilde{x}_N(t) = 0 \ . \tag{4}$$

As shown in Figure 1, the North's *production range* at time t consists of all product cycle positions from zero to $\tilde{x}_S(t)$, while that of South consists of all positions from $\tilde{x}_S(t)$ to x. The borderline of Southern production is a pivotal trade-determined variable.

Each country has a *learning range* that runs from its borderline of production to its borderline of experience. The wider is the learning range, the more new technologies are being learned and, *ceteris paribus*, the faster the flow of products through the cycle. In Figure 1, North's learning range runs from $\tilde{x}_N(t) = 0$ to $\bar{x}_N(t)$, and South's learning range runs from $\tilde{x}_S(t)$ to $\bar{x}_S(t)$. The learning spillover technology specified by Equation (3) places an upper bound on the breadth of these learning ranges.

$$\bar{x}_j(t) - \tilde{x}_j(t) \leq g \ , \quad j = N, S \ . \tag{5}$$

The structure of demand that we will come to adopt below will drive North to always stretch its *learning range* to the maximum extent so that it adopts the maximum feasible range of new goods.

$$\bar{x}_N(t) = g \ . \tag{6}$$

Whereas the breadth of North's learning range is always exactly g, we will see later that the breadth of the South's learning range is typically less than g.

For the simple North-South product cycle outlined in Figure 1 to remain stable over time, North must always be able to finish learning a technology before the associated product is transferred to the South. In a stable product cycle, therefore, the good at the South's borderline of production always falls later in the product cycle than North's borderline of experience.

$$\tilde{x}_S(t) > \gamma . \tag{7}$$

In the text we assume this condition always holds, but in the Appendix we discuss alternative scenarios.

Based on Equation (1), the labour requirement per unit of output of the good in position x at time t in country j is:

$$a_j(x,t) \equiv \frac{l_j(x,t)}{q_j(x,t)} = \frac{1}{f_j(x,t)g_j(x,t)} , \quad j = N, S . \tag{8}$$

For all goods in which a country has exhausted the direct learning and spillover opportunities, the labour requirement is equal to one. For all other goods where direct learning and experience spillovers are still occurring, the required labour input is greater than one. Given that North completes its learning before South starts its learning, the North's labour requirement for each product cycle position is always at least as low as that of South. The North, therefore, is never at an absolute disadvantage.

The ratio of unit labour requirements provides a measure of the degree of comparative advantage for the good in position x at time t.

$$A(x,t) \equiv \frac{a_N(x,t)}{a_S(x,t)} = \frac{f_S(x,t)g_S(x,t)}{f_N(x,t)g_N(x,t)} . \tag{9}$$

For positions on the interval $(0, \bar{x}_S(t) - \gamma]$ where it is not feasible for South to learn, $A(x,t) = 0$; for positions on the interval $(\bar{x}_S(t) - \gamma, \bar{x}_S(t))$ where South is inexperienced but learning is feasible, $0 < A(x,t) < 1$; and for positions on the interval $[\bar{x}_S(t), \chi]$ in which the South, as well as the North, is experienced $A(x,t) = 1$.

For the good that occupies the South's borderline of production, the unit cost of production must be the same in both countries as in Dornbusch *et al*. (1977).

$$w_S(t)a_S(\tilde{x}_S(t),t) = w_N(t)a_N(\tilde{x}_S(t),t) \quad \text{or} \quad \omega(t) = A(\tilde{x}_S(t),t) . \tag{10}$$

Here, $\omega(t) \equiv w_S(t)/w_N(t)$ represents the South-to-North-relative wage at time t.[4] Two broad scenarios are possible in the short run. First, if the South's borderline of production at time t falls on the interval $[\bar{x}_S(t), \chi]$ over which South already has experience and is not learning, then $\omega(t) = 1$. This first scenario, however, is not sustainable indefinitely because continuous innovation in North will eventually require a transfer of products, which must be learned, to South so as to preserve the balance of trade. In the second scenario where South is learning and its borderline of production falls on the interval $(\bar{x}_S(t) - \gamma, \bar{x}_S(t))$:

4. Prices are equal to unit costs so that Equation (10) merely states that the price of the borderline good would be the same regardless of where it is produced.

$$\omega(t)=\left(\delta+(1-\delta)\frac{Q(\tilde{x}_S(t),t)}{\theta}\right)\left(1-\frac{\bar{x}_S(t)-\tilde{x}_S(t)}{\gamma}\right)<1\,, \tag{11}$$

where: $\left.\frac{\partial\omega(t)}{\partial\tilde{x}_S(t)}\right|_{\text{SCS}}>0\,,\ \left.\frac{\partial\omega(t)}{\partial\bar{x}_S(t)}\right|_{\text{SCS}}<0\,,\ \left.\frac{\partial\omega(t)}{\partial\delta}\right|_{\text{SCS}}>0\,,\ \left.\frac{\partial\omega(t)}{\partial\gamma}\right|_{\text{SCS}}>0\,,\ \left.\frac{\partial\omega(t)}{\partial\theta}\right|_{\text{SCS}}<0\,.$

Equation (11) determines competitive specialization over South's potential learning range conditional on the Southern borderline of experience that prevails in the short run at time t. *Ceteris paribus*, when South's borderline of production rises within this interval and South begins its production later in the product cycle where it is at less of a productivity disadvantage, it is competitive at a higher relative wage.[5] The *short-run competitive specialization* (SCS) curves, thus, are positively sloped, as shown in Figure 2. A later Southern borderline of experience where South is learning a wider set of goods, on the other hand, requires a lower relative wage for South to be competitive. In Figure 2, the $\text{SCS}(\bar{x}(0))$ and $\text{SCS}(\bar{x})$ curves correspond to two different borderlines of Southern experience where $\bar{x}_S(0)>\bar{x}_S$.

Within the scenario where Southern learning takes place, South may or may not be starting to learn new commodities at time t. In the former more interesting sub case, the South's direct learning coefficient for the good at its borderline of production is $f_S(\tilde{x}(t),t)=\delta$ because cumulative Southern output is equal to zero. Consequently, when South is starting to learn new products:

$$\omega(t)=\delta-\delta\frac{\bar{x}_S(t)-\tilde{x}_S(t)}{\gamma}<\delta<1\,. \tag{12}$$

As the world economy evolves toward a steady-state product cycle, South must eventually start to learn new products making this equation directly relevant to competitive specialization.

IV. Demand and the Balance of Trade

To highlight the dynamics of the learning-based product cycle we assume all goods are perishable and we abstract from international borrowing and lending. For simplicity, both countries have a common single-period Cobb-Douglas utility function of the following form.

$$\ln U_j(t)=z(t)\int_0^x B(x,x)\ln C_j(x,t)dx\,,\quad j=N,S\,, \tag{13}$$

5. Notice that $Q(x,t)$ is increasing in x since cumulative output is greater for goods occupying positions later in the product cycle.

$$\text{where: } B(x,\boldsymbol{x}) = \begin{cases} 2(\boldsymbol{x}-x)/\boldsymbol{x}^2 & \text{if } 0 \le x \le \boldsymbol{x}, \\ 0 & \text{if } \boldsymbol{x} \le x \le \boldsymbol{z}(t). \end{cases}$$

Here $C_j(x,t)$ represents country j's consumption of the good in product-cycle position x at time t, and $B(x,\boldsymbol{x})$ is the corresponding expenditure share parameter. Expenditure shares depend on product positions rather than products *per se* to be consistent with a product lifecycle approach. The utility function has been formulated such that there will be no expenditure over the range of old goods beyond the obsolescence point, $\boldsymbol{x}$. Among non-obsolete goods, expenditure shares are assumed to peak at the new-product adoption point, and then uniformly to diminish to obsolescence. More generally, it would be possible to allow expenditure shares to peak at a position somewhat later in the product cycle. New product adoption is beneficial, because utility increases when $\boldsymbol{z}(t)$ rises and the consumption level at each product-cycle position, x, remains unchanged. As mentioned above, this means that there is an imperative for North to adopt as many new products as possible in every period.

The expenditure shares on goods in all positions, of course, must add to one regardless of the breadth of the range of non-obsolete goods represented by $\boldsymbol{x}$.

$$\int_0^{\boldsymbol{x}} B(x,\boldsymbol{x})dx = \left[-(\boldsymbol{x}-x)^2/\boldsymbol{x}^2\right]_0^{\boldsymbol{x}} = 1 . \tag{14}$$

The cumulative expenditure share devoted to all goods in positions of Southern production by residents of either North or South is:

$$\boldsymbol{J}(\tilde{x}_S(t),\boldsymbol{x}) \equiv \int_{\tilde{x}_S(t)}^{\boldsymbol{x}} B(x,\boldsymbol{x})dx = \left[-(\boldsymbol{x}-x)^2/\boldsymbol{x}^2\right]_{\tilde{x}_S(t)}^{\boldsymbol{x}} = (\boldsymbol{x}-\tilde{x}_S(t))^2/\boldsymbol{x}^2 . \tag{15}$$

A later Southern borderline of production, $\tilde{x}_S(t)$, decreases the South's production range and thereby lowers the cumulative expenditure share going to Southern products. By contrast, an increase in the range of non-obsolete commodities raises the cumulative expenditure on Southern produced commodities.

For convenience, we select an efficiency unit of Northern labour to be the numeraire so that in every period the North's wage and income per efficiency units of labour is equal to one. Consequently, $w_N(t)=1$ and $w_S(t)=\boldsymbol{w}(t)$. Aggregate world income at time t is:

$$Y(t) \equiv w_S(t)\Lambda_S + w_N(t)\Lambda_N = \boldsymbol{w}(t)\Lambda_S + \Lambda_N , \tag{16}$$

given that Λ_j represents country j's exogenous endowment of efficiency units of labour. Trade balance at time t requires that North's cumulative expenditure on Southern-produced goods be equal to South's cumulative expenditure on Northern-produced goods.

$$(1-\boldsymbol{J}(\tilde{x}_S(t),\boldsymbol{x}))w_S(t)\Lambda_S = \boldsymbol{J}(\tilde{x}_S(t),\boldsymbol{x})w_N(t)\Lambda_N . \tag{17}$$

Like the short-run specialization condition, the trade balance condition is equivalent to Dornbusch *et al*. (1977). Given that $\Lambda \equiv \Lambda_N / \Lambda_S$ is the number of efficiency units of Northern labour per Southerner, the trade balance condition can be rewritten as:

$$\omega(t) = \Lambda \frac{\vartheta(\tilde{x}_S(t), \xi)}{1 - \vartheta(\tilde{x}_S(t), \xi)} = \Lambda \frac{(\xi - \tilde{x}_S(t))^2}{\xi^2 - (\xi - \tilde{x}_S(t))^2}, \qquad (18)$$

where: $\left.\frac{\partial \omega(t)}{\partial \tilde{x}_S(t)}\right|_{\mathrm{TB}} < 0$, $\lim_{\tilde{x}_S(t)\downarrow 0} \omega(t) \to \infty$, $\lim_{\tilde{x}_S(t)\uparrow \xi} \omega(t) = 0$,

$\left.\frac{\partial \omega(t)}{\partial \Lambda}\right|_{\mathrm{TB}} > 0$, $\left.\frac{\partial \omega(t)}{\partial \xi}\right|_{\mathrm{TB}} > 0$.

As the borderline of production rises and South commences production later in the product cycle, South produces a narrower range of goods, its terms of trade must deteriorate and the relative wage must decline to prevent a Southern trade deficit. Consequently, the trade balance locus, TB, is negatively sloped as shown in Figure 2.

Figure 2 Product-Cycle Dynamics

V. Short-Run Equilibria

At any moment in time, t, the trade balance condition, Equation (18), and the short-run competitive specialization condition, Equation (11), simultaneously determine South's borderline of production, $\tilde{x}_S(t)$, and the relative wage, $\omega(t)$, conditional on the prevailing level of Southern experience, $\bar{x}_S(t)$. In Figure 2, the initial borderline of Southern experience is $\bar{x}_S(0)$, the short-run competitive specialization locus is $\mathrm{SCS}(\bar{x}_S(0))$, and the trade balance locus is TB. In the initial short-run equilibrium, the relative wage is $\omega(0)$ and the borderline of production is $\tilde{x}_S(0)$. Both countries obtain period-by-period (static) gains from trade based on specialization in accordance with Ricardian comparative advantage as in Dornbusch *et al*. (1977). Whereas North imports over a range of less-advanced product-cycle positions, [$\tilde{x}_S(t), \xi$], at a lower resource cost through trade than domestic production, South imports over a range of more advanced positions, [0, $\tilde{x}_S(t)$]. Essentially, North competes on the basis of the technological advantage associated with its lead in experience while South competes on the basis of lower wages.

VI. The Steady-State Product Cycle

Provided that condition (8) holds so that North completes the learning process, goods will be continually moving through the product cycle and North will always be developing and adopting newer more advanced technologies and goods. This leads to a positive new-product adoption rate, $\dot{z}(t) > 0$. Further, this rate of new-product adoption also represents the rate at which goods pass through every position in the product cycle.

$$\dot{z}(t) = h(\omega(t), \delta, \theta, \gamma, \xi, \Lambda_N, \Lambda_S) > 0, \tag{19}$$

where by assumption: $\dfrac{\partial h(\cdot)}{\partial \omega(t)} > 0$, $\dfrac{\partial h(\cdot)}{\partial \delta} > 0$, $\dfrac{\partial h(\cdot)}{\partial \theta} < 0$,

$\dfrac{\partial h(\cdot)}{\partial \gamma} > 0$, $\dfrac{\partial h(\cdot)}{\partial \xi} < 0$, $\dfrac{\partial h(\cdot)}{\partial \Lambda_j} > 0$, $j = N, S$.

The rate of new-product adoption depends positively on the output levels of goods in North's learning range, which is directly related to the world consumption levels for such goods. World consumption rises with world income so that an increase in the relative wage, or the labour endowment of either country, will raise the new-product adoption rate. A similar result is found in Grossman and Helpman (1991a, b). Whereas in the current paper higher output leads to faster learning and innovation, in Grossman and Helpman higher output results in greater profits, since the profit function is modeled as direct function of output. As profits rise, investment in innovation increases. Increases in either of the learning parameters, δ or γ, or a reduction in the cumulative output threshold, θ, reduce the prices of goods in the North's learning range, and thereby increase world consumption. Earlier obsolescence brought about through a reduction in x would increase world consumption by raising the expenditure for goods in the North's learning range.

While the world economy is always non-stationary, it will eventually approach a steady state or long-run equilibrium. The steady-state innovation rate is:

$$\dot{z} = h(w, d, q, g, x, \Lambda_N, \Lambda_S) > 0 \tag{20}$$

We remove the reference to time to denote steady-state equilibrium values of variables. North's borderline of experience is always constant over time in accordance with Equation (6), but South's borderline of experience can vary over time.

$$\bar{x}_N(t) = g \Rightarrow \dot{\bar{x}}_N(t) \equiv 0 \tag{21}$$

$$\dot{\bar{x}}_S(t) = k(\bar{x}_S(t) - \bar{x}_S)\text{, where by assumption: } k'(\cdot) < 0\,. \tag{22}$$

If $\bar{x}_S(t)$, South's borderline of experience at time t, falls later (earlier) in the product cycle than $\bar{x}_S$, its steady-state borderline of experience, then South will complete the learning process and amass experience sufficiently quickly (slowly) that its borderline of experience will move earlier (later) in the product cycle over time. Further, the fact that the South's borderline of experience can vary over time implies that the proportion of goods produced in each country can also change over time.

A non-trivial requirement for a steady state is that the South's borderline of experience remains constant over time. In accordance with Equation (22), $\dot{\bar{x}}_S(t) = 0$ if and only if South's borderline of experience is equal to its steady state value, $\bar{x}_S(t) = \bar{x}_S$. For South to keep pace with the North, its steady state borderline of experience must come later than its borderline of production so that its learning range is positive (i.e., $\bar{x}_S > \tilde{x}_S$) and learning must be feasible (i.e., $\bar{x}_S \leq \tilde{x}_S + g$). Within this range, we can infer that South's steady-state borderline of experience depends on its steady-state borderline of production and the relative wage.[6]

$$\bar{x}_S = M(\tilde{x}_S, w), \tag{23}$$

where by assumption: $\dfrac{\partial M(\cdot)}{\partial \tilde{x}_S} > 1$, $\dfrac{\partial M(\cdot)}{\partial w} > 0$.

6. Recall from the discussion of the new product adoption rate (i.e., Equation (19)), that all the parameters of the model affect consumption levels through their impact on prices, world income or expenditure shares. Since any parameter change will have the same proportionate effect on the products that North and South are learning, South can keep pace without any change in the breadth of the its learning range. Consequently, the South's steady-state borderline of experience, $\bar{x}_S$, does not depend directly on the parameters of the model.

When the South's steady state borderline of production, $\tilde{x}_S$ increases such that South produces fewer goods, there must be more than a one-for-one increase in the its steady-state borderline of experience, $\bar{x}_S$. As the South's borderline of production moves later in the product cycle, there is less demand for the products that South is learning by merit of the smaller expenditure shares on older goods. Output in each Southern position subject to learning falls, thereby increasing the duration of time that it takes for South to learn any single good. To compensate, the breadth of South's steady state learning range, $\bar{x}_S - \tilde{x}_S$, must increase so that South learns more products simultaneously and can continue to accommodate the same flow of products through the cycle.

There are two channels through which an increase in the steady-state relative wage pushes the steady state borderline of Southern experience later in the product cycle. First, a higher relative wage raises the South's demand for each good in positions that North is learning. As we have seen this increases the new product adoption rate so that products flow through the product cycle more rapidly. Second, world consumption of each good subject to Southern learning falls because the increase in the relative wage raises world income by a smaller proportion than the prices of Southern goods. On the one hand, a one percent increase in the relative wage raises the prices of Southern products by exactly one percent since prices are equal to unit costs (e.g., in reference to the borderline of Southern production, recall the construction of Equation (10)). On the other hand, a one percent increase in the relative wage raises world income by less than one percent in accordance with Equation (16). With the Cobb-Douglas specification of utility, there is thus a reduction in the quantity demanded for each Southern good. As a result, steady-state output declines for all of the goods that South is learning, and the time duration that South needs to accumulate experience in any product rises. To accommodate both the more rapid flow of products and the slower Southern learning, South's learning range must span a broader range of products. In the steady-state South's borderline of experience must consequently, rise.

We obtain a *long-run competitive specialization* (LCS) condition by substituting Equation (23) into Equation (12).

$$\omega = \delta - \delta \frac{M(\tilde{x}_S, \omega) - \tilde{x}_S}{\gamma} \leq \delta < 1, \tag{24}$$

where: $\left.\frac{\partial \omega}{\partial \tilde{x}_S}\right|_{LCS} < 0$, $\left.\frac{\partial \omega}{\partial \delta}\right|_{LCS} > 0$, $\left.\frac{\partial \omega}{\partial \gamma}\right|_{LCS} > 0$.

From Equation (23) where $\tilde{x}_S < M(\cdot) \leq \tilde{x}_S + \gamma$, it can be deduced that South's wage is positive but less than that of North in a steady state. The LCS curve is negatively sloped as shown in Figure 2. We have seen from the discussion of Equation (23) that when the steady-state Southern borderline of production occurs later in the product cycle it must be associated with a wider learning range. This implies that the product at South's borderline of production must have a higher labour requirement relative to North. A lower relative wage is, therefore, required for South to remain competitive when its steady-state borderline of production falls later in the product cycle.

The long-run competitive specialization condition (i.e., Equation (24)) and the trade balance condition (Equation (18)) can be solved simultaneously for steady-state values of the South's borderline of production and the relative wage. The trade balance condition applies in the long run as well as the short-run because it is independent of the Southern borderline of experience. In Figure 2, the steady-state equilibrium is at $(\tilde{x}_S, \omega)$ where the long-run competitive specialization (LCS) and the trade balance (TB) loci intersect. For simplicity we assume the existence of a unique globally stable product-cycle equilibrium such as $(\tilde{x}_S, \omega)$ throughout the text of the paper. Existence and stability are discussed further in the Appendix.

VII. The Product-Cycle Dynamics of Learning and Experience

We can now examine the dynamic adjustment path to the steady-state equilibrium. If the momentary equilibrium point $(\tilde{x}_S(t), \omega(t))$ lies below, rather than on, the long-run competitive specialization locus, then the South's borderline of experience will be moving earlier in the product cycle over time (i.e., $\dot{\bar{x}}_S(t) > 0$) and visa versa. Consider any arbitrary initial value of South's borderline of experience such as $\bar{x}_S(0)$ in Figure 2. Given that the relative wage is lower than its long-run value for the Southern borderline of production, $\tilde{x}_S(0)$, Southerners will be purchasing fewer of the products North is learning relative to a steady state. Northerners conversely, will be purchasing more of the products that South is learning. Since this implies that South will be learning more rapidly than North, its borderline of experience will be moving earlier in the product cycle over time, and the world economy will gravitate toward the long-run equilibrium at $(\tilde{x}_S, \omega)$ along the dynamic path shown by the arrows in Figure 2.[7] As a result of an accelerated transfer of production and new learning in South, its borderline of experience falls from $\bar{x}_S(0)$ toward $\bar{x}_S$. Over time, the short-run competitive specialization curve shifts to the left and converges with the $\mathrm{SCS}(\bar{x}_S)$ curve. This earlier borderline of Southern experience is associated with continuous increases in the relative wage as the margin of production occurs at progressively more advanced positions in the cycle. Given that South learns progressively newer goods that are subject to greater demand, its learning range shortens placing it at less of a productivity disadvantage and enabling it to compete with North at a higher relative wage.

There are overall gains for North in moving from autarky to product-cycle-based free trade. In addition to the period-by-period Ricardian gains noted in Section V, North innovates and acquires experience in new products more rapidly when it can cater to the larger world demand. There is also a strong presumption of overall gains to the South. If the

7. According to Equation (24), the current relative wage $\omega(0)$ is too low to keep $\bar{x}_S(0)$ and $\tilde{x}_S(0)$ stationary. From Equation (23), the value of the steady-state borderline of Southern experience, $M(\tilde{x}_S(0), \omega(0))$, that would be consistent with stationary product cycle positions is less than the current borderline of experience, $\bar{x}_S(0)$ because $\partial M(\cdot)/\partial w > 0$. The borderline of experience will consequently, be moving earlier in the product cycle (i.e., $\dot{\bar{x}}_S(t) = k(\bar{x}_S(t) - \bar{x}_S) < 0$) over time in accordance with Equation (22).

initial learning gap is large, and the adjustment to free trade involves an earlier Southern borderline of experience over time, South will gain from trade. For example, suppose that the Southern borderline of experience is $\bar{x}_S(0)$ in Figure 2. In moving from autarky to the initial short-run trading equilibrium at $(w(0), \tilde{x}_S(0))$, South realizes static Ricardian gains from trade. In addition to these period-by-period Ricardian gains, South benefits from a dynamic improvement in its relative position *vis à vis* the North. Over time, the high rate of transfer of technology and production leads to an earlier Southern borderline of experience and a rising relative wage as the world economy converges toward the long-run equilibrium at $(\tilde{x}, w)$. The South, like the North, also enjoys the dynamic benefits from accelerated new product adoption.

Alternatively, suppose that when free trade commences the Southern borderline of experience places the initial equilibrium above the long-run specialization locus, LCS, in Figure 2. The adjustment to a steady state now involves a gradual reduction in the relative wage and increase in the experience gap. As the South' s borderline of production moves later in the product cycle, South is forced to compete at a lower relative wage so as to learn over a broader range of products that are less in demand. Overall, South will gain from trade if and only if the benefits from its static gains and the accelerated rate of global innovation are sufficient to offset the dynamic deterioration in its relative position.

While free trade results in static efficiency contingent on given levels of experience, there remain dynamic inefficiencies associated with learning and acquiring experience. Positive externalities arise from learning because there are general as well as product-specific benefits from gaining experience. For all feasible positions subject to learning that fall earlier in the product cycle than a country' s borderline of experience, the marginal social benefit of production consequently, exceeds the marginal private benefit. Any private decision-maker that produces a particular good neglects the present value of the future benefits that would accrue to producers of other goods if experience were acquired more quickly through greater levels of current output. Both countries, therefore, under-produce goods subject to learning.[8]

VIII. Alternative Learning Regimes

The model can be used to compare alternative learning regimes.[9] Consider two alternative scenarios that differ only with respect to the economies associated with learning by doing. In both regimes, the trade balance curve is TB in Figure 3.

8. While firms would have an incentive to partially internalize these learning externalities by integrating into horizontally-related technologies and goods subject to the limits posed by internal coordination costs (Coase (1937)), we do not explicitly model this partial internalization for simplicity. To the extent that the learning spillovers are not fully internalized, South will gain from production subsidies directed at goods that are subject to learning as in Bardhan (1971), Helpman (1984) and Succar (1987). It is interesting that in the current context, North could possibly gain from such Southern subsidies because of the induced increase in new product adoption.

9. We examine the comparative dynamics of regimes with alternative values of learning parameters. While it would be easy to analyze the impact of a sudden change to a learning parameter within a particular regime, changes are

Figure 3 Larger Economies of Learning by Doing

In the first scenario, learning economies are smaller so that the ease of learning-by-doing parameter, d, takes on a larger value than the second regime (i.e., $d' > d''$). This implies that the initial productivity gap between North and South, for a good in which South has no prior experience, is larger in the second regime. More product-specific learning must therefore, occur to close the productivity gap.

Assuming that both regimes have the same initial Southern borderline of experience, $\bar{x}_S(0)$, and given that South is at a greater labour productivity disadvantage when it commences learning in the second regime, a lower relative wage is required to keep South competitive in the second regime. Both the short run and long run competitive specialization loci for scenario two consequently, lie below their counterparts for scenario one. In scenario one, the product cycle is initially in a steady state at $(\tilde{x}_S', w')$. In scenario two, there is an initial short run equilibrium at $(\tilde{x}_S''(0), w''(0))$. With greater learning required to close the productivity gap with the North, a lower relative wage and a later Southern borderline of

more likely to arise gradually with a particular good going through the cycle rather than suddenly a particular point in time.

production is needed to offset the greater amount of learning that must occur. Over time the South's borderline of experience gradually moves later in the cycle and the proportion of goods produced in North rises. This pulls South's borderline of production still later in the product cycle and requires further gradual reductions in the relative wage to keep trade in balance. In scenario two, the product cycle approaches a steady state at $(\tilde{x}_s'', w')$. The more learning that must occur, the greater the degree of wage inequality eventually required to stabilize the product cycle.

With a larger amount of required learning North faces some of the same difficulties as the South. Northern learning in scenario two leads to a lower rate of new product adoption and slower movement of products through the cycle. A higher required amount of learning by doing implies that goods move more slowly through the learning phase. This leads to a slower rate of product innovation in the North.

Southern welfare is definitely lower when the required learning by doing becomes larger both because the lower relative wage implies that all goods produced by North are less affordable and because the rate of new product adoption is lower. Northern welfare is also likely to be lower when greater learning is required. Like the South, North loses from the lower rate of product adoption. At any point in time, t, North is also harmed because goods on the interval $(\tilde{x}_s', \tilde{x}_s''(t)]$ that it produces in scenario two could have been produced less expensively by South in scenario one. There is, however, a source of benefit for North in that the prices of those goods that South continues to produces with experience in scenario two are cheaper than in scenario one due to the lower relative wage.

Greater difficulty in product adoption arising from a lower value of g has the same qualitative effects as a lower value of d since the South, once again, is at a greater productivity disadvantage in the goods that it is learning. The smaller learning spillover coefficient that results gives rise to higher costs in adopting new products, and thus is associated with greater North-South inequality in addition to a slower rate of new-product adoption. A larger value of the cumulative output threshold, q, which is required for experience, has no impact on the configuration of the product cycle, but it does lead to lower welfare in both countries by reducing the rate at which new products can be adopted.

IX . Changes in Obsolescence and Endowments

The model can also be used to assess the effects of an increase in the range of products in use by increasing the product-life parameter, x. In Figure 4, the trade balance curve would shift upward from $\mathrm{TB}(x')$ to $\mathrm{TB}(x'')$. There is, thus, an immediate, but short run, increase in the relative wage from w' to $w''(0)$ that is just sufficient to prevent a Southern trade deficit from arising.

Figure 4 Later Obsolescence

Although South initially produces a larger proportion of goods, its borderline of production moves later in the product cycle from $\tilde{x}_S'$ to $\tilde{x}_S''(0)$. South's pace of learning falls relative to that of North. Over time the South's borderline of experience moves later in the cycle at a more rapid pace than its borderline of production. As a result, the South's learning range gradually expands and the relative wage falls. In the long run the relative wage falls below its initial level to w''. A longer product life span, therefore, reduces North-South inequality temporarily, but ultimately increases inequality.[10]

The model can also shed light on labour endowment issues. Consider an increase in South's endowment of efficiency units of labour where Λ_S rises, Λ_N remains constant and $\Lambda \equiv \Lambda_N / \Lambda_S$ falls. As a result of the shock, the trade balance curve shifts down to prevent a Southern deficit. There is an immediate fall in the South-versus-North relative wage in response to the change in the relative labour supply, and an accompanying move by South into newer products that make use of its additional labour. In the aftermath of these orthodox short-run effects, the Southern borderline of experience moves over time to earlier

10. As the change in product life comes about as a result of a change in tastes, welfare changes cannot be assessed.

points in the product cycle, propelling the world economy to an eventual long-run equilibrium where the relative wage rises back above its initial level and South moves into even newer products. Dollar (1987) and Grossman and Helpman (1991a) derive similar non-standard effects of labour endowment increases on the relative wage. In Dollar, an increase in the Southern labour endowment leads to an increase in the South-to-North relative wage due to the transfer of capital from North to South. In Grossman and Helpman this result is obtained because of a rise in the rate of technology transfer to South relative to the rate of innovation in North.

The overall impact of the increase in South's labour endowment on each country's welfare is ambiguous in the current model. North gains in the short-run because the reduction in the relative wage lowers the price of Southern goods. As the relative wage rises back above its initial level, however, the prices of Southern goods in product cycle positions that were not originally subject to learning rise back above their original level and hurt the North. By contrast, the prices of goods in product cycle positions that South takes over from North become cheaper. Both North and South benefit from an increase in the rate of new-product adoption that accompanies the increase in world income. Southerners gain or lose in the short-run depending on whether the increase in the endowment of efficiency units of labour was due to increased effectiveness of labour (e.g., with improved sanitation, nutrition, etc.) or a larger population. In either case, of course, Southern period-by-period welfare would rise during the adjustment phase due to the increase in the relative wage as well as the increase in the new product adoption rate.

While an increase in North's labour endowment would have the opposite product-cycle dynamics, the impact on the product adoption rate is more complex. Since the steady-state relative wage falls, the direct increase in world income is partially offset and the increase in the steady-state new-product adoption rate is smaller.

X. Conclusion

The model developed in this paper features a learning-driven product cycle that permits an examination of how key product-cycle parameters influence North-South wage inequality and the pattern of trade over time. A product cycle reminiscent of Vernon (1966) emerges in which all goods are initially developed and produced by the North. New products are relatively expensive to produce. As North learns to produce the product, the costs of production fall. The knowledge acquired from producing these new goods, spills over onto other Northern industries. A country's ability to learn from any specific good is, however, bounded and eventually the learning opportunities for each good are exhausted. Over time, as goods occupy positions later in the product cycle it becomes feasible to shift their production to the South. This then starts a new cycle of learning in the South. The advantage of shifting production to South is that with lower wages certain products can be produced at a lower cost. As a good ages however, demand for the product declines and eventually the good becomes obsolete.

Within this framework we examine the effects of altering the values of critical product cycle parameters such as the ease of learning, the ease of adopting new products, and the pace at which goods become obsolete. In a world in which learning or adopting new products is more difficult, South is always at a greater relative disadvantage. The higher demand for newer products, and earlier accumulation of learning, puts North at an advantage over the South. Catch-up on the part of South now becomes more difficult. Although we model the learning parameters as exogenous, it is not hard to see that a country's ability to learn could be endogenous, possibly determined by the level of education of its population or investment in education. Policy measures in developing countries that make learning easier, thus, could become vital to the development process. For example, countries with a highly educated and adaptable labour force will be at an advantage, over less educated and adaptable countries.

Likewise, if developing countries try to hold on to old goods for a longer period of time, this tends to increase inequality in the long run even though there may be a temporary increase in the relative wage. In particular, if slowing the pace of obsolescence also reduces the rate at which a country learns to produce new products, then inequality will increase in the long run. In spite of the apparent short-term benefits, therefore, policies designed to prolong the life of obsolete industries should be undertaken with great care by developing countries because they may inadvertently stifle new learning.

Appendix

Existence and Stability of Long-Run Equilibria

Suppose that South would be in a position of trade deficit or balance, but not surplus, at the point where $\tilde{x}_S(t)=g$ and $w=1$. Consequently, the trade balance curve would cut through or above this point. Using Equation (19) this would imply:

$$\Lambda\frac{J(g)}{(1-J(g))}\geq 1. \qquad \text{(A1)}$$

This condition is more likely to hold: (i) the larger is North's relative endowment of efficiency units of labour; (ii) the smaller is extent of North's learning range, g, relative to the entire span of the product cycle, x. Under this condition, the values of w that are consistent with trade balance fall continuously from a value greater than or equal to one when $\tilde{x}_S(t)=g$ to zero when $\tilde{x}_S(t)=x$. Over the same interval, the values of w that are consistent with long-run competitive specialization fall continuously, but remain strictly less than one. The TB and LCS curves must, therefore, intersect at least once. If they intersect only once, the TB curve will cut the LCS curve from above so that the steady state equilibrium is locally stable as shown in Figure 2. Given that $\bar{x}_N(0)<\bar{x}_S(0)$, Equations (16)-(18) require that $w(0)\leq 1$, which in conjunction with condition (A1) implies that $\tilde{x}_S(0)>g$. The steady-state equilibrium is consequently globally, as well as locally, stable. Multiple steady-state equilibria are also possible when condition (A1) holds.

If condition (A1) does not hold, the TB and LCS loci *may* not cross in which case there are no long-run product-cycle equilibria where North maintains a lead in experience.

As a result, there will eventually be full convergence (i.e., $\bar{x} = 0$ and $\tilde{x}_S = \boldsymbol{x}$ with each country producing half the output of each of the goods that is subject to learning) or South will overtake North. Whether the latter or former situation arises depends on whether the analogue of condition (A1) applicable to South producing the most advanced goods does or does not hold. Even if the TB and LCS loci do cross when condition A1 is violated, we would obtain $\tilde{x}_S(0) < \boldsymbol{g} = \bar{x}_N$ for sufficiently small values of $\bar{x}_S(0)$. Such a short-run situation precludes global stability because it is inconsistent with North maintaining a lead in experience. With $\tilde{x}_S(0) < \boldsymbol{g}$, the long-run equilibrium again implies either full convergence or South overtaking North.

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Figure 1: Product-Cycle Overview

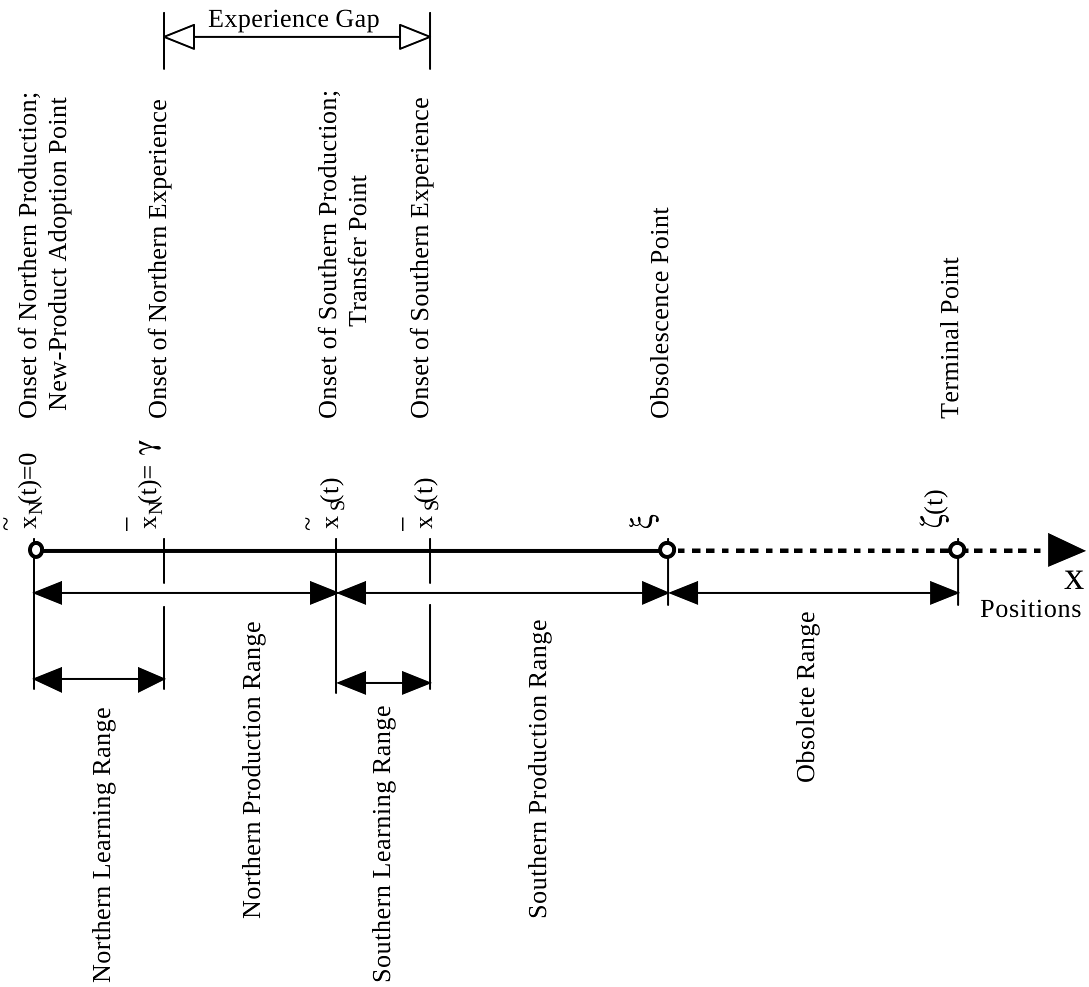

Figure 2: Product-Cycle Dynamics

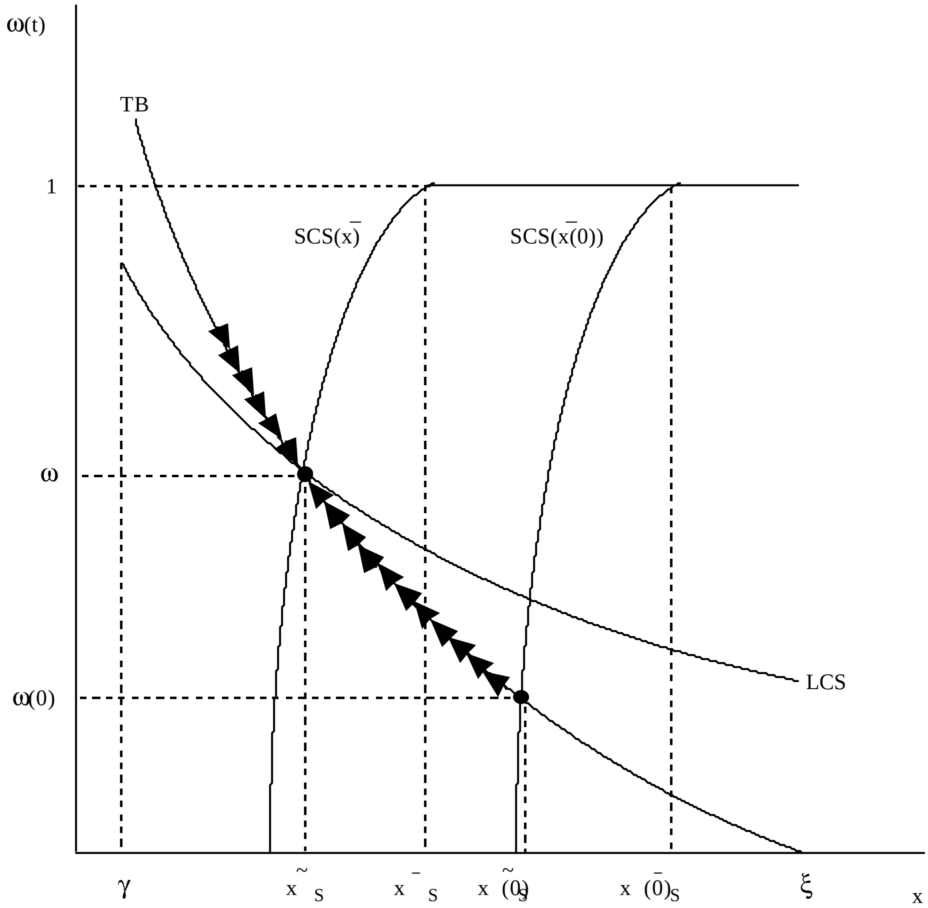

Figure 3: Larger Economies of Learning by Doing

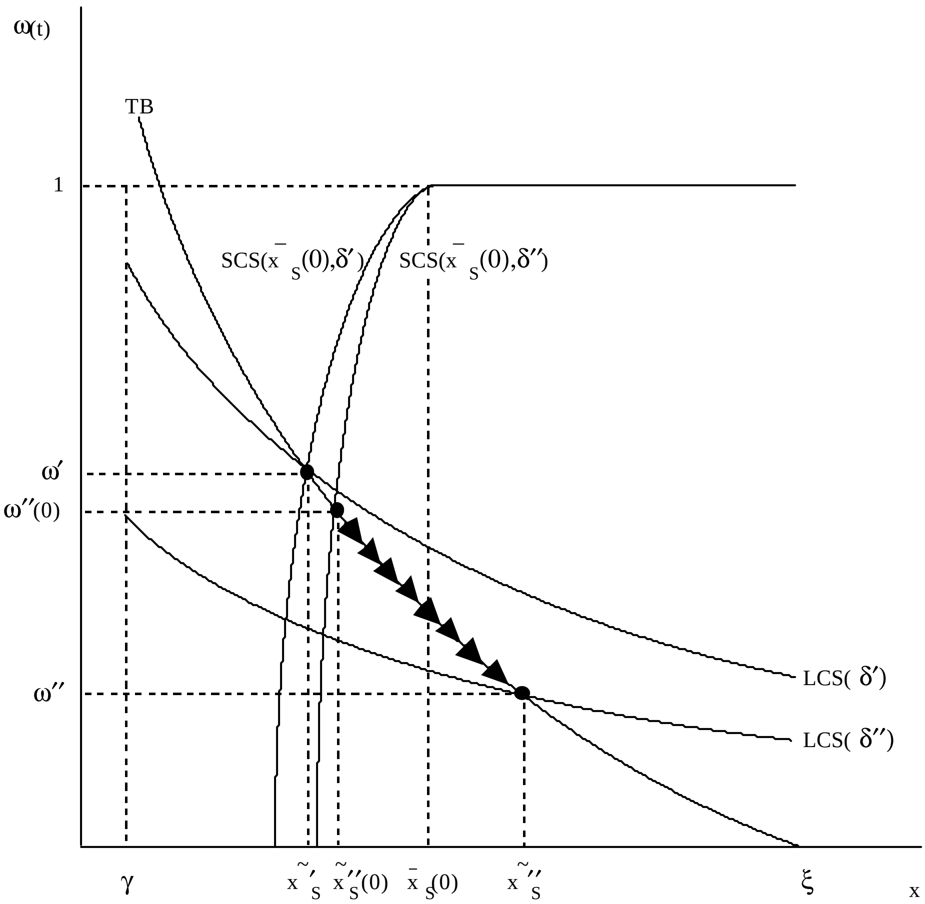

Figure 4: Later Obsolescence