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Industrial Development and the Convergence Question

By Marvin Goodfriend and John McDermott*

This paper studies endogenous world balanced-growth equilibria in which national learning productivity differentials govern relative per capita products. Learning productivities depend on the national share of world specialized-goods production, national and world scale, and familiarity with the foreign economy. Familiarity indexes the extent to which imported specialized goods enhance learning productivity. We find that mutual familiarization causes per capita products to converge. Unfamiliar economies diverge substantially and persistently. Unilateral familiarization of a less-developed country (LDC) with the leading economy causes the LDC to catch up to, and even overtake, the leader. (JEL F12, F43, N1, O11)

On the eve of the Industrial Revolution the variation in national living standards around the world was relatively small by today's standards. Per capita products diverged substantially during the nineteenth century as industrialization spread across Europe and North America. Only toward the end of the century did forces making for convergence among the leaders once again begin to assert themselves (Angus Maddison, 1982; William J. Baumol and Edward N. Wolff, 1988; J. Bradford DeLong, 1988). By 1900 a succession of 22 countries had achieved "turning points" marked by a significant, sustained jump in per capita product growth, and 12 more achieved turning points after that (Lloyd G. Reynolds, 1983). Industrialization was limited, however, and by the middle of the century it became clear that a large and persistent productivity gap had opened between industrial leaders and less-developed countries (World Bank, 1991; Stephen L. Parente and Edward C. Prescott, 1993). Lant Pritchett (1997) estimates that between 1870 and 1985 the proportional per capita income gap between the richest and poorest countries grew fivefold, increasing from 9 to 45.

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Industrial development has seen numerous shifts in relative standing among individual countries. Most famous perhaps is the overtaking of Great Britain by the United States at the end of the last century. Using Maddison's data for the period 1870 to 1979, Moses Abramovitz (1986) notes that Switzerland fell by eight places and Britain by ten in per capita product, while the United States and Germany both rose by four, and Norway, Sweden, and France rose by five, seven, and eight places, respectively. Japan achieved the most remarkable record of overtaking in the last 100 years, but the post-World War II growth miracles of the newly industrialized nations of the Pacific Rim also constitute spectacular and unexpected cases of less-developed countries rising rapidly into the ranks of the developed world (World Bank, 1993).

This paper presents a model designed to interpret the record of divergence, convergence, and overtaking of per capita products that has accompanied industrial development. We think that by modeling sweeping observations from economic history we can uncover clues about economic development not as apparent in data from specific countries and shorter time periods. Our model embodies three basic ideas. First, there must be a form of localized increasing returns that induces geographically concentrated industrialization. Such localized elements are the basis for divergence in the model. Second, it must be possible for knowhow developed in the industrial leaders to flow to the followers. This creates the potential for convergence. Finally, the model turns crucially on the idea that there is an important form of jointness in production—one analogous to the jointness in production emphasized in learning-by-doing models. Local production of certain goods enhances local production of human capital.

Many models that have looked at learning by doing alone predict divergence. Early leaders never lose their advantage. The combination of all three elements in our model shows how this prediction can go wrong. This possibility comes from the mix of localized elements in learning and the international flow of knowledge. These are mediated by a combination of trade in goods and a process that we summarize with a "familiarity" parameter.

Growth rates converge in our model, but national per capita products generally do not. If a lagging economy is unfamiliar with the leader, then the location of specialized-goods production matters a great deal. A growing share of specialized-goods production attracted to the leader reinforces its learning productivity advantage. And the world converges to a balanced-growth equilibrium with a wide gap in living standards. On the other hand, when countries are broadly familiar with each other the location of specialized-goods production matters little for learning productivity. Per capita products tend to converge because world scale exercises a more favorable effect on growth in the lagging than in the leading economy. In the limit, when familiarity is complete, so is the convergence of living standards.

Our notion of familiarity builds on the work of Luis A. Rivera-Batiz and Paul M. Romer (1991), who emphasize the importance of the international flow of ideas for growth. They study the effect on growth rates of integrating two identical economies, however, while we explore the implications of familiarity for relative per capita products. Our model is also reminiscent of one in Robert Tamura (1991), in which knowledge spillovers in the investment sector of an endogenous growth model cause incomes to converge. We, however, show how limited familiarity can account for incomplete convergence, and how familiarization of the lagging economy with the industrial leader makes overtaking possible.

The plan of the paper is as follows. World goods production is characterized in Section I. Section II motivates and describes the learning technology. World balanced growth is characterized in Section III. The model is employed in Section IV to interpret the history of industrial development. First, we use it to understand the divergence of national per capita products following the Industrial Revolution and the convergence among leading industrial economies thereafter. Then, we show why a large and persistent productivity gap can arise between a leading economy and a less-developed follower, and why it is so difficult to close. Finally, we analyze growth miracles—catching up and overtaking—by building on our analysis of the productivity gap. Section V concludes with a brief summary of our results.

I. World Goods Production

The world contains two countries each of which produces an identical, nonstorable final good with two inputs: human-capital augmented (effective) labor and nonstorable specialized intermediate inputs. Intermediate goods are produced with effective labor alone on a continuum over the range $M = M^A + M^B$, where M^A are produced in Country A and M^B in Country B. Through trade each country uses the full range of the world's specialized goods to produce the final good. The Appendix contains the formal specification of the goods-producing technology and the market structure, as well as the relevant derived equilibrium conditions. Each intermediate good is produced in identical fixed supply by a single firm in equilibrium. Moreover, the equilibrium world range of intermediate-goods production, M, is proportional to world scale as measured by the global effective labor supply, E.

National labor forces are immobile, but trade in goods equalizes the cost of comparably skilled labor across countries. This means that the cross-country wage differential is proportional to the difference in national per capita human capital. Since effective labor is the only factor of production, national per capita final-good output equals the product of the world base (unskilled) wage, national human capital per capita, and national work effort per person. The common worldwide base wage rises with world scale, E, due to increasing returns to specialization in the manner of Romer (1987).

We assume a small shipping cost so that intermediate-goods firms choose to locate in the country with the greatest demand for intermediate goods.[1] Intermediate-goods firms will exist in both countries if and only if sales in each market are the same. Hence, we determine the share S_M of intermediate-goods firms located in Country A under the condition of equal intermediate input use in the two countries:

(1) $$S_M = \frac{1}{2} + \frac{2S-1}{2\alpha},$$

[1] In general, both the final good and intermediate goods are traded, but since final-good firms produce a homogeneous good and are price takers, they are indifferent to location in equilibrium.

where $S_M \equiv M^A/M, S \equiv E^A/E$ is the share of world effective labor in Country A, and $0 < \alpha < 1$.[2] Since S_M must lie between 0 and 1, equation (1) is valid only for $(1-\alpha)/2 < S < (1+\alpha)/2$. Above this range, $S_M = 1$ and Country A produces all the world's intermediate goods; below it, $S_M = 0$ and all intermediate-goods production is located in Country B.

Equilibrium condition (1) says that a country's share of world specialized-goods production depends positively on its share of world effective labor. The dependence works as follows. An increase in the share of world effective labor in one country relative to the other raises the relative marginal product of intermediate inputs in the former, and so raises relative demand there, too. Specialized-goods producers react by moving to the larger market in sufficient number to eliminate the incipient inequality in market size unless the larger economy already produces all the world's specialized inputs.

II. National Learning Technologies

Individuals can devote time to learning in order to accumulate human capital. We identify three key elements that govern the productivity of the representative individual's learning time: own human capital, worldwide specialization, and familiarity with the foreign economy. We combine these in the following learning technology for the representative individual in Country i:

$$\dot{h}^i = e_L^i \left(h^i\right)^{1-\gamma} \left(\frac{\hat{M}^i}{n^i}\right)^{\gamma}, \tag{2}$$

where e_L is the fraction of time allocated to learning as opposed to working ($e_L \equiv 1 - e_W$), h is per capita human capital, n is city population, and $0 < \gamma < 1$. The functional form and exponent restrictions in (2) are chosen so that the model supports endogenous world balanced growth.

The argument $\hat{M}$ captures the effect of specialization on the learning productivity of a resident of Country i. Exposure and routine access to specialized goods enhances the productivity of time spent learning for two reasons. First, innovation involves problem solving which is facilitated by access to specialized tools and techniques. Second, specialized goods embody technical knowledge that helps point the way to future advances in technical know-how.

The variable $\hat{M}$ is a weighted average of the specialized intermediate goods produced domestically and globally. For Country A this is:

$$\hat{M}^A = (1-\kappa^A)M^A + \kappa^A M. \tag{3}$$

The parameter κ^A, which lies between 0 and 1, governs the extent to which the representative resident of Country A is familiar with Country B.

A value of κ near 1 indicates a *familiarity* with the foreign economy so great that the importation of specialized goods hardly involves a learning disadvantage. In this case, domestic residents understand well, through written material and personal experience, how imported

[2] S_M in (1) is found by equating (A6) and (A7) from the Appendix.

goods work and how they are made. Among other things, geographical proximity, active commercial relations, and a common language and culture facilitate indirect acquisition of technical understanding. A value of κ near 0, on the other hand, indicates that technical knowledge from abroad flows poorly, so that hands-on domestic production of specialized goods greatly facilitates learning.[3] Lack of familiarity acts as a brake on the international flow of ideas. In effect, our familiarity parameter governs the extent to which technological spillovers are geographically concentrated.[4]

We divide $\hat{M}$ by n so that the model supports a balanced-growth path in the presence of a growing population. Each country is allowed to have multiple cities because otherwise relative national per capita products would vary inversely with relative population size.[5] The distinction between intensive population (people per city) and extensive population (number of cities) enables the model to explain the convergence of national per capita products in countries with widely different populations.[6]

From (2) the rate of growth of per capita human capital in Country i can be compactly expressed as:

(4)
$$\left(\frac{\dot{h}}{h}\right)^i = LP^i e_L^i,$$

where:

$$LP^i \equiv \left(\frac{\hat{M}^i}{n^i h^i}\right)^\gamma.$$

Using (1), (3), (A4), and the definition of S_M we can express the LP (learning productivity) coefficients in (4) as follows:[7]

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3 De Long (1992) and Nathan Rosenberg (1976) present evidence that locally produced specialized goods used in production generate ideas for improving productivity more readily than less-well-understood imports.
4 See Romer (1986 example 3) and Gene Grossman and Elhanan Helpman (1991 Ch.8).
5 Cities within a country are entirely symmetric except that each produces a different subset of the range of the specialized goods produced nationally. Through trade each city acquires the full range of world specialized goods for use in final-good production. Our characterization of goods market equilibrium is unaffected by the distinction between extensive and intensive population.
6 See the related discussion in Robert E. Lucas, Jr. (1993 p. 263).
Duncan Black and Vernon Henderson (1997) present a model in which growth occurs in an economy with a stable relative size distribution of cities. Individual cities grow with human capital accumulation; and cities grow in number if national population growth is high enough.
7 In terms of the underlying goods-producing technology described in the Appendix, the constants are as follows: $a \equiv 1/C(\tilde{x}), b \equiv (1+\alpha)/2C(\tilde{x})$, and $\tilde{\kappa} \equiv (1-\alpha)/(1+\alpha)$.

$$(5) \quad LP^A \equiv (e_W^A v^A)^\gamma \times \left[a(1-\kappa^A) + b(\kappa^A - \tilde{\kappa}) \frac{1}{S} \right]^\gamma,$$

$$(6) \quad LP^B \equiv (e_W^B v^B)^\gamma \times \left[a(1-\kappa^B) + b(\kappa^B - \tilde{\kappa}) \frac{1}{1-S} \right]^\gamma,$$

where, as noted above, S is Country A's share of the world effective supply of labor: $S \equiv E^A/E, E \equiv E^A + E^B$, and $E^i \equiv e_W^i h^i n^i v^i$.[8] The parameter v^i represents the number of cities in Country i, so that $v^i n^i$ is national population.

As will be seen in Section IV, the essence of our model is embodied in expressions (5) and (6). In particular, the three arguments, v^i, κ^i, and S will be central to our characterization of balanced growth. They influence the respective national learning productivities as follows.

First, a parametric increase in the number of a country's cities v^i raises its learning productivity through a national scale effect that raises the range of specialized goods available locally.

Second, as long as a country imports some specialized inputs, a parametric rise in its familiarity with the foreign economy (higher κ^i) raises its learning productivity due to a familiarity effect.[9]

Third, a change in S has conflicting effects on learning productivity. From the perspective of Country B, for instance, an increase in Country A's share, S, of world effective labor raises B's learning productivity by increasing the range of specialized goods available through trade. But the increase in S also causes some intermediate-goods production to relocate to Country A. The world scale effect raises B's learning productivity and the relocation effect reduces it. The scale effect dominates if Country B is sufficiently familiar with Country A that $\kappa^B > \tilde{\kappa}$. Then, Country B's learning productivity rises with S. On the other hand, when Country

[8] Expressions (5) and (6) only determine the national LP coefficients when $0 < S_M < 1$. When $S_M = 1$, the LP coefficients are given by (B1) in the Appendix; when $S_M = 0$, they are given by (B2). We make use of the corner cases in Section IV.
[9] Formally, this follows from the definitions of a and b in footnote 7, and the expression for the interior range of S that appears after (1).

B is insufficiently familiar with Country A, so that $\kappa^B < \tilde{\kappa}$, the relocation effect dominates and a rise in S reduces Country B's learning productivity.

III. World Balanced Growth

Our goal in this section is to characterize world balanced-growth equilibria in the model using the expressions for national learning productivity derived in Section II. In particular, we seek to determine the stationary value of Country A's share of world effective labor, S^*, that supports world balanced growth. Assuming that the world is populated by infinitely lived, utility-maximizing households, it is straightforward to show that the model economy converges to a balanced path along which effort allocations are constant and national per capita products grow at a common, constant rate.[10]

Since effort allocations are constant in balanced growth, and we take the number of cities v in a country as a fixed parameter, S is stationary if and only if hn grows at the same rate in the two countries. If we assume further that national population growth rates are the same, then the stationarity of S requires that per capita human capital grow at the same rate. Time allocated to learning depends positively and identically on the respective national learning productivity coefficients, LP^i. Hence, according to (4), S^* is the value that equates the national learning productivities, LP^A and LP^B.[11]

We characterize balanced growth diagrammatically because it is more convenient for our purposes than working with the analytical solution for S^*. The balanced-growth equilibrium is illustrated in Figure 1 for two countries sufficiently familiar with each other that both κ^A and κ^B exceed $\tilde{\kappa}$. The solid locus represents LP^A and the dashed locus LP^B. In the interior, where specialized inputs are produced in both countries, the loci are representations of (5) and (6), respectively. The segments of the loci in the corners (where intermediate inputs are produced only in one country) are representations from (B1) and (B2) in the Appendix.[12] Familiarity with the foreign economy is irrelevant for a country that imports no intermediate inputs. A country's learning productivity locus is anchored along the vertical axis by its value in autarky.[13]

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[10] The wealth and substitution effects of human capital per capita are offsetting in balanced growth, so that effort allocations are independent of h.

[11] Equality of LP^A and LP^B supports balanced growth when national population growth rates (η), pure rates of time preference (ρ), and γ in (2) are the same for Country A and Country B. In this case, the national effort allocations are identical. Using a procedure that parallels the one in Goodfriend and McDermott (1995) we can show that work effort is given by $e_W^* = (1/(1+\gamma))[\gamma + (\rho - \eta)/LP^*]$, where $\rho > \eta$. Learning effort is then $e_L^* = 1 - e_W^*$.
If the parameters above are not the same across countries, the values of LP^A and LP^B that support a stationary share of effective labor, S^*, differ from each other, as do the national effort allocations.

[12] To restrict the relevant LP loci to reflect balanced growth we require that $e_W = e_W^*$ as given in footnote 11. Notice that the direct effect of a change in κ^i or S on LP^A or LP^B is attenuated somewhat by an indirect negative effect of LP^i working through e_W^*.

[13] The respective national learning productivities in autarky are given by $\phi_{aut}^i(v^i)^\gamma$, where $\phi_{aut}^i \equiv (\alpha e_W^i / C(\tilde{x}))^\gamma$.

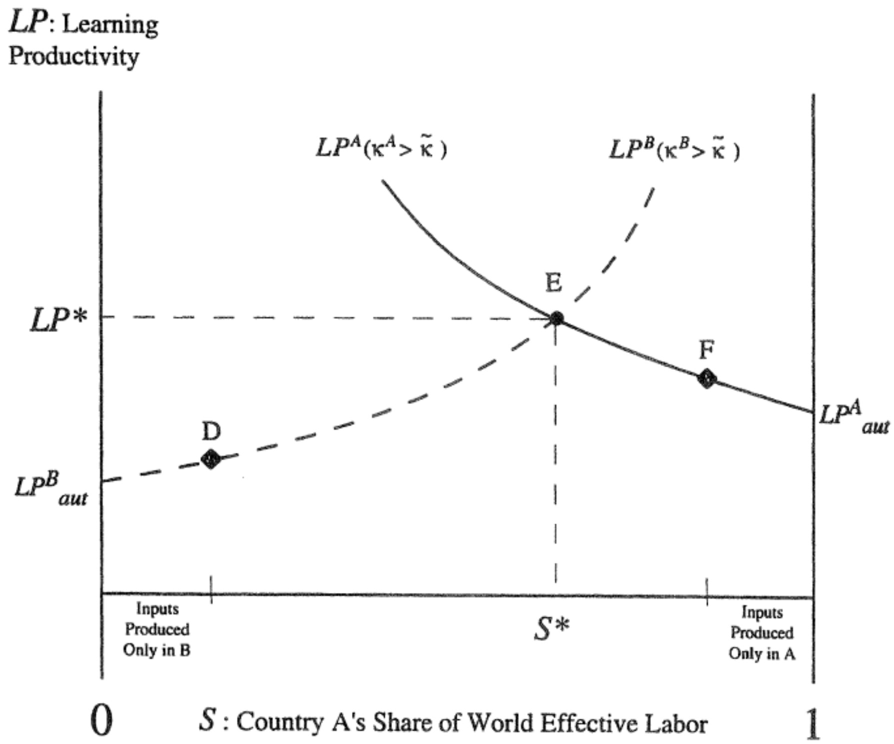

FIGURE 1. WORLD BALANCED GROWTH

The stationary value S^* and the common learning productivity coefficient LP^* are determined by the intersection of the learning productivity loci at point Ein Figure 1. The common balanced-growth rate of national per capita products in the model is the sum of human capital growth and a term reflecting the scale effects of a growing world effective supply of labor. The latter term grows, in turn, with the sum of human capital and population growth. Hence, by differentiating (A5) in the Appendix and substituting from (4), the balanced-growth rate of per capita product can be expressed as:

(7) $$\frac{\dot{y}}{y} = (2-\alpha)LP * e_L^* + (1-\alpha)\eta,$$

where η is a common national population growth rate. Effort allocated to learning de- pends positively on learning productivity, so world per capita product growth varies directly with learning productivity.[14]

Although growth rates converge in our model, national per capita products can vary widely along a balanced path. We shall see why this is the case below, when we use the model to interpret the history of industrial development in Section IV. However, we note here that the ratio of Country A's to Country B's per capita product in balanced growth can be expressed as:[15]

[14] The balanced-growth allocation of effort to learning is given by $e_L^* = 1 - (1/(1+\gamma))[\gamma + (\rho - \eta)/LP^*]$.
[15] Equation (8) is easily derived using (A5) together with the definitions of E^i and S.

(8) $$\frac{y^A}{y^B} = \frac{v^B}{v^A}\frac{n^B}{n^A}\frac{S^*}{(1-S^*)}.$$

Given the v^i and n^i that index relative national scale, expression (8) indicates that the ratio of the per capita product of Country A to Country B varies directly with Country A's share, S, of the world effective supply of labor. We use (8) extensively in the analysis that follows.

To illustrate the mechanics of the model, consider what would happen if the two countries became more familiar with each other, rotating the two LP curves in Figure 1 upward so as to keep S^* unchanged. According to (8), relative per capita product would stay the same. Mutual familiarization, however, would increase LP^* and raise the world growth rate by (7) as knowledge flowed more easily in both directions. If only one nation increased its familiarity with the other, world growth would still increase but, since S^* would change in this case, the nation that increased its familiarity with the other would experience a relative rise in its living standard.

IV. Interpreting the History of Industrial Development

Prior to the Industrial Revolution, the variation in living standards around the world appears to have been due to differences in regional market size and proximity to international trade routes. In Europe, for instance, the fact that some regions were not well integrated with the rest—the Iberian Peninsula and Eastern Europe—while others such as the Netherlands profited greatly from trade, meant that there could be substantial variation in incomes. For those portions of Europe linked by trade, however, the variation in living standards was probably smaller on the eve of the Industrial Revolution than it was to be for the next 150 years.

The potential profit from commerce encouraged an ongoing effort to reduce transport costs that steadily expanded trade in the centuries before the Industrial Revolution (Daniel Boorstin, 1983; Carlo M. Cipolla, 1985). Along with the rising tide of commerce came rising living standards based on ever-greater specialization made possible by increasing market size. Goodfriend and McDermott (1995) argue that trade and population growth increased specialization and eventually raised learning productivity enough to initiate the self-sustaining technological progress that gives rise to modern industrial growth.[16]

A. The Divergence and Subsequent Convergence of National Per Capita Products

Our model provides a natural interpretation of the tendency for industrialization to cause national per capita products to diverge initially and to converge again over time. The interpretation flows from the fact that the model implies that two very different mechanisms determine equilibrium relative per capita products in the pre-industrial and post-industrial eras.

In terms of the model, we interpret the preindustrial era as the period prior to the activation of national learning technologies, that is, prior to the period of fundamental technological progress marked by the accumulation of human capital. In the pre-industrial interpretation of the model, per capita product differentials are governed by the fact that trade

[16] The idea that trade assisted the growth of knowledge is an old one. It is found, for example in the work of David Landes (1969) and Walt W. Rostow (1975).

equalizes the cost of comparably skilled labor across countries. Thus, national per capita products are tied to differences in know-how indexed by human capital per person. By all accounts, know-how did not differ widely across countries tightly linked by trade on the eve of the Industrial Revolution. Hence, our model leads one to expect that differences in standards of living would not be very large either.

In marked contrast, human capital accumulation is the engine of modern industrial growth in our model. The per capita product differential between two industrial economies is governed by forces pushing them toward balanced growth according to Figure 1. In particular, relative national standing is determined by relative national learning productivities, which in turn depend on familiarity and national scale. Other things the same, the country more familiar with its trading partner achieves higher per capita product; and the country with more cities ultimately does better. Our model suggests that industrialization caused national per capita products to diverge initially because of differences among nations in scale and familiarity with foreign economies.

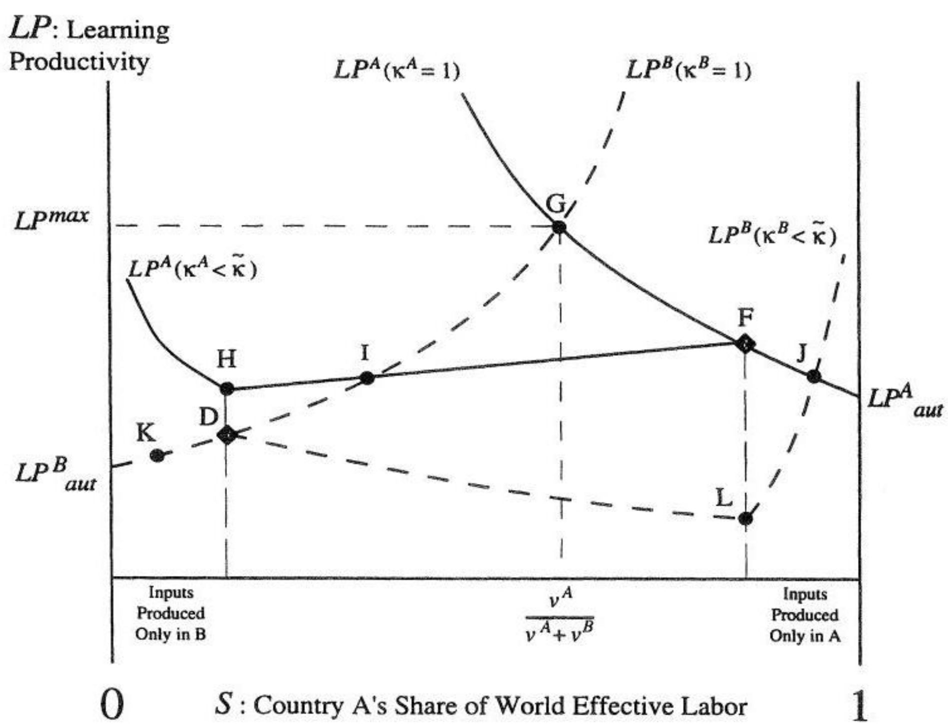

FIGURE 2. ANALYSIS OF BALANCED-GROWTH EQUILIBRIA

Although familiarity is a parameter in our model, it is easy to see that familiarity would grow over time with the economy. Nations become more familiar with each other as technological progress lowers transport and communication costs, trade increases, and business and cultural contacts multiply. The limit to mutual familiarization in our model occurs when $\kappa^A = \kappa^B = 1$. The equilibrium that results from such complete or perfect familiarity is shown as point Gin Figure 2. There is no longer any learning productivity advantage to the domestic production of specialized goods. The common learning productivity goes to LP^{max} and according to (7) world growth reaches its maximum. Mutual familiarization also moves S^* to $v^A/(v^A + v^B)$ so that according to (8) per capita products converge absolutely if national city sizes (n^i) are equal.[17] To the extent that national scale is associated with number of cities rather than average city size, our model identifies in mutual familiarization a powerful force causing the per capita products of industrialized countries to converge over time.

B. The Great Productivity Gap

One of the most disturbing outcomes in the history of industrial development has been the emergence and persistence of a large gap in living standards between the leading industrial economies and less-developed countries. Our model locates the problem in an LDC's extreme lack of familiarity with the leading economy due to such barriers as distance, language, and culture, or deliberate impediments to commercial intercourse.[18]

To illustrate the point, suppose that Country B is so unfamiliar with Country A that κ^B is less than $\tilde{\kappa}$ and Country B's learning productivity locus looks like KDLJ in Figure 2. Lack of Country B familiarity with Country A causes the relocation effect of an increase in S to dominate the scale effect, so that the LP^B locus slopes downward between points D and L. Thus, the LP^B locus passes below the LP^A locus until the former comes up to intersect the latter from below at point J. The extreme lack of familiarity of Country B with Country A puts the balanced-growth equilibrium at point J far to the right and leaves Country A with a very large fraction, S^*, of the world's effective labor supply. According to (8), a value of S^* near unity makes Country A's per capita product enormously greater than that of Country B.

Even though wages for comparably skilled workers are the same in the two countries, the typical worker in Country A has accumulated far more human capital in balanced growth than his counterpart in Country B. The differential in human capital per capita sustains the huge productivity gap that supports the large difference in living standards. Nevertheless, S^* is large enough in balanced growth that the national learning productivity coefficients are the same and the two countries grow at the same rate.

The wide productivity gap develops because the lagging economy's lack of familiarity with the leader makes the relocation effect dominate the scale effect. The growing share of specialized-goods production attracted to the leading country reinforces its initial learning productivity advantage. The leader grows faster, and the follower grows more slowly, until the leader has attracted all of the world's specialized-goods production.[19] Thereafter, the relocation

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[17] To see that complete familiarity drives S^* to $v^A/(v^A\ v^B\ )$, set $\kappa^A = \kappa^B = 1$ in (5) and (6), equate the two, anc solve for S.

[18] Parente and Prescott (1994) study the effect on relative living standards of deliberate barriers to technology adoption.

[19] The force making for divergence in our model is reminiscent of that in Alwyn Young (1991). In his model, trade creates a divergence in growth rates by shifting the composition of output in the follower to older industries for which learning by doing has been nearly exhausted, and does the reverse in the leader.

effect ceases to operate and the leader's learning productivity begins to fall toward its level in autarky. Simultaneously, the follower's learning productivity begins to rise as the lagging economy benefits increasingly from the growing relative size of the leader. National learning productivities converge gradually as the world asymptotically approaches balanced growth.

Our model suggests that an enormous productivity gap is hard to close because it inhibits the kind of commercial interaction that promotes familiarization. In the model, the LDC produces no specialized goods for export to the leader and imports very little.[20] Thus the model reproduces a pattern that has become well established and is likely to continue for some time: most developed and less-developed countries continue to grow at similar rates, but with staggering differences in income levels.[21]

C. Growth Miracles: Catching Up and Overtaking

History has recorded extraordinary examples of catching up and overtaking of per capita products of leading economies by less-developed countries. Much has been written about growth miracles in an effort to isolate the secret of their success.[22] Our model identifies the familiarization of the less-developed country with the leading economy as the source of growth miracles. Familiarization not only explains catching up, but also the more puzzling phenomena of overtaking.

We understand growth miracles in our model by building on the analysis of the productivity gap. To begin, suppose that Countries A and B are so unfamiliar with each other that both κ^A and κ^B fall short of $\tilde{\kappa}$. Take the LP^A locus in Figure 2 to be HIFJ and the LP^B locus to be KDLJ so that a unique balanced-growth equilibrium exists initially at point J, where as before Country A is the leading economy and Country B lags far behind.

To see what happens when Country B familiarizes itself with Country A consider a parametric increase in κ^B. We justify holding κ^A fixed by the fact that Country A produces all the world's specialized goods and would have little interest in the less-developed economy. As κ^B increases, the LP^B locus rotates counterclockwise around point D, moving the balanced-growth equilibrium first to F and eventually all the way to I if Country B completely familiarizes itself with Country A.

Familiarization raises Country B's LP schedule because it better enables the less-developed country to learn from imported specialized goods. As a result, Country B begins to

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[20] See (A6) and (A7), recognizing that x^A and x^B differ from each other in a corner where S_M equals 0 or 1.

[21] It is worth pointing out that multiple equilibria are possible in our model when mutual national familiarity is low enough. If Country A's familiarity with Country B were even lower than that shown in Figure 2, the LP^A locus could end up crossing the LP^B locus three times. Another stable balanced-growth equilibrium could exist to the left of point D and there would be an unstable balanced-growth equilibrium in the interior.

[22] For a recent example, see Lucas (1993).

accumulate technological know-how (human capital) more rapidly than Country A and Country A's share of world effective labor, S, falls as the world converges to the new balanced-growth equilibrium.

If city sizes are the same in the two countries, we see from (8) that Country B catches up, i.e., achieves equality, with Country A in per capita product if S falls to $v^A/(v^A + v^B)$. Overtaking of per capita products occurs if Country B familiarizes itself sufficiently with Country A to push S below $v^A/(v^A + v^B)$. The room for overtaking is greater the less familiar the initial leader remains with the surging economy. In fact, Figure 2 makes clear that if Country A were to completely familiarize itself with the rising economy, the best the latter could do would be to achieve equality of per capita products at point G (again, assuming city sizes to be the same).

Figure 2 reveals a possible side effect of catching up: in this case catching up is only good for world growth up to a point. Country B's familiarization with A raises the common world growth rate only until point F is reached. Once the equilibrium has moved to the left of F, however, increases in B's familiarity cause specialized-goods firms to leave A. If A is sufficiently unfamiliar with B that the relocation effect dominates the scale effect, as assumed here, then the common balanced-growth rate actually falls as B continues to catch up with A. Thus, world growth could fall over some range because Country B experiences a growth miracle.[23]

This suggests that the world productivity slowdown since the 1970's (e.g., Parente and Prescott, 1993) may have been due, in part, to the Asian growth miracles. Catching up, accomplished by familiarization with the West, has led to a surge in the number of specialized goods produced in the East. According to our model, the relocation is potentially harmful to growth in the West, and may reduce growth worldwide if Western nations remain unfamiliar with the rising nations of the Pacific.[24] By the same token, world growth will ultimately increase as Western nations familiarize themselves with the East.

Our view that catching up reflects a familiarization with industrial leaders on the part of less-developed countries appears to be consistent with the evidence. The Japanese growth miracle, for example, seems closely tied to increasing familiarity with the West. It began in 1868 with deliberate steps following the Meiji Restoration to adopt Western ways (William Lockwood, 1954 Ch. 6). The significant U.S. presence in Japan immediately following World War II and during the Korean and Vietnam Wars further familiarized Japan with developments outside of Asia. Our model suggests that the protracted U.S. involvement in the Far East, especially in Japan and South Korea, may have helped lay the groundwork for the postwar

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[23] Point I could be higher or lower than J, so ultimately B's growth miracle could be either good or bad for world growth.

[24] What we have in mind here, for example, is the idea that Japanese firms have become increasingly familiar with the chip-making techniques developed originally in the United States. On the other hand, the United States has been slower to learn about Japanese technology for making LCD screens. Thus, firms in the United States that once had direct access to the latest technology, are now unable to access parts that are being developed in Japan.

growth miracles of the Pacific Rim by familiarizing people in those nations with the United States.[25]

The model predicts that anything building a "familiarity bridge" from less-developed countries to industrial leaders helps the former to catch up. In this view, the first wave of developed nations on the Pacific Rim may be serving as a bridge for a second wave of Asian nations. China's rapidly growing coastal provinces have benefited greatly from the nearby Chinese-speaking economies of Hong Kong and Taiwan (*Economist*, November 28, 1992). One might even imagine that the westernmost nations of the old Soviet bloc might reindustrialize first and then serve as a familiarity bridge for the regions of the old Soviet Union itself.[26]

8. Conclusion

We began by summarizing the diverse patterns of convergence, divergence, and overtaking that have characterized industrial development. Although such phenomena would appear to fit together awkwardly, we presented a model of endogenous growth capable of delivering the wide range of outcomes that we have observed.

We endowed two countries with identical goods-producing technologies and, through trade, gave each access to the full world range of specialized intermediate goods. Goods productivity differentials arose because of differences in national know-how as indexed by per capita human capital. At the heart of our model was the idea that national learning productivities would differ depending on how well technical knowledge could be absorbed without the hands-on experience that comes with domestic production. Familiarity with the foreign economy raised a country's learning productivity by enabling it to better understand the design and manufacture of imported specialized goods. Learning productivity differentials did not lead to permanent growth differentials, however, but rather determined relative international standing in world balanced growth.

The major theme of our paper is that the efficiency with which knowledge can be acquired is a primary determinant of relative per capita products in the long run. Countries that promote openness and familiarity with others find it easier to acquire know-how and will eventually catch up to or even overtake the per capita product levels of more advanced trading partners. Less-developed countries that cannot increase their familiarity with the developed world will persistently lag world leaders, perhaps by staggering amounts. On the other hand, countries that now lead cannot afford to be complacent—a refusal to keep in touch with the know-how being developed abroad may force them to surrender their lead.

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[25] The source of growth miracles remains controversial. Young (1995), for instance, shows that much of Singapore's growth was due to rising labor-force participation rates and physical capital, not technical change.

[26] The beneficial effects of a familiarity bridge would be offset to the extent that familiarization gives rise to an out-migration of the sort commonly referred to as a brain drain.

APPENDIX A: Goods-Market Equilibrium

Two countries, A and B, each produce an identical final good, Y, with the same technology. Output is generated by perfectly competitive firms within Country $i(i = \text{A}, \text{B})$ using the following production function:

$$Y^i = \left(e_Y^i h^i N^i\right)^{1-\alpha} \times \left\{\int_0^{M^A} [x^{Ai}(\tau)]^\alpha d\tau + \int_{M^A}^{M} [x^{Bi}(\tau)]^\alpha d\tau\right\}, \tag{A1}$$

where $0 < \alpha < 1$. The labor-force numbers N^i individuals, each possessing human capital h^i, and working a fraction e_Y^i of time in the final-good sector. Effective labor, $e_Y^i h^i N^i$, cooperates with intermediate-input goods (indexed by τ) that are produced in both countries. Inputs produced in Country A, called x^{Ai}, exist on a continuum over the range M^A, while those from Country B, x^{Bi}, are produced on the range $M^B = \dot{M} - M^A$. This production function exhibits constant returns to scale given M^A and M^B, but it also captures the notion that specialization raises worker productivity.

Intermediate-good inputs that originate in Country i are produced with effective labor alone by M^i different monopolistically competitive firms. The labor cost of producing the quantity x of any input in either country is given by $C(x)/h$, where $C'(x) > 0$ and $C''(x) > 0$.

Each individual in Country i splits his total work effort e_W^i between final production and intermediate production:

$$e_W^i = e_Y^i + e_I^i. \tag{A2}$$

The total demand for labor to produce intermediates must equal the available supply:

$$M^i \frac{C(x^i)}{h^i} = e_I^i N^i. \tag{A3}$$

In equilibrium, each input is produced by a single monopolistic competitor in fixed supply $\tilde{x}$. Global specialization, *M,* is proportional to the world effective labor supply, *E*:

$$M = \frac{\alpha}{C(\tilde{x})} E. \tag{A4}$$

Per capita output of Country i is proportional to h and e_W, and increases with *E*:

$$y^i = \beta E^{1-\alpha} h^i e_W^i, \tag{A5}$$

where $\beta \equiv \alpha(1-\alpha)^{1-\alpha}\tilde{x}^\alpha / C(\tilde{x})$, and $\beta E^{1-\alpha}$ is the common worldwide base wage, or the wage of a worker with one unit of human capital.

Intermediate-goods uses in the two countries are as follows:

(A6) $$x^A = \theta(S - \alpha S_M),$$

(A7) $$x^B = \theta[(1 - S) - \alpha(1 - S_M)],$$

where: $S_M \equiv M^A/M, \theta \equiv \tilde{x}/(1-\alpha)$, and $S \equiv E^A/E$ is Country A's share of the world's effective labor supply.

The interior solution for S_M given in equation (1) in the text is found by equating (A6) and (A7). To see that the value of S_M in (1) is indeed an equilibrium, consider an arbitrary relocation of intermediate-goods firms between the two countries. This positive perturbation of S_M shifts labor from the final good to the intermediate-goods sector in Country A and does the reverse in Country B. By (A6) and (A7) this decreases the demand for intermediate inputs in A and increases it in B, causing intermediate-goods producers to relocate to B until the initial perturbation is reversed.

APPENDIX B: Learning Productivity in the Corners

According to (1), Country A produces all of the intermediate inputs ($S_M = 1$) when $S \geq (1+\alpha)/2$. In this case, the national learning productivity coefficients are given by:

(B1)
$$\begin{aligned} LP^A &= \phi^A (v^A)^\gamma \left(\frac{1}{S}\right)^\gamma, \\ LP^B &= \phi^B (v^B)^\gamma \left(\frac{\kappa^B}{1-S}\right)^\gamma, \end{aligned}$$

where $\phi^i \equiv \left(\alpha e_W^i / C(\tilde{x})\right)^\gamma$.

On the other hand, when $S \leq (1-\alpha)/2$ Country B produces all of the intermediate inputs ($S_M = 0$) and we have:

(B2)
$$\begin{aligned} LP^A &= \phi^A (v^A)^\gamma \left(\frac{\kappa^A}{S}\right)^\gamma, \\ LP^B &= \phi^B (v^B)^\gamma \left(\frac{1}{1-S}\right)^\gamma. \end{aligned}$$

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