GROWTH, TECHNOLOGY TRANSFER, AND THE LONG-RUN THEORY OF INTERNATIONAL CAPITAL MOVEMENTS

Jian-Ye WANG*

International Monetary Fund, Washington, D.C. 20431, USA

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This paper provides a model of growth and international capital movements. Technology is assumed to be transferred via international capital movements from the developed North to the developing South. It is shown that when the South shifts from autarky to free capital mobility, its steady-state growth rate of per capita income rises. Also, under free capital movements, an increase in the autarkic growth rate of human capital and/or technological diffusion rate in the South, lowers the steady-state income gap between the North and the South.

1. Introduction

Two theories have played prominent roles in our understanding of long-run international capital movements: the static, one-commodity models originated by MacDougall (1960) and Kemp (1961); and the neoclassical theory of growth, typically the one-sector models à la Solow [e.g. see Ruffin (1979) and Buiter (1981)]. Both assume a constant-returns-to-scale production function with inputs of capital and labor. Technological change is assumed to be exogenous or an ad hoc function of variables that can be analyzed separately from the basic factors of production. In the absence of international factor mobility, these theories predict that countries with the same preferences and technology will converge to identical levels of income and asymptotic growth rates. Factor mobility reinforces this prediction. Capital will flow from capital-abundant countries to where it is scarce. It makes no difference whether capital moves to join labor or the other way around. The long-run equilibrium is characterized by the international equalization of capital–labor ratios and factor prices.

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In addition to these unsatisfactory predictions, the theoretical literature on growth and international capital movements neglects technology transfer via direct foreign investment, with few exceptions [e.g. Findlay (1978)]. It is somewhat surprising that despite its empirical importance, the subject of foreign investment and technology transfer in a growth setting has received such scant investigation.

The purpose of this paper is to build a dynamic two-country model to study the interactions among growth, technological change, and international capital movements. The model extends the MacDougall–Kemp–Ruffin framework by adding to the production function a country-specific variable labeled human capital. Perfect capital mobility links the two regions. Human capital plays an important role in determining the effective rate of return for physical capital and hence affects the direction and the magnitude of international capital movements. The analysis incorporates a hypothesis on technology transfer, proposed by Findlay (1978), that the rate of technological change in a less developed country (LDC) will be an increasing function of the amount of foreign capital operating in the LDC and of the extent to which the technology in the advanced country exceeds that in the LDC. The predictions of the model are consistent with the observations on North–South capital movements and wage differentials.

In this model, shifting from autarky to perfect capital mobility raises the long-run growth rate of the South. This implies that the South's long-run level of income or consumption is higher under free capital movements than under autarky. The income gap between North and South, defined as the two regions' ratio of per capita incomes, is narrowed and becomes a constant in the steady state. Saving propensities and the autarky rates of technological progress in the two regions as well as the South's technology diffusion rate jointly determine the steady-state income gap. With capital already moving internationally, the steady-state income gap is narrowed by an increase in the autarkic growth rate of human capital and/or technology diffusion rate in the South. The model thus admits the possibility that the LDC can catch up completely. These results extend Ruffin's (1979) and Buiter's (1981) theorems on the gains from free capital mobility. Ruffin uses a two-country version of the one-good Solow model, while Buiter uses a Diamond (1965) overlapping generations framework. Ruffin shows that shifting from autarky to free capital mobility raises the levels of per capita income in both countries.

The analysis presented in this paper also relates to the recent literature on the relationship between international trade and economic growth. This new line of inquiry, drawing on the recent developments in the theory of growth and industrial organization, highlights the roles of knowledge

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1See Grossman and Helpman (1989a,b) for a list of references. An earlier survey and discussion of the topic is contained in Helpman (1988).
accumulation and international dissemination in explaining how trade structure and trade policy affect rates of growth. While Grossman and Helpman (1989a, b) and Wang (1989) deal with international technology diffusion associated with trade in goods, this paper focuses on technology transfer via international capital movements. Helpman (1988) discusses briefly the implications of international capital movements in the context of endogenous growth, focusing on how economies of scale, which rival diminishing returns in affecting the marginal productivity of capital and eventually drive long-run growth, interact with free capital movements. He observes that there may be agglomeration effects in capital accumulation in models where the externality comes from the stock of capital. Technology transfer along with foreign investment, which is central in this paper, is not an explicit element in Helpman's discussion, however.

Section 2 of this paper presents the static model and some useful comparative static results that prepare the ground for the dynamic analysis. Section 3 introduces the dynamic equations, which contain a key hypothesis on technology transfer. 'Endogenized' technical change thereafter drives the model along its long-run growth path. Steady-state comparisons between autarky and free capital mobility, which generate our main propositions, are presented there. The long-run equilibrium effects of changes in various parameters, such as saving rates and the rate of technology diffusion, are analyzed in section 4. Finally, section 5 concludes with brief remarks on policy implications and suggestions for possible future work.

2. The static model

For simplicity, the model assumes a one-good, two-country configuration. The two economies not only have different capital-labor ratios, but also have different qualities of labor or different stocks of technical knowledge. I use the term 'human capital' to refer to human knowledge, which can be accumulated over time without bound, so it cannot be measured by observables like schooling and experience. In aggregate, the average human capital within an economy gives a measure of the stock of technical knowledge, and hence can be regarded as an indicator of the technology level there.

Suppose that the total labor supply is \( L \). Full employment is assumed. Let \( L(h) \) be the number of workers with knowledge \( h \). Then total labor is \( L = \int_{h \in H} L(h) \, dh \) and the effective work force is \( E = \int_{h \in H} hL(h) \, dh \). The average level of human capital in this economy is \( h_a = E/L \). For simplicity, and without loss of generality, I assume each worker has the identical level of human capital, \( h \), so \( h_a = h \). The production function is assumed to be \( Q = F(K, E) \). \( F(\cdot) \) is twice differentiable and homogeneous of degree one with
respect to both arguments. In the rest of the paper, the specific functional form of $F$ is taken to be Cobb-Douglas, that is, $Q = K^\beta (hL)^{1-\beta}$. I can write per capita output as $Q/L = h^{1-\beta} (K/L)^\beta = \Omega(h)f(K/L)$. The contribution of human capital to production is summarized by the power function, $\Omega(h) \equiv h^{1-\beta}$. $\beta$ is assumed to be identical for both countries. By the previous assumption, $h_s = h$, $\Omega(h)$ can be interpreted as an index of the technology level of an economy.

Endowments of labor in both countries are assumed to be identical, for simplicity. Let the subscripts $S$ and $N$ denote home (South) and foreign (North), respectively. The two economies are endowed with different amounts of both physical and human capital:

$$K_S < K_N, \quad h_S < h_N.$$ (1)

Define the usual per capita quantities:

$$y_i = Y_i/L_i, \quad k_i = K_i/L_i,$$

$$w_i = W_i/L_i, \quad z = Z/L_N, \quad i = S, N,$$

where $Y_i$ and $W_i$ are national income (GNP) and the wage bill in country $t$, respectively, and $Z$ is the amount of foreign capital located in the home country. I define two fundamental variables of this paper: relative (physical) capital intensity, $k$, and the technology gap, $q$, between the two regions:

$$k = k_S/k_N, \quad q = h_N/h_S.$$  

Note that $k_S$ is in the numerator of $k$ and $h_S$ in the denominator of $q$. This convention is made to facilitate a diagrammatic presentation of the equilibria of the world economy in the discussion that follows.

The capital-labor ratio is $k_S + z$ at home and $k_N - z$ abroad, hence the per capita production functions for both countries can be written as $\Omega(h_S)f(k_S + z)$ and $\Omega(h_N)g(k_N - z)$, respectively. The functions $f(\cdot)$ and $g(\cdot)$ are identical and satisfy all the neoclassical properties, including Inada

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2This specification is adopted to simplify the algebraic presentation. Allowing human capital to have a positive external effect on the production possibilities of the economy [e.g. Lucas (1988)] will reinforce the analysis in this paper. More generally, our main results are consistent with the production technology $Q = \Omega(\cdot)f(K, E)$, where $\Omega(\cdot)$ is an increasing function of some generalized technology factor. It receives no compensation and could arise from spillovers when $E$ or $K$ increases, from government-funded research, or from some combination of these influences.

3Allowing differences in the sizes of the populations will not alter the basic analytic results. In per capita terms, however, one has to carry the ratio $L_N/L_S$ throughout.
conditions. The notations $f(\cdot)$ and $g(\cdot)$ are used to facilitate distinguishing between the two countries' production functions.

National income, $Y$, is equal to GDP $Q$ plus or minus the foreign investment earning, $rZ$, where $r$ is the rate of return of capital in the world. In per labor terms,

$$y_S = \Omega(h_S)f(k_S + z) - rz,$$

$$y_N = \Omega(h_N)g(k_N - z) + rz.$$  \(2a, 2b\)

The two countries are linked in an international capital market. The static equilibrium in this world is obtained when the rental rate of physical capital is equalized across countries, assuming that capital is perfectly mobile.\(^4\) The arbitrage equation that should hold every moment is

$$\Omega(h_S)f'(k_S + z) = \Omega(h_N)g'(k_N - z) = r.$$  \(3\)

I have now laid out the entire static model. Given endowments $K_i$ and $h_i$, $i = S, N$, $y_S$, $y_N$, $z$, $r$, $w_S$, and $w_N$ are endogenously determined by the system (2) and (3). The following properties of the static equilibrium are useful in the later parts of the paper.

The direction and quantity of foreign investment are uniquely determined by the configuration of the initial endowments of both physical and human capital. Let $x = z/k_S = Z/K_S$:

$$x = x(k, q), \quad \partial x/\partial k < 0, \quad \partial x/\partial q < 0.$$  \(4\)

Eq. (4) can be obtained as follows. Multiplying both sides of eq. (3) by $k_S^{-\beta}$, noting that $\Omega(h_N)/\Omega(h_S) = q_1^{-\beta}$ by previous assumptions, I have eqs. (5), (6), and (7), which imply eq. (4).

$$f'(1 + x) = q_1^{-\beta}g'(k^{-1} - x).$$  \(5\)

$$\partial x/\partial k = -g''q_1^{-\beta}k^{-2}/(f'' + g''q_1^{-\beta}) < 0,$$

\(^4\)In the static equilibrium, there will be a net service flow into the North, which pays for net imports.
Eq. (4) can be elaborated more intuitively with the help of fig. 1. Given the initial endowments of human capital, \(q^0\), I can find the value of \(k, k^0\), such that \(x\), the proportion of foreign capital operating in the South to the domestically owned capital, is equal to zero by eq. (3) or (5). This is point A in the diagram. Holding Northern human capital, \(h_N\), fixed and raising Southern human capital, \(h_S\), results in a drop in \(q\). The rise of \(h_S\) increases the marginal productivity of capital located in the South, and Northern capital flows in, making \(x > 0\). To restore the \(x = 0\) situation, the Southern capital-labor ratio must increase, i.e. \(k\) increases. This increase generates point B. Linking points A and B through point (1, 1), I construct the \(x = 0\) locus. Northeast of the \(x = 0\) schedule, \(x < 0\). Capital flows abroad from the home country because the combination of higher \(k_S/k_N\) and higher \(h_N/h_S\) make the rental on capital higher in the foreign country than at home. The farther a point is from the \(x = 0\) schedule, the larger the magnitude of \(|x|\). The horizontal line \(k = 1\) divides the quadrant into two parts: the home country is capital-poor below the \(k = 1\) line and capital-rich above it. The \(x = 0\) and \(k = 1\) schedules divide the \(k-q\) plane into four regions. The relative capital intensities of the two countries and direction of international capital movement in each region can be deduced easily. When \(q = 1\) or some positive constant, the model shrinks to a vertical line in fig. 1, which is what the MacDougall–Kemp modelling has.
In the static equilibrium, labor earns higher wages in the North as long as \( q > 1 \). It is evident that in the model where the effect of the variable that captures the impact of technology is felt only within the borders of the country where it is produced, the internationally immobile factor of production will earn a higher return in the developed country. Labor would migrate to the North to seek higher wages, if allowed, even under the assumption of perfect capital mobility.

The static model does not take into account economic growth, which is precisely what foreign investment promotes. In a dynamic setting, the indexes \( \Omega(h_S) \) and \( \Omega(h_N) \) are not constant. The interactions among capital accumulation, technological change, and international capital movements are taken up in the next section.

3. Growth, technology transfer, and long-run equilibrium

To dynamize the static model, the accumulation functions of both physical and human capital need to be specified. The (physical) capital formation functions are the standard ones.

\[
Dk_i = \sigma_i y_i - \dot{\lambda}_i k_i, \quad i = S, N, \tag{8}
\]

where the operator \( D \) stands for the time derivative of the variable, \( \sigma_S \) and \( \sigma_N \) are fixed propensities to save out of income, and \( y_S \) and \( y_N \) are as defined in (2). Per capita gross investment is \( \sigma_i y_i \). To maintain the existing capital-labor ratio, \( \dot{\lambda}_i k_i \) amount of investment is required, where \( \dot{\lambda}_i \) is the sum of the growth rate of labor and the capital depreciation rate. It is assumed for simplicity that both countries share the same labor growth rate and depreciation rates.

How the system evolves over time hinges on the assumptions about the dynamics of human capital, the 'engine of growth'. I assume that both countries' stocks of human capital grow at constant rates, \( \mu_S \) and \( \mu_N \), respectively, in autarky.\(^5\) Following Findlay (1978), I assume that \( Dh_S \) is an increasing function of the degree to which the Southern country is open to direct foreign investment, measured by the ratio of foreign investment to domestically owned capital, \( x \). I also adopt the hypothesis that the greater the relative backwardness of a country, the faster the rate at which it can catch up.

\[
Dh_S = \mu_S \theta(x, q) h_S, \tag{9a}
\]

\[
\theta_1 \equiv \partial \theta / \partial x > 0, \quad \theta_2 \equiv \partial \theta / \partial q > 0, \quad \theta(0, 1) = 1,
\]

\(^5\)There are alternative ways to model the augmentation of aggregate human knowledge. The stock of knowledge can be increased through research or education that uses real resources [see Uzawa (1965), Shell (1967), Romer (1986), and Lucas (1988)] or through learning by doing [Lucas (1988)].
\[ \Delta h_N = \mu_N h_N, \quad \mu_N > \mu_S. \] (9b)

Eq. (9a) is defined only when \( x \geq 0 \) (therefore \( Z \geq 0 \)) and \( q \geq 1 \). The intuitive explanation of the term \( \theta(\cdot) \) is that a typical developing country wants foreign investment not only because it is capital, but also because it embodies superior technology. The presence of foreign firms generates positive technology spillovers to the LDC firms [e.g., see Blomström and Persson (1983)]. This process is called technology transfer in this model and has been empirically important in the world economy. In the rest of the paper, the parameter \( \mu_S \) will also be interpreted as the technological diffusion rate or technology adaptive efficiency in the South. The growth rate of Northern human capital, \( \mu_N \), is assumed to be exogenous. Because strong evidence suggests that physical capital investment leads to the simultaneous creation of new knowledge that spills over and has positive external effects [see Romer (1987)], one could link \( \Delta h_N \) to the level of investment activities in the North. The present specification in (9) is therefore weakly justified. The assumption that in autarky technical knowledge grows more slowly in the South than in the North makes sense if \( \mu_i \) is in some way related to \( k_i \) and \( h_i \), \( i = S, N \). Better education and research facilities as well as higher average human capital enable the North to augment technical knowledge at a relatively faster pace than the South.

Eqs. (8) and (9) form the dynamic system. To obtain the solution, the following preliminary results are needed.

Lemma 1.
\[ \begin{align*}
    y_s/k_s &= C\bar{y}_s(k, q), \quad \delta \bar{y}_s/\delta k < 0, \quad \delta \bar{y}_s/\delta q < 0, \\
    y_n/k_n &= C\bar{y}_n(k, q), \quad \delta \bar{y}_n/\delta k > 0, \quad \delta \bar{y}_n/\delta q > 0,
\end{align*} \] (10a) (10b)

where
\[
C = (h_s/k_s)^{-\beta} > 0, \quad \forall t.
\]

Proof. See appendix A.

With the help of Lemma 1, I can convert the system (8) and (9) into another system of three differential equations in terms of \( k, q \) and \( C \). The definition of \( k \), together with eqs. (8) and (10), yields:

Strictly speaking, 'technological diffusion rate' should be a shift parameter, say \( \tau \), in \( \theta(\cdot) \), with the property \( d\theta/d\tau > 0 \). Because \( \tau \) has the same qualitative effects as \( \mu_S \) on \( k \) and \( q \), introducing \( \tau \) into the model unnecessarily complicates the notation. In the rest of this paper, whenever technological diffusion rate is mentioned, I refer to \( \tau \) with its effects captured by \( \mu_S \).
\[ \frac{Dk}{k} = C[\sigma_s \tilde{y}_s(k, q) - \sigma_N \tilde{y}_N(k, q)] \]
\[ = C\phi(k, q; \sigma_s, \sigma_N) \tag{11} \]

where \( \tilde{y}_i, i = N, S, \) and \( C \) are defined in Lemma 1. Similarly,
\[ \frac{Dq}{q} = \mu_N - \mu_S \theta(x(k, q), q) \]
\[ = \psi(k, q; \mu_s, \mu_N), \tag{12} \]

\[ \frac{DC}{C} = (1 - \beta)\{\mu_s \theta(x(k, q), q) - [C \sigma_s \tilde{y}_s(k, q) - \lambda]\} \]
\[ = \Gamma(k, q, C; \mu_s, \sigma_s). \tag{13} \]

There are two opposite effects on the growth rate of Southern human capital in the technology transfer function, \( \theta(\cdot) \), specified in (9a). A decreasing \( q \) induces more foreign capital inflow [recall eq. (4)], which tends to drive up \( Dh_s/h_s \). However, the narrowing gap also slows down the pace at which the backward country can catch up. I assume that the latter effect dominates the effect of induced capital inflow:
\[ \theta_1 > |\theta_1(\partial x/\partial q)|. \tag{14} \]

With the inequality (14), it can be shown that the 3 x 3 system, (11), (12), and (13), satisfies the Routh–Hurwitz stability conditions (see appendix B). The world steady state is characterized by \( (k^*, q^*, C^*) \) such that
\[ C^* \phi(k^*, q^*) = 0, \tag{15a} \]
\[ \psi(k^*, q^*) = 0, \tag{15b} \]
\[ \Gamma(k^*, q^*, C^*) = 0. \tag{15c} \]

It is obvious from (15) that the system (11), (12), and (13) can be decoupled; that is, eqs. (11) and (12) are sufficient to determine the steady-state values of \( k^* \) and \( q^* \). With \( k^* \) and \( q^* \) determined, there exists a unique constant, \( C^* \), that satisfies (15c).

The subsystem (11) and (12) can be dissected by employing the phase diagram technique in the now familiar \( k-q \) plane. Fig. 2 depicts the phase diagram of this subsystem.

The \( KK (Dk = 0) \) schedule is downward sloping. Given the value of \( k \), as \( q \) decreases, the South becomes more attractive to foreign capital, and its presence \( (x) \) will increase. From (10) and (11), we know that \( Dk > 0 \). To keep
Fig. 2

Dk = 0, k has to increase to deter an increasing x. The QQ (Dq = 0) schedule is upward sloping. With a constant growth rate of human capital in the North, any change in Dq is determined by the accumulation of human capital in the South. With a fixed value of k, a reduction in the technology gap slows down the rate at which the South can catch up, but also induces a higher x. By assumption (14), Dq < 0. To restore Dq = 0, k needs to decrease to induce more foreign capital flows from the North to the South. The horizontal and vertical arrows in fig. 2 indicate the directions of variables in the zone where they are drawn. The superscript asterisk denotes the equilibrium values of the variables under free capital mobility, and the superscript 0 denotes the initial values of the variables. The intersection of the KK and QQ curves gives the steady state (k*, q*) of the world economy.

Given assumptions (1) and (9), the relevant region in the k-q space in the dynamic analysis is the one bounded by the x=0 curve, q=1 line, and the horizontal axis. The discussion of the steady state is confined to this region.

The steady state of this model is quite different from that of previous models. Driven by technological progress, each country's steady-state capital-labor ratio is not really steady. A constant k* implies that both kS and kN grow at an equal steady-state rate, μN. Both hS and hN also grow at the same pace set by μN in the steady state. In contrast, in autarky the

7For instance, see Oniki and Uzawa (1965), Ruffin (1979), and Buiter (1981). In these models, both countries share the identical, fixed steady-state capital-labor ratio in the free trading world economy.
backward country may persistently grow more slowly. Comparisons between the steady states in free capital mobility and autarky yield the following theorem.

**Theorem 1.** Perfect capital mobility raises the steady-state growth rates of wage rate, capital–labor ratio, and per capita income in the South from \( \mu_S \) to \( \mu_N \), provided \( x^* > 0 \) and \( \mu_S < \mu_N \). The corresponding growth rates remain the same in the North.

**Proof.** The autarkic steady-state growth rates of the capital–labor ratios in both regions can be easily deduced from (8), (9), and (3) by letting \( z \) be zero:

\[
Dk_i/k_i = Dh_i/h_i, \quad i = S, N.
\] (16)

Note that (16) also holds in the perfect capital mobility equilibrium. Any autarkic steady state requires \( \sigma_i y_i = \lambda k_i \), and \( w_i = y_i - r_i k_i \). The autarkic rental rate on capital, \( r_i = \Omega(h_i) f'(k_i) = \beta(h_i/k_i)^{1-\beta} \), and eq. (16) imply the steady-state constancy of \( r_i \). It follows that \( w_i, y_i, \) and \( k_i \) all grow at the same rate, \( \mu_i, i = S, N \). Clearly the South grows more slowly than the North in autarky if \( \mu_S < \mu_N \).

With perfect capital mobility, \( Dk_S^*/k_S^* = Dk_N^*/k_N^* = \mu_N \) in the long-run equilibrium \( (k^*, h^*, C^*) \). The long-run equilibrium rate of return to capital, \( r^* \), is a constant and equal to \( C^* f'(1+x^*) \) from eq. (3). The wage rate, \( w_i \), now equals \( y_i \) minus \( r k_i \), with \( y_i \) defined as in (2). Lemma 1 and eqs. (15) imply that \( y_i^* \) grows at the same rate as \( k_i^* \). It follows that \( w_i^*, y_i^*, \) and \( k_i^*, i = S, N \), all grow at the rate \( \mu_N \).

Intuitively, the relations among \( y_i, k_i, w_i, \) and \( r_i \) in the autarkic steady state are analogous to their relations in a Solow growth model with exogenous labor augmenting technological progress. Marginal productivity of capital, \( r_i \), is a constant because the augmenting effects of technological progress exactly offset the effects of diminishing returns associated with capital accumulation. In general, \( r_S \) and \( r_N \) will not be equal. From the steady-state conditions \( \sigma_i y_i = \lambda k_i \), wage can be expressed as a constant fraction of per capita income, \( w_i = (1 - r \sigma_i / \lambda) y_i, \) \( r \sigma_i / \lambda < 1, \) \( i = S, N \), given the assumed constancy of \( \sigma_i \) and \( \lambda \). The wage rate in country \( i \) will grow at the same rate as per capita income, \( y_i \), which is dictated by the growth rate of \( h_i \).

Under perfect capital mobility, the growth rate of \( h_S \) (and hence the long-run growth rate of income, \( y_S \)) is no longer constrained by \( \mu_S \). Instead, the rate of change of \( h_S \) is endogenized in the model by the inflow of foreign capital from the North, \( \mu_S \theta(x, q) \geq \mu_S, \) \( x \geq 0, \) \( q \geq 1 \). In the steady state, the rental rate, \( r \), becomes a constant and allocates a constant fraction of per capita income to wage in each country. The Southern wage will grow faster than in autarky because income, \( y_S \), also grows faster.
Corollary.

(i) In the autarkic steady state the per capita income gap between the two countries, \( y^* (y \equiv y_N/y_S) \), will be enlarging at the rate of \( \mu_N - \mu_S \), if \( \mu_S < \mu_N \).

(ii) Shifting from autarky to perfect capital mobility prevents the income gap from enlarging, and this gap becomes a constant in the steady state. The steady-state income gap is jointly determined by the parameters \( \sigma_i \) and \( \mu_i \), \( i = S, N \). \( y^* < y^*_S \) if \( k^* > k^*_S \), where \( y^*_S \) and \( k^*_S \) are steady-state values under autarky.

Proof. Statement (i) follows immediately from Theorem 1. From (10) and (11), with \( Dk = 0 \), the relation between \( y \) and \( k \) in any steady state under free capital mobility therefore is

\[
y^* = (\sigma_N / \sigma_S) / k^*.
\]

Statement (ii) is implied by (17). Because \( k^* \) depends on \( \sigma_i \) and \( \mu_i \), \( i = S, N \), \( y^* \) must also depend on these parameters.

Theorem 1 and its corollary constitute the gains from free capital mobility propositions of this paper, emphasizing the South’s substantial gains in technological change and income growth. Theorem 1 indicates that an initially backward country benefits in the long run from direct foreign investment from more advanced countries. The corollary shows that the Southern economy can close its income gap with the North, depending on the relevant parameters. It also suggests that the average growth rate of the South during the convergence transition could be higher than that of the North if the steady-state income gap under free capital mobility is smaller than that before the South opens to international investment. The relative income level narrows if \( k^* > k^*_S \). Note that eq. (17) can be obtained under the autarkic steady state from eq. (8). In the case of \( p_S < p_N \), \( y^* \) goes to infinity in the long run as \( k^*_S \) approaches zero. The condition \( k^* > k^*_S \) is surely satisfied.

A possible trajectory is indicated as the path \( AE \) in fig. 2. The developing country starts with the initial condition \((k^0, q^0)\), a low level of

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8It can be shown that the North also gains from free capital mobility in terms of per capita income, which is a known result in the literature [see Ruffin (1979)]. The crucial assumption for the asymmetric mutual gains results in the present paper is that the Northern rate of technological progress is constant, not affected by capital outflow, but even if this assumption is abandoned, the Southern growth gains in this model will not disappear.

9The system (11) and (12), though stable in the neighborhood of the steady-state solution, may have a stable nondegenerate node, a stable degenerate node, or a stable focus, depending on the discriminant. Based on the assumption that the technology gap, \( q \), changes monotonously during the transition to the steady state, I confine my discussion in the rest of this paper to the case of a stable nondegenerate node with the convergence path leading to the steady state from its Southeast in \( k-q \) space. I am indebted to a referee for pointing out my errors in the previous drafts.
capital stock, and a backward technology. With the inflow of foreign capital, advanced technology as well as managerial skill are transmitted through the presence of foreign firms. The growth rate of $h_S$ increases. International capital movements promote capital accumulation in the South relative to that in the North mainly because of the South's efficiency gains. An increasing $h_S$ increases $y_S$ through its positive effects on Southern production. Given the fixed saving rate, $Dk_S$ tends to increase. The system eventually converges to the steady state.

The steady state of the system and the implied income gap between the two countries are determined by the relevant parameters. In the next section, I consider the impacts of altering these parameters on the long-run equilibrium.

4. Shocks to the long-run equilibrium

The long-run effects of exogenously shifting the technology parameters, $\mu_S$ and $\mu_N$, can be studied formally with the help of eqs. (11) and (12). Differentiating the system totally and taking $d\mu_S$ as an increase in the South's rate of technological progress under autarky,

$$\partial k^*/\partial \mu_S = -\partial \phi_q/\partial \psi_k > 0,$$

$$\partial q^*/\partial \mu_S = \partial \phi_k/\partial \psi_q < 0,$$

where $\Delta \equiv \partial \phi_k/\partial \psi_q - \partial \phi_q/\partial \psi_k > 0$, and $\phi_i$ and $\psi_i$ denote the partial derivatives of eqs. (11) and (12) with respect to their arguments $i$, $i=k,q$. All the partial derivatives are evaluated at the steady state. The impact of changing $\mu_S$ is seen clearly in fig. 3.

Because the parameters $\mu_i$, $i=S,N$, appear only in the $Dq$ equation, the $KK$ schedule does not shift when they change. An increase in $\mu_S$, which captures both the human capital growth rate under autarky and the technological diffusion rate, shifts the $QQ$ schedule to the left ($Q'Q'$). In the new steady state, the home country enjoys a higher capital-labor ratio and higher level of human capital relative to the rest of the world. Thus, the higher the $\mu_S$, the narrower the per capita income gap between the North and South in the new equilibrium.

An increase in $\mu_N$ has the opposite effects on the system. The $QQ$ schedule shifts to the right ($Q''Q''$) in fig. 3, $k$ is lower and $q$ higher in the new steady state than in the original equilibrium. The booming innovative drive in the rich country may hold back the capital that would otherwise flow to the less developed country. The division between the rich and the poor is not only perpetuated but also aggravated. It seems that the worst thing for an open developing economy in this world is to allow its growth rate of human
capital (or technology) to lag behind the rate of rich countries. Efforts to increase $\mu_S$ can alleviate or offset the adverse effects of an increase in $\mu_N$ on the relative income between the North and the South.

Now consider the effects of altering saving propensities. Both $\sigma_S$ and $\sigma_N$ appear only in the $D_k$ equation. Changes in these variables therefore do not affect the $QQ$ schedule. Formally, I differentiate the system (11) and (12) and obtain the following partial derivatives:

\[
\frac{\partial k^*}{\partial \sigma_S} = -\bar{\gamma}_S \psi_q / \Delta > 0, \tag{20}
\]

\[
\frac{\partial q^*}{\partial \sigma_S} = \bar{\gamma}_S \psi_k / \Delta > 0. \tag{21}
\]

An exogenous increase in the saving propensity in the home country shifts the $KK$ schedule upwards. The new steady-state levels of $k$ and $q$ are higher than before. Foreign investment will be crowded out (i.e. $x$ decreases). For a backward country, this deterrence of capital inflow will retard the technological learning process. A drop in the foreign saving rate has a similar impact on the long-run equilibrium. Conversely, a rise in the foreign saving propensity has effects similar to those of a decrease in the home saving rate: lower equilibrium values of $k$ and $q$.

In this model, policies that raise the South's saving propensity, $\sigma_S$, have an
ambiguous effect on the steady-state relative income, \( y^* \), depending on the relative magnitude of \( \sigma S \frac{\partial k^*}{\partial k} \frac{\partial \sigma S}{\partial} \).

5. Conclusions

The model developed in this paper highlights the importance of human capital, technology diffusion, and their interactions with foreign investment and domestic physical capital formation in economic development. Two main policy messages emerge from the analysis. First, from a developing country point of view, opening to direct foreign investment from more advanced countries has important beneficial implications. In addition to the well-known effects on income level as well as on employment, foreign investment facilitates domestic technological change, and hence increases the rate of income growth. Policies prohibiting investment from more advanced countries deprive the LDC of potential gains in the growth rate and may also lead to an increasing income gap between the rich and poor in the world. Second, after opening up to foreign capital, an initially backward country making efforts to increase domestic human capital accumulation and technology adoptive efficiency of domestic firms may eventually reduce the equilibrium per capita income gap between itself and more advanced countries. These results extend and reinforce the gains from trade theorems obtained in the previous literature.

Extension of this model is possible. One might want to relax the assumptions (9) to make technological progress really endogenous and to derive saving rates from more basic assumptions. Issues concerning policies and welfare, which have not been addressed in this paper, can also be investigated.

Appendix A: Proof of Lemma 1

Substituting (3) into (2), noting \( x = z/k \) and \( x = x(k, q) \), and the definition of \( C = (h_S/k_S)^{1-\beta} \), we obtain the following expressions:

\[
y_S = \frac{\Omega(h_S)k_S^{\beta-1}}{k_S}[f(1 + x) - f'(1 + x)x]\]

\[= C \bar{y}_S(k, q), \quad \text{(A.1)}\]

\[
y_N/k_N = \frac{\Omega(h_S)k_S^{\beta-1}q^{1-\beta}g(k^{-1} - x) + f'(1 + x)x]}{k_S}\]

\[= C \bar{y}_N(k, q). \quad \text{(A.2)}\]

\(^{10}\text{sgn}(\partial y^*/\partial \sigma S) = \text{sgn}[1 - (\sigma S/k^*)(\partial k^*/\partial \sigma S)] \text{ from eq. (17). The equilibrium income gap will be narrowed if } (\sigma S/k^*)(\partial k^*/\partial \sigma S) > 1.\)
Let \( f(\cdot) \) and \( g(\cdot) \) denote \( f(1+x) \) and \( g(k^{-1}-x) \), respectively. In deriving (A.5) and (A.6), use eq. (5) in section 2:

\[
\frac{\partial \tilde{y}_S}{\partial k} = -f''(\cdot)x\frac{dx}{dk} < 0, \quad x > 0, \quad (A.3)
\]

\[
\frac{\partial \tilde{y}_S}{\partial q} = -f''(\cdot)x\frac{dx}{dq} < 0, \quad x > 0, \quad (A.4)
\]

\[
\frac{\partial \tilde{y}_N}{\partial k} = q^{-\beta}[g(\cdot) - g'(\cdot)(k^{-1} - x)] + f''(\cdot)xk\frac{dx}{dk} > 0, \quad x > 0, \quad (A.5)
\]

\[
\frac{\partial \tilde{y}_N}{\partial q} = (1 - \beta)q^{-\beta}g(\cdot) + f''(\cdot)xk\frac{dx}{dq} > 0, \quad x > 0. \quad (A.6)
\]

(A.1), (A.3), and (A.4) yield eq. (10a). (A.2), (A.5), and (A.6) imply (10b). Given the initial conditions \((h^0_s, k^0_s)\), both \( h_s \) and \( k_s \) are growing over time. \( C = (h_s/k_s)^{1-\beta} \) therefore is always positive and becomes a constant, \( C^* \), in the steady state because of (16).

Appendix B: Stability of the system (11), (12), and (13)

For analytical tractability, we consider only the local behavior of the system, linearizing \( \phi, \psi, \) and \( \Gamma \) in the neighborhood of the long-run equilibrium \((k^*, q^*, C^*)\). This gives the linear approximation:

\[
\begin{bmatrix}
\frac{Dk}{k^*} \\
\frac{Dq}{q^*} \\
\frac{DC}{C^*}
\end{bmatrix} =
\begin{bmatrix}
C^*\phi_k & C^*\phi_q & 0 \\
\psi_k & \psi_q & 0 \\
\Gamma_k & \Gamma_q & \Gamma_c
\end{bmatrix}
\begin{bmatrix}
k - k^* \\
q - q^* \\
C - C^*
\end{bmatrix}, \quad (B.1)
\]

where

\[
\phi_k = [\sigma_s(\partial \tilde{y}_S/\partial k) - \sigma_N(\partial \tilde{y}_N/\partial k)] < 0, \quad (B.2)
\]

\[
\phi_q = [\sigma_s(\partial \tilde{y}_S/\partial q) - \sigma_N(\partial \tilde{y}_N/\partial q)] < 0, \quad (B.3)
\]

\[
\psi_k = -\mu_s\theta_1(\partial x/\partial k) > 0, \quad (B.4)
\]

\[
\psi_q = -\mu_s[\theta_1(\partial x/\partial q) + \theta_2] < 0, \quad (B.5)
\]

\[
\Gamma_c = -(1 - \beta)\sigma_s\tilde{y}_S < 0. \quad (B.6)
\]

All the partial derivatives are evaluated at the steady state \((k^*, q^*, C^*)\). (B.2) and (B.3) are the consequences of Lemma 1. (B.5) follows from assumption (14). It is transparent that the Routh–Hurwitz conditions for stability are satisfied. All three roots of the system have negative real parts.
References


