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Capital Mobility with Convergence in Open Economies

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ABSTRACT

The major objective of the paper is to provide a theoretical description of convergence in neoclassical models with various initial ratios of human to physical capital. To avoid immediate convergence, adjustment costs (higher for human capital than for physical capital investment) are introduced. The model is calibrated consistently with empirically-observed slow long-run convergence. Economies with high initial ratios of human to physical capital are, however, predicted to grow quickly in the short run. Moreover, substantial current-account deficits may occur due to high marginal products of physical capital and resulting high levels of domestic physical capital investment. This analysis seems relevant to Malaysian economies, which exhibit high ratios of human to physical capital, current-account deficits, and relatively high average growth rates.
Keywords: Capital mobility, neoclassical models, Cobb-Douglass production function, social optimum.

1. Introduction

The issue of convergence has received a great deal attention in recent economic research. There are two major concepts of convergence ;

i. Convergence is absolute if poor economies tend to grow faster than rich economies.

ii. Convergence is conditional if economies grow faster the further they are below their steady states.

Economies may converge conditionally and still not absolutely if poor economies have relatively low steady states (Barro and Sala-i-Martin, 1995).

Several empirical studies have shown that economies converge conditionally at a relatively low rate of about 2 % per year. It is remarkable that slow convergence has been observed both for open and closed economies; in particular, more open economies such as regions within countries have not been found to converge much faster than less open individual countries.

For closed economies, the basic neoclassical model (Solow, 1956) predicts slow convergence if the capital share is sufficiently high. This may be realistic if, for example, human capital is included in the model. However, for open economies with perfect capital mobility, the basic neoclassical model fails since it predicts infinite convergence speed-capital flows immediately equalize the rates of return around the world. Therefore, several modifications of the neoclassical model have been developed to avoid such an unrealistic implication. Such modifications include, for example, borrowing restrictions (Barro *et al*, 1995) or adjustment costs for investment. Adjustment costs alone cannot explain slow convergence unless they are substantially large. Barro *et al.* (1995) introduce borrowing restrictions instead; in their model, physical capital can be financed by borrowing on the world credit market, whereas human capital cannot. The slow convergence of open credit-constrained economies is accounted for quite well in this model; the model is, nevertheless, somewhat restrictive regarding initial conditions.

In this paper, an open-economy model with two kinds of capital (physical and human capital) is developed. The model resembles that of Barro et al. (1995), although it differs from it in two respects : First, for simplicity, both kinds of capital are allowed to be financed by foreigners. Second, adjustment costs for investment in both kinds of capital are introduced, with the assumption that the adjustment costs for human capital investment are higher than those for physical capital investment. A log-linearized approximation of this model is solved analytically. It is shown that the model can be calibrated for slow asymptotic convergence, although it may result in fast initial growth in economies with high ratios of human to physical capital.

2. The Model

The model extends the analysis of Barro and Sala-i-Martin (1995). The Cobb-Douglas production function of the augmented neoclassical model is considered:

$$Y = F(K, H, Le^{xt}) = AK^{\alpha} H^{\eta} (Le^{xt})^{1-\alpha-\eta}, \tag{1}$$

where $\alpha > 0$, $\eta > 0$, $\alpha + \eta < 1$, Y is GDP, A is a fixed technological parameter, K is physical capital, H is human capital, and L is raw labor, which grows at a constant, exogenous rate, n. Technological progress is labor-augmenting at a constant, exogenous rate, x. The equations of motion for physical and human capital are ;

$$\dot{K} = I_K - \delta K, \tag{2}$$

$$\dot{H} = I_H - \delta H, \tag{3}$$

where I_K and I_H stand for gross investment in physical and human capital, respectively, and δ is the depreciation rate, which is, for simplicity, assumed to be the same for K and H. The economy can borrow capital on the world credit market at a constant real interest rate, r.

We assume that there are costs (adjustment costs) associated with the installation of capital and that these costs depend positively on the level of investment relative to the level of existing capital. The cost of the installation of a capital unit is assumed in the form $\phi_K(I_K / K)$ with $\phi_K(0) = 0$, $\phi_K^{'}(.) > 0$, and $\phi_K^{''} \geq 0$ for physical capital; and $\phi_H(0) = 0$, $\phi_H^{'}(.) > 0$, $\phi_H^{''} \geq 0$ for human capital. Let D denote the net foreign debt of the economy. The time evolution of D is,

$$\dot{D} = I_K[1 + \phi_K(I_K / K)] + I_H[1 + \phi_H(I_H / H)] + C - Y + rD, \tag{4}$$

where $\dot{D}$ is the current-account deficit (time derivative of D), and C is domestic consumption.

$I_K[1 + \phi_K(I_K / K)] + I_H[1 + \phi_H(I_H / H)] + C - Y$ is the trade-balance deficit, and rD are net factor payments to foreigners. Note that we abstract from labor mobility so that factor payments do not include wage components.

It turns out to be convenient to work with variables per unit of effective labor:

$y = \dfrac{Y}{(Le^{xt})}$, $k = \dfrac{K}{(Le^{xt})}$, $h = \dfrac{H}{(Le^{xt})}$, $d = \dfrac{D}{(Le^{xt})}$, $i_k = \dfrac{I_K}{(Le^{xt})}$, $i_h = \dfrac{I_H}{(Le^{xt})}$, and $c = \dfrac{C}{(Le^{xt})}$. Consequently, let us change the notation for adjustment costs, i.e., let us write ϕ_k and ϕ_h instead of ϕ_K and ϕ_H. The production function takes the intensive form,

$$y = f(k, h) = Ak^{\alpha} h^{\eta} \tag{5}$$

The equations of motion are,

$$\dot{k} = i_k - (\delta + \eta + x)k. \tag{6}$$

$$\dot{h} = i_h - (\delta + \eta + x)h. \tag{7}$$

$$d = i_k[1 + \phi_k(i_k / k)] + i_h[1 + \phi_h(i_h / h)] + c - y + (r - x - n)d. \tag{8}$$

The social optimum is given by maximizing the discounted utility of a typical household subject to the constraints of the economy. Since ce^{xt} is per capita consumption, this term enters the instantaneous utility function, $u(.)$. The problem is,

$$\max_{c,i_k,i_h} \int_0^\infty e^{(n-\rho)t} u(ce^{xt})dt.$$

If the elasticity of inter temporal substitution of consumption is constant, the problem takes the form,

$$\max_{c,i_k,i_h} \int_0^\infty e^{(n-\rho)t} \frac{(ce^{xt})^{1-\theta}-1}{1-\theta} dt,$$

subject to (6), (7), and (8), where $\rho > 0$ is the rate of time preference, and $\theta > 0$ is the inverse elasticity of inter temporal consumption substitution; *k, h*, and *d* are state variables, whereas c, i_k, and i_h are control variables. The natural extension-logarithmic limit-is assumed if $\theta = 1$. The current-value Hamiltonian for this problem is

$$\Im_1 = \frac{(ce^{xt})^{1-\theta}-1}{1-\theta} + \lambda_d[i_k(1+\phi_k(i_k/k)) + i_h(1+\phi_h(i_h/h)) + c - f(k,h) + (r-x-n)d] + \lambda_k[i_k - (\delta+n+x)k] + \lambda_h[i_h - (\delta+n+x)h],$$

where λ_d, λ_k, and λ_h are co state variables (analogs of Lagrange multipliers), indicating the marginal shadow values of the corresponding state variables. The first-order condition for this problem are,

$$\frac{\partial \Im_1}{\partial c} = c^{-\theta} e^{xt(1-\theta)} + \lambda_d = 0 \quad (9)$$

$$\frac{\partial \Im_1}{\partial i_k} = \lambda_d[1+\phi_k(i_k/k) + (i_k/k)\phi'_k(i_k/k)] + \lambda_k = 0, \quad (10)$$

$$\frac{\partial \Im_1}{\partial i_k} = \lambda_d[1+\phi_h(i_h/h) + (i_h/h)\phi'_h(i_h/h)] + \lambda_h = 0, \quad (11)$$

$$\dot{\lambda}_d = (\rho-n)\lambda_d - \frac{\partial \Im_1}{\partial d} = (\rho+x-r)\lambda_d, \quad (12)$$

$$\dot{\lambda}_k = (\rho-n)\lambda_k - \frac{\partial \Im_1}{\partial k} = (\rho+\delta+x)\lambda_k + \left[\frac{\partial f}{\partial k} + (i_k/k)^2 \phi'_k(i_k/k)\right]\lambda_d, \quad (13)$$

$$\dot{\lambda}_h = (\rho-n)\lambda_h - \frac{\partial \Im_1}{\partial h} = (\rho+\delta+x)\lambda_h + \left[\frac{\partial f}{\partial h} + (i_h/h)^2 \phi'_h(i_h/h)\right]\lambda_d, \quad (14)$$

Sufficiency of the first-order conditions is ensured by the concavity of u(.) and the convexity of $\phi(.)$. The system (6) – (14) can be transformed into a set of 6 first-order ordinary differential equations for 6 independent variables. The initials conditions for this boundary problem are,

$$k(t=0) = k_o, \quad (15)$$

$$h(t=0) = h_0, \quad (16)$$

$$d(t=0) = d_0, \quad (17)$$

The transversality conditions are (in dynamic programming problems with infinite horizons, present discounted values of state variables must converge to zero as $t \to \infty$),

$$\lim_{t\to\infty} \lambda_k e^{(n-\rho)t} k = 0, \tag{18}$$

$$\lim_{t\to\infty} \lambda_h e^{(n-\rho)t} h = 0, \tag{19}$$

$$\lim_{t\to\infty} \lambda_d e^{(n-\rho)t} d = 0, \tag{20}$$

Equation (9) represents the equality between the marginal utility of an additional amount of consumption and the marginal disutility arising from a corresponding increment in the debt. In equations (10) and (11), the shadow values of installed and uninstalled capital are compared. The marginal shadow values of installed capital are higher than those of uninstalled capital by factors of q_k and q_h for physical capital and human capital, respectively, where,

$$q_k = 1 + \phi_k(i_k / k) + (i_k / k)\phi'_k(i_k / k), \tag{21}$$

$$q_h = 1 + \phi_h(i_h / h) + (i_h / h)\phi'_h(i_h / h), \tag{22}$$

From (10) – (14), (21), and (22) it follows that,

$$\frac{\dot{q}_k}{q_k} = \frac{\dot{\lambda}_k}{\lambda_k} - \frac{\dot{\lambda}_d}{\lambda_d} = r + \delta - \frac{\frac{\partial f}{\partial k} + (i_k / k)^2 \phi'_k(i_k / k)}{q_k}, \tag{23}$$

$$\frac{\dot{q}_h}{q_h} = \frac{\dot{\lambda}_h}{\lambda_h} - \frac{\dot{\lambda}_d}{\lambda_d} = r + \delta - \frac{\frac{\partial f}{\partial h} + (i_h / h)^2 \phi'_h(i_h / h)}{q_h}. \tag{24}$$

From (21) and (22), it is possible to express i_k / k and i_h / h in terms of q_k and q_h, respectively:

$$\frac{i_k}{k} = \psi_k(q_k), \tag{25}$$

$$\frac{i_h}{h} = \psi_h(q_h), \tag{26}$$

$\psi'_k(.) > 0$ and $\psi'_h(.) > 0$.

Substituting (25) and (26) into (6), (7), (23), and (24) leads to,

$$\frac{\dot{k}}{k} = \psi_k(q_k) - (\delta + n + x), \tag{27}$$

$$\frac{\dot{h}}{h} = \psi_h(q_h) - (\delta + n + x), \tag{28}$$

$$\frac{\dot{q}_k}{q_k} = r + \delta - \frac{\frac{\partial f}{\partial k} + \psi_k^2(q_k)\phi'_k[\psi_k(q_k)]}{q_k}, \tag{29}$$

$$\frac{\dot{q}_h}{q_h} = r + \delta - \frac{\frac{\partial f}{\partial h} + \psi_h^2(q_h)\phi'_h[\psi_h(q_h)]}{q_h}, \tag{30}$$

The behavior of k and h is described by (27) – (30): therefore, it can be studied separately from the behavior of consumption, c, and debt, d. Equations (10), (11), (12), (18), (19), (21), and (22) imply,

$$\lim_{t\to\infty} e^{-(r-x-n)t} q_k k = 0, \tag{31}$$

$$\lim_{t\to\infty} e^{-(r-x-n)t} q_h h = 0, \tag{32}$$

From (27) and (28), it follows that $q_k = q_k^*$ and $q_h = q_h^*$ are constant in the steady state (all variables are, in this convention, required to grow at a constant and not necessarily zero) rate. Then, from (29) and (30), $k = k^*$ and $h = h^*$ must also be constant in the steady state. Both (31) and (32) then imply $r - x - n > 0$, which constitutes a restriction on exogenous parameters r, x, and n. From (12) and (20), it follows that,

$$\lim_{t\to\infty} e^{-(r-x-n)t} d = 0. \tag{33}$$

From (9) and (12) it follows that consumption per effective worker, c, grows at the rate of $(r-\rho)/\theta - x$:

$$c = c_0 e^{[(r-\rho)/\theta - x]t}. \tag{34}$$

Consumption must satisfy the intertemporal budget constraint which is given by discounting and integrating equation (8):

$$\int_0^\infty c_0 e^{-[r-n-(r-\rho)/\theta]t} dt =$$

$$\int_0^\infty \{f(k,h) - i_k[1+\phi_k(i/k)] - i_h[1+\phi_h(i/h)] - (r-x-n)d + \dot{d}\} e^{-(r-x-n)t} dt, \tag{35}$$

Integration by parts and equation (33) yield:

$$\frac{c_0}{r-n-(r-\rho)/\theta} = \int_0^\infty \{f(k,h) - i_k[1+\phi_k(i/k)] - i_h[1+\phi_h(i/h)]\} e^{-(r-x-n)t} dt - d_0. \tag{36}$$

This equation basically indicates that the present discounted value of consumption equals the present discounted value of income.

It is difficult to solve the system (27) – (32) exactly for a general form of functions $\phi_k(.)$ and $\phi_h(.)$. Therefore, the following specifications are considered:

$$\phi_k(i_k/k) = \frac{b_1}{2}\frac{i_k}{k}, \tag{37}$$

$$\phi_h(i_h/h) = \frac{b_2}{2}\frac{i_h}{h}, \tag{38}$$

where $b_2 > b_1 > 0$, i.e., adjustment costs are higher for human capital accumulation than for physical capital accumulation. The problem then simplifies into the following:

$$q_k = 1 + b_1 \frac{i_k}{k}, \tag{39}$$

$$q_h = 1 + b_2 \frac{i_h}{h}, \tag{40}$$

$$\psi_k(q_k) = (q_k - 1)/b_1, \tag{41}$$

$$\psi_h(q_h) = (q_h - 1)/b_2, \tag{42}$$

$$\frac{\dot{k}}{k} = (q_k - 1)/b_1 - (x + n + \delta), \tag{43}$$

$$\frac{\dot{h}}{h} = (q_h - 1)/b_2 - (x + n + \delta), \tag{44}$$

$$\frac{\dot{q}_k}{q_k} = r + \delta - \frac{\frac{\partial f}{\partial k} + (q_k - 1)^2/(2b_1)}{q_k}, \tag{45}$$

$$\frac{\dot{q}_h}{q_h} = r + \delta - \frac{\frac{\partial f}{\partial h} + (q_h - 1)^2/(2b_2)}{q_h}. \tag{46}$$

Steady-state values of q_k^* and q_h^* satisfy,

$$q_k^* = 1 + b_1(x + n + \delta), \tag{47}$$

$$q_h^* = 1 + b_2(x + n + \delta), \tag{48}$$

Steady-state values of k^* and h^* can be determined from steady-state marginal products:

$$\left(\frac{\partial f}{\partial k}\right)^* = A\alpha k^{*\alpha-1} h^{*\eta} = (r + \delta)q_k^* - (q_k^* - 1)^2/(2b_1), \tag{49}$$

$$\left(\frac{\partial f}{\partial h}\right)^* = A\alpha k^{*\alpha} h^{*\eta-1} = (r + \delta)q_h^* - (q_h^* - 1)^2/(2b_2). \tag{50}$$

Using identity $z = e^{\ln z}$ and Taylor's expansion around the steady state, we can log-linearize the system of four differential equations (43) – (46) around the steady state. This log linearization describes the behavior of the economy locally around the steady state. The advantage of this approach is the possibility of an analytical solution; the disadvantage is, however, the inability to precisely describe the behavior of economies which are far from steady states. Future research should thus focus on the numerical solutions to the exact equations (43) –(46).

$$\frac{\dot{k}}{k} = \frac{d\ln(k/k^*)}{dt} = A\ln(q_k/q_k^*), \tag{51}$$

$$\frac{\dot{q}_k}{q_k} = \frac{d\ln(q_k/q_k^*)}{dt} = B\ln(k/k^*) + C\ln(q_k/q_k^*) + D\ln(h/h^*), \tag{52}$$

$$\frac{\dot{h}}{h} = \frac{d\ln(h/h^*)}{dt} = E\ln(q_h / q_h^*), \tag{53}$$

$$\frac{\dot{q}_h}{q_h} = \frac{d\ln(q_h / q_h^*)}{dt} = F\ln(k/k^*) + G\ln(h/h^*) + H\ln(q_h / q_h^*), \tag{54}$$

or, in a matrix notation,

$$\begin{pmatrix} \dfrac{d\ln(k/k^*)}{dt} \\ \dfrac{d\ln(q_k / q_k^*)}{dt} \\ \dfrac{d\ln(h/h^*)}{dt} \\ \dfrac{d\ln(q_h / q_h^*)}{dt} \end{pmatrix} = \begin{pmatrix} 0 & A & 0 & 0 \\ B & C & D & 0 \\ 0 & 0 & 0 & E \\ F & 0 & G & H \end{pmatrix} \begin{pmatrix} \ln(k/k^*) \\ \ln(q_k / q_k^*) \\ \ln(h/h^*) \\ \ln(q_h / q_h^* \end{pmatrix},$$

where

$$A = \frac{q_k^*}{b_1} > 0, \tag{55}$$

$$B = \frac{1-\alpha}{q_k^*}\left(\frac{\partial f}{\partial k}\right)^* > 0, \tag{56}$$

$$C = \frac{\left(\dfrac{\partial f}{\partial k}\right)^* + (1-q_k^*)(1+q_k^*)/(2b_1)}{q_k^*} = r - x - n > 0, \tag{57}$$

$$D = -\frac{\eta}{q_k^*}\left(\frac{\partial f}{\partial k}\right)^* < 0, \tag{58}$$

$$E = \frac{q_h^*}{b_2} > 0, \tag{59}$$

$$F = -\frac{\alpha}{q_h^*}\left(\frac{\partial f}{\partial h}\right)^* < 0, \tag{60}$$

$$G = \frac{1-\eta}{q_h^*}\left(\frac{\partial f}{\partial h}\right)^* > 0, \tag{61}$$

$$H = C = r - x - n > 0. \tag{62}$$

The key problem now is to find the eigen values of the matrix,

$$\begin{pmatrix} 0 & A & 0 & 0 \\ B & C & D & 0 \\ 0 & 0 & 0 & E \\ F & 0 & G & H \end{pmatrix}$$

These eigen values, ε, are the solutions to the characteristic equation, which is a fourth-order algebraic equation:

$$\varepsilon^4 - (H + C)\varepsilon^3 + (HC - EG - AB)\varepsilon^2 + (ABH + ECG)\varepsilon + AE(BG - DF) = 0. \tag{63}$$

Solutions to fourth-order algebraic equations can be generally expressed in an analytical form; nevertheless, this procedure is relatively cumbersome. Surprisingly, (63) takes a special form which can be decomposed into a product of two quadratic equations. This can be done due to the proportionality between B and D, and between F and G. These quadratic equations are:

$$\varepsilon^2 + z_1\varepsilon + z_2 = 0\,, \tag{64}$$

$$\varepsilon^2 + z_3\varepsilon + z_4 = 0\,, \tag{65}$$

where

$$z_1 = z_3 = -C = x + n - r < 0, \tag{66}$$

$$z_2 = \frac{-EG - AB + \sqrt{(AB + EG)^2 - 4ABEG\frac{1-\alpha-\eta}{(1-\alpha)(1-\eta)}}}{2} < 0, \tag{67}$$

$$z_4 = -AB - EG - z_2 = \frac{ABEG(1-\alpha-\eta)}{z_2(1-\alpha)(1-\eta)} < 0. \tag{68}$$

Two eigen values are positive, and two eigen values are negative. The positive eigen values correspond to explosive paths and must consequently be excluded for the transversality conditions to be satisfied. The two negative eigen values are:

$$\varepsilon_1 = \frac{-z_1 - \sqrt{z_1^2 - 4z_2}}{2}, \tag{69}$$

$$\varepsilon_2 = \frac{-z_3 - \sqrt{z_3^2 - 4z_4}}{2}. \tag{70}$$

The time evolution of k, q_k, h, and q_h is,

$$\ln(k / k^*) = \mu_1 e^{\varepsilon_1 t} + \mu_2 e^{\varepsilon_2 t}, \tag{71}$$

$$\ln(q_k / q_k^*) = v_{1,1}\mu_1 e^{\varepsilon_1 t} + v_{2,1}\mu_2 e^{\varepsilon_2 t}, \tag{72}$$

$$\ln(h / h^*) = v_{1,2}\mu_1 e^{\varepsilon_1 t} + v_{2,2}\mu_2 e^{\varepsilon_2 t}, \tag{73}$$

$$\ln(q_h / q_h^*) = v_{1,3}\mu_1 e^{\varepsilon_1 t} + v_{2,3}\mu_2 e^{\varepsilon_2 t}, \tag{74}$$

where $(1, v_{i,1}, v_{i,2}, v_{i,3})$ is the eigenvector corresponding to the eigen value ε_i. Coefficients μ_1 and μ_2 could then be determined from the initial conditions for k and h:

$$v_{i,1} = \frac{\varepsilon_i}{A}, \tag{75}$$

$$v_{i,2} = -\frac{B + \varepsilon_i (C - \varepsilon_i) / A}{D}, \tag{76}$$

$$v_{i,3} = \frac{\varepsilon_i}{E} v_{i,2}, \tag{77}$$

$$\mu_1 = \frac{\ln(h_0 / h^*) - v_{2,2} \ln(k_0 / k^*)}{v_{1,2} - v_{2,2}}, \tag{78}$$

$$\mu_2 = \frac{\ln(h_0 / h^*) - v_{1,2} \ln(k_0 / k^*)}{v_{2,2} - v_{1,2}}. \tag{79}$$

3. Growth, Convergence, and Current Account

The time evolution of output per effective worker, y, is

$$\ln(y / y^*) = \alpha \ln(k / k^*) + \eta \ln(h / h^*) = \Theta_1 e^{\varepsilon_1 t} + \Theta_2 e^{\varepsilon_2 t}, \tag{80}$$

where $\Theta_1 = \mu_1 (\alpha + \eta v_{1,2})$ and $\Theta_2 = \mu_2 (\alpha + \eta v_{2,2})$. The growth rate of y is,

$$\gamma \equiv \frac{\dot{y}}{y} = \frac{d \ln(y / y^*)}{dt} = \Theta_1 \varepsilon_1 e^{\varepsilon_1 t} + \Theta_2 \varepsilon_2 e^{\varepsilon_2 t}. \tag{81}$$

Note that γ is related to the output per effective worker. The growth rate of output per capita is therefore $\gamma + x$. The convergence coefficient, β, is,

$$\beta \equiv -\frac{\gamma}{\ln(y / y^*)} = -\frac{\Theta_1 \varepsilon_1 e^{\varepsilon_1 t} + \Theta_2 \varepsilon_2 e^{\varepsilon_2 t}}{\Theta_1 e^{\varepsilon_1 t} + \Theta_2 e^{\varepsilon_2 t}} \tag{82}$$

Note that β is a "weighted average" of $|\varepsilon_1|$ and $|\varepsilon_2|$; if $t \to \infty$, $\beta \to \min\{|\varepsilon_1|, |\varepsilon_2|\}$. If the values of ε_1 and ε_2 differ, convergence speed may change over time.

Having found solutions for k and h, we can determine the initial consumption level, c_0, from equation (36). This procedure requires numerical integration on the right-hand side of (36). When c is determined as a function of time, d can be found by solving (8) numerically. The current-account ratio is given by,

$$\frac{\dot{D}}{Y} = \frac{\dot{d}}{y} + (n + x)\frac{d}{y}. \tag{83}$$

In order to provide an illustrate example, the model is calibrated in the following way: $\alpha = 0.3, \eta = 0.65$, n = 0.01/year, x= 0.02/year, δ = 0.05/year, and r = 0.006/year (These values correspond to those used by Barro, Robert. J., N. Gregory Mankiw, and Xavier Sala-i-Martin, 1995). Except for η, we choose a higher value (0.65 instead of 0.5) is not empirically counterfactual; it pushes the model closer to its endogenous limit and can account for slower convergence. Adjustment cost parameters are chosen consistently with two empirical requirements: First, asymptotic convergence is sufficiently slow (e.g., at the rate of about 2%). Second, the steady-sate value of Tobin's q for physical capital, q_k^*, is only slightly higher than 1. These conditions are met if for example, q_k^*=1.2, and q_h^*=2.0. In this calibration, ε_1=-1.9% and ε_2=-18%. Convergence coefficients and growth rates depend on the initial ratio of human to physical capital. Let,

$$m = \frac{h_0 / h^*}{k_0 / k^*}, \tag{84}$$

$$y_0 = y(t=0) = A k_0^{\alpha} h_0^{\eta} \tag{85}$$

Initial levels k_0 and h_0 then satisfy,

$$\ln(k_0 / k^*) = \frac{\ln(y_0 / y^*) - \eta \ln m}{\alpha + \eta}, \tag{86}$$

$$\ln(h_0 / h^*) = \frac{\ln(y_0 / y^*) - \alpha \ln m}{\alpha + \eta} \tag{87}$$

If this is substituted into (78) and (79), γ and β can be expressed in terms of y_0 / y^* and *m*.

We need further to specify preference parameters and express the predicted current-account balance. The economy is as "patient" as the rest of the world if $r = \rho + \theta x$ (Note that consumption per effective worker is constant in this case), which is achieved if, for instance, $\theta = 2$ and ρ = 0.02/year. The predicted current-account ratios are, however, unrealistically high in this case: the initial current-account deficit amounts to 15.4% of GDP if m = 1, and it reaches even higher values for a higher *m*. We can reconcile this finding with the economic reality in two ways. First, the model analyzed here abstracts from any borrowing restrictions. If we introduced some restrictions, the current-account deficit could be much smaller. Second, the sensitivity of the current-account to preference parameters turns out to be extremely high: if we considered, for example, $\theta = 5$ and ρ = 0.015/year, the initial current-account deficit would be 2.6% of GDP if $d_0 = 0$ and m = 1. However, if the economy is as patient as that, it asymptotically accumulates all the world's assets, which is clearly inconsistent with the assumption of a small economy. Future extensions of the model considering finite horizons or precautionary savings could lead to effective preference parameter variations which should make the asymptotic consumption behavior more realistic. In this case, the initial deficit grows very rapidly with *m*, reaching, for example, 13.3% of GDP if m = 2.

The economic interpretation of the positive relationship between the current-account deficit and *m* is straightforward: If the ratio of human to physical capital is\large, the marginal product of physical capital is large. High returns to physical capital induce substantial physical capital investment. Domestic savings are, however, too limited to finance all of this investment; in other words, the economy runs a current-account deficit. Even large current-account deficits, which are rarely observed elsewhere in the world, may be optimal in relatively human-capital abundant economies.

4. Concluding Remarks

This paper investigates the behavior of convergence in open economies under the assumption of large adjustment costs for human capital accumulation, moderate adjustment costs for physical capital accumulation, and no borrowing restrictions. The analysis of the log-linearized model shows that the model can be calibrated for slow asymptotic convergence. Economies with high initial ratios of human to physical capital are, however, predicted to converge quickly initially. The model also indicates a stronger tendency towards current-account deficits in human-capital abundant economies.

The fact that convergence may be fast initially is not inconsistent with the slow convergence typically observed in cross-sectional studies as long as developing economies included in these studies do not exhibit high ratios of human to physical capital. Former centrally planned economies could, however, be exceptional in being endowed with a relatively well-educated labor force. Future long-run performance of these economies could tell us more about the role of human capital in the process of convergence.

5. References

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