13

Endogenous Growth Under International Capital and Labor Mobility

In this chapter, we provide an extension of the exogenous growth model developed in the previous chapter. The standard model assumes that human capital accumulation, which drives long run growth, is exogenously determined. Our extension involves endogenizing the rate of human capital formation by deriving it from the optimizing decisions of private households. The extended model emphasizes the role of saving (broadly defined to include investment in both physical and human capital) in the entire (short and long run) growth process. Cast in a stochastic framework, the engine of growth in this model (human capital) generates a unique feature, i.e., transitory shocks have long-lasting level and growth effects.

In an integrated world economy, capital and labor mobility are potentially key elements in equalizing differences in levels and rates of growth of income across countries. Are labor mobility and capital mobility substitutes or complements for cross-country convergence?

These issues are subject matters of the analysis in this chapter.

13.1 The Closed Economy

We extend the closed economy model of Chapter 12 in one particular dimension pertaining to the accumulation of human capital as described by (12.3). More specifically, we can rewrite (12.3) as $H_{t+1} = N_{t+1}h_{t+1} = [(1+g_N)N_t][(1+g_{ht})h_t] = (1+g_H)H_t$. Expressing $1+g_{ht}$ as a function of the time invested in human capital (e_t for education) and the rate of depreciation of human capital (δ_h), we have

$$h_{t+1} = Be_t^{\gamma}h_t + (1-\delta_h)h_t, \tag{13.1}$$

where $Be^{\gamma}h$ is the human capital production function, B the knowledge efficiency coefficient, and γ the productivity parameter.

As implicitly assumed before, each household is endowed with one unit of time in each period. But instead of spending it only on work, the household splits it between work (n_t = $1-e_t$) and education (e_t). Taking this into account, the consumer budget constraint has to be rewritten as follows:

$${}_t + K_{t+1} - (1-\delta_k)K_t = w_t(1-e_t)N_th_t + r_{kt}K_t + B_{t+1} - (1+r_t) \tag{13.2}$$

Denoting the consumer's full income as $FI_t = w_tN_th_t + r_{kt}K_t$, we can define two saving rate: (a) physical-capital-saving rate, $s_{Kt} = [K_{t+1}-(1-\delta_k)K_t]/FI_t$, and (b) human-capital-saving rate, $s_{Ht} = w_te_tN_th_t/FI_t$. These two saving rates will have an important role to play in the long run growth process.

The consumer chooses $\{c_t,e_t,B_{t+1},K_{t+1},h_{t+1}\}$ to maximize his/her utility (12.5) subject to the above budget constraint (12.2) and the law of motion of human capital (13.1). The endogeneity of human capital decision is captured by two additional first order conditions corresponding to the choice of e_t and h_{t+1}. Combining them with the first order conditions for c_t, K_{t+1}, and B_{t+1} yields an analogue of (12.7):

$$\frac{1}{\beta}\left(\frac{c_{t+1}}{c_t}\right)^{\sigma} = R_{Bt+1} = R_{Kt+1} = R_{Ht+1}, \tag{13.3}$$

where the gross rate of interest on bonds $R_{Bt+1} = 1 + r_{t+1}$, the gross rate of return on physical capital $R_{Kt+1} = 1 + r_{kt+1} - \delta_k$, and the gross rate of return on human capital R_{Ht+1} is given by

$$R_{Ht+1} = \left(\frac{w_{t+1}}{w_t} \right) (1+g_N)(Be_t^{(-1} .$$

This expression of R_{Ht+1} shows its dependence on wage growth, population growth, and the marginal productivity of schooling time. These three rates of return are equalized through arbitrage among the three forms of investment.

Long Run Growth

The most crucial element of this extended model is the possibility of having sustainable long run growth which is endogenously determined through human capital accumulation. Recall that $g_{ht} = Be_t^{\gamma} - \delta_h$. Assume for simplicity complete depreciation so that $\delta_h = 1$. We can then show (see Appendix A) that the steady state value of the time invested in human capital ($\hat{e}$) satifies the following equation:

$$1 + (\left(\frac{1-e}{e} \right) = (1+g_N)(Be^{(})^{1-F}, \qquad (13.4)$$

Observe that it is necessary to have $\sigma \leq 1$ in order to guarantee the existence of a solution to the above equation with $0 < \hat{e} < 1$. From (13.1), under further parameter restrictions on B, γ, and g_N, g_h can be shown to be positive.[1]

$$g_h = \left[\frac{\beta(1-\alpha)}{s_K(1+g_N)}\right]^{\frac{1}{1-\sigma}} - 1.$$

This long run growth rate can be related to the saving rates as follows.

$$g_h = B\left(\frac{s_H}{\alpha+s_H}\right)^{\gamma} - 1.$$

These expressions reveal that the long run growth rate is positively related to the human-capital saving rate, but either negatively related or totally unrelated to the physical-capital-saving rate (depending on whether $\sigma < 1$ or $\sigma = 1$). This justifies labelling human capital as the `engine of growth'. Consequently, policies which target the human-capital-saving rate can directly affect the long run growth rate of the economy.[2]

In a world of isolated economies with similar preferences and technology but possibly different initial endowment of physical and human capital (hence, different initial incomes), our analysis implies that they will converge over time to the same long run steady state growth path with the same growth rates. Like the exogenous growth model of the previous chapter, these economies will have the same detrended income levels. This is illustrated in Figure 13.1 portraying the steady state relation between the detrended stocks of physical and human capital. Since the ratio between these two forms of capital ($\hat{x}$) is constant in the long run, this relation is represented by a ray from the origin with slope equal to $\hat{x}N_0(1-e)$. Countries may start from any initial position on the $\hat{h}_t$-$\hat{K}_t$ plane. The arrows in the figure show how they move from their respective initial positions to possibly different long run positions on the ray, implying different levels of income. But since they all end up on the ray with the same capitals ratio ($\hat{x}$), their detrended levels of income ($\hat{y}_t/h_t$) will be equalized in the long run, similar to the exogenous growth case.

[insert Figure 13.1 here]

Human Capital Externality

In analyzing cross-country differences in wage rates and rates of return on capital, Lucas (1988,1990) isolates an important element in human capital formation. This element captures the possibility that, through investment in human capital, the individual not only enhances his earning ability, but also generates an external effect by contributing to the aggregate level of productivity. This latter effect, dubbed `Lucas-externality', is modelled as follows:

$$Y_t = AK_t^{1-\alpha}[(1-e_t)N_t h_t]^{\alpha}\bar{h}_t^{\epsilon}, \tag{13.5}$$

where $\bar{h}_t$ is the economy-wide average level of skill, and ϵ the externality parameter. While this production function exhibits increasing returns in K_t, H_t, and $\bar{h}_t$ (since $1-\alpha+\alpha+\epsilon > 1$), it still retains the constant returns property in the two private inputs K_t and H_t.

Under this specification of technology, the intertemporal condition becomes $(c_{t+1}/c_t)^{\sigma} = \beta(1-\alpha)A(K_{t+1}/H_{t+1})^{-\alpha}\bar{h}_{t+1}^{\epsilon}$. Along the steady state growth path, the constancy of c_{t+1}/c_t and e_{t+1} requires that $(K_t/N_t h_t)^{-\alpha}\bar{h}_t^{\epsilon}$ be constant. This implies that K_t must grow at the same rate as $N_t h_t^{\zeta}$, where $\zeta = 1+\epsilon/\alpha$ (> 1) and the equilibrium condition: $\bar{h}_t = h_t$ is imposed. Rearranging terms, we can write

$$\hat{K}_t = \left[\frac{\beta(1-\alpha)A}{(1+g_c)^{\sigma}-\beta(1-\delta_k)}\right]^{1/\alpha} \phi_0(1-e)\hat{h}_t,$$

where $1+g_c$ can be shown to equal $(1+g_h)^{\zeta}$. This equation is represented by the convex curve between $\hat{K}_t$ and $\hat{h}_t$ in Figure 13.2. Similar to the case where the Lucas-externality is absent ($\zeta = 1$), countries starting from different initial positions on the $\hat{h}_t$-$\hat{K}_t$ plane will converge to different long run positions on the curve, implying different levels of income. However, unlike the no-externality case, the slope of the ray varies (increases) with $\hat{h}_t$, thus implying that the capitals ratio $\hat{x}$ will, in general, be different across countries. Their detrended levels of income ($\hat{y}_t/h_t$) will not be equalized in the long run, in sharp contrast to the exogenous growth case. The Lucas-externality is therefore a fundamental force behind long run income diversity.

[insert Figure 13.2 here]

13.2 The Open Economy: Capital Mobility

From a global perspective, there is an important issue as to whether countries with different income levels will exhibit similar rates of growth or whether the low-income countries exhibit higher growth rates so that they can catch up with the high-income countries over time. We have shown in the previous section that, in the presence of knowledge spillovers, if cross-country differences are due to differences in initial positions, then growth rates will converge but levels will not.

In the absence of externality, international capital mobility will speed up the convergence to the steady state as in the exogenous growth model. In this section, we ask whether, in the presence of externality, capital mobility will also bring about convergence in long run income levels across countries.

Consider, as before, a small open economy which is integrated into the world capital market. The rest of the world is assumed to be travelling along its long run steady state growth path. Opening up the capital market implies an immediate equalization of returns on both financial and physical capital (net of depreciation). Accordingly, from intertemporal condition (12.7), the home country consumption growth rate will converge in one period to the consumption growth rate in the rest of the world. The fact that $r_{kt} - \delta_k = r^*$ implies that $K_t/N_t h_t^{\zeta}$ is constant and equal to its steady state value. This is the main difference between the autarky and capital mobility cases.

But the long run detrended levels and rates of growth of output are the same in both cases, given the similarity in preferences and technology.[3]

13.3 Open Economy: Labor Mobility

In the exogenous growth case, labor mobility and capital mobility are perfect substitutes. In this section, we examine whether this property still holds under conditions of endogenous growth. If not, can labor mobility achieve level convergence, something that is not achievable under capital mobility?

Consider again two isolated economies that have identical preferences and technologies, but possibly different endowments of physical and human capital. Even without capital mobility, interest rates will be equalized across these two economies in the long run (i.e., along their autarky balanced growth paths) as their steady state physical capital-human capital ratios converge to the same value. In the presence of the Lucas-externality, wage rates in these two economies will differ as long as the skill levels of their workers are different. With labor mobility, workers will naturally move from low wage (human-capital-poor) countries (say, the home country) to high wage (human-capital-rich) countries (say, the rest of the world). Since labor will flow from the home country to the rest of the world, the fraction of native effective labor working in the rest of world, n^*, equals 1 and the corresponding fraction in the home country, n, lies between 0 and 1. The effective work force in the home country is $nN_t h_t$ and that in the rest of the world is $N_t^* h_t^* + (1-n)N_t h_t$. The average levels of human capital are $\bar{h}_t = h_t$ and $\bar{h}_t^* = \theta_t h_t + (1-\theta_t)h_t^*$ in equilibrium, where $\theta_t = N_t/(N_t + N_t^*)$.

Suppose that while some workers from the home country choose to work in the rest of the world, they continue to accumulate their human capital in their own country. Although the extent of knowledge spillovers may be limited by national boundaries, labor mobility provides an indirect channel of productivity transmission across countries. This is because workers from the home country can enjoy the fruits of the knowledge externality while working with the more skilled workers in the rest of the world, and then transmit this superior knowledge to their countrymen during the process of human capital accumulation. In other words, these workers can be viewed as `messengers' of technological progress. Over time, this knowledge transmission will lead to equalization of wage rates as well as levels of human capital and income per capita in the whole world.

In more formal terms, the above level-equalizing argument can be stated and proved as follows.

Along the steady state growth path with nonzero labor flows and $\epsilon > 0$, $g_h = g_h^*$ (given $g_N = g_N^*$, hence $0 < \theta < 1$) and $\hat{h} = \hat{h}^*$.

Proof: As this proof applies only to the steady state, we drop the `hat' (^) used to denote steady state values to simplify notations.

Along the equilibrium balanced path, we have

$$\left(\frac{1+g_c}{1+g_c^*}\right)^F = \left(\frac{1+g_h}{1+g_h^*}\right)^F = \frac{r_k}{r_k^*} = \frac{x_t^*}{x_t}$$

$$\textit{where } x_t = \frac{K_t}{n_t N_t h_t} \quad \textit{and} \quad x_t^* = \frac{K_t^*}{N_t^* h_t^* + (1-n_t) N_t h_t}.$$

The first equality reflects the balanced growth condition between c_t and h_t^{ζ}, implied by (13.2) and (13.5). The second equality follows from the intertemporal condition (12.7). The third equality is derived from the relation between the rental rate of capital and the wage rate [i.e., $r_k = (1-\alpha)w_t/\alpha x_t$, and likewise for the rest of the world] and the wage equality condition: $w_t = w_t^*$.[4]

Symmetric preferences and technology imply that $g_h = g_h^*$, leading to equality of interest rates and hence capital-effective-labor ratios (x_t and x_t^*). Substituting back into the wage equality condition, $x_t = x_t^*$ implies that $h_t = \bar{h}_t^* = \theta h_t + (1-\theta)h_t^*$, so that $h_t = h_t^*$ for $\theta \in (0,1)$. This concludes the proof of the proposition.[5]

In the first two sections, we show that the spillovers associated with human capital formation are essential in order to generate diversity in long run income levels. In its absence, (detrended) income levels of countries similar in preferences and technology will converge. In this last section, we show that a combination of human capital externality and labor mobility is essential to restore level convergence. Thus, the Lucas-externality is both a source of divergence (in the absence of labor mobility) and a source of convergence (in the presence of labor mobility).

13.4 Stochastic Growth and Time Series Implications

The stochastic version of the endogenous growth model has important implications for empirical implementations. To highlight its time series implications, we recast the closed economy model in a stochastic environment, similar to that of Chapter 7.

Assume that productivity is subject to random shocks, which evolve according to the following law of motion:

$$a_{t+1} = \mathrm{D}a_t + <_{t+1},$$

where a = ln(A) and   is an i.i.d. disturbance. [Recall that A is the productivity level in the production function.] Similar law of motion can be introduced for the human capital productivity level (B).

The stochastic Euler equations (first order conditions) look similar to their deterministic counterparts spelled out in Appendix A except for the addition of expectation operators on future values of the variables. In Appendix B, we describe the log-linearization technique which can generate solutions for consumption (c_t), education (e_t), physical capital (K_{t+1}), and human capital (h_{t+1}) in terms of past and present realizations of the shock ($_t$) and the initial values of the capital stocks (K_0 and h_0). In other words, we get reduced form equations in these variables which can be used as regression equations for empirical analysis. The coefficients of these regressions can be related explicitly to the deep structural parameters ($\beta,\sigma,\alpha,\delta_k,B,\gamma,\delta_h,$) of the model.

A key feature of the growth model is the existence of a unit root in the reduced form regression equations. To see this, consider the law of motion of the growth engine, human capital, in its detrended form:

$$(1+g_h)^{t+1}\hat{h}_{t+1} = B\hat{e}_t^{\gamma}(1+g_h)^t\hat{h}_t + (1-\delta_h)(1+g_h)^t\hat{h}_t$$

Upon simplification, this can be expressed as:

$$(1+g_h)\hat{h}_{t+1} = [B\hat{e}_t^{\gamma} + (1-\delta_h)]\hat{h}_t. \qquad (13.6)$$

At the deterministic steady state (around which the nonlinear stochastic dynamic system is linearized), $\hat{h}_{t+1} = \hat{h}_t$ and $\hat{e}_t = \hat{e}$ constant so that $1+g_h = B\hat{e}^{\gamma}$. Log-linearizing this equation around the steady state yields

$$\Delta\ln(\hat{h}_{t+1}) = \Delta\ln(\hat{h}_t) + \left[\frac{\gamma B\hat{e}^{\gamma}}{B\hat{e}^{\gamma} + (1-\delta_h)}\right]\Delta\ln(\hat{e}_t), \qquad (13.7)$$

where $\Delta\ln(x) = \Delta x/x$. Equation (13.7) reveals that the evolution of the detrended engine of growth ($\hat{h}$) is characterized by a unit root. This feature reflects the growth-sustainability property of the human capital engine. This unit root feature, in turn, implies that any transitory shocks will generate persistent effects on equilibrium values of all the detrended variables. Obviously, the same applies to these variables in their original non-detrended forms as well. [For an empirical application of this idea, see Jones (1995).]

Appendix 1: Derivation of Equation (14.4)

The consumer's first order conditions with respect to c_t, e_t, B_{t+1}, K_{t+1}, and h_{t+1} are given by:

$$c_t^{-F} = \mu_t, \tag{A.1}$$

$$\mu_{h_t}(Be_t^{(-1} = \mu_t w_t N_t, \tag{A.2}$$

$$\mu_t = \$\mu_{t+1}(1+r_{t+1}), \tag{A.3}$$

$$\mu_t = \$\mu_{t+1}(1+r_{kt+1}-*_k), \tag{A.4}$$

$$\mu_{h_t} = \$[\mu_{h_{t+1}}Be_{t+1}^{(}+\mu_{t+1}w_{t+1}(1-e_{t+1})N_{t+1}]. \tag{A.5}$$

where μ_t and μ_{ht} are the Lagrange multipliers (μ for `mu'ltipliers) at time t associated with the consumer budget constraint (13.2) and the law of motion of human capital (13.1) respectively. The firm's first order conditions are

$$w_t = "A\left(\frac{x_t}{1-e_t}\right)^{1-"}, \text{ and} \tag{A.6}$$

$$r_{kt} = (1-")A\left(\frac{x_t}{1-e_t}\right)^{-"}. \tag{A.7}$$

The equilibrium conditions in the labor and capital markets are

$$(1-e_t)N_t h_t = H_t^d, \text{ and} \tag{A.8}$$

$$K_t = K_t^d . \quad \textbf{(A.9)}$$

Substituting (13.1) and (A.6) into (A.2), we get,

$$\frac{\gamma \mu_{h_t} h_{t+1}}{e_t} = \frac{\alpha \mu_t Y_t}{1-e_t} . \quad \textbf{(A.10)}$$

Along the balanced growth path, time allocations are constant, i.e., $e_t = e_{t+1}$, so that (A1.1) implies that

$$\frac{\beta \mu_{h_{t+1}} h_{t+2}}{\mu_{h_t} h_{t+1}} = \frac{\beta \mu_{t+1} Y_{t+1}}{\mu_t Y_t} , \quad \textbf{(A.11)}$$

where the three terms in (A.11) are given respectively by

$$\frac{\mu_{h_t} h_{t+1}}{\beta \mu_{h_{t+1}} h_{t+2}} = 1 + \alpha \left(\frac{\mu_{t+1} Y_{t+1}}{\mu_{h_{t+1}} h_{t+2}} \right) , \quad \textbf{(A.12)}$$

from (13.1), (A.5), and (A.6), and

$$\frac{\mu_t Y_t}{\beta \mu_{t+1} Y_{t+1}} = \frac{1-\alpha}{s_K} . \quad \textbf{(A.13)}$$

from (A.1) and (A.3), with $s_K \equiv K_{t+1}/Y_t = \beta(1-\alpha)(1+g_N)(Be^{\gamma})^{1-\sigma}$. Combining (A.10)—(A.13) yields equation (13.4) in the text.

Appendix B: Log-linearization of the Stochastic Growth Model

In this appendix, we follow King, Plosser, and Rebelo (1988) and Campbell (1994) by providing a log-linear approximation of the stochastic growth model to derive expressions for the endogenous variables in terms of the underlying exogenous shocks.

To reduce the dimension of the problem, we substitute the firm's first order conditions and the market clearing conditions into the consumer's first order conditions to eliminate the factor prices (w_t and r_{kt}). The result is a set of six equations in the two control variables (c_t and e_t), the two state variables (K_{t+1} and h_{t+1}), and the two co-state variables (the Lagrange multipliers μ_t and μ_{ht}).

Since we want to linearize the stochastic dynamical system around its deterministic steady state, we need to first detrend the set of six equations in order to solve for its steady state in the absence of shocks. Direct inspection of the original nonlinear dynamical system suggests the following detrending rules:

$$\hat{c}_t = \frac{c_t}{(1+g_h)^t}, \quad \hat{e}_t = e_t,$$

$$\hat{K}_t = \frac{K_t}{(1+g_N)(1+g_h)^t}, \quad \hat{h}_t = \frac{h_t}{(1+g_h)^t},$$

$$\hat{\mu}_t = \mu_t(1+g_h)^{\text{F}t}, \quad \hat{\mu}_{h_t} = \frac{\mu_{h_t}(1+g_h)^{\text{F}t}}{(1+g_N)^t},$$

where g_h is the steady state growth rate of human capital. Naturally, this detrended system has the property that, in the steady state, all the detrended (`hat') variables are time-invariant.

Using the above detrending rules, we can rewrite the equilibrium system in terms of these detrended variables. Shutting down the shocks and dropping the expectation terms and the time subscripts yields a set of six nonlinear deterministic steady state equations in $\{\hat{c}, \hat{e}, \hat{K}, \hat{h}, \hat{\mu}, \hat{\mu}_h\}$. We then log-linearize the set of six original stochastic nonlinear dynamical equations around its deterministic steady state.

Solving the linearized version of the control equations for $(\hat{c}_t, \hat{e}_t)$ as functions of $(\hat{K}_{t+1}, \hat{h}_{t+1}, \hat{\mu}_t, \hat{\mu}_{ht})$ and substituting them into the state and co-state equations, we obtain a linear system with four difference equations in the state and co-state variables $(\hat{K}_{t+1}, \hat{h}_{t+1}, \hat{\mu}_t, \hat{\mu}_{ht})$.

Problems

1. Consider a special case of the closed economy model in Section 14.1 with a single capital input in the production function: $Y_t = AK_t$. The accumulation of this input follows the same law of motion as that of physical capital in (13.2). Find the long run steady state, and describe the transitional dynamics. What if the production function takes the form: $Y_t = A(1-e_t)N_t h_t$, and the capital input (h_t) follows the law of motion of human capital in (14.1)? How does the growth rate depend on the saving rate in these cases? Compare these growth rate-saving rate relations with that in the two-capital case considered in the text.

2. Consider the closed economy model in Section 14.1. How will the presence of the Lucas-externality as specified in (14.5) alter the growth rate of human capital in the steady state? Compare this with the efficient growth rate where the external effect is fully internalized (i.e., solution to the social planner's problem). Show also that, in both cases, $1+g_c = (1+g_h)^{\zeta}$ in the steady state.

3. Consider a case of external economies of scale in which technology at the firm's level exhibit constant returns to scale, but its productivity depends on the size of aggregate output: $\tilde{y}_t = AK_t^{1-\alpha}[(1\text{-}e_t)N_t h_t]^{\alpha} Y_t^{\beta}$. At the competitive equilibrium, $\tilde{y}_t = Y_t^{\beta}$. Compare the long run growth rates and the ratios between physical and human capital between two symmetric economies (in preferences and technology) that start at different initial positions. Could these two economies achieve growth rate convergence? Income level convergence? What if barriers to labor flows between these two economies are lifted? Compare to the labor mobility case discussed in the text (in the presence of Lucas-externality).

4. Consider the model in Section 14.4. Assume, for simplicity, that g_h is given as in the exogenous growth model. Solve explicitly the log-linearized system. Show whether transitory shocks will have permanent effects on output.

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Endnotes

1. Since $\hat{e} = [(1+g_h)/B]^{1/\gamma}$ from (14.1), (14.4) can be restated in terms of g_h as:

$$(1+g_N)(1+g_h)^{1-\sigma} = 1+\gamma\left[\left(\frac{B}{1+g_h}\right)^{1/\gamma}-1\right].$$

The parameter restrictions on σ, B, γ, and g_N for a positive g_h are implicit in the solution to the above equation. In the log utility case, $B[\gamma/(\gamma+g_N)]^{\gamma} > 1$ gives such restriction for $g_h > 0$.

2. This suggests that the AK-style model, which lumps all forms of capital into one broad aggregate and applies a single saving rate which drives the accumulation of this all-encompassing capital, may lead to imprecise policy implications.

3. Note, however, that as in the exogenous growth case, the long run detrended level of consumption under capital mobility will not be equal to their counterpart in the autarky case.

4. Even though there may not exist any labor flows along the steady state growth path due to the symmetry in preferences and technology between the home country and the rest of the world, the absence of barriers to labor mobility guarantees the cross-country wage equality:

$$w_t = \alpha x_t^{1-\alpha} h_t^{\gamma} = \alpha x_t^{*1-\alpha} \bar{h}_t^{*\gamma} = w_t^{*}.$$

5. We conjecture that, even without symmetry in technology and preferences across countries, labor mobility combined with knowledge spillovers will be a level-equalizing force although complete equalization of income levels will not be achieved.