

Chapter 6

Economic Growth and Economic Development

Most economists feel passionate about economic growth and its relation to development problems. This passion has translated into a vast literature, which includes both theoretical and empirical streams. My objective here is to introduce the basic time-honoured concepts, without making any claims about comprehensiveness.

Historically, economists have applied the theoretical and empirical tools of economic analysis to address two related questions. The first question has a distinctly time-series bent: what are the primary drivers of long-term economic growth? The second question, on the other hand, has distinctly cross-sectional bent: why are some countries richer than others? I will loosely refer to the former questions as the “growth problem” and the latter as the “development problem.” The development problem is an intrinsically comparative approach to income per capita. The growth problem can be both a single or multi-country approach. For instance, there is a large literature on a comparative growth question: why do some countries grow faster than others? In a comparative setting, then, the development problem is about the distribution of income across countries, and the growth problem is about the changing distribution of income across countries.

Undoubtedly, economic and social factors that determine the current global development landscape are also likely to shape the growth problem in the future. However, our understanding of the links between such initial conditions and future economic performance is far from satisfactory. So far, a vast literature on the determinants of long-term economic *growth* has produced very little convincing evidence, leaving some economists advocating the study of income *level* differentials as the most meaningful research agenda (e.g., Temple, 1999).¹

I start the discussion by focusing on *proximate* causes of economic growth. Despite its well-known shortcomings, most economic and policy focus has been on understanding the determinants of the growth rate of GDP per person. As a mundane observation, economic growth, measured as such, is driven by growth rates of inputs and population. Growth accounting measures the contribution of the growth rate of individual inputs to the growth rate of output (or output per worker). I then turn to a classic model

¹For instance, Barro (1991) and Sala-i Martin, Doppelhofer, and Miller (2004) advocate the growth approach, and Temple (1999) advocates the development approach.

of economic growth. The model is simple, but provides surprisingly rich set of insights. I conclude this chapter by providing a conceptual paradigm to tackle growth and development problems from an empirical standpoint.

6.1 Growth Accounting

Production of a particular commodity or service typically requires more than a single factor of production. In such multi-factor environments a natural question arises: what is the contribution of each factor of production to observed changes in real output? *Growth accounting* addresses this question. It does so by accounting for the growth rate of output in terms of a weighted sum of the growth rates of the factors of production. The crux of growth accounting, then, is to find a reasonable method of calculating these weights. The most conventional growth accounting scheme assigns each factor's share in total income as weight to the growth rate of the corresponding factor of production.

6.1.1 A Framework

In particular, consider an environment in which a (differentiable, and homogenous of degree one) production function, F summarizes all the technical production possibilities available to an economy:

$$Y = F(A_K K, A_L L), \quad (6.1)$$

where Y is output. The factors of production are as follows: capital services, which are proportional to the capital stock, K ; labour services, L ; and capital and labour augmenting technology, A_K , and A_L , respectively.

Now, let $\ln X$ denote the natural logarithm of a variable X . When time is continuous, the instantaneous growth rate of X is denoted by $d \ln X(t)/dt = g_{Xt}$. Then, total differentiation of equation (6.1) and the homogeneity property F give (omitting time)

$$g_Y = g_A + \left(\frac{K}{Y} F_K \right) g_K + \left(\frac{L}{Y} F_L \right) g_L, \quad (6.2)$$

where $\frac{X}{Y} F_X$ is the "weight" assigned to each input, and g_A is referred to as the growth rate of *total factor productivity* (TFP), which is a combination of capital and labour augmenting technological change.

It turns out that when factor markets are competitive, share of a factor in GDP is equal to its elasticity with respect to output:

$$\alpha \equiv \frac{rK}{pY} = \frac{K}{Y} F_K,$$

$$1 - \alpha \equiv \frac{wL}{pY} = \frac{L}{Y} F_L.$$

With this in mind, to implement equation (6.2) in practice, consider a discreet time approximation, whereby the growth rate of X between two periods $t-1$ and t is measured by $\Delta \ln X(t) = \ln X(t) - \ln X_{t-1}$, with

$$\Delta \ln Y(t) = \hat{\alpha}(t) \Delta \ln K(t) + (1 - \hat{\alpha}(t)) \Delta \ln L(t) + g_{At}, \quad (6.3)$$

where $\hat{\alpha}(t) = \frac{1}{2}(\alpha(t) + \alpha_{t-1})$.

Next, I discuss the measurement issues surrounding this growth accounting framework.

6.1.2 Measurement Issues

In principle, the *share of capital* in income, α (and share of labour, $1 - \alpha$) can be calculated from the national income and product accounts (NIPA). In practice, the difficulty is that NIPA does not provide an unambiguous measure of compensation of labour services. For instance, it includes an entry called “operating surplus of unincorporated business,” which must be allocated between capital and labour services, and then added to the NIPA entry “compensation of employees.” Assuming that this allocation can be done suitably, the share of labour in income can be computed as the ratio of compensation of all income from labour services to GDP minus indirect taxes, which do not constitute part of capital or labour income.

It is very difficult to directly measure *capital services*. In fact, this requires the measurement of both *capital stock* and the utilization rate of capital stock. Ideally, measurement of capital stock would be based on (rather expensive) censuses (or representative surveys) in which firms report the *market* value of their capital stocks. Even in industrial countries these censuses are only carried out periodically (“benchmark years”). On the other hand, even developing countries tend to have good estimates of investment in physical capital, or *gross capital formation*. So, most estimates of capital stock use cumulative measures of investment, linking an initial benchmark year estimate of capital stock to the next benchmark year’s capital stock—a method known as the “perpetual investment method.” This method is based on the following capital accumulation equation:

$$K(t) = I(t) + (1 - \delta)K_{t-1}, \quad (6.4)$$

where $0 < \delta < 1$ is the rate of depreciation, and I is gross real investment. Naturally estimates of capital stock are highly sensitive to benchmark estimates of capital stock, deflator used for calculating constant price capital stock and investment series, and depreciation rates. Moreover, most capital stock estimates in benchmark years are based on historical values of capital stock or replacement values of existing capital—not market values. (Market value estimates may be only available for a limited portion of the total capital stock, such as publicly traded firms.) Also, depreciation rates are often imputed by statistical agencies, and do not necessarily reflect the true depreciation rates. Moreover, converting current price investment series into constant prices requires adjustment for price inflation, as well as for changes over time in the quality of machinery and equipment—which are often neglected or imperfectly accounted for by statistical agencies. Finally, even if the measurement of capital stock is relatively accurate, capital stock tends to be a poor indicator of capital services when there are cyclical variations in the utilization of capacity.

Similar measurement issues arise in the context of *labour services*: while a proper measure should capture both the quality and intensity of labour units (e.g., educational attainment, effort, total hours worked) even in industrial countries, these measures are not often available over time on a consistent basis. (When measures of human capital are not available, cross-country studies use employment data to measure labour services.)

The growth rate of total factor productivity, g_A , in the growth accounting equations (6.2) or (6.3) is of particular interest. It measures the productivity growth that affect both capital and labour, either through factor *neutral* or factor *augmenting* technological progress. Of course, it is not directly observable. In the growth accounting framework above, it is measured as a residual, hence known as the “Solow residual”, after Solow (1957). The above-mentioned measurement errors involving inputs and factor shares are automatically included in this residual, so I recommend caution in interpreting this residual strictly as a measure of

Table 6.1: Growth Accounting for East Asia, 1966–1990

	Hong Kong	Singapore	South Korea	Taiwan
GDP per worker	4.7	4.2	5.6	5.4
Output	7.3	8.7	10.3	9.4
Capital	8.0	11.5	13.7	12.3
Labour	3.2	5.7	6.4	4.9
Total factor productivity	2.3	0.2	1.7	2.6
Labour share	62.8	50.9	70.3	74.3

Note: All numbers are in percent. For Hong Kong, the period is 1966–1991. Labour is measured by hours worked. Source: Young (1995, Tables 1, and 5–8).

“technological progress.”

6.1.3 Applications

Growth accounting asks the following question: what is the contribution of factors of production and efficiency (technology) to observed changes in real output? When computed for a single country and over time, it provides a way to assess the contribution of factors, such as capital deepening, increase in labour force participation, and efficiency (total factor productivity), to economic growth. The same methodology can be used for comparative analysis, as long as the data and variables are comparable.

Comparative growth accounting in the context of East Asia and Sub-Saharan Africa is one interesting context in which this methodology has been fruitfully applied. Four East Asian economies, Hong Kong, Singapore, South Korea, and Taiwan, consistently grew very fast between the 1960s and mid-1990s. By contrast, the growth rate of output per worker in Sub-Saharan Africa was disappointingly low.

In Tables 6.1 and 6.2 I compare the determinants of growth in East Asia and Sub-Saharan Africa by means of growth accounting based on the calculations of Young (1995) and Ndulu and O’Connell (1999). Growth rates of output per worker differ considerably across countries, as well as over time. Growth accounting suggests that this was in part due to differential capital deepening effects and in part due to differential growth rates of efficiency (TFP growth). Specifically, in the East Asian economies the contributions to the growth rate of GDP per worker of capital deepening and increased participation of women to the paid labor force (“marketization”) were both substantial. In Sub-Saharan Africa, both the speed of capital deepening and marketization were smaller. In the East Asian economies the contribution of TFP to the growth rate of GDP per worker was also considerable—although there is variation across countries and these TFP growth rates are comparable to those observed in many other developing countries. In Sub-Saharan Africa, however, average TFP growth rate was negative, suggesting remarkable efficiency losses during a 35 year period.²

6.2 The Solow-Swan Growth Model

Although growth accounting is an informative method to sort out the contribution of different factors to economic growth, it does not explain why these factors might have changed over time. For instance, both

²See Bosworth, Collins, and Virmani (2007), and Young (2003) for recent growth accounting exercises on India and China, respectively.

Table 6.2: Growth Accounting for Developing Countries, 1960–1994

Region and Sub-period	Growth in real GDP per worker	Contribution of:		
		Physical capital	Education	Total factor productivity
21 Sub-Saharan African countries				
1960–94	0.39	0.60	0.23	−0.44
1960–73	1.76	1.05	0.18	0.53
1973–94	−0.44	0.33	0.26	−1.02
45 Other developing countries				
1960–94	3.14	1.44	0.33	1.34
1960–73	2.07	1.19	0.39	0.46
1973–94	1.65	1.45	0.49	−0.30

Note: All numbers are in percent. Unweighted averages of endpoint-to-endpoint annualized growth rates across countries. Source: Ndulu and O’Connell (1999, Table 1).

capital accumulation and change in the labour force participation may be driven by technological progress. I now turn to a model of economic growth, to conceptually sort out these endogenous responses.

The Solow-Swan growth model is a simple but analytically powerful way to think about the contribution of capital accumulation to economic growth. Economists have long debated the long-run importance of capital accumulation for economic development and growth: is accumulation of capital the main driver of (capitalist) economic growth? The answer by Solow (1956) was, stunningly, “no.” An attendant question is about the stability of capitalist economies: is accumulation of capital an inherently unstable process, within which individual economies constantly run the risk of collapse? Solow’s answer to this question was also, “no.” These questions reflect the urgent and complex economic problems economists were facing when Solow wrote his article, especially as the dark shadow of the Great Depression loomed large in the minds of many macroeconomists. Given the complex development problems economists continue to face today, Solow’s approach may appear simplistic. However, it was, and continues to be, an immense intellectual accomplishment—a remarkably elegant formal framework that addresses the main questions on hand. Let me now present a special case of this model.

The entire model consists of four equations. There are three factors of production: capital, labour and technology. The first equation summarizes the production possibilities frontier—a Cobb-Douglas production function, which describes how these factors of production can be combined to produce an aggregate output. The remaining three equations explain how these factors of production change over time. Specifically, the second equation describes the evolution of the capital stock, driven by an exogenously given saving function. The third equation describes how the labour force (or population) changes over time. The fourth and the final equation describes how “technology” changes over time.

$$Y(t) = K(t)^\alpha (A(t)L(t))^{1-\alpha}, \quad 0 < \alpha < 1, \quad (6.5)$$

$$\dot{K}(t) = sY(t) - \delta K(t), \quad K(0) > 0, \quad 0 < s < 1, \quad 0 \leq \delta \leq 1, \quad (6.6)$$

$$L(t) = L(0)e^{nt}, \quad L(0) > 0, \quad n \geq 0, \quad (6.7)$$

$$A(t) = A(0)e^{gt}, \quad A(0) > 0, g \geq 0, \quad (6.8)$$

where t denotes time, which is continuous, and s is the saving rate. A dot above a variable represents its derivative with respect to time. Only the rate of change in capital is endogenous in the model. By contrast, the growth rates of labour and technology are exogenous: equations (6.7) and (6.8) indicate that both the labour force and labour augmenting technology grow exponentially at rates $\dot{L}(t)/L(t) = n$ and $\dot{A}(t)/A(t) = g$, respectively.

The model has five parameters, α, s, δ, n and g ; three initial conditions, $K(0), L(0)$, and $A(0)$; and two endogenous variables $K(t)$ and $Y(t)$. Equation (6.6) is critical because it pushes the saving-consumption decisions to the background by assuming a *constant* saving rate, s . However, the key insights of the model can be easily generalized to situations in which saving decisions are *endogenous*.³

A solution of this model involves determining the time paths of K and Y . It is, however, easier to solve the model after dividing these two variables by units of “effective worker,” AL . Denote capital per effective worker by $\tilde{k} = K/AL$, output per effective worker by $\tilde{y} = Y/AL$, and restate equations (6.5) and (6.6) as:

$$\tilde{y}(t) = \tilde{k}^\alpha(t), \quad (6.9)$$

$$\dot{\tilde{k}}(t) = s\tilde{k}^\alpha(t) - (n + g + \delta)\tilde{k}(t), \quad (6.10)$$

with the initial condition given by $\tilde{k}(0) = K(0)/A(0)L(0)$. The left-hand side of equation (6.10) is net investment per effective worker, the first term on the right-hand side is gross investment per effective worker, and the last term is the “break-even level of investment per effective worker.” At the break-even level, gross investment endows each new member of the workforce by exactly the same amount of capital as the older workers, after accounting for depreciation and technological progress. When gross investment per effective worker exceeds the break-even level, capital per effective worker grows over time. This then leads to growth in output per worker and this is the only endogenous component of economic growth that is accounted for by this model.

There is an analytic solution to equation (6.10), given by⁴

$$\tilde{k}(t) = \left[\left(\frac{s}{n + g + \delta} \right) (1 - e^{-\eta t}) + \tilde{k}(0)^{1-\alpha} e^{-\eta t} \right]^{\frac{1}{1-\alpha}}, \quad (6.11)$$

where $\eta = (1 - \alpha)(n + g + \delta)$. Equation (6.11) shows that when $t = 0$, $\tilde{k}(t)$ satisfies the initial condition. Also, given that $\lim_{t \rightarrow \infty} e^{-\eta t} = 0$, capital stock per effective worker \tilde{k} eventually stops changing over time ($\dot{\tilde{k}}(t) = 0$) and reaches a *steady-state* value of

$$\lim_{t \rightarrow \infty} \tilde{k}(t) = \tilde{k}^* = \left(\frac{s}{n + g + \delta} \right)^{\frac{1}{1-\alpha}}. \quad (6.12)$$

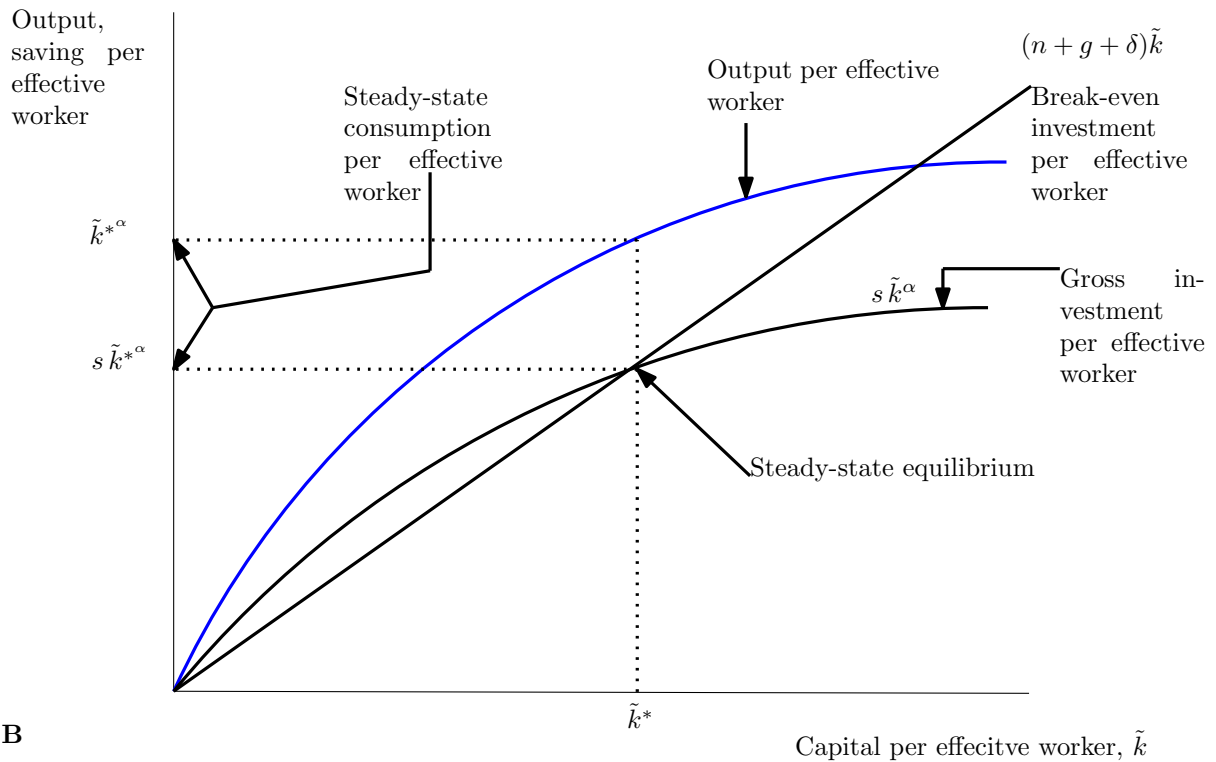
With this in mind, η in equation (6.11) is called the *rate of convergence* to the steady-state value of capital per effective worker.

Figure 6.1a shows graphically output (equation (6.9)), gross investment and break-even investment per effective worker (equation (6.10)) as functions of capital per effective worker. The time dimension of the

³My emphasis on the accumulation equation (6.6) should not be interpreted as suggesting that the rest of the model is straightforward and inconsequential. Needless to say, understanding variables summarized by each of these equations constitutes a large subfield in economics. However, they are not central to the core question posed above.

⁴For those familiar with Bernoulli differential equations, the solution is easier to see once one re-states equation (6.10) in terms of the capital-to-output ratio, $\tilde{k}^{1-\alpha}(t)$.

A



B

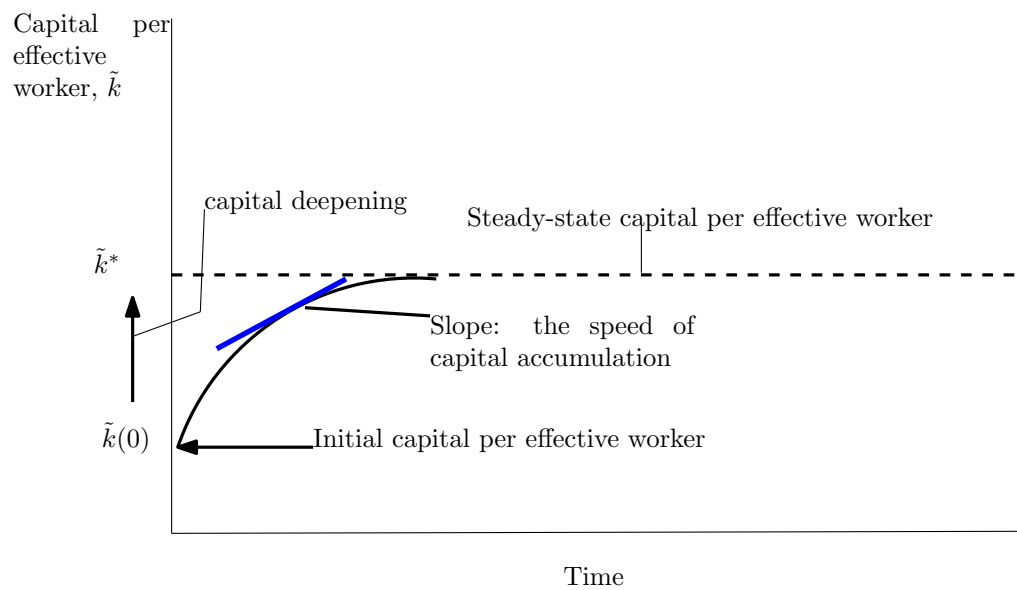


Figure 6.1: The Solow model of economic growth model

Note: (A) Steady-state equilibrium in the Solow model of economic growth. (B) Convergence to the steady-state equilibrium in the Solow model of economic growth.

Table 6.3: Steady-state equilibrium and rate of convergence in the Solow growth model

Parameters	Steady-state capital per effective worker	Rate of convergence
$s = 0.2, \alpha = 0.33$	1.902	0.087
$s = 0.2, \alpha = 0.60$	2.936	0.052
$s = 0.1, \alpha = 0.33$	0.676	0.087
$s = 0.1, \alpha = 0.60$	0.519	0.052

Note: See equation (6.11) for the rate of convergence η and equation (6.12) for the steady-state capital per effective worker. s is the exogenous saving rate, and α is the share of capital in income. The remaining parameter values are as follows: growth rate of labour augmenting technology $g = 0.02$, population growth rate $n = 0.01$, and depreciation rate $\delta = 0.10$.

model does not appear in this figure, but it is possible to infer changes in capital per effective worker by studying the three “regions” in the figure: when gross investment per effective worker exceeds, is equal to or falls short of the break-even level of investment. When gross investment per effective worker exceeds the break-even level, net investment is positive, and both capital and output per effective worker grow over time (Figure 6.1b). When gross investment per effective worker falls short of the break-even level, net investment is negative, and both capital and output per effective worker decline over time. When gross investment is zero, both capital and output per effective worker stop growing. In the literature such a situation is called as the *steady state equilibrium* of this model.

At the steady state, capital and output per effective worker are both constant. Although output per effective worker is constant, output per worker and output continue to grow. Output and capital per effective worker both grow at a rate g , because the technology is growing, and output and capital both grow at a rate $g + n$, because both the technology and population are growing. The steady state of the Solow-Swan model thus admits a *balanced-growth path* along which output, capital and consumption growth at constant and identical rates.

Table 6.3 demonstrates the sensitivity of steady-state level of capital per effective worker \tilde{k}^* and the speed of convergence η to the share of capital in income α , and the saving rate s . The table has two saving rates, $s = 0.1$ and $s = 0.2$, and two distinct shares of capital, $\alpha = 0.33$ and $\alpha = 0.60$. A comparison of the results indicates that a higher value of α amplifies significantly the sensitivity of \tilde{k}^* to even relatively small variations in the saving rate.

Another way to see the result that, although capital stock per effective worker ultimately stops growing, capital and output per worker continue to grow is by substituting equation (6.11) into (6.9), and multiplying both sides by $A(t)$, giving

$$\frac{Y(t)}{L(t)} = \left[\left(\frac{s}{n + g + \delta} \right) (1 - e^{-\eta t}) + \left(\frac{Y(0)}{A(0)L(0)} \right)^{\frac{1-\alpha}{\alpha}} e^{-\eta t} \right]^{\frac{\alpha}{1-\alpha}} A(t). \quad (6.13)$$

Now, even when $\dot{\tilde{k}}(t) = 0$, output per worker continues to grow, because the technology term on the right-hand-side of equation (6.13) grows at the constant rate g . Thus, the ultimate long-run source of growth of output per worker in this model is technology—capital accumulation has only transitory effects on growth.

Figure 6.2 shows, using a parameterized version of equation (6.13), how *capital per worker* evolves over time in such a model economy. The solid line in Figure 6.2a shows the balanced growth path of capital

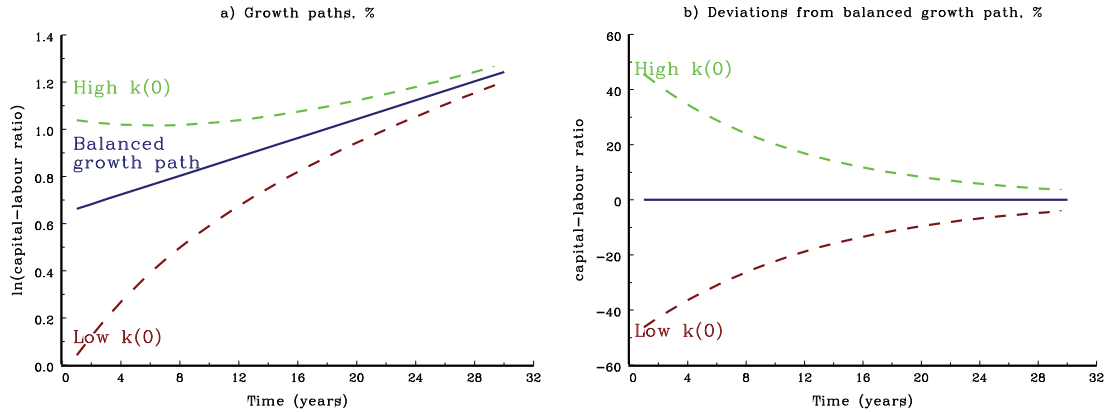


Figure 6.2: Transition dynamics in the Solow growth model: Numerical examples

Note: The numerical examples use the following parameter values: $n = 0.01$, $g = 0.02$, $\delta = .10$, $s = .2$, “low” and “high” $k(0)$ correspond to below and above balanced growth path values of capital-labour ratio at time 0, and the initial value of labour augmenting technology is $A(0) = 1$.

per worker—it has a constant slope, because along the balanced growth path capital per worker grows at rate g . The dashed lines demonstrate how this economy behaves when it is away from its balanced growth path. The dashed lines in Figure 6.2b, on the other hand, show the percentage deviation of the low and high initial capital stock economies from the balanced growth path. There are two cases: when the capital per worker either exceeds or falls short of its balanced growth path value. In each case, capital per worker asymptotically approaches to its balanced growth path. This figure also serves as a numerical demonstration of the *stability* of the Solow growth model.

While the model exhibits for long term economic growth, the growth rates along the balanced growth path are accounted for exogenously determined growth rates of technology and population. Thus, at the steady state, all growth is exogenous in this model. Outside the steady state, output, capital and consumption grow at different rates. So, outside the balanced-growth path, net investment is either positive or negative, and there is an endogenous component of economic growth due to capital deepening (Figure 6.1b) or labour deepening. This model has strong stability properties: regardless of the initial conditions, it always reaches to steady state. Thus, endogenous capital accumulation-based economic growth is a *transitory* driver of economic growth in this model.

6.3 The Solow-Swan Model and Shocks

Figure 6.3 demonstrates the response of a parameterized version of the Solow model to “level” and “growth” shocks. The level shock corresponds to an unanticipated 10% decline in the level of productivity. Figure 6.3 panels a and b show the response of log capital-labour ratio along and off balanced growth path, respectively, to the level shock. Initially the economy is along its balanced growth path. The level shock temporarily tips the economy off its balanced growth path, and the economy approaches to the balanced growth path from above. After the shock, the economy reduces its capital-labour ratio, but not to the point of immediately reaching the balanced growth path.

A growth shock, on the other hand, corresponds to an unanticipated permanent 50% reduction in the

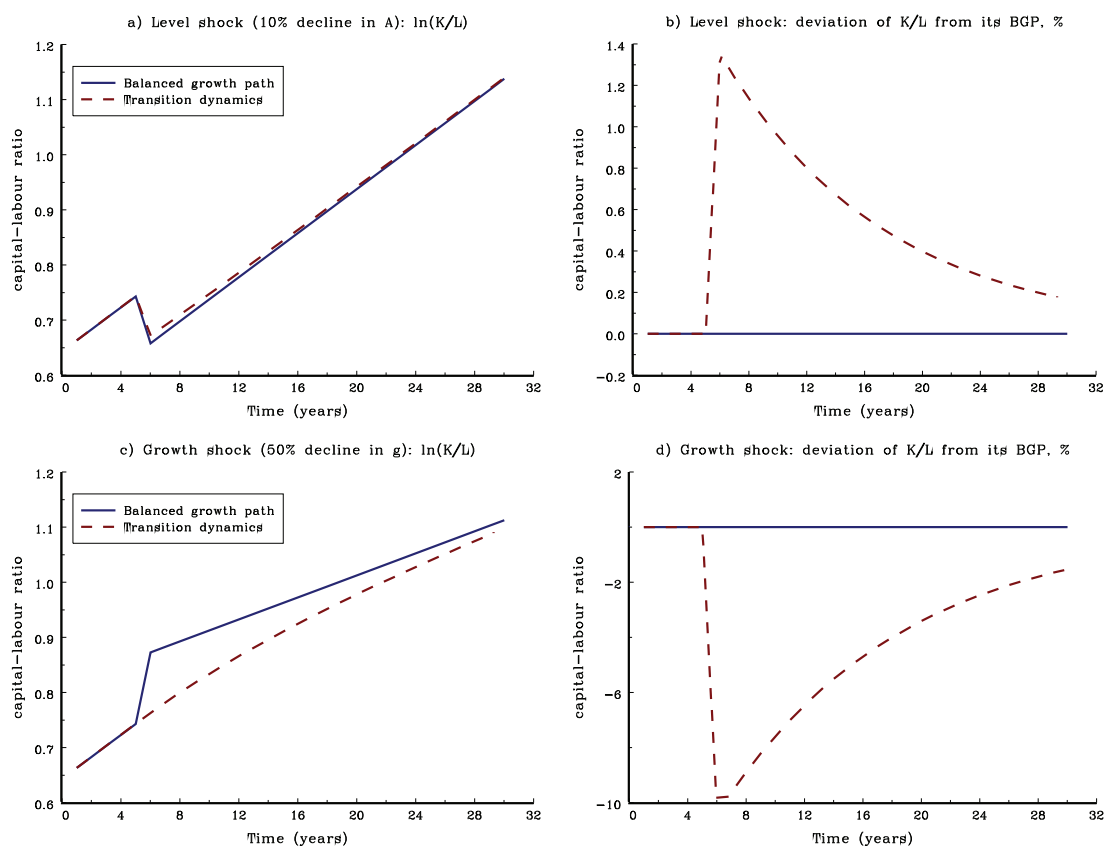


Figure 6.3: Transition dynamics in the Solow growth model: Level and growth shocks to productivity

Note: The numerical examples use the following parameter values: $n = 0.01$, $g = 0.02$, $\delta = .10$, $s = .2$, and the initial value of labour augmenting technology is $A(0) = 1$. The “level shock” corresponds to an unanticipated 10% decline in A , and the “growth shock” corresponds to an unanticipated 50% decline in g .

growth rate of technology. Figure 6.3 panels c and d show the response of log capital–labour ratio to the growth shock. Again, initially the economy is along its balanced growth path. The growth shock permanently changes the course of the balanced growth path, and the economy approaches to its new balanced growth path from below. After the growth shock, the economy faces a new steady-state level of capital per effective worker \tilde{k}^* that exceeds the pre-shock level of \tilde{k}^* . The reason for this is that, to maintain a constant long-run consumption–income ratio, the slower growth rate of productivity forces the economy to accumulate more capital per worker. So, after the shock the economy is below the capital–labour ratio which is consistent with the balanced growth path, and gradually accumulates capital.⁵

6.4 Empirical Approaches

Historically, economic growth problem has attracted the most attention within economics. This literature has evolved on two fronts: growth accounting and econometric growth models. Both strands in the liter-

⁵For the record: Solow has repeatedly cautioned against using his and similar growth models to think about macroeconomic fluctuations. He has been particularly critical of those who claim that shocks to technology drive macroeconomic fluctuations. For instance, with respect to (popular) macro models that have taken such an approach, Solow (2006, p. 236) writes: “Maybe there is in human nature a deep-seated perverse pleasure in adopting and defending a wholly counterintuitive doctrine that leaves the uninitiated peasant wondering what planet he or she is on.”

ature accommodate single country as well as multi-country, comparative analysis. However, cross-country econometric models have been more pervasive within the econometric, growth-regressions camp.

6.4.1 Econometric Growth Models

Econometric growth models, by far the most popular methodology, range from highly structural models that directly build on a theoretical model to reduced form models that are loosely motivated by a theoretical model. In general, the structural models use the Solow-Swan model or its extensions, whereas the reduced form models borrow several main themes of the Solow-Swan model, but otherwise rely on a less structured framework. I will briefly review the first approach here.

Structural models.— The Solow-Swan model is by far the most popular model for econometric modeling, because it has a closed form solution, which lends itself to a (linear) regression analysis.⁶ The empirical literature I discuss below is largely based on two important implications of the Solow-Swan growth model, but they differ in the way they interpret the actual position of each country relative to its steady state. One set of studies assume that countries are at their steady states, and a second set of studies assumes that countries are converging to their steady states.

In order to empirically implement each of these approaches, for each country i , we need data on a measure of efficiency (or technology, depending on the context), $A_{Li}(t)$, where $A_{Li}(t) = A_{Li0}e^{g_i t} > 0$ and $t > 0$. However, this variable is not observable, so the empirical validity of both the steady-state and convergence regressions depend on how they account for unobserved cross-country heterogeneity in efficiency (both in terms of its level and growth rate).

Specifically, first consider the steady-state assumption, and assume that country i in our sample is at its own steady-state level of output per effective worker

$$\tilde{y}_i^* = \left(\frac{s_i}{n_i + g_i + \delta_i} \right)^{\alpha_i / (1 - \alpha_i)}. \quad (6.14)$$

Taking logs and representing this in terms of output per worker gives a log-linear expression

$$\ln y_{it}^* = \ln A_{Lit} + \frac{\alpha_i}{1 - \alpha_i} [\ln s_i - \ln(n_i + g_i + \delta_i)]. \quad (6.15)$$

In an influential paper, Mankiw, Romer, and Weil (1992) assume that α_i , δ_i , and g_i are common across countries, and that $\ln(A_{Lit}) = \ln(A_{Li0}) + g t$ with $\ln(A_{Li0}) = a + \varepsilon_{it}$. Then, they estimate the following cross-section regression equation, assuming that all countries are at their steady states:

$$\begin{aligned} \ln y_{it}^* &= \ln A_{Li0} + g t + \frac{\alpha}{1 - \alpha} [\ln s_i - \ln(n_i + g + \delta)], \\ &= (a + g t) + \frac{\alpha}{1 - \alpha} [\ln s_i - \ln(n_i + g + \delta)] + \varepsilon_{it}. \end{aligned} \quad (6.16)$$

In this specification, each country has its own steady-state level of capital per effective worker, and therefore capital per worker differ across countries even along their balanced growth paths. At the same time, there are no output per worker growth rate differentials along the balanced growth path (i.e., $g_i = g$ for all i).

Second, consider the convergence assumption, whereby each country in our sample is approaching to a steady-state level of output per effective worker. If this steady state is the same for all countries in the

⁶An important generalization of the Solow-Swan model (the Ramsey model) considers an endogenous saving decision. However, this more general model has a closed form solution only under highly restrictive cases.

sample, then we say that there is *unconditional convergence*. If, on the other hand, each country in the sample is approaching to its own steady state, then we say that there is *conditional convergence*. In other words, the convergence approach is less restrictive than the steady-state approach, because it does not require $\tilde{y}(t)$ be identical across.

Consider the case of unconditional convergence. In this case, countries would have identical steady-state levels of income per effective worker, and all growth and income level differentials would be transitory. It then follows that within a sample of countries the standard deviation of income per capita should be declining over time. This test is known as σ -convergence.

An alternative test, known as the β -convergence exploits the convergence idea that countries that start the growth process late (“poor”), have significant opportunity to catch up with the early starters (“rich”), and therefore tend to grow more rapidly. This suggests that initial income should have a *negative* impact on the subsequent rate of economic growth. This idea is formally tested using the the following regression equation

$$\underbrace{\ln y_{iT}/y_{i0}}_{\text{output growth}} = a - \underbrace{(1 - e^{-\eta T}) \ln y_{i0}}_{\beta \times \text{initial log output}}; \quad (6.17)$$

where a is determined by the long-run components, namely steady-state level of income per effective worker \tilde{y}^* and gT (permanent component) and the second component is the transitory component of growth due to the catch-up process. In this second expression η is the “speed of convergence,” which depends positively on δ, g, n , and α . Of course, as $T \rightarrow \infty$, $e^{-\eta T} = 0$, initial incomes start to matter less for subsequent growth, and growth rate differentials across countries disappear.

In the case of conditional convergence, individual countries not only have different steady-state levels of output per effective worker, but they also approach this income per effective worker at different rates. Moreover, for the empirically observable output per worker, the transition dynamics differ across countries, even if they have identical growth rates of population and technological progress, and have identical saving rates because of differences in their initial *levels* of labour augmenting technology.

Specifically, these issues lead to the following regression expression (Okada, 2006):

$$\ln \frac{y_{iT}^*}{\tilde{y}_{i0}} = \frac{\alpha}{1 - \alpha} \left[\ln \bar{s}_i - \ln(\bar{n}_i + g_i + \delta) - \ln \frac{k_{i0}}{y_{i0}} \right] + g_i T + \varepsilon_{iT}, \quad (6.18)$$

where \bar{s} and \bar{n} represent, for each country, sample averages of the saving rate and population growth rate. This specification controls for initial income and technology differentials through

$$\frac{k_{i0}}{y_{i0}} = \left[\frac{A_{Li0}}{y_{i0}} \right]^{(\alpha-1)/\alpha}. \quad (6.19)$$

Based on this empirical specification, Okada (2006) finds that, while OECD countries exhibit conditional convergence, non-OECD countries exhibit considerable variation in convergence patterns. Within the non-OECD sample those countries that approach their balanced growth paths from above exhibit conditional convergence, and those that approach from below do not. This finding is consistent with the literature on significant cross-country divergence in output per person over time (Pritchett, 1997).

Reduced-form models.—This approach is extensively discussed in Barro and Sala-i Martin (2003, chp. 13), and I will not review this literature here. In general, empirical estimates of cross-country growth regressions

have concluded that long-run growth rates have a large unexplained component and that future growth rates are highly unpredictable.⁷ With this in mind, many economists have turned their attention to understanding income level differentials as a more fruitful approach to understanding problems of economic growth in the long run.

6.4.2 Development Accounting

This approach also has two components: development accounting and econometric development models. Development accounting is an attempt to answer the following question (Caselli, 2005): how much of the cross-country differences in (physical and human) capital, and how much to differences in the efficiency in which capital is used? To achieve this development accounting starts with a specific functional form for output, and decomposes it into “factors” and “efficiency units.”⁸

Specifically, consider a Cobb-Douglas production function which uses capital, labour and human capital as factors of production, and write it in per worker terms:

$$y_i = A_i k_i^\alpha h_i^{1-\alpha}. \quad (6.20)$$

Given observations on output per worker, capital per worker, and human capital per worker (h_i), one can solve for A_i .⁹

An alternative approach is to account for these cross-country differentials in this (residual) efficiency by using regression models (after controlling for factors that account for differences in capital per worker and human capital per worker). Much of this literature is reduced form and is loosely motivated by theoretical growth models.

6.5 Empirical and Conceptual Issues

The Solow model of economic growth provides many important insights—and makes several testable predictions. While the Solow model tackles the determinants of economic growth *over time* within a country, almost all the empirical growth models use *cross-country* data. This methodology has several conceptual problems, at least if one wishes to interpret the regression equations and the results through the lenses of the Solow growth model.¹⁰

⁷Sometimes these reduced-form regression models have been used to “test” alternative theories of economic growth. However, not everyone is impressed by such battery of regression tests. For instance, Paul Samuelson writes: “We all pity warm-hearted scholars who get stuck on The pity of it increases for one who adopts a simple theory of positivism that exonerates a nominated theory, even if its premises are unrealistic Particularly vulnerable is a scholar who tries to *test* competing theories by submitting them to *simplistic* linear regressions with no sophisticated calculations. . . .” (italics in the original Samuelson and Barnett, 2007, p. 146).

⁸As in the case of growth accounting, development accounting is agnostic about the position of each country’s output per worker relative to its balanced growth path.

⁹Another approach pursued by Hall and Jones (1999) also starts with a Cobb-Douglas production function, but writes output per worker in a given year as

$$y_i = A_i \left(\frac{k_i}{y_i} \right)^{\alpha/(1-\alpha)} h_i$$

where H/L is human capital stock per worker. The difficulty here is that, in this decomposition, the efficiency parameter also determines the capital–output ratio, on the right hand side.

¹⁰Of course, Solow model, or any growth model for that matter, should not straightjacket our thinking in interpreting empirical data. We may, for instance, let “data speak” through a battery of empirical specifications, several of which might

Representative country problem.—The main thrust of the methodology based on cross-country data is the following: while the cross-country data has countries with very different per capita income levels, each of these countries can be thought of observations representing a single country at different stages of its economic development. In other words, there is a representative country, and each snapshot of the world is informative about the time-series properties of this representative country. This conceptual leap is troublesome, because, at a minimum from a geographical standpoint, in a cross section, there is no representative country that one can speak of.

More importantly, treating countries with different levels of per capita income as time-series observations on a representative country sits uncomfortably with the historical record in which countries “enter” and “exit” the world theater, and for reasons that are hardly irrelevant for economic growth. The world map today consists of countries that were both endogenously formed by their citizens due to strategic alliances, leading to “strong” states, and dictated on their citizens through arbitrary treaties, leading to “weak” states. Many “strong” states have survived to this day (sample selection); and many “weak” states have either been absorbed by others or reduced in size over time (censored samples and incomplete spells). One would thus think that endogenous state formation has implications for future economic growth, and cross-country regressions sidestep this problem entirely.

Conditioning variables problem.—In econometric models, the recognition that there may be cross-country heterogeneity leads to an attempt to control for observable characteristics of the countries in the sample. (In the jargon of growth regressions, these observable characteristics are called the “conditioning variables.”)

However, conditioning variables do not fully address the core problem for two reasons. First, the number of countries on which we have comparable and high quality data is small, and therefore in a theory free framework the number of potential conditioning variables can quickly exceed the number of countries in the sample (micronumericity).¹¹

Second, conditioning variables are uninformative about structural parameters. For instance, take the case of saving rate, which varies substantially across countries. One could, going beyond the Solow model’s assumption of constant saving rate, argue that differences in income per capita levels—i.e., distance to steady state—drive differences in saving rates: subsistence societies tend to have lower saving rates, middle income countries high, and rich countries low saving rates. Alternatively, different saving rates may be entirely due to differential government policies: in the absence of these differences in national policies, one might argue, we would be observing identical saving rates. So far, cross-country regressions have not informed us about the validity of these competing hypotheses.

Unobservable variables problem.—How about country characteristics that are not directly observable? One common approach in the literature is to construct measures that proxy for these characteristics. However, two problems arise in this context. First, those who construct these proxies may be biased toward matching certain stylized facts (such as output per capita), or the “benefit of hindsight” may be coloring their choices (look-ahead bias). Second, these proxies contain a heavy dose of subjectivity and are open to multiple interpretations (arbitrariness).

For instance, Acemoglu, Johnson, and Robinson (2001) argue that strong property rights institutions

be loosely based on the Solow model. The conceptual issues that I discuss below are acutely relevant for interpreting such empirical models as well.

¹¹There is a potential compromise: using a small number of conditioning variables. But, this raises the question of robustness.

are decisive for observed income per capita levels, and differences across countries in these institutions help explain income per capita differentials across countries. If correct, this hypothesis has profound implications for institutional policy.

The difficulty is that property rights institutions are not directly observable. Instead, Acemoglu et al. (2001) use “risk of foreign capital expropriation” as a measure for one particular aspect of property rights institutions. This expropriation risk measure is compiled by Political Risk Services (PRS), which publishes country risk reports and ratings by combining the results of surveys of country “experts” (academics, journalists), and, in the context of Acemoglu et al. (2001), it measures “average protection against foreign capital expropriation risk, 1985–1995” on a scale from 0 to 10, where a higher score represents greater protection.

From a measurement standpoint, it is not clear whether those surveyed by PRS form a representative sample. And, from a conceptual standpoint, while the measure is explicitly about foreign capital expropriation (PRS targets clients with “global business” intensions) and as such may well be a good measure of risk of expropriation faced by foreign investors, it is unclear whether domestic investors perceive the same level of risk. As such, one must take it as faith that this measure of “property rights institutions” does not suffer from stylized-fact bias, look-ahead bias, and arbitrariness.

Causality problem.—Even if we constrain our sample to surviving countries and can be agreeable to the comparability of existing data on a larger set of countries, and even if we circumvent unobservable variables problem, several additional problems remain. First, countries go through, often quickly, enormous transformations, not only in terms of their economic structures, but also in terms of their political or “institutional” structures. To what extent such transformations drive future economic growth or are driven by economic growth (causality)? This is a fiercely debated topic in modern economics. For instance, does more financial intermediation lead to faster economic growth, or is it the case that financial intermediation is a by-product of high income per capita?

Most proposed solutions to such complex issues about causality have been statistical in nature (instrumental variables). Consider Acemoglu et al. (2001) once again. They argue that cross-country differences in property rights institutions are responsible for a large share of observed income per capita differentials. Testing this hypothesis is not straightforward: the correlation between measures of property rights and output per capita may reflect reverse effects of income per capita on property rights institutions (or the simultaneous influence of omitted factors on both output per capita and property rights institutions, or both). To this end, they specify an equation determining GDP per capita across previously colonized countries, and advance the following arguments: (i) during the colonial period, Europeans were more likely to settle places where they had a lower risk of dying from local diseases; (ii) colonies where Europeans ultimately settled strongly protected foreign investment rights; (iii) colonies where Europeans did not settle only weakly protected foreign investment rights; and (iv) over time, the direct effects of mortality from local diseases and European settlement on domestic output per capita faded, while the indirect effect through foreign capital expropriation persisted.¹² Needless to say, each of these steps is an intriguing hypothesis on

¹²In Acemoglu et al. (2001) and the vast literature that ensued the publication of this influential article, the reference to “risk of foreign capital expropriation” has been transformed into a far more sweeping “property rights institutions.” One apparent advantage of this transformation is that, “property rights institutions” project a far more persuasive attendant story for step (iii): in colonies where Europeans did not settle, they set up extracting institutions. However, extracting economic surplus from these colonies invariably involved foreign-owned trading companies, which presumably would have required more, not less, protection from local expropriation.

its own right.

With these pieces in place, Acemoglu et al. (2001) use European settler mortality rates from local diseases as an instrument for risk of foreign capital expropriation, and find that there is a large effect of foreign capital expropriation risk on GDP per capita, explaining a significant portion of the variation in output per capita across countries.¹³

Prediction problem.—Aside from these conceptual issues, empirical growth models do not have a good predictive power. While, over the last fifty years, many countries exhibited rapid economic growth and reduced their income per capita gap with the richest nations, many others fell behind. In the data there does not appear to be a systematic relationship between the initial conditions and the catch-up rates. In fact, long-term growth forecasts have notoriously been off the mark: back in the early 1970s, compared to Asia, many economists viewed Africa and Latin America as having more favorable conditions for faster future economic growth. For instance, in a popular textbook on agricultural development, Johnston and Kilby (1975, p. 13) wrote:

...in the face of high rates of population growth, the tasks of agricultural development—mobilizing savings, adapting high-productivity technologies, shaping new organizations—are very much more difficult in the land scarce Asian and Caribbean economies than in the countries of Africa and Latin America where 10 to 50 times more land per capita provides a good deal more spatial and temporal room for experimentation.

¹³Statistically, their European settler mortality data is a valid instrument (step iv). Economically, however, it is unclear why such bad institutions persist for so long in some but not in all countries, and improved property rights institutions have not provided quick release from the low income per capita trap. It also turns out that their European settler mortality data is a mixture of death rates of civilians, soldiers at barracks, and soldiers on campaigns, and in many instances are attributions to contemporary countries from others or small samples or both (Albouy, 2008).