FRAMEWORK AND EVIDENCE

This annex provides a framework and empirical evidence for chapter 2.

A Welfare Function

Define an additive and separable welfare function, U, for a society that consists of N individuals

$$(A2.1) \quad U = \sum_{i=1}^{N} u(c_i) + \sum_{i=1}^{N} v(h_i; R),$$

where c_i is the consumption of individual i, h_i is the human capital of individual i, and R is the (aggregate) level of environmental assets. R is assumed to be a pure public good, and hence its distribution among the population is irrelevant. Also, $u(\cdot)$ and $v(\cdot)$ are increasing and strictly concave in their arguments. A second-order approximation of U evaluated at the mean or average values of c and h yields

$$(A2.2) \quad U \approx Nu(\bar{c}) + \sum_{i=1}^{N} u'(\bar{c})(c_i - \bar{c}) + \frac{1}{2}\sum_{i=1}^{N} u''(\bar{c})(c_i - \bar{c})^2$$
$$+ Nv(\bar{h}; R) + \sum_{i=1}^{N} v'(\bar{h}; R)(h_i - \bar{h}) + \frac{1}{2}\sum_{i=1}^{N} v''(\bar{h}; R)(h_i - \bar{h})^2,$$

where $\bar{c}$ is average or per capita consumption, $\bar{h}$ is average or per capita human capital, $u'(\bar{c})$, $v'(\bar{h}; R)$ are first derivatives with respect to c and h, respectively, evaluated at mean values $\bar{c}$ and $\bar{h}$ and $u''(\bar{c})$, and $v''(\bar{h}; R)$ are second derivatives. Taking expectations we obtain the average welfare per individual i,

$$(A2.3)\quad E(U) \approx u(\bar{c}) + \frac{1}{2}u''(\bar{c})\sigma_c^2 + v(\bar{h}; R) + \frac{1}{2}v''(\bar{h}; R)\sigma_h^2,$$

where σ_c^2 is the variance of consumption across the population and σ_h^2 is the variance of the distribution of human capital across the population. By strict concavity of $u(\cdot)$ and $v(\cdot)$, we have that $u'' < 0$ and $v''(\cdot) < 0$. Thus, aggregate or expected welfare is increasing in $\bar{c}$ and $\bar{h}$ and decreasing in σ_c^2 and σ_h^2. Moreover, because $v(\cdot)$ is increasing in R, $\partial v''/\partial R \approx 0$ is sufficient to obtain that E(U) is also increasing in R.

From the definition in the text, sustained growth requires that the expansion of physical capital through time be accompanied by positive growth of human capital without worsening its distribution. Also, sustained growth is likely to diminish poverty and is not consistent with a worsening of income distribution. Sustained growth increases $\bar{c}$ and $\bar{h}$ and reduces, or at least does not increase, σ_c^2 and σ_h^2. Thus, sustained growth is likely to increase welfare, E(U) in equation (A2.3), as long as R does not fall or falls at a sufficiently slow pace.

Private Sector Optimization

As indicated in the text, human capital (h) and natural capital (R) are subject to two possible externalities associated with consumption and production. Consumption externalities stem from the fact that the positive direct effects of h and R on the welfare function may be only partially considered by the private sector in its resource allocation decisions. Production externalities arise because much of the positive technological spillovers associated with h may not be considered by the private sector. In addition, part of the value of R as a productive resource may also be ignored by the private sector, particularly in cases where natural capital property rights are not well defined.

Here we make an extreme assumption: that all the direct consumption values of h and R on the welfare function (as well as the distributional effects represented by σ_c^2 and σ_h^2) are ignored by the private sector's production decisions. Moreover, we assume that production externalities establish a wedge between the private marginal products of h and R and the true marginal products of these resources. That is, the private sector only considers a fraction of the contribution of h and R to production. In addition, we assume that a minimum subsistence consumption level, c_s, exists. The representative household needs a consumption level of c_s to survive and will not allow consumption to reach levels below c_s. That is, we impose a subsistence constraint, $c - c_s \geq 0$.

Under these assumptions, the relevant problem is maximization of the discounted present value of $u(\bar{c})$—as opposed to that of $E(U)$—subject to the following constraints:

$$\text{(A2.4)}\quad \begin{aligned} &\text{(i)} && \dot{k} = G(k, h; R; A(k, h); p) - c - I_h^g - I_h^p - I_R^g \\ &\text{(ii)} && c - c_s \geq 0 \\ &\text{(iii)} && \dot{h} = I_h^g + I_h^p \\ &\text{(iv)} && \dot{R} = \phi(R) + \beta I_R^g - \psi[G(\cdot)], \\ &\text{(v)} && k(0) = k_0; \quad h(0) = h_0; \quad R(0) = R_0 \end{aligned}$$

where k is per capita physical capital, $G(\cdot)$ is the economy's per capita GDP function, $A(\cdot)$ is a productivity index, p stands for policy variables and exogenous factors, I_h^g is government investment in human capital, I_h^p is private investment in human capital, β is a parameter, I_R^g is government investment in natural capital, $\phi(R)$ is a growth function of the renewable resources through time, and $\psi(\cdot)$ is an increasing function of GDP that reflects the possibly negative direct impact of increased economic activity on natural capital. We assume that population, N, is fixed, so that by using appropriate units it can be normalized to 1. Hence, the distinction between total and per capita variables in equation (A2.4) becomes irrelevant. Also, for algebraic simplicity we assume a zero rate of depreciation of k and h. Assuming a constant logarithmic depreciation rate for these assets, as is usually done, does not affect any of the results.

Several comments about equation (A2.4) are in order:

- It is assumed that I_h^g and I_R^g are policy variables.
- We assume that the effect of GDP on natural capital is not at all internalized by the private sector, and that, as a consequence, the private sector will not invest in natural capital. Thus, equation (A2.4) (iv) is only used as an accounting identity and is not directly (and ex ante) taken into consideration in decisions by the private sector, even though the evolution of R will affect its future decisions.
- The effect of h on $G(\cdot)$ is only partially incorporated into the decisions of the private sector. The government may fill a part or the full extent of the possible human capital underinvestment gap left by the private sector.
- We allow k and h to affect knowledge represented by the productivity function $A(\cdot)$. It is assumed that knowledge is a public good that any firm can access at zero cost. In line with the "learning by doing" hypothesis, we follow Arrow (1962) and Romer (1986) and assume that learning by doing works through each firm's investment in k. However, we specify that learning by doing requires

human capital, or that human capital facilitates and increases the effectiveness of this process. Thus, the function $A(\cdot)$ is assumed to be increasing in its arguments and the marginal effect of k on A increases with h, that is, $\partial^2 A/\partial k \partial h > 0$.

- Equation (A2.4) (i) implies that public investment in human capital is financed out of total savings via lump sum taxes. An alternative approach is to assume that public investments are financed via an income tax proportional to GDP, as in Barro (1993).
- Production of human capital is assumed to be generated through the same productive process as physical capital and consumer goods. This assumption has often been used in the literature (see, for example, Barro and Sala-I-Martin 1995). Alternatively, one may postulate a separate production function of h as in Lucas (1988) or Rebelo (1991). Although the latter is a more realistic approach, the assumption of a common production function for consumer and all investment goods considerably reduces the algebra and does not alter the basic conclusions.

The Case of a Middle-Income Economy with Initial Consumption far above Subsistence

First we assume that constraint (A2.4) (ii) is not binding; the economy is sufficiently rich to allow $c > c_s$ at all times. We will analyze the role of the subsistence constraint in the case of the poor economy.

It can be shown that the private sector in this model invests only in k if the marginal product of physical capital, $G_k(\cdot)$, is higher than the marginal product of human capital as perceived by the private sector, $G_h^p(\cdot)$.[1] It will invest in both k and h if $G_h^p = G_k$ and will only invest in h if $G_h^p > G_k$. Thus, assuming that k is initially relatively low, $I_h^p = I_R^p = 0$ and $\dot{k} > 0$. Of course, the main reason why the private sector only invests in one factor is our assumption that all factors are produced out of a common production function. If we allow for a different production function for h, the private sector may be shown to invest in both k and h even outside the long-run equilibrium. However, the essential point is that the private sector tends to underinvest in human and natural capital relative to physical capital. That is, the private sector tends to have too narrow an investment portfolio as long as the positive external effects associated with h and R are larger than those associated with k regardless of whether h or R have separate production functions. In a sense, the extreme specification (apart from simplifying the algebra) helps to highlight the fact that the market economy tends to overspecialize its investment choice.

From the first-order conditions of the above problem one can derive the growth rate of the economy in the usual way if $G_k > G_h^p$. Economic growth is an increasing function of the gap between the marginal return to capital and its marginal cost, $b(\cdot)$. Under the usual assumption of constant risk aversion—for example, that $-u''(c) \cdot c/u'(c) \equiv \theta > 0$, is a constant—and where $u(c)$ is defined in equation (A2.3), the rate of economic growth is

$$\text{(A2.5)} \quad \dot{c}/c = \frac{1}{\theta}[G_k(k, h; R, A; p) - b(r; p)],$$

where $\dot{c}/c$ is the rate of growth of consumption per capita (we have suppressed the bar over c) $G_k(\cdot)$ is a function reflecting the marginal product of physical capital for a given level of A, and r is the discount rate.[2]

There are four possible cases:

i. *Sustained growth requires absolute balanced asset growth.* This case occurs if the aggregate production function $G(\cdot)$ is subject to constant returns to scale (CRS); for example, the spillover effects of k and h on $A(\cdot)$ are negligible. Therefore, G_k is a function only of factor ratios. Assume that h and R remain constant as $\dot{c}/c > 0$ and $\dot{k}/k > 0$. In this case the private sector does not invest in R and h. Thus, growth will be unbalanced relying exclusively on the accumulation of k. Because of CRS, $G_k(\cdot)$ declines as k increases. As a result, the expression in square brackets in (A2.5) declines and the "Solow curse" applies. A positive rate of growth cannot be sustained unless the government invests in h and/or R. (The growth decline is, of course, more rapid if R falls as a consequence of growth). So in this case, sustained growth can only be achieved by the government investing in h and R, so that $\dot{k}/k = \dot{h}/h = \dot{R}/R$. Absolute balanced growth of the three assets is required to sustain a positive growth rate.
ii. *Sustained growth can be achieved with unbalanced asset growth.* This case may occur if large technological spillovers associated with capital accumulation exist. In this case it is possible that the marginal product of k does not decline because A is increasing in k. Now even if h and R do not increase or if they decline at a sufficiently low rate, the growth rate can still be sustained. So in this case we can have sustained yet unbalanced growth based purely on physical capital growth and technological spillovers.
iii. *Sustained growth can be achieved with semibalanced asset expansion.* This could happen if there is a high degree of substitution between h and R in the G_k function. Substitution between h and R allows for two possible subcases as $h > h^c$, where h^c is a critical level of human capital:

a. Under CRS with no spillover effects growth can be sustained if h and k grow at identical rates, that is, the k/h ratio remains constant. *Absolute semibalanced asset growth* is necessary to produce this scenario.

b. Spillover effects that effectively imply that the production function exhibits increasing returns to scale in k and h, but that the net marginal product of k is decreasing in k. In this case, h may grow at a pace slower than k, that is, *relative semibalanced asset growth* is needed.

In this case $\partial G_k/\partial R$ decreases as h increases and $\partial G_k/\partial R \approx 0$ as $h \geq h^c$, where h^c is at a certain critical level. That is, as h increases over h^c, economic growth becomes independent of R, although R still has a positive marginal product. Note that the relevant substitution is for the marginal product of k function, not for the production function, as is usually assumed. This implies that the relevant substitution between h and R relates to third-order effects and not to second-order effects as the usual Hicksian or Allen elasticities of substitution imply.

iv. *Sustained growth can be achieved with relative asset growth balance.* This case may occur if technological spillovers are dependent on both k and h, with a strong complementary relationship in the A function and $h < h^c$. We argue in the text that the technological spillovers associated with physical capital are not likely to be large in developing countries that do not have a sufficiently high and increasing level of general education. That is, the elasticity of substitution between h and k in the $A(\cdot)$ function is small. If h is too low, the effect of k on A will be small. In this case, sustained growth can be achieved only if h and R increase so that $G_k(\cdot)$ does not fall as k increases. This implies that sustained growth can be achieved with relative, rather than absolute, balanced asset growth. An economy can sustain a positive rate of growth when the public sector invests in h and R at a rate generally lower than the rate of physical capital accumulation.

The empirical results presented in the text allow us to rule out the first and second cases. That is, although complete or absolute asset balance is not necessary for sustained growth, growth based only on physical capital accumulation is not sustainable either. According to the empirical findings, the last two cases are empirically the most relevant. Poor countries that do not have large levels of human capital require that human and natural capital grow at a certain rate, which is generally lower than that of physical capital, to sustain growth. That is, the last case reflects best the situation for poor economies that have not yet developed a solid human capital base. The third case, especially subcase (iii)b, is the most relevant to middle-income countries that already have a significant level of human capital.

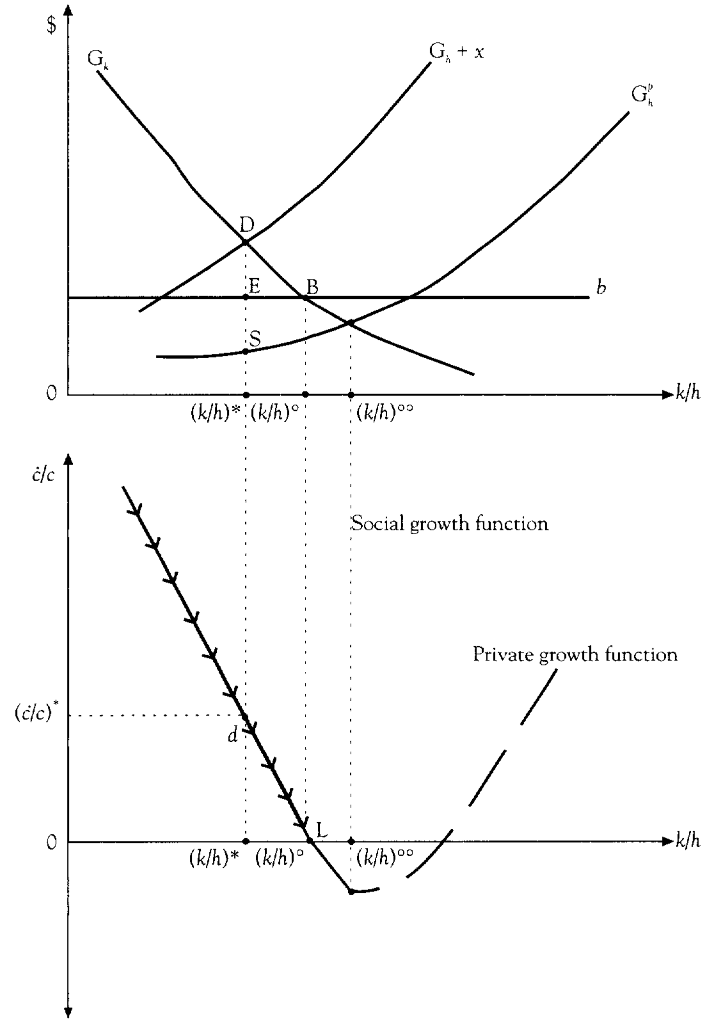
Figure A2.1 illustrates balanced and unbalanced growth processes under the assumption that there are no economies of scale or technological spillovers associated with capital accumulation and that $h > h^c$, which implies that changes in R play no role on economic growth. The marginal product $G_k(G_h)$ is decreasing (increasing) in the physical capital to human capital ratio. In the figure, G_h is the true marginal product of human capital, x is the marginal contribution of human capital to welfare as a consumer good, and therefore $G_h + x$ is the total and true marginal social contribution of human capital. G_h^p is the marginal contribution of human capital as perceived by the private sector.

For an economy that grows from a low k/h ratio, the marginal product of k falls along the G_k schedule as k/h increases. In the absence of intervention, a laissez faire economy will continue accumulating physical capital until it reaches point B, at which juncture no further growth occurs; k/h does not increase. At this point, $G_k = b$ where b is the marginal cost and, hence, growth stops. In the lower quadrant of figure A2.1 we relate growth of consumption, $\dot{c}/c$, to the level of k/h. In the absence of intervention, $\dot{c}/c$ continuously declines until it reaches point L at $(k/h)^0$ where $\dot{c}/c = 0$. (This case represents growth pattern 1 discussed in chapter 2.)

If the public sector invests in human capital, however, long-run growth is possible. An optimal intervention would entail a public sector investment in human capital once the economy reaches $(k/h)^*$ or point D, where the marginal product, G_k, of physical capital is equal to the social marginal product of human capital $G_h + x$. At this point, $G_k = G_h + x > b$, so the economy is still growing. However, as growth is now balanced with $\dot{k}/k = \dot{h}/h$, k/h remains constant at $(k/h)^*$. In the lower quadrant, the optimal intervention implies that the k/h stops growing at $(k/h)^*$ at point d. Here we have a positive and sustainable growth rate of consumption equal to $(\dot{c}/c)^*$. (This situation reflects growth pattern 3 in chapter 2.)

Alternatively, the government may choose to subsidize investors in physical capital by reducing b or increasing G_k over time (see equation A2.5). However, these subsidies must be financed. Assuming that they are financed through lump sum taxes, the budget constraint, equation A2.4 (i), implies that the government must reduce I_h^g and/or I_R^g. However, this means that the economy becomes even more dependent on subsidies as a means to sustain growth. In figure A2.1 this pattern of growth can be shown by a shift to the right of the G_k schedule due to the capital subsidies (or by a fall of b). But the budget constraint implies that the government has less resources to

Figure A2.1. Constant Returns to Scale and No Technological Spillovers



Source: Author.

invest in human capital. Thus to preserve growth (to maintain a positive gap between G_k and *b*) subsidies must be continuously increased over time. That is, schedule G_k should be constantly shifting to the right by permanent and increasing subsidies. Economic growth becomes dependent on ever increasing subsidies to capital owners with the consequent negative impact on income distribution and human and natural capital. (This is growth pattern 2 discussed in chapter 2.)

The Case of a Poor Economy

Here we consider a poor economy where the initial level of consumption is only slightly above subsistence and is in the process of growing toward a steady-state level of growth. We call this a semisubsistence economy. The idea is that the poor constitute by themselves a subeconomy where most of the growth arises from their own efforts to save and invest. The semisubsistence economy does have contacts with the modern sectors because the poor sell some of their products to the modern sectors and because some of the poor are able to migrate into the modern sectors. For the sake of brevity and simplicity we do not explicitly model either of these processes. We simply postulate that the GDP function of the poor is dependent on shocks arising from the rich sectors through the variable p in the $G(\cdot)$ function. For example, a recession in the modern economy is translated into a fall in p, which in turn causes both the $G(\cdot)$ and the $G_k(\cdot)$ functions to be displaced downward. Another possible shock arises from the degradation of R caused by an expansion of the modern sector into areas where the poor live.[3] We assume that the economy is initially growing by investing primarily in k. The growth of h depends 100 percent on government expenditures in human capital.

We define two limiting cases. The first is where income minus depreciation of the asset stocks is exactly sufficient to cover the level of subsistence consumption:

$$\text{(A2.6)} \quad c^s = h_0\left\{G\left[\left(\frac{k}{h}\right)^s, 1; \frac{R_0}{h_0}, A; p\right] - \delta_k\left(\frac{k}{h}\right)^s - \delta_h\right\},$$

where h_0 is the initial level of human capital and R_0 is the initial level of natural capital, and we now assume a postive depreciation rate for k and h (δ_k and δ_h).

That is, for a given level of R_0, h_0 and exogenous policy variables p, there is a unique level $(k/h)^s$ that permits the economy to exactly satisfy its minimum subsistence consumption. If $k/h > (k/h)^s$, the economy is above subsistence with potential for positive net savings and growth. If $k/h < (k/h)^s$, the economy is not able to cover the depreciation of its stocks of capital, and therefore, with actual consumption equal to c^s, stocks are being reduced. That is, the economy is running down its capital. This causes negative growth as k/h falls.

The other limiting case is when the economy is barely able to satisfy its subsistence consumption only if it uses its total output without allowing any replacement of stocks:

$$\text{(A2.7)} \quad c^s = h_0G\left[\left(\frac{k}{h}\right)^{ss}, 1; \frac{R_0}{h_0}, A; p\right].$$

Once $k/h = (k/h)^{ss}$, households need to use all their output for consumption. At $(k/h)^{ss}$ the economy becomes infeasible.

Note that both $(k/h)^s$ and $(k/h)^{ss}$ are dependent on the levels of h_0, R_0, A, and p. It can easily be seen that $(k/h)^s$ and $(k/h)^{ss}$ are both decreasing in h_0, R_0, A, and p (assuming that $G(\cdot)$ is increasing in p, that is, p represents positive exogenous factors). Thus, a negative shock due, for example, to a recession in the modern economy that reduces the terms of trade of the poor or the level of R due to intrusion of commercial interests on the natural resources owned by the poor (which ironically is more likely to happen during boom times in the modern sector), will increase $(k/h)^s$.

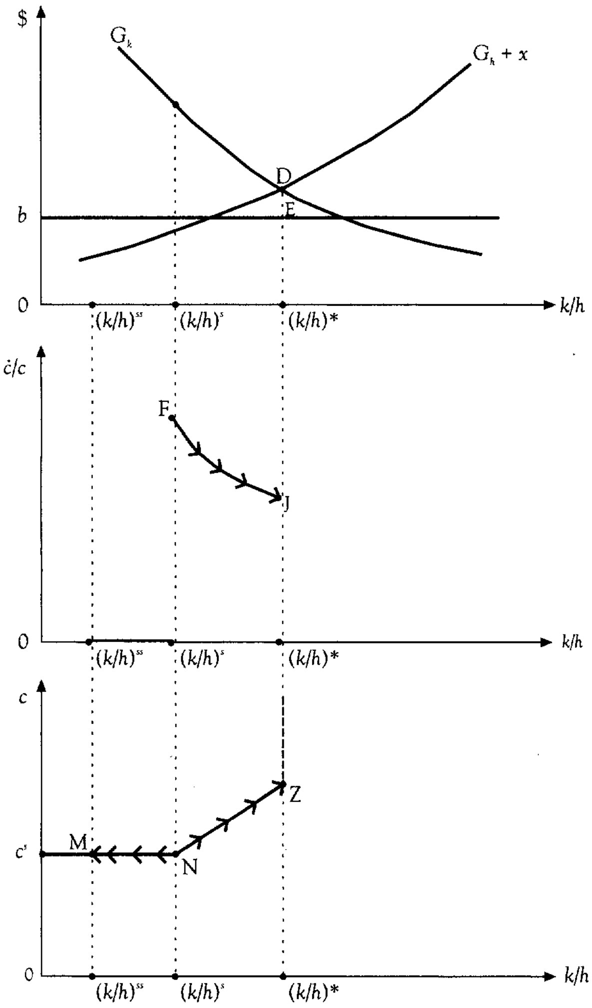
Suppose that the economy is initially at $(k/h)_0$ greater than $(k/h)^s$. That is, it is growing toward $(k/h)^*$ (see figure A2.2). Suppose now that a recession occurs in the modern sector reducing p. This will cause $(k/h)^s$ to increase. If the new $(k/h)^s$ is now greater or equal to $(k/h)_0$, then the semisubsistence economy is thrown into a subsistence trap that could lead to negative growth driving k/h toward $(k/h)^{ss}$.

Consider the case where the initial shock occurs at time t and is eventually reversed and p is brought back to its original level at time $t + \tau$. Here there are two possibilities:

- The fall of k/h between times t and $t + \tau$ is not too large and $(k/h)^s_t > (k/h)_{t+\tau} > (k/h)^s_{t+\tau}$. That is, at $t + \tau$, when the policy is returned to its original level, the critical $(k/h)^s_{t+\tau}$(which is equal to the original level $(k/h)^s_0$) is still below the level of $(k/h)_{t+\tau}$ (which is lower than the initial level $(k/h)_0$). In this case, the shock had only a temporary negative effect on growth. But once p is returned to its original level, the semisubsistence economy retakes its growth path.
- The fall of k/h between t and $t + \tau$ is large so that $(k/h)^s_t > (k/h)^s_{t+\tau} > (k/h)_{t+\tau}$. That is, as p returns to its original level at time $t + \tau$, the level of $(k/h)_{t+\tau}$ has fallen so low that it is now lower than the original critical level. In this case we have what is referred to as "hysterisis": the temporary shock has a permanent effect on the economy, and even if the shock disappears, the economy does not return to its original level. The effect of the shock causes an irreversible retrocess of the poor economy. The economy falls in a poverty cycle leading k/h to continuously fall towards $(k/h)^{ss}$, at which point it ceases to exist as a viable economy.

Figure A2.2 may help clarifying these points. The figure shows possible paths for the poor economy. If initially the k/h ratio is above the critical $(k/h)^s$, the economy is in a path of accumulation following the FJ line in the middle panel in figure A2.2 toward $(k/h)^*$. Throughout this path per capita

Figure A2.2. Subsistence, Growth, and Poverty Traps among the Poor: The Case of Constant Returns to Scale and No Spillovers



Source: Author.

consumption is continuously growing, although at a decreasing rate. Eventually, the economy reaches $(k/h)^*$, at which point it grows at a constant rate indefinitely. The lower panel shows the evolution of the consumption level, which increases permanently. Suppose now that a negative shock takes place while the economy is along the FJ path. This causes both the schedules G_k and G_h +x to shift downward with a new intersection at a point lower than

D, which implies a lower rate of long-run growth. But the most important consequence is that $(k/h)^s$ will move to the right as it increases because of the reduced level of G implied by a negative shock. The key issue is whether the initial (k/h) ratio is now below or above the new critical $(k/h)^s$ after the shock. If (k/h) is below the new $(k/h)^s$, the path of the economy reverses along a stagnation path such as the path NM in the lower panel of the figure. That is, the economy, which was originally growing, becomes stagnant and eventually, as it reaches point M, becomes infeasible.

Suppose the initial k/h is sufficiently low so that the economy enters a stagnation phase, with a declining k/h ratio, but that after a period of time the level of p is reestablished at its original level. The question is whether or not the new $(k/h)^s$ is above the current k/h ratio. If it is above, then the economy does not retake its original growth path. It continues into a downward spiral, further reducing its wealth. That is, the reversal of the growth process becomes permanent and a purely temporary shock has had a permanent, irreversible effect, triggering a vicious cycle of poverty and asset disaccumulation.

Econometric Specification Used to Estimate Growth Functions

A basic behavioral equation arising from both neoclassical and endogenous growth models is the following:

$$\text{(A2.8)} \quad g = \phi[F_K(K, H, R; A, p) - C_K(r, \delta, p)],$$

where g is the rate of GDP growth per capita; K, H, and R are per capita physical, human and natural capital, respectively; p is a vector of policy variables and prices; A is a productivity factor; F_K is the marginal return to K; C_K is the marginal cost of capital that typically depends on the discount rate (r), depreciation rate (δ), and presumably on policy variable p (such as subsidies to investment); and $\phi(\cdot)$ is a monotonic and increasing function.

Equation (A2.8) indicates that growth is dependent on the gap between the marginal returns to capital and its marginal cost. If such a gap is positive, growth is also positive, and growth comes to a halt if such a gap disappears. Moreover, under certain commonly assumed conditions, growth is directly proportional to this gap.

Thus, this basic behavioral expression relates economic growth to the level of asset stocks, total factor productivity, discount rates, and policy variables. Most empirical growth studies, however, do not use this behavioral approach and instead rely on various forms of growth accounting identities that relate growth to *changes* in asset stocks instead of their levels as a growth theoretic model suggests.

Our empirical analysis is based on equation (A2.8). If one includes time in a discrete form, it is natural to postulate that growth in one period depends on asset stocks at the end of the previous period. Thus a more operational expression for equation (A2.8) is,

$$\text{(A2.9)} \quad g_{it} = \phi[F_K(K_{it-1}, H_{it-1}, R_{it-1}; A_{it}, p_{it}, \alpha_i) - C_K(r^i, \delta_{it}, p_{it}; \alpha_i)],$$

where i stands for country and t is time. We assume that r^i and α_i are country fixed characteristics that influence technology and costs. That is, countries differ in terms of their discount rates, r^i, and technological or institutional characteristics, α_i (for example, property rights and rule of law).

We note that in equation (A2.9) growth at time t is dependent on *lagged asset stock levels* instead of *current flow of asset changes* as assumed in many empirical studies. That is, this growth theoretic equation provides for natural "instrumental" variables by postulating growth as a function of last period stock levels. This goes some way in decreasing biases arising from contemporaneous correlation between explanatory variables and the error term due to endogeneity of such variables. Lagged stock *levels* are much less likely to be endogenous to growth rates than contemporaneous stock *changes*.

Since we are relating current growth to lagged stocks of assets, we have that $K_{it-1} = (1-\delta)K_{it-2} + I_{it-1}$, where I_{it-1} is investment per capita in period $t-1$. So replacing this in equation (A2.9), we find that using lagged stock levels in the growth regression is equivalent to regressing growth on twice lagged stocks and lagged investment. If we repeat this process by substituting K_{it-2}, using a similar expression we can go back to the first year asset stock. So estimating equation (A2.9) is equivalent to estimating growth on the per capita lagged investment levels of each asset and the "initial" level of each asset. Hence, this specification implicitly uses the initial level of income (given that the initial income level is a function of all initial assets) as an explanatory factor. That is, we could, in principle, relate the estimated coefficients of assets to analyses of convergence of growth rates across countries.

We also assume that the unobserved total factor productivity is related to assets stocks and other country characteristics, for example, $A_{it}(K_{it-1}, H_{it-1}, R_{it-1}, \alpha_i)$. That is, even if F_K is declining in K_{it-1}, the growth rate can be increasing or nondecreasing in K_{it-1} if the technological and scale spillovers are powerful enough. That is, if the partial effect of K_{it-1} on A_{it} is positive and of sufficient magnitude so that $dF_K/dK_{it-1} = \partial F_K/\partial K_{it-1} + (\partial F_K/\partial A_{it})(\partial A_{it}/\partial K_{it-1}) > 0$. Thus, we estimate a reduced form of equation (A2.9) allowing for fixed country effects,

$$\text{(A2.10)} \quad g_{it} = \psi[K_{it-1}, H_{it-1}, R_{it-1}, p_{it}] + \beta_i + f_t + \mu_{it},$$

where $\psi(\cdot)$ is a general well-defined function, β_i is a coefficient capturing the country fixed effect related to the effects of α_i and r^i in equation (A2.9), and μ_{it} is a random disturbance. The coefficient f_t corresponds to time effects. The empirical estimation uses various functional forms for $\psi(\cdot)$, including a logarithmic one and a translog form to allow for interasset and policy interactions.

The use of country fixed effects deals with biases arising from omitted variables corresponding to possibly large numbers of country-specific variables that are not observed. Thus, the specification in equation (A2.10) helps to reduce biases due to both endogeneity of explanatory variables by using lagged asset stock variables as instruments, and omitted variables by using fixed effects.

Evidence from Developing Countries

Table A2.1 presents the empirical evidence for the section "Econometric Evidence: 20 Middle-Income Countries."

Tables A2.2 and A2.3 show empirical results for the section "Econometric Evidence: 70 Developing Countries."

Table A2.4 shows some empirical studies on the impact and size of capital subsidies.

Notes

1. Consistent with the discussion above, $G_{bh} < G_h$, where G_h is the true marginal product of human capital.
2. The marginal cost function, b, is equal to $r + \delta$, where δ is the depreciation rate of capital. Here we allow for policies, p, to affect the marginal cost of capital.
3. This is consistent with one stylized fact that is valid for several tropical countries, especially in Latin America and Asia: though the poor are most dependent on natural resources, most destruction of these resources is caused by large commercial interests that intrude into resources owned by the poor (see the ample empirical evidence on these issues provided by Kates and Haarmann 1992).

Table A2.1. The Growth Equation under Various Specifications
(dependent variable: GDP growth per capita)

	Fixed effects		*Random effects*	
Variables	*Equation 1*	*Equation 2*	*Equation 3*	*Equation 4*
Average schooling	0.005	0.004	–0.012	–0.013
	(0.025)	(0.020)	(0.009)	(0.009)
Schooling × reform dummy variable	0.084**	0.084**	0.049**	0.049**
	(0.024)	(0.024)	(0.018)	(0.018)
Per capita capital stock	–0.021*	–0.021**	–0.012**	–0.009**
	(0.012)	(0.010)	(0.005)	(0.004)
Capital × reform dummy variable	–0.016**	–0.016**	–0.008**	–0.008**
	(0.005)	(0.005)	(0.004)	(0.004)
Dummy 1982–85	–0.019**	–0.019**	–0.017**	–0.018**
	(0.005)	(0.005)	(0.005)	(0.005)
Labor force	–0.001	n.a.	–0.006	n.a.
	(0.067)	n.a.	(0.006)	n.a.
Standard deviation of log of schooling	–0.018	–0.018	–0.034**	–0.033**
	(0.019)	(0.016)	(0.012)	(0.012)
Homoscedasticity (Breusch-Pagan test)	Rejected at 5 percent	Rejected at 5 percent	Not rejected at 5 percent	Not rejected at 5 percent
White test of specification	Rejected at 5 percent	Rejected at 5 percent	n.a.	n.a.
Hausman test: Fixed vs. random effects	n.a.	n.a.	Not rejected at 5 percent	Not rejected at 5 percent

n.a. Not applicable.
* Significant at the 10 percent level.
** Significant at the 5 percent level.
Note: All variables are in log form. All explanatory variables are lagged by one period. Standard errors of the coefficients are in parentheses. Data from 20 countries are presented. White's heteroscedasticity consistent standard errors are reported under fixed effects.
Source: López, Thomas, and Wang (1998).

Table A2.2. GDP Growth Rates Regressed on Stocks Per Worker, Using All Countries with Available Data from 1965 to 1990

Variables	*No cross-products: fixed effects (with country dummies)*	*No cross-products: fixed effects (with country and time dummies)*	*Translog: fixed effects (with country and time dummies)*
Observations	335	335	335
Countries	67	67	67
Log likelihood	–631.70	–606.30	–605.80
ln (capital/labor)	10.34	11.36	13.21
	(4.79)	(5.67)	(3.19)
ln (forest area/labor)	–1.31	–0.54	8.86
	(–0.68)	(–0.31)	(2.15)
ln (education)	–19.56	–21.41	–12.32
	(–5.68)	(–6.60)	(–2.42)
[ln (capital/labor)]^2	–0.74	–0.95	–1.11
	(–6.34)	(–6.93)	(–4.88)
[ln (forest area/labor)]^2	0.31	0.36	0.09
	(2.74)	(3.25)	(0.62)
[ln (education)]^2	1.36	1.44	0.84
	(5.52)	(6.20)	(1.64)
ln (capital/labor) × ln (forest area/labor)	n.a.	n.a.	0.108
	n.a.	n.a.	(–0.54)
ln (capital/labor) × ln (education)	n.a.	n.a.	0.467
	n.a.	n.a.	(0.78)
ln (forest area/labor) × ln (education)	n.a.	n.a.	–0.596
	n.a.	n.a.	(–2.03)

n.a. Not applicable.

Notes:

1. t-statistics are in parentheses.

2. The dependent variable is annual per capita GDP growth computed over a five-year interval using annual data. The regression is ln(GDP) = $a + bt + e$, where e is the residual. Growth rate equals 100*[exp(b)-1].

3. Parameters were computed by iterated feasible generalized least squares (FGLS), and therefore should be equivalent to maximum likelihood estimation.

4. The correction for AR(1) selected a single parameter for all countries together.

5. The correction for groupwise heteroscedasticity was done by computing a group variance for each country.

6. Measures of per capita GDP and labor were taken from Summers' and Heston's Penn World Tables Mark 5.6. Measures of education were taken from Barro and Lee (1997). They represent average years of education for people 25 years and older. Measures of per capita capital were taken from King and Levine (1993). Measures of forest area (resource stock) were taken from World Resources 1996–97 Data Disk, and is originally from FAOSTAT. The Penn World Tables may be downloaded from http://www.nuff.ox.ac.uk/Economics/Growth/. The Barro-Lee and King-Levine datasets may be downloaded from the World Bank's Web page at http://www.worldbank.org/html/prdmg/grthweb/ddkile93.htm. The forest data may be downloaded from the Food and Agriculture Organization of the United Nations web page at http://apps.fao.org/.

Source: López, Thomas, and Wang (1998).

Table A2.3. Elasticities for Stocks Per Worker on GDP per Capita Growth Rates

	Elasticity		
Variables	*Minimum value*	*Maximum value*	*Average*
No cross-products allowed			
Capital/labor	0.038	–0.081	–0.040
	(0.019)	(0.022)	(0.009)
Forest area/labor	0.007	0.071	0.047
	(0.046)	(0.027)	(0.022)
Education (average schooling of labor force)	–0.056	0.056	0.018
	(0.011)	(0.020)	(0.011)
Translog function			
Capital/labor	0.046	–0.093	–0.045
	(0.022)	(0.026)	(0.012)
Forest area/labor	0.034	0.050	0.044
	(0.049)	(0.029)	(0.023)
Education	–0.031	0.035	0.012
	(0.028)	(0.022)	(0.013)

Notes:

1. Elasticities are computed by converting the percentage growth rate to the log of the growth rate by dividing the percentage by 100.

2. Marginal effects are computed using the fixed effects regression with country and time dummies, corrected for groupwise heteroscedasticity for all countries, and a common AR(1) term for autocorrelation. Data are for all countries, 1965–90.

3. Marginal values (dy/dx) computed for the unlogged x's are simply the exponential of their respective logged values. This means that x bar is not the true mean.

4. Marginal values for the translog formulation utilize the mean values of the log of the crossed term.

5. Standard errors are in parentheses. They are based on variability in the parameter estimates only (including covariances between parameters) and not on any variability in the minimum or maximum variable mean.

6. The elasticity of labor is computed as the negative of the sum of the elasticities for capital/labor and resources/labor.

Source: López, Thomas, and Wang (1998).

Table A2.4. Selected Empirical Studies on the Impact and Size of Capital Subsidies

Authors	*Methods*	*Major findings*
Studies on the impact of subsidies		
Bergström (1998). "Capital Subsidies and the Performance of Firms."	The study examines the effects on TFP of public capital subsidies to firms in Sweden between 1987 and 1993. Panel data were used.	"In many countries, governments grant different capital subsidies to the business sector in order to promote growth... The results suggest that subsidization can influence growth (in a short run), but there seems to be little evidence that the subsidies have affected productivity" (p. 1).
Bregman, Fuss, and Regev (1999). "Effect of Capital Subsidization on Productivity in Israeli Industry."	It uses a time-series cross-section microdata set for 620 firms for Israel.	"An industrial policy of subsidizing physical capital investment has been utilized in many countries.... We estimated that for the years 1990-94, this policy has resulted in production inefficiencies ranging from 5 to 15 percent for subsidized firms" (p. 77).
Harris (1991). "The Employment Creation Effects of Factor Subsidies."	Uses CES (constant elasticity of substitution) production function and a simulation model for the Northern Ireland manufacturingindustry, 1955–83.	"The results indicate that, since manufacturing industry in the province tends to operate with a labor-intensive technology and, its price elasticity of demand for output is very low, the employment-creating effects of capital subsidies are strongly negative" (p. 49).
Lee (1996). "Government Interventions and Productivity Growth."	Uses four-period panel data for the years 1963–83.	"Industrial policies, such as tax incentives and subsidized credit, were not correlated with total factor productivity growth in the promoted sectors" (p. 391).
Lim (1992). "Capturing the Effects of Capital Subsidies."	Uses firm-level data from 3,900–4,900 firms in Malaysia, from 1976 to 1979.	"Most developing countries provide fiscal incentives to encourage domestic and foreign investment. This study shows that these schemes subsidize significantly the use of capital and produce greater capital intensity in Malaysian manufacturing" (p. 705).
Oman (2000). "Policy Competition for Foreign Direct Investment," OECD Development Centre.	The study addresses three sets of questions: (a) to what extent do governments compete for FDI, (b) the effect of competition, and (c) implications for policymakers.	"Incentive-based competition for FDI is a global phenomenon: governments at all levels in both OECD and non-OECD countries engage in it worldwide... The distortionary effect of incentives...can be significant... It can be counterproductive for governments to offer costly investment incentives" (p. 7–9). Investment incentives in the automobile industry are shown in a table on page 73.
Studies on the size of subsidies		
Gandhi, Gray, and McMorran (1997).	Estimated subsidies that damaged the environment.	"Estimated subsidies to energy, roads, water, and agriculture in developing and transition economies total over $240 billion per year in the 1990s. Cutting these subsidies in half would free over $100 billions of finance for sustainable development" (p. 10).
Moore (1999). "Corporate Subsidies in the Federal Budget."	A testimony before the Budget Committee, U.S. House of Representatives.	"Corporate welfare is a large and growing component of the federal budget" (p. 1). In 1997, the Fortune 500 corporations are estimated to have received nearly US$75 billion in government subsidies.

(table continues on following page)

Table A2.4 continued

Authors	*Methods*	*Major findings*
de Moor and Calamai (1997). *Subsidizing Unsustainable Development: Undermining the Earth with Public Funds.*	A report to the Earth Council, which estimated public subsidies in four sectors.	"In OECD countries, total annual subsidies in four sectors, energy, road transport, water and agriculture, amounted to \$490 –\$615 billion, and in non-OECD countries, \$217–\$272 billion. Total subsidies in all four sectors are estimated at \$710–\$890 billion worldwide" (p. 93).
Gulati and Narayanan (2000). "Demystifying Fertilizer and Power Subsidies in India."	This paper estimates the amount of subsidies and examines the real beneficiaries.	"Broadly half of the huge agricultural subsidy on fertilizers and power... comprising 2 percent of GDP, is either going to industry in the case of fertilizers or is being stolen by non-agricultural consumers in the case of power" (p. 784).

Note: A more detailed table is available on request from the authors.
Source: Authors.