THRESHOLD EXTERNALITIES IN ECONOMIC DEVELOPMENT*

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Standard one-sector growth models often have the counterfactual implication that economies with access to similar technologies will converge to a common balanced growth path. We propose an elaboration of the Diamond model that permits multiple, locally stable stationary states. This multiplicity is due to increasing social returns to scale in the accumulation of human capital.

I. INTRODUCTION

International evidence on growth rates in per capita income reveals striking and persistent differences in development patterns among nations. Some countries manage to sustain high growth rates over long periods of time; others advance at acceptable if not spectacular rates; while still others seem to stagnate in low growth "traps," exhibiting persistently low rates of growth or relatively low levels of economic development, or both. Tables I and II illustrate the relative economic performance in the last two centuries of several developed and less developed countries.

These persistent differences are not explained by faster growth in early stages of development, that is, by poorer countries growing faster as they catch up with richer ones. From Table I we see, for instance, that Norway experienced accelerating growth for a whole century (1867 to 1965), while Egypt and India grew more slowly than the richer countries of Western Europe and North America. Table II shows that each of the three countries in the sample which grew fastest between 1940 and 1970 (Japan, Greece, and Finland) started out with higher per capita income than any of the three slowest growing countries (Egypt, Thailand, and India). Over the

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TABLE I
COMPARATIVE LONG-RUN RATES OF GROWTH

	Comparative rates of growth (% per decade)			
Country	Time period	GNP per capita (beginning of period)	GNP per capita (end of period)	Growth rate
Britain	1922–1965		1,870	16.9
France	1896–1965		2,047	18.6
Germany	1910–1965		1,939	20.5
Italy	1897–1927	271		16.9
	1927–1952			14.3
	1952–1965		1,100	60.4
Japan	1890–1910	79		25.5
	1910–1927			32.8
	1927–1953			9.9
	1953–1965		876	128.4
United States	1800–1840			13.5
	1840–1874			13.9
	1874–1894			20.3
	1890–1910			20.1
	1905–1927			16.5
	1927–1952			19.2
	1952–1965		3,580	20.8
Norway	1867–1890			10.8
	1890–1910			14.3
	1910–1927			21.4
	1927–1952			29.1
	1952–1965			38.0
Australia	1902–1965	930	2,023	13.1
Argentina	1902–1965		811	10.1
Mexico	1897–1965		461	18.2
Ghana	1901–1965		312	15.6
Philippines	1902–1965		255	10.3
Egypt	1897–1965		185	4.8
India	1905–1965		84	6.8

Sources. Kuznets [1971a] and Rostow [1978].
Notes: All GNP figures are in constant (1965) U. S. dollars. Growth rates are percent per decade.

last two decades upper middle income countries as a group appear to develop a good deal more rapidly than the very poorest countries. In fact, six of the world's slowest growing nations[1] (that is, those with per capita GNP growth rates below *minus* 1.5 percent per annum in 1965–1985) were already among the very poorest in 1965.

1. See *World Development Report* [1987].

Neoclassical models of economic growth like Solow's [1956] or Diamond's [1965] do not suggest such a pattern. Countries with basically similar physical environments and apparent access to similar technologies may show temporary differences reflecting different initial conditions, but should not exhibit such wide and persistent dispersion in growth rates. On the contrary, many of the growth models with which we are familiar imply convergence to a unique balanced growth path under standard convexity assumptions, while all available evidence argues against uniqueness.

One explanation, of course, is that persistent differences in national economic performance are due entirely to systematic variations across countries in culture, religion, national economic policies, or broadly defined social institutions, that is, to economically "exogenous" factors. This paper explores the alternative possibility that sustainable differences in per capita growth rates could appear even among economies with *identical* structures.

Our interest in the multiplicity of growth paths, however, extends beyond purely theoretical manipulations of standard growth models. As Lucas [1988] argued in discussing international differences in growth patterns, the welfare gains that could be achieved from even a small sustained increase in the rate of per capita GNP growth could dwarf the gains from smoothing GNP fluctuations around an unchanging trend.[2]

To capture the phenomenon of nonconvergent long-term growth paths, we shall augment the neoclassical model of economic growth with a feature that is sufficient to produce multiple, locally stable balanced growth paths in equilibrium. This feature is *technological externalities with a "threshold" property* that permits returns to scale to rise very rapidly whenever economic state variables, such as

2. Explaining persistent differences in growth rates was an active line of research several decades ago, but such work fell out of favor by 1970. Earlier investigators focused on the "preconditions" that an economy must satisfy to move from low to sustained high growth. Examples include the development debates in the Soviet Union in the 1920s (for example, see Preobrazhensky [1926] for the concept of "primitive socialist accumulation") which preceded the policy of rapid industrialization in the 1930s, Rosenstein-Rodan's [1943] big-push theory of economic development, and Nelson's [1956] explanation of how an economy with endogenous population growth can fall into a low-level development trap.

Perhaps the best-known attempt in this vein was Rostow's [1960] work on self-sustaining growth that took place in specific "stages." Work on the stages of economic growth, as epitomized by Rostow's book of that title, largely ceased because it failed to elucidate the economic mechanisms responsible for the jump from slower stages of the development path to more rapid ones in a way that we would consider theoretically acceptable. (See Fishlow [1965] and Kuznets [1971b].)

the quality of labor, take on values in a relatively narrow "critical mass" range.

Among the types of externalities we consider are spillovers from the stocks of different types of capital (to capture in a primitive way the notion of "infrastructure") as well as the labor-augmenting outcomes of externalities arising in the process of creating human capital. Both of these allow us to define rigorously the hazy notion of "takeoff" which appears essential in earlier work on growth stages. We assume throughout that credit markets are perfect, leaving for later investigation issues of financial deepening, that is, of the possible contributions to economic development that arise from the smoother operation of capital markets.

The rest of this paper is organized as follows. Section II introduces neutral technological externalities in the standard overlapping generations model of growth and shows that, in the absence of some mechanism leading to a "threshold effect," the resulting increasing returns are not by themselves sufficient for multiple, locally stable stationary states. Section III focuses on labor-augmenting externalities that relate private rates of return on human investment to current and past values of aggregate human capital. These externalities can induce multiple balanced growth paths as stationary equilibria. Section IV gives an example of an economy with two locally stable balanced growth paths: one is an underdevelopment trap with minimal labor quality and zero growth in per capita income; the other has higher labor quality and positive growth. Section V investigates the existence and stability of multiple *interior* steady states, that is, ones involving positive training.

Section VI considers empirical evidence for the view that threshold externalities are associated with human capital accumulation. We argue that rapid growth cannot occur without relatively overqualified labor, that is, without a *high level of human investment relative to per capita income.* We give this hypothesis a preliminary examination in a sample of 32 countries for the period 1940–1985 with generally encouraging results. We sum up in Section VII and discuss a number of unresolved theoretical and empirical issues.

II. Threshold Externalities and Multiple Equilibria

The empirical finding that countries with access to similar technologies and (one supposes) not wildly dissimilar rates of time preference can have persistent differences in growth rates suggests

TABLE II
COMPARATIVE MEDIUM-RUN RATES OF GROWTH

	% Literacy		Per capita output		Growth in per capita output		Output-to-literacy ratio	
Country	1940	1960	1940[a]	1960[b,c]	1940–70[a]	1960–80[b]	1940[a]	1960[b]
Australia	98	99	1,128	5,182	2.86	2.41	11.6	52.3
Belgium	96	98	715	4,375	4.11	3.80	7.5	44.6
Canada	97	98	1,041	6,069	3.81	3.17	10.8	61.9
Chile	72	84	371	2,932	1.70	1.90	5.2	34.9
Colombia	56	63	190	1,362	2.13	3.19	3.4	21.6
Denmark	99	99	971	5,490	3.71	2.83	9.8	55.5
Egypt	15	26	167	496	0.64	3.54	11.1	19.1
Finland	91	99	419	4,073	5.35	3.68	4.6	41.1
Greece	67	80	187	1,474	5.91	5.60	2.8	18.4
Guatamala	35	32	78	1,268	5.06	2.18	2.2	39.6
Honduras	34	45	109	748	2.95	1.83	3.2	16.6
India	14	28	67	533	1.01	.71	5.0	19.0
Ireland	99	99	665	2,562	2.11	3.33	6.7	26.4
Japan	80	98	260	2,237	6.32	6.66	3.3	22.8
Korea	31	71	—	700	—	6.28	—	9.9
Mexico	49	65	138	2,157	5.32	3.55	2.9	33.2
Netherlands	99	98	889	4,690	3.25	3.33	9.0	47.9
New Zealand	99	98	1,055	5,571	2.25	1.40	10.7	56.8
Nicaragua	37	53[d]	105	1,588	4.76	1.19	2.9	29.9
Panama	65	73	374	1,255	1.84	4.11	5.7	17.2
Peru	48	61	89	1,721	4.04	1.79	1.9	28.2
Philippines	62	72	113	885	2.33	2.84	1.9	12.3
Portugal	51	63	—	1,429	—	4.92	—	22.7
Spain	77	87	361	2,426	3.03	4.74	4.7	27.8
Sweden	99	99	1,091	5,149	4.17	2.75	10.9	52.0
Switzerland	99	100	1,246	6,834	2.92	1.93	12.6	68.3
Thailand	54	68	128	688	0.88	4.61	2.2	10.1
Turkey	21	38	212	1,255	1.66	3.12	10.1	33.0
United Kingdom	99	99	1,334	4,970	1.36	2.39	13.5	50.2
United States	96	98	1,549	7,380	3.45	2.20	16.2	75.3

Sources. Preston [1980], World Bank [1987], Summers and Heston [1988].
a. Real GNP in 1970 U. S. dollars.
b. Real GDP as computed by Summers and Heston [1980] in "International Dollars," computed to take account of purchasing power differences.
c. Columns for a given variable using World Bank versus Summers-Heston data are not easily comparable. The conversion factor from "International Dollars" to Real U. S. Dollars varies with the level of development. See Summers and Heston.
d. 1970 literacy.

to us the following notion of "stages of growth." For a given transformation technology available to individual producers, moderate differences in the stocks of factor inputs may imply markedly different growth rates. Once state variables such as physical capital or the stock of "knowledge" surpass certain critical values, aggregate production possibilities may expand especially rapidly. In other words, as product per capita rises beyond some critical value, the state variables become more favorable to economic expansion and are, in turn, stimulated by that expansion.

Key to this argument is the distinction, made recently by Romer [1986], between *private* and *social* factors of production, that is, between those inputs controlled by individual producers and those not controlled by any single producer alone. We purposely leave this vague for now, as we want the notion of social factors of production to cover a number of phenomena. As a first illustration of this distinction (and also to fix notation for later use) we begin with the well-known one-sector overlapping-generations model of capital accumulation due to Diamond [1965]. Population is constant, and there is no national debt or exogenous technical progress. Each individual is endowed with one unit of leisure when young that he supplies to market activity inelastically. Let $c^t = (c_1^t, c_2^t)$ be the consumption vector of a generation-t individual, and let $u(c^t)$ be his utility function.

Production is carried out by "firms." Firms producing at t borrow capital at $t - 1$, hire labor services at t, sell their output, pay out factor rewards, and go out of business. Capital depreciates fully on use, and maximum profits are zero because private returns to scale are constant. Specifically, firms operate in period t with the production function,

$$Y_t = A_t F(K_t, L_t), \tag{1}$$

where (K_t, L_t) are private capital and labor inputs, Y_t is output, and F is a linear homogeneous function with the normal monotonicity and concavity properties. The scale factor A_t may depend functionally on a vector of *social* inputs that are not controlled by any one producer. Among these inputs one may in principle count economy-wide averages of private inputs (see Lucas [1988]), lagged values of input or output (as in Arrow [1962]), or intangible factors such as knowledge [Romer, 1986; Kohn and Marion, 1988].

In all cases, social returns to scale are increasing whenever A is a weakly increasing function: a general doubling of all inputs in all periods will boost aggregate output by a factor greater than or equal to two in *each* period. In the interest of concreteness, we suppose first that A_t depends on the economywide capital stock.

Dynamic equilibria in this economy satisfy three familiar relations expressed in terms of the intensive production function

$f(k) = F(K/L,1)/L$ and the scale factor $A_t = A(k_t)$:

$$k_{t+1} = s(R_t,w_t) \tag{2}$$

$$R_t = A_{t+1} f'(k_{t+1}) \tag{3a}$$

$$w_t = A_t[f(k_t) - k_t f'(k_t)]. \tag{3b}$$

The first of these equates investment per head at t (and, hence, capital per head at $t + 1$) with saving by workers who earn wage income w_t and face a gross yield R_t on loans. Technically, the function $s(R,w)$ is the maximizer of $u(w - s,Rs)$ in the interval $[0,w]$. Equations (3a) and (3b) are standard factor demand schedules by firms. We assume that labor is fully employed and normalize aggregate labor supply to unity.

Equilibrium paths in the closed economy of equations (2) and (3) are fully described by any capital intensity sequence (k_t) which satisfies

$$k_{t+1} = s[A(k_{t+1})f'(k_{t+1}),A(k_t)w(k_t)]. \tag{4}$$

The function $w(k)$ in this equation simply equals $f(k) - kf'(k)$. Steady states are constant (rather than geometric) sequences of capital per head and output per head; the fixity of labor supply per person simply rules out balanced growth.

Consider first the case where social inputs are nonexistent, so that external effects on production vanish, and we may write $A(k) = \alpha$ for all k. Equation (4) then reduces to the standard Diamond model of capital accumulation with zero internal national debt. The set of solutions to the difference equation (4) for $A = \alpha$ is well-known (see Azariadis [1986, Ch. 2]); for each fixed $\alpha > 0$ it is easy to derive sufficient conditions for the existence of at least one locally stable stationary equilibrium with positive capital intensity.

It is also well-known that the basic Diamond model may easily exhibit multiple steady states.[3] However, our interest is to discover

3. Under the assumption that all consumption is normal and that the saving function s is monotone in the interest rate, then, for each value of the positive parameter α, equation (4) corresponds to an upward-sloping line through the origin in (k_t,k_{t+1})-space, as in Figure I. Furthermore, we may easily show that $\lim_{k_t \to \infty} \times (k_{t+1}/k_t) = 0$. Hence, *at least* one locally stable stationary equilibrium with positive capital intensity will exist for *each* fixed $\alpha > 0$ whenever equation (4) satisfies $\lim_{R_t \to \infty} (k_{t+1/k_t}) > 1$. Uniqueness is not guaranteed by the continuity and convexity assumptions on tastes and technology or by any intuitively justifiable strengthening of these assumptions. If the utility function is homothetic and the two dated consumption goods are gross substitutes, then the existence and stability of a nontrivial stationary solution to equation (4) is guaranteed by Inada-like conditions on the intensive production function.

how differences in growth patterns relate to the phenomenon of social inputs, not whether they can arise from particular (and perhaps "pathological") specifications of the underlying tastes and technology. Therefore, we restrict consideration to economies in which equation (4) has a unique, nontrivial locally stable steady state $k = \bar{k}(\alpha) > 0$ for each fixed $\alpha > 0$. Figure I graphs equation (4) for two distinct values of α; the upper frontier corresponds to the higher value of α.

Using that figure as a background, we introduce variable scale factors A_t and ask how technological externalities transform the set of equilibria in this extremely simple neoclassical model of accumulation. If the variation of A_t with k_t is slight (so that, for example, the strictly increasing function $A(k)$ lies in the neighborhood of α_1 for all k), then increasing returns do not appreciably change the qualitative properties of equilibrium.

An economy may generate multiple stable stationary states if it is described by sharply different dynamics for different parameter values; technically speaking this economy exhibits *bifurcations* at critical points. We call *threshold effects* radical differences in dynamic behavior arising from local variations in social returns to scale. We shall argue below that such bifurcations may result from the technical features of the accumulation process in an economy with both physical and human capital. To illustrate very simply how important threshold effects can be in explaining differences in growth patterns, we assume a discontinuity in technology and study

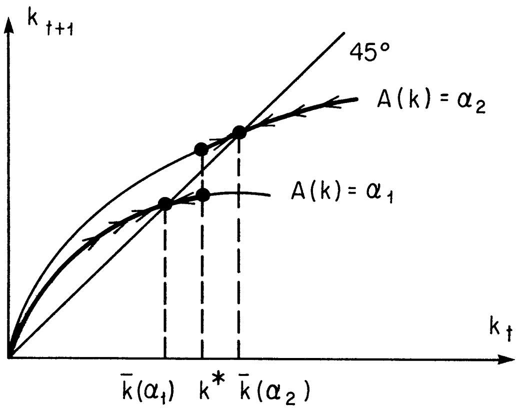

FIGURE I

the resulting dynamics. Specifically, we postulate that the scale factor is a step function with one jump at k^*; namely, $A(k) = \alpha_1$ for $k < k^*$, $= \alpha_2$ for $k \geq k^*$. Figure I shows how two nontrivial locally stable steady states will arise in this case if the threshold k^* satisfies

$$\bar{k}(\alpha_1) < k^* < \bar{k}(\alpha_2), \tag{5}$$

that is, lies between the steady states that correspond to the scale factors α_1 and α_2. Economies that start out with capital below the critical value k^* will converge monotonically to a steady state in which capital, consumption, and income per head remain relatively low forever. In the absence of outside incentives or direct government intervention, the initial stock of capital is the only factor affecting which steady state will be reached. The economy "takes off" toward $\bar{k}(\alpha_2)$ if the initial capital per head is above k^*.

Leaving aside what puts the economy on one or the other side of the threshold, it should be clear that the multiplicity of stable stationary states does not logically *require* discontinuities in the scale factor A. What is really at work here is the interchange of increasing with decreasing returns to social inputs, that is, the existence of ranges for the state variables over which social returns to scale alternate from low to high as the size of production externalities varies. Increasing social returns alone need not yield multiplicity; alternating increasing and decreasing returns in the production process may do so.

III. Balanced Growth with Human Capital

The example of the previous section raises the question of whether multiple steady states due to threshold effects are a mere theoretical curiosity, or whether they are instead a pervasive feature of dynamic economies with realistic technological and demographic characteristics. We shall argue that threshold externalities may easily arise in the accumulation of human capital. We shall first set out a general model and then consider various specialized versions of it that help us isolate the origins of threshold effects.

We begin by assuming that all individuals have access to a common training technology. This technology converts time investments when young to subsequent labor quality, enhancing the stock of knowledge, skills, or of health capital, and thereby permitting a higher flow of labor services per unit time when workers are older. In particular, the flow of efficiency units of labor from any old worker supplying labor at $t + 1$ is

(6) $$x^i_{t+1} = x_t h(\tau^i_t, x_t),$$

where $\tau^i_{t+1} \in (0,1)$ is the fraction of time invested at t in labor quality, i.e., in formal education, training, or health maintenance. We may assume h to be a weakly increasing and concave function of τ such that $h(0, x) \geq 0$ for all $x > 0$; and x_t is the quality of labor services inherited by *all* generation-t households.[4]

A noteworthy feature of this specification is that different steady state values of τ, the fraction of time devoted to training, will yield different (and generally time-varying) *rates of growth* in labor quality x. This appears to be a natural assumption as long as educational attainment does not fully depreciate from one period to the next. Next period's stock of knowledge, x^i_{t+1}, attained by individual i, should depend positively on currently available knowledge, and the change in x will depend on τ. The expression on the right-hand side of equation (6) need not be multiplicative; what matters is simply that the elasticity of x_{t+1} with respect to x_t be greater than one.

Note that the variable x_t on the right-hand side of (6) represents both the *average* quality of labor of both young and old at t, and the number of efficiency units of labor services per unit time with which the young are endowed. We continue with the assumptions of homogeneous households and zero population growth (both of which are dispensed with at little cost in notation); all young households at t start out with an initial endowment of time (equal to 1) and of quality of labor services (equal to x_t).

The individual's labor supply decision is no longer trivial as in the previous section, for he must decide what fraction of his time to invest in training when young. Assuming that training provides zero nonpecuniary benefits, τ^i is simply chosen to maximize discounted lifetime income,

(7) $$(1 - \tau^i_t) w_t x_t + w_{t+1} x_t h(\tau^i_t, x_t)/R_t.$$

Maximizing over τ^i_t leads to a first-order condition,

(8) $$R_t = (w_{t+1}/w_t) h_\tau(\tau^i_t, x_t),$$

4. This specification encompasses a variety of return structures; it allows for diminishing private and constant social returns to human capital, or for a combination of constant private with increasing social returns. An example of the first case is $h = (\tau^i/x)^\theta$, where $0 < \theta < 1$; the second case is illustrated by $h = [1 + \gamma(x)](\tau^i/x)$ for any positive increasing function γ.

which equates the yields on human and physical capital at any interior maximum.

Because all individuals in this model have equal ability and equal access to credit (facing the same schedule h and the same rate of interest), they will choose identical investments. As a result, equation (6) also describes the evolution of "average" labor quality x_t when the i superscripts are suppressed. Total labor supply in effective units is then $N_t = (1 - \tau_t)x_t + x_t$, where the two terms on the right-hand side are quality-adjusted labor supply by the young and old, respectively.[5]

The market-clearing conditions that a dynamic equilibrium must satisfy are the analogues of equations (2) and (3) plus equation (8) which determines investment in training. The relevant equations are

$$N_{t+1}k_{t+1} = s[R_t, w_t x_t(1 - \tau_t), w_{t+1}x_{t+1}] \tag{9a}$$

$$R_t = A_{t+1} f'(k_{t+1}) \tag{9b}$$

$$w_t = A_t[f(k_t) - k_t f'(k_t)] \tag{9c}$$

$$A_t = A(k_t x_t, x_t) \tag{9d}$$

$$N_t = (2 - \tau_t)x_t \tag{9e}$$

$$R_t = (w_{t+1}/w_t)h_\tau(\tau_t, x_t) \tag{9f}$$

$$x_{t+1} = x_t h(\tau_t, x_t). \tag{9g}$$

Equations (9a)–(9d), in particular, correspond exactly to (2) and (3) with k_t denoting capital *per unit of efficiency labor services* and w_t describing the wage rate per efficiency unit. Specifically, (9a) balances investment with saving: the function $s(R, y_1, y_2)$ now describes saving by a representative household with income profile (y_1, y_2).[6] Equations (9b) and (9c) are factor demands, while (9d) allows both physical and human capital to be social inputs.

The role of human capital in the growth process is described by equations (9f) and (9g); (9f) is the first-order condition for individual choice of labor quality by homogeneous individuals, while (9g) gives the evolution of average skills implied by individual decisions. A steady state of the economy that evolves according to (9a)–(9g) is a competitive equilibrium in which intensive variables such as τ and

5. One quickly notes that since N_t is proportional to x_t (so that F is linear homogeneous in K and x), any dependence of A_t on inputs will induce increasing returns in an otherwise constant returns model, exactly as in Romer [1986].

6. Note that the function s in equation (2) describes saving for an income profile of the form $(y_1, 0)$, i.e., with zero second-period income.

k are constant over time while extensive ones like c_t^1, c_t^2, x_t, K_t, N_t, and Y_t may either be constant or grow geometrically.

Let us now consider some specific cases. A *unique* balanced growth path obtains if the utility function is homothetic, the scale factor A is constant, and the rate of labor quality change is independent of current quality, so that $A_t = 1$ for all (k,x) and $h(\tau, x) = H(\tau)$ for all x. Here steady states are balanced growth paths compactly described by

$$(10a) \qquad (2 - \tau)H(\tau)kx = s[f'(k),(1 - \tau)w(k)x,H(\tau)w(k)x]$$

$$(10b) \qquad R = H'(\tau) = f'(k)$$

$$(10c) \qquad x_t = [H(\tau)]^{t-1},$$

where x_1, the beginning-of-time labor quality, has been normalized to unity, and $w(k) = f(k) - kf'(k)$, as before, is the wage rate as a function of capital intensity.

The homotheticity assumption means that the savings function s is linearly homogeneous in the income profile, that is, in its second and third arguments, so that equations (10a)–(10b) reduce to

$$(11a) \qquad \frac{k}{w(k)} = s\left[f'(k), \frac{1 - \tau}{(2 - \tau)H(\tau)}, \frac{1}{2 - \tau}\right]$$

$$(11b) \qquad H'(\tau) = f'(k).$$

On the assumption that consumption when young and old are both strict normal goods and gross substitutes, the savings function s is increasing in its first and second arguments, decreasing in the third. This implies that the right-hand side of equation (11a) is decreasing in both k and τ (since increases in τ decrease first-period and increase second-period income); thus, a sufficient condition for (11a) to describe a downward-sloping frontier in (k,τ) space is that $k/w(k)$ be an increasing function for k, or more precisely, that $(kf'/f)\,(1 - kf''/f') < 1$. This inequality requires the elasticity of substitution between capital and labor services, $\sigma = -(f'/kff'')\,(f - kf')$, to exceed capital's share in output.

Equation (11b), on the other hand, traces an upward-sloping line in (k,τ) space when both sorts of capital exhibit diminishing returns, so that at most one solution to (11a)–(11b) exists. A sufficient condition for existence is that both f and H are continuous functions satisfying Inada conditions in their respective arguments.[7]

7. Note that this implies that, along (11b), $k \rightarrow 0$ as $\tau \rightarrow 0$, while $k \rightarrow \infty$ as $\tau \rightarrow 1$. Along (11a), since $\tau \times 1$ implies negative saving (and, hence $k < 0$), s and k will be zero for some $\bar{\tau} < 1$. Continuity then ensures an interior intersection.

Therefore, equations (11a) and (11b) possess a unique solution, i.e., a balanced growth path supported by labor-augmenting technical progress in the accumulation of human capital.

Intuitively, adding human capital to the basic model of Section III cannot yield multiple equilibria unless it induces increasing returns somewhere. There are two ways in which human capital accumulation can result in multiple balanced growth paths and thus explain development takeoffs. Reaching a given level of knowledge *either* makes it easier to acquire further knowledge (formally, the function h is increasing in x, perhaps with a strongly positive derivative at some critical value) *or* induces a sharp increase in production possibilities (A_t jumps up as in the last section). Both of these possibilities mean that threshold externalities are due to the attainment of *critical mass* in human capital.[8]

The next two sections focus on the existence and stability of stationary solutions to equations (9a)–(9g): we first examine steady states with zero training, and then look at the possibility of multiple locally stable states with positive training.

IV. Underdevelopment Traps

In this section we investigate economies that possess two steady states (one with zero training, another with positive training) when private rates of return on human investment depend *positively* on the existing *average* quality of human resources. Externalities in the technology of human capital accumulation will then imply bifurcations that yield quite different development paths out of small differences in initial conditions. In the no-training steady state, the social return to higher average human capital may be high, but the private return to training will be too low to support positive training and therefore a high-income equilibrium.

To formalize our argument, we consider the training technology,

$$h(\tau^i,x) = 1 + \gamma(x)\tau^i, \tag{12}$$

where, γ, the private yield on human capital, is an increasing function of x that approaches some maximum $\hat{\gamma}$ as $x \longrightarrow \infty$. The dependence of γ on x describes how existing human capital

8. Bowman and Anderson [1963] were the first economists we know of to formalize a threshold-type hypothesis that connects economic growth to human capital. Drawing on data from the 1950s, they suggest that a literacy rate of 30–40 percent is a precondition for rapid growth. See Easterlin [1981] for a refinement of this position.

influences the efficacy of current training; it means that individual incentives follow the state of the economy, being stronger when labor quality is higher than when it is lower.[9]

These incentives endow economies like the one described in equations (9a)–(9g) with a tendency to perpetuate the successes and failures of the development process. To see this more clearly, suppose that the utility function is homothetic; and that technical progress is purely labor augmenting, so that the scale factor A_t in the aggregate production function is identically equal to unity. This allows us to stress induced nonconvexities in the training technology rather than in the scale factor A itself.

Then equations (9f) and (9g) become

$$R_t \geq (w_{t+1}/w_t)\gamma, \quad \text{with equality if } \tau_t > 0 \tag{13a}$$

$$x_{t+1}/x_t = 1 + \gamma(x_t)\tau_t. \tag{13b}$$

These equations are almost identical to Section III: (13b) describes the human capital accumulation technology, and (13a) states that *the yield on physical capital is greater than or equal to the yield on human capital, exactly equal if positive human investments are taking place.*

Any equilibrium sequence satisfying (13a) with inequality, and $\tau_t = 0$ for all t after some finite T, is a no-training equilibrium path. We refer to such sequences as *underdevelopment traps.*[10] That is, we require for all $t \geq T$

$$f'(k_{t+1})w(k_t)/w(k_{t+1}) \geq \gamma \tag{14a}$$

$$2k_{t+1}/w(k_{t+1}) = s[f'(k_{t+1}),w(k_t)/w(k_{t+1}),1]. \tag{14b}$$

To show that such sequences exist, we note that $2k/w(k) = s[f'(k),1,1]$ has a unique, nontrivial stationary solution $\bar{k} > 0$. Furthermore, it is obvious that along a path described by equations (14), x_t, and therefore γ, is constant. Hence, if $\bar{k}$ is stable and satisfies (13a) with strict inequality, then a steady state underdevelopment trap results, i.e., a capital accumulation path leading to a stable, no-training steady state. Local stability follows easily from

9. It is also easy to see from (12) the importance of a positive cross-derivative between τ and x, which clarifies the connection between this paper and work on strategic complementarities that produces multiple equilibria in unemployment models. See Drazen [1987] or Cooper and John [1988].

10. A similar phenomenon was studied by Richard Nelson [1956] who analyzed how, at low levels of per capita income, investment fails to promote growth in the standard of living because it induces offsetting increases in the rate of population growth and in aggregate income.

our assumptions on preferences and on the monotonicity of $k/w(k)$. We summarize these results in

PROPOSITION 1. Suppose that preferences satisfy the assumptions of normality, homotheticity, and gross substitutability, and $k/w(k)$ is an increasing function of k. Then the unique stationary solution $\bar{k}$ to the difference equation (14b) is locally stable and, for $\gamma < \bar{\gamma} \equiv f'(\bar{k})$, there exists a family of underdevelopment-trap equilibria corresponding to zero investment in labor quality. Specifically, there is a continuum of dynamic equilibria $(k_t)_{t=1}^{\infty}$ in the neighborhood of $\bar{k}$ indexed on the initial value k_1, all of which converge monotonically and asymptotically to $\bar{k}$.

Another type of solution to equations (9) and (13) is an *interior* equilibrium with positive investment in training along the whole path, that is, along which $\gamma_t > \bar{\gamma}$ for all t. These equilibria are sequences (τ_t,k_t) that satisfy equation (13b) plus

$$\text{(15a)} \quad \gamma(x_t)w(k_{t+1})/f'(k_{t+1}) = w(k_t)$$

$$\text{(15b)} \quad (2 - \tau_{t+1})k_{t+1} = s[f'(k_{t+1}), \times (1 - \tau_t)w(k_t)/(1 + \gamma(x_t)\tau_t), w(k_{t+1})].$$

One may easily show that these equations admit at least one steady state solution which is locally saddlepath stable.[11] Any sequence (τ_t,k_t) that begins on the saddlepath converges monotonically and asymptotically to (τ^*,k^*), the steady state of (15). We sum up in

PROPOSITION 2. There is a steady state (τ^*,k^*) such that $\tau^* > 0$ and $f'(k^*) = \hat{\gamma}$. This steady state has local saddlepath stability, and corresponds to constant growth of all per capita quantities at the rate $\hat{\gamma}\,\tau^*$.

It is worthwhile to summarize the implications of these two propositions taken together, for they are the essence of this section. *Multiple, locally stable balanced growth paths will exist in this model economy whenever individual yields on human capital rise with the average quality of labor* as suggested by equation (12). Hence, even without a region of strongly increasing returns to scale

11. Defining $k_{t+1} - k^* = \epsilon_{t+1}$ and $\tau_{t+1} - \tau^* = u_{t+1}$, the linearization of (15a) and (15b) around a steady state (k^*,τ^*) may be written as (after some manipulation) $\epsilon_{t+1} = A_1\epsilon_t$, $u_{t+1} = B_1\,\epsilon_t + B_2u_t$, where $A_1 = k^*f'(k^*)/f(k^*)$ and $B_2 = s_yw(1 + \gamma)/k(1 + \gamma\tau)^2$. It is clear that $0 < A_1 < 1$. Homogeneity of $s(\ )$ implies that $s_y(1 - \tau)w/(1 + \gamma\tau) + s_0w = s = (2 - \tau)k$ (where all variables are evaluated at their steady state levels). This, in turn, implies that $s_y(1 - \tau)w/(1 + \gamma\tau) > s$, so that $B_1(1 - \tau) > (2 - \tau)(1 + \gamma)/(1 + \gamma\tau)$. It follows that $B_1 > 1$.

in human capital, the dynamics will bifurcate depending on initial values of the average level of human capital.

The economics of this bifurcation becomes more transparent on comparing the no-training and training cases: in the first case an initial value of γ above $\bar{\gamma}$ would perpetuate itself, while in the second case, a starting value of γ below $\bar{\gamma}$ implies that γ will rise over time toward its upper bound $\hat{\gamma}$. Hence, very small initial differences in γ are magnified if they lead to qualitatively different training decisions.

V. Multiple Interior Equilibria

The previous section demonstrated that nonconvexities in the technology of training are not necessary to generate multiple stable steady states if individual decision problems admit both interior and corner solutions. Here we explore whether nonconvexities can generate multiple *interior* equilibria, and if so, what economic phenomena correspond to nonconvex segments in the training function h.

We demonstrate first that, if different constant sequences of τ are associated with different *rates of growth* of x_t (i.e., if h is at least unit-elastic in x_t), then nonconvexities will yield a trajectory that resembles Rostow's "stages of growth": the economy converges to the steady state associated with the maximal $\hat{\gamma}$ but may remain close to a balanced growth path associated with a lower value of γ for quite some time. To obtain multiple steady states, one needs to modify equation (13b) so that different constant sequences of τ yield either different *levels* of x_t (if h is at least zero-elastic), or different *growth rates* in x (if private rates of return depend on τ rather than x).

To understand the implications of nonconvexities, we use again the expositional device of a step function. We rewrite equations (13b) with γ as a step function; that is, $\gamma(x) = \gamma_1$ for $x < x^*$, $\gamma(x) = \gamma_2 > \gamma_1$ for $x > x^*$. If γ equaled γ_1 for all values of x, then Proposition 2 would imply the existence of a stable steady state with positive training as long as $\gamma_1 > \bar{\gamma}$. Therefore, in the range $x \in (0,x^*)$ where $\gamma = \gamma_1$, the dynamics will be described by the saddlepath that converges to a balanced growth path (τ_1^*, k_1^*). Once x_t exceeds x^*, the economy will leave this quasi-steady state and approach a proper steady state where $\gamma = \gamma_2$. If we had multiple steps (or a logistic with multiple relatively flat sections), then the economy would go through multiple "stages," approaching a particular balanced growth path in each stage. While the economy lies near a given growth path j, labor quality improves at a rate near $\gamma_j\tau_j^*$ until we reach the next threshold value. At that point, yields on human capital increase rapidly, and the economy takes off toward a faster growth path. The process is complete in this simplified environment when labor quality attains the highest possible value and the system settles down on the "ultimate" stage of growth.

Multiple balanced growth paths become true stationary equilibria if γ in equation (12) is a function of τ rather than x. Increasing returns in γ would then yield multiple equilibria, each characterized by a different growth rate. Making γ a function of τ means that the individual return is an increasing function of aggregate *investment* in training, rather than of the aggregate *stock* of human capital. This occurs, for instance, if institutions of learning generate externalities. (Formally, this means that the function $H(\tau)$ in equations (11) is not everywhere concave.)

All these examples show how nonconvexities in the technology of training are indeed crucial for multiple interior equilibria. Are such nonconvexities a simple theoretical curiosity, or do they capture prevalent economic phenomena? And what relation do they have to the training possibilities of individual households? Here we use a variant of an argument made earlier by Weitzman [1982] and more recently by Murphy, Shleifer, and Vishny [1988]. The basic idea is that there may be numerous ways to accumulate human capital, where techniques that have higher skill accumulation per unit time also have higher setup costs. If the relative return to techniques with high setup costs rises with the overall level of knowledge, x, the chosen training technique will change with x, and the training technology will be nonconvex in x.

Specifically, we suppose that there are two time costs involved in training: there is a setup cost τ_1, which one might think of as "preparation" time that must be invested prior to use of a given training technology (such as the time to learn a foreign language in order to study abroad or time to prepare for university); and a variable length of time τ_2 spent in acquiring knowledge via the chosen learning technology. Total time τ is the sum of setup and variable costs. Suppose that there are a number of technologies, and that the return per unit of variable cost actually spent learning (i.e., τ_2) is increasing in τ_1 (high-fixed cost technologies yield higher returns), and as before, in x. In comparing two techniques, an individual will choose the high-fixed cost technique if the higher *relative* return compensates him for longer preparation time. If the relative return increases in x, as seems reasonable, then as x increases the chosen technique will change as well. Our thresholds are values of x_t at which use of the next more efficient technique for training becomes individually optimal. The function $h(\tau,x)$ above will then be the envelope of these techniques. Even if each technique is convex in x, the envelope will not be.[12]

Actual economic environments are a good deal more complicated than what appears in this section because the private returns to human investment depend on a number of factors that distort individual choices away from what appears in equation (14a). In particular, credit rationing, educational subsidies, and various types of taxes will generally destroy the equality of yield between physical and human capital on which we base our account of growth stages. Nonetheless, we may ask how well actual development data conform to the predictions of a model that abstracts from these complications. The next section looks at this question.

VI. A Look at the Evidence

What characteristics of the development process would be observed if the threshold externalities associated with human capital accumulation are important in explaining the differences in growth rates set out in Table I? The simplest answer is that which comes out of a literal interpretation of Figure II and the theoretical apparatus that precedes it. First, consider pairs of economies that are on opposite sides of a given threshold (which implies sharp differences in future growth rates), but still close in terms of income per head (such as A and A' or B and B' in Figure II). Economies to the right of the threshold are investing far more heavily in human capital and accumulating it faster than those to the left of the threshold. Hence, though income would be a poor predictor of future growth rates, sharp differences in the ratio of some human investment measure to income would be correlated with sharp growth differences according to the simple threshold model. Once a particular "stage" has been reached, as in the case of economies such as B' and B'', the economies should converge, at least temporarily, to a given balanced growth path.

Of course, for the model to have sharp predictions, one would need to know the location of such human capital thresholds. Do these differ across economies? In the absence of such information,

12. Formally, this may be represented as follows. For technique j let $x_{t+1} = G^j(\tau_{1j},\tau_{2j},x_t)$, where τ_{1j} is fixed for each j and total time spent is $\tau = \tau_{1j} + \tau_{2j}$. The function $h(\tau,x)$ is given by $\max_j \{G^j(\tau_{1j},\tau - \tau_j,x)$; it is the outer envelope of the $G^j(\cdot)$. Concavity of the $G^j(\cdot)$ in x does not imply that the envelope is convex.

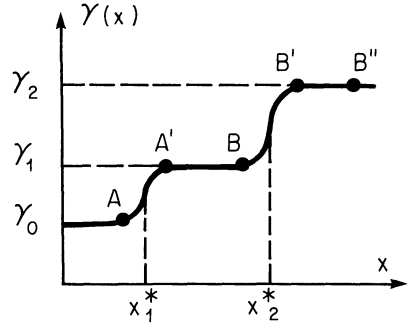

FIGURE II

the working hypothesis that emerges is that *economic growth should be correlated with human investment relative to per capita income,* with high rates of growth being associated with the prior attainment of especially high levels of human investment relative to per capita income. Put another way, economies with an "overqualified" labor force should grow faster than economies with relatively less qualified workers, all other things being equal. Were there no other influences involved, one would expect the relation to be fairly tight. In reality, other factors could mean that the potential growth benefits of a highly qualified labor force could be "wasted." We therefore think of a highly qualified labor force as a *necessary but not a sufficient precondition for growth.* Wasteful economic policies, wars and other political upheavals, natural disasters, and other events may delay progress in an otherwise promising economic environment.

To see whether this prediction receives any support, we look in Table II at the development experience from 1940 to 1980 of 32 countries for which data are available over the entire sample period. The difficult question of course is how to measure human capital. We use literacy among individuals over ten years old as a proxy for the median amount of human investment, realizing that reliable data on some higher level of educational attainment might be preferable if available.[13] We use GNP per capita as our income measure.

Figures III and IV are scatter diagrams of the evidence in Table

13. A better, but less easily accessible, measure of human investment could be computed by combining median years of schooling of the working-age population with some index of health, e.g., nurses or physicians per thousand population. Schultz [1980] has explored how health is related to economic development.

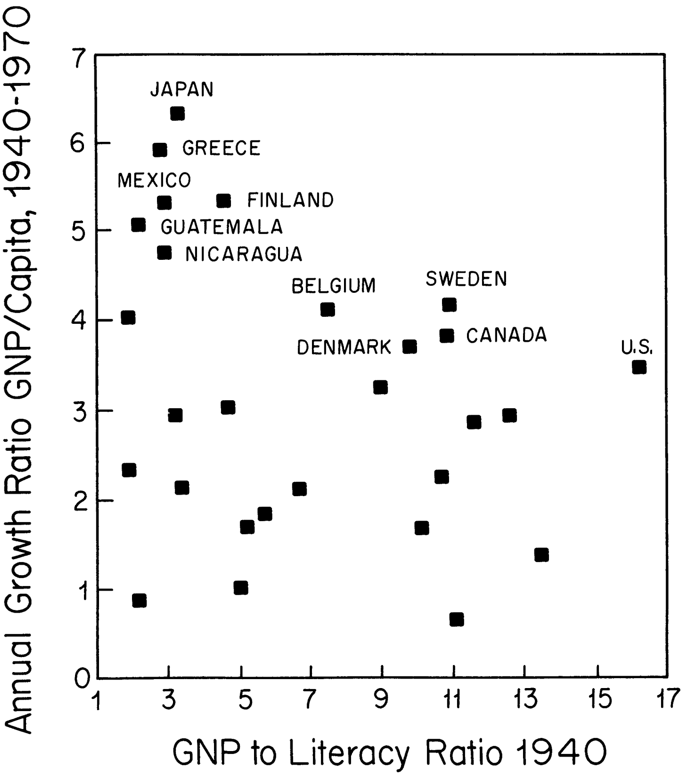

FIGURE III
Growth versus Human Capital 1940–1970

II. Figure III plots compounded annual growth in per capita GNP from 1940 to 1970 against a measure of relative labor quality in 1940, the (per capita) GNP-to-literacy ratio. Figure IV covers the period 1960–1980, using the Summers-Heston [1988] data set for real GDP, plotting compounded annual growth in per capita GDP against the GDP-to-literacy ratio in 1960.

The key observation is that no data points appear in the upper right-hand side of either plot, which appears to be consistent with the weaker form of the threshold hypothesis outlined above. No country was able to grow quickly during either subinterval without the benefit of a highly qualified labor force. And all those that did grow quickly (Japan, Greece, Mexico, Finland, Guatemala, and Nicaragua in the earlier period; Korea, Japan, Greece, Portugal, Spain, and Thailand in the later period) possessed a labor force that

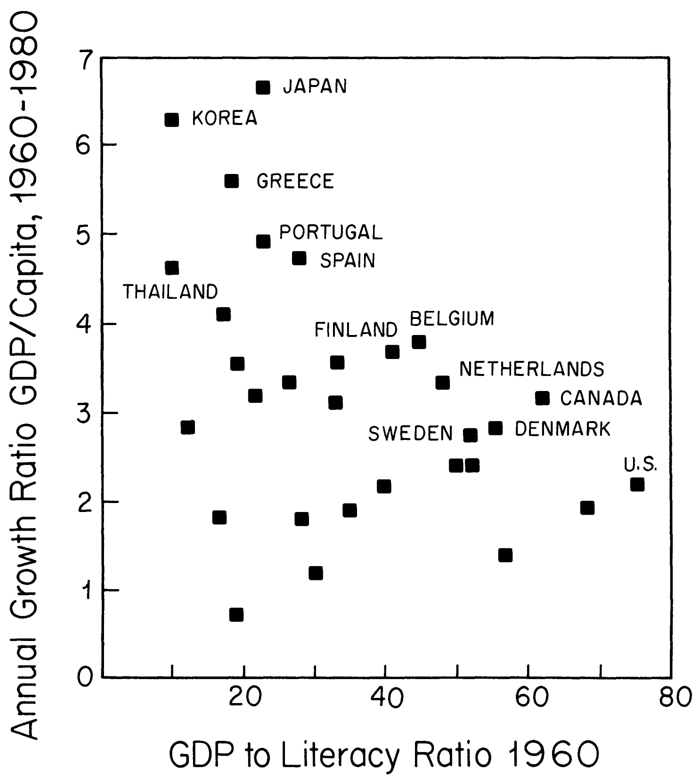

FIGURE IV
Growth versus Human Capital 1960–1980

was exceptionally well qualified given their starting level of per capita income. Note also that the two diagrams, using very different output data, look quite similar.

Each diagram displays a "frontier" of economic performance. On this frontier, or close to it, lie countries whose growth rates are the highest given their literacy-to-per-capita-GNP ratio or, more generally, their development stage. Examples are Japan, Greece, Finland, Belgium, Denmark, Sweden, Canada, and the United States for both subperiods.

A good distance below the frontier lies a mass of countries that have been expanding much more slowly (and, in some cases, contracting) than the qualifications of their working population would seem to warrant. Many of these countries are in Latin America; some are in Asia; few are in Europe. It is not immediately obvious to us what departures from the idealized model of Section IV are responsible for these slower rates of development. Is it imperfections in the working of credit markets, the distortionary effects of government policies, acts of nature, differences in fertility, or some other key feature from which we have abstracted? One part of our agenda for future research is to model how credit market imperfections, endogenous population growth, distinctions of general versus specific human capital, or subsidies to human investment would affect the working and therefore the empirical predictions of the model set out above. However, some preliminary observations about types of countries that lie inside the frontier do suggest themselves.

First, it is not surprising that countries characterized by high fertility (most LDCs) or by outmigration of skilled labor (e.g., India and, to an extent, Ireland) would lie inside the frontier. Second, a number of countries with extremely poor growth performance relative to educational attainment in 1940–1970 show much higher growth rates in 1960–1980 (Egypt, Philippines, Turkey, Thailand), suggesting a long lag between educational attainment and growth takeoff, rather than the absence of an effect. When one removes these two classes, the countries that remain well below the frontier are almost exclusively those in South and Central America. We have no explanation for this characteristic and leave it for future elucidation.

The evidence also seems to agree with the *convergence prediction* of standard neoclassical growth models in one respect: the most advanced countries do appear to converge. All of these countries have been fully literate since 1940 or earlier, with literacy rates typically in the 95–99 percent range. Among them, the income-to-literacy ratio is a very good proxy for per capita income. As Figures III and IV show, the level and growth rate of income per capita appear to be negatively correlated within this group.

We conclude by reporting on some preliminary OLS regressions using the Summers-Heston data for 1960–1980 for a wider set of countries than in Figures III and IV. We first split the sample into low (real per capita GDP below $700 in 1960), medium (real per capita GDP between $700 and $3,500 in 1960) and high-income countries, and removed large oil exporters. We found, not surprisingly, that variation in adult literacy has no explanatory power for variations in growth rates for the high-income countries, reflecting the fact that adult literacy was between 98 and 100 percent in these countries. This left us with 71 low- and middle-income, nonoilexporting countries for which we could find adult literacy data for 1960. We regressed the logarithm of the ratio of per capita GDP in 1980 to per capita GDP in 1960 against literacy and the level of per capita GDP in 1960. (Population growth was originally added as an explanatory variable, but had little explanatory power if literacy is included.) The results were as follows (t-statistics in parentheses):

Low-income countries (31 observations)

$$LRAT6080 = \underset{(0.91)}{0.209} + \underset{(3.40)}{0.0122}LIT60 - \underset{(9.69)}{0.00034}GDP60 \qquad \bar{R}^2 = 0.24$$

Middle-income countries (40 observations)

$$LRAT6080 = \underset{(2.87)}{0.128} + \underset{(3.09)}{0.0025}LIT60 - \underset{(1.46)}{0.0013}GDP60 \qquad \bar{R}^2 = 0.18$$

Whole sample

$$LRAT6080 = \underset{(2.76)}{0.183} + \underset{(5.24)}{0.0103}LIT60 - \underset{(1.65)}{0.00013}GDP60 \qquad \bar{R}^2 = 0.38.$$

The human capital variable is always significant and of the correct sign.

VII. Summing Up

Under relatively mild restrictions on preferences and technology, the standard one-sector representative-agent models of neoclassical economic growth due to Solow [1956] and Diamond [1965] predict that otherwise identical closed economies will eventually converge to the same rate of growth in per capita income, even if they start out with different per capita stocks of physical and human capital. Since this prediction is at variance with much of what is actually observed, we propose an elaboration of the Diamond model so that its predictions more closely correspond to actual observations. Our elaboration is based on threshold externalities in the accumulation of human capital, that is, on the existence of increasing social returns to scale which become particularly pronounced when economic state variables attain critical mass or "threshold" values.

Technological externalities mean that private rates of return on human investment depend positively on the average quality of existing human resources. Keeping other factors invariant, the private yield on education should be greater in developed countries than in less developed ones. We should mention here that empirical estimates of both social and private rates of return to education [Jamison and Lau, 1982; Psacharopoulos, 1985] tend to show that returns are generally lower in developed countries than in developing ones. However, these estimates typically ignore external effects of education, because there is no generally accepted way of measuring educational externalities. (See the survey by Schultz [1988, p. 586].) If yields were measured properly, international differences in yields (or the implied direction of migration for skilled labor) could be used to test our theory.

The threshold property is sufficient to produce multiple, locally stable balanced growth paths as stationary states in the augmented neoclassical model of growth; a particular version produces growth paths that resemble Rostow's stages of growth. Another testable implication of this framework is that, keeping all other things constant, a high ratio of human investment to per capita income is a necessary condition for sustained growth at a rapid rate.

Preliminary comparisons of our model against the development history of 32 countries over the period 1940–1985 are reasonably encouraging: Korea, Japan, Finland, and many other countries that grew rapidly over the sample period started out with a very high level of literacy relative to their income per head.[14] We should add that a relatively highly qualified labor force seems to be a necessary—not a sufficient—condition for rapid growth. Many countries in our sample possess a highly qualified labor force, but have apparently failed to put it to good use.

Refinements in the theoretical structure should allow room for some natural, and empirically relevant, extensions of our framework from which we hope to learn more about the factors that determine the "distance" of a specific economy from the growth possibility frontiers of Figures III and IV. Two of these extensions concern public policy—in particular, potential subsidies to investors in human capital, and credit rationing. Subsidies to externality-generating activities, like education and basic research, will typically lead to Pareto-improvements even if taxes are raised in a distortionary fashion. The "depth" of financial markets is listed by development economists like Gurley and Shaw [1967] as one of the most important factors affecting the rate of economic development.

14. If education is a normal consumption good, then any positive correlation between literacy and the level of income is the property of any expansion path. The demand-driven correlation differs in a key respect from the supply-driven relationship that appears here: in our augmented growth model human investment causes growth in income; it is not caused by a high level of income. In other words, more education precedes an acceleration in income *growth* instead of following a higher *level* of income.

In retrospect, it is not very hard to see why financial "depth" matters if we interpret it as the absence of credit rationing, that is, as a relaxation of borrowing constraints which accompany moral-hazard or adverse-selection problems faced by wage earners in the credit market.[15] Credit-rationed workers will typically attempt to relax tight borrowing constraints by redistributing their labor supply over time; they will supply more labor in their youth, and invest less in the improvement of labor quality, than will unrationed workers of similar ability. As a result of reduced human investment, an economy with credit rationing may experience slower growth in quality-adjusted labor inputs and income per capita than will an otherwise identical economy with perfect credit markets. Here financial deepening will have important consequences for growth rates in a model with human capital such as ours.

A separate issue is the task of assembling an index of labor quality that is better than literacy, especially for developed countries. We expect that literacy is highly correlated with elementary school attendance rates and less correlated with participation at higher levels of education. An improved proxy of average labor quality should combine data on schooling, health, and training or experience. Health could be particularly helpful during the early stages of growth, for example, for countries in eighteenth century Western Europe and twentieth-century Africa. At the other extreme, university education could explain part of the difference in recent economic performance among the most economically advanced nations.

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15. See Hubbard and Judd [1986] for a useful general survey in this area and Bencivenga and Smith [1988] on how adverse selection in the credit market influences long-run growth.

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