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Working Paper **6393**

NBER WORKING PAPER SERIES

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Working Paper 6393
http://www.nber.org/papers/w6393

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
February 1998

We are grateful to numerous seminar participants for helpful comments. Saasha Celestial-One and Yongsung Chang provided excellent research assistance. Any opinions expressed are those of the authors and not those of the National Bureau of Economic Research.

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NBER Working Paper No. 6393
February 1998
JEL Nos. E1, J3, O4

ABSTRACT

Barro (1991) and others find that growth and schooling are highly correlated across countries, with each additional year of 1960 enrollment associated with about .6% per year faster growth in per capita GDP from 1960 to 1990. In a model with finite-lived individuals who choose schooling, schooling can influence growth, but also faster technology-driven growth can induce more schooling by raising the effective rate of return on investment in schooling. We consider a variety of evidence to determine the strength of these channels, with two main findings. First, faster-growing countries have at most modestly flatter cross-sectional experience-earnings profiles, consistent with a minority role for the channel from schooling to growth. Second, we calibrate the model using evidence from the labor literature and employ UNESCO attainment data to construct schooling going back well before 1960. We find the channel from schooling to growth to be too weak to generate even half of Barro's coefficient under a range of plausible parameter values. The reverse channel from expected growth to schooling, in contrast, is capable of explaining the empirical relationship. We conclude that the evidence favors a dominant role for the reverse channel from growth to schooling.

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1. Introduction

Barro (1991), Levine and Renelt (1992), Benhabib and Spiegel (1994), Barro and Sala-i-Martin (1995) and many others find schooling to be positively correlated with the growth rate of per capita GDP across countries. Their results are consistent with "AK" models, such as Rebelo (1991), in which growth in human capital drives growth in per capita GDP.[1] Their results are also consistent with models, such as that of Barro, Mankiw and Sala-i-Martin (1995), in which transitional differences in human capital growth rates explain temporary differences in country growth rates.

In these models infinitely-lived dynasties devote a fraction of their time to human capital investment. The corollary with finite-lived individuals is each generation spending a fraction of its finite lifetime at school. We examine a model with finite-lived individuals in which each generation learns from previous generations. The ability to build on the human capital of one's elders provides the potential for endogenous growth, as stressed by Lucas (1988). If learning exhibits no diminishing returns with respect to the human capital of the elders, then the quality of education can grow over time, generating growth in per capita GDP.[2] Furthermore, policies that affect the level of schooling in a country can affect the country's long run rate of growth. And even if intergenerational learning exhibits diminishing returns, rising school attainment over succeeding generations can contribute to the growth rate.

Our human capital formulation builds on Mincer (1974) and Rosen (1976). Central is the schooling choices of individuals. These choices depend on factors such as the rate of learning in school versus work and the effective market rate of discount. A primary result is that anticipated growth reduces the effective discount rate, increasing the demand for schooling. Schooling involves sacrificing current earnings for a higher profile of future

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[1] "AK" refers to a linear production technology in a broad measure of capital K which incorporates both physical and human capital. Technology A is constant and K grows over time.

[2] Denison (1985), Mulligan and Sala-i-Martin (1995), Klenow and Rodríguez-Clare (1997), and Jones (1997) all find that growth in total factor productivity cannot be entirely attributed to growth in the quantity of schooling. Thus attributing most or all of average growth to schooling requires growth in the quality of schooling.

earnings. Economic growth, even of the skill-neutral variety, increases the earnings gain from schooling.[3] Just as faster growth induces more investment in physical capital, faster growth induces people to stay in school longer. Thus an alternative explanation for the Barro et al. findings is that growth drives schooling, rather than the other way around.[4]

We construct several empirical tests to gauge the strength of the "schooling to growth" and "growth to schooling" channels. First, we show that one percent faster growth in the average quality of schooling attained by the workforce – which should contribute to a one percent faster country growth rate – implies a one percent flatter cross-sectional experience-earnings profile within that country. The intuition is straightforward. Rising school quality within a country means young cohorts of workers have better schooling than do older cohorts. The faster the rate at which schools improve in a country, the less the wage disadvantage of young cohorts relative to more experienced cohorts. To estimate the fraction of growth coming from rising school quality, we obtain estimates of Mincerian (1974) experience-earnings profiles for 52 countries, largely from the work of Psacharopoulos (1994). When we regress the country experience-earnings slopes on country growth rates we find a small, statistically insignificant positive coefficient, suggesting school quality does not grow faster in faster-growing countries. When we make a generous allowance for the possibility that workers with more schooling learn faster on-the-job, we find that growth in school quality might explain a small portion of growth rate differences. In short, country experience-earnings profiles suggest a minority role for rising school quality.[5]

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[3] Foster and Rosenzweig (1996) find evidence for a channel from growth to schooling that involves skill-bias of the technical change. They document that Indian provinces benefitting from the Green Revolution in the 1970s saw increases in returns to and enrollment in schooling.

[4] We stress that, although we formally treat exogenous growth as the alternative to schooling-driven growth, this is only for simplicity. We have in mind growth caused by the development and diffusion of technology, e.g. as in Eaton and Kortum (1996). Of course, schooling might contribute to the development and diffusion of technology in ways not reflected in conventional estimates of human capital. But if technology adoption and development occurs at the level of the worker or firm with no externalities, then conventional estimates of human capital gained from schooling (privately higher wages) will capture the effect of schooling on technology.

[5] Rudd (1996) applies our test to U.S. states and likewise finds at most modestly flatter profiles in states with faster growth in per capita income.

We also explore robustness of Barro-type cross-country growth regressions. We find that growth is better explained by current than past schooling. Related, schooling is more highly correlated with past than with future growth. We also instrument for schooling with factors that are arguably exogenous to a country's growth rate, such as climate. These results reinforce the message of the Barro regression that schooling is correlated with growth.

Lastly, we calibrate versions of the two competing models. We find that the "schooling to growth" channel explains much less than half of the empirical cross-country estimate unless there are no diminishing returns to schooling and we allow TFP (purged of human capital) to be uncorrelated with income per capita. By contrast, expected growth has a large impact on desired schooling. The "growth to schooling" channel is sufficient to generate a coefficient as large as Barro's coefficient even if schooling has no impact on a country's growth rate (and taking into account that a large component of the variations in growth rates are not anticipated).

We conclude that Barro's results mostly reflect the impact of growth on schooling, not the impact of schooling on the growth rate. So our proffered answer to the question posed in the title is "the other way around." Our primary caveat to this conclusion is that schooling might be further influencing growth through externalities to technology creation and adoption.

2. A Model of Schooling and Growth with Finite-Lived Individuals

Consider an open economy facing a constant world real interest rate r. Each individual is finite-lived and chooses a consumption profile and years of schooling to maximize

$$(1) \qquad \int_0^T e^{-\rho t} \frac{c(t)^{1-1/\sigma}}{1-1/\sigma}\, dt$$

subject to

$$(2) \qquad \int_s^T e^{-rt}\, w(t)\, h(t)\, dt \;\geq\; \int_0^T e^{-rt}\, c(t)\, dt + \int_0^s e^{-rt}(\mu-1)\, w(t)\, h(t)\, dt$$

where c = consumption, T = lifespan in years, w = the wage *per unit of human capital*, h = the individual's stock of human capital, s = the individual's years of schooling, and $(\mu - 1) > 0$ is the ratio of school tuition to the opportunity cost of student time.[6] Individuals go to school until age s and work from age s through age T. The economy contains a continuum of such finite-lived individuals, with each cohort having measure one.[7]

Each individual's human capital stock follows

$$(3) \qquad h(t) = \bar{h}^{\phi}\, e^{\eta + f(s) + \gamma(t-s)} \quad \forall\, t > s$$

where $0 \leq \phi \leq 1$. $f'(s) > 0$ and $\gamma > 0$ are the percentage gains in human capital from each year of education and experience, respectively. The term $\bar{h}$ denotes the human capital of a prior generation, i.e. teachers. We specify that each cohort learns from the cohort born N years earlier. Later we will calibrate N using the average age difference between students and workers. In (3) we ignore non-labor inputs because evidence suggests that teacher and student time constitute about 90% of all instructional costs (see Kendrick, 1976, and U.S. Department of Education, 1996).

The first order condition for an individual's optimal choice of schooling is

$$(4) \qquad \mu\, e^{-rs}\, w(s)\, h(s) \;=\; (f'(s) - \gamma) \int_s^T e^{-rt}\, w(t)\, h(t)\, dt\,,$$

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[6] We make instruction costs proportional to the opportunity cost of student time because, in the data, spending per student rises with the level of education (U.S. Department of Education, 1996).

[7] Although we do not incorporate intergenerational altruism, none of the schooling and growth implications that we draw upon depends on this assumption.

which equates the sum of tuition and the opportunity cost of student time for the last year spent in school (the left hand side) to the discounted present value of the resulting increments to future wages (the right hand side). The gap between human capital gained from education and that gained from experience ($f'(s) - \gamma$) enters since staying in school means foregoing experience. A necessary condition for $s > 0$ is that $f'(0) > \gamma$; if human capital does not accumulate more rapidly at school than on the job there is no reason to forego working.

To determine the privately-optimal amount of schooling we need to specify how the wage per unit of human capital evolves. At moment t, firms in this economy operate with the production technology

$$Y(t) = K(t)^{\alpha}\Big(A(t)\,H(t)\Big)^{1-\alpha} \tag{5}$$

where

$$H(t) = \int_{s}^{T} h(a, t)\, da$$

and

$$A(t) = e^{g_A t} A(0)\,. \tag{6}$$

The integration is across working-age cohorts. In the preceding we considered an individual born at moment 0, so that age and time were synonymous. Aggregating the human capital stocks of different cohorts requires us to add distinct time and age arguments. Recall that each cohort is of measure one, and let h(a, t) denote the human capital at moment t of the cohort that is age a. A(t) denotes the level of technology, which grows exogenously at the rate $g_A \geq 0$. With the price of output in the world normalized to one each period, firm first order conditions are

$$\alpha \frac{Y(t)}{K(t)} = r + \delta \tag{7}$$

and

$$(1-\alpha)\frac{Y(t)}{H(t)} = w(t) \tag{8}$$

where δ is the depreciation rate of physical capital. (7) implies that the capital-output ratio is constant over time, consistent with evidence in Maddison (1982). Combining (5), (7), and (8), one can easily show that

$$w(t) \propto A(t), \tag{9}$$

which means the wage per unit of human capital grows at the rate $g_A \geq 0$.

We can now express the privately-optimal quantity of schooling as an implicit function of the model's parameters. Combining $h(t) = h(s)e^{\gamma(t-s)} \; \forall \; t > s$ from (3), $w(t) = w(s)e^{g_A(t-s)}$ from (6) and (9), and first order condition (4), we have

$$s^* = T - \left[\frac{1}{(r-g_A)-\gamma}\right] \mathrm{Ln}\left[\frac{f'(s^*)-\gamma}{f'(s^*)-\gamma-\mu(r-g_A-\gamma)}\right]. \tag{10}$$

A necessary condition for $s^* > 0$ to be optimal is that $f'(s^*) > \gamma$. The human capital gained from the last year of education must exceed the human capital that would have been obtained from experience. The second order condition which ensures that (10) is utility *maximizing* holds if $\mu(r - g_A - \gamma) < (f'(s^*) - \gamma)$.[8] Note that neither the level of teacher human capital ($\bar{h}$) nor its contribution to learning (ϕ) affects the schooling decision, since they affect the marginal cost and benefit of schooling in the same proportion. Similarly, the *level* of technology A (equivalently, the wage rate per unit of human capital) does not affect the optimal amount of schooling. Since the interest rate r and exogenous growth g_A enter the schooling decision through their combination $(r - g_A)$, comparative statics of the schooling decision with respect to g_A mirror those for the real interest rate. Higher g_A growth acts just like a lower market interest rate: by placing more weight on future human capital, it induces more schooling.

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[8] When we calibrate the model below we verify that the first and second order conditions are satisfied for all parameter values considered.

We now consider, in order, two special cases of endogenous, schooling-driven growth and exogenous, technology-driven growth.

Schooling-Driven Growth: $\phi = 1,\ g_A = 0$

If all the parameters in (10) are constant over time the optimal level of schooling is the same across cohorts. With $\phi = 1$ in (3) human capital grows from generation to generation:

$$\frac{h(t)}{\bar{h}} = e^{\eta + f(s) + \gamma(t-s)} \quad \forall\, t \in (s, T] \ \text{ for all cohorts.}$$

Recall that $\bar{h}$ is the human capital, when the individual is born, of the cohort born N years earlier. Thus each individual has, by age N, raised their human capital above $\bar{h}$ by the exponential factor $f(s) + \gamma(N - s) + \eta$. The annual growth rate of the individual's human capital relative to the prior generation is thus

$$g_h = \frac{f(s) + \gamma\,(N-s) + \eta}{N}$$

Because each generation stands on the shoulders of its teachers, human capital grows at rate g_h from cohort to cohort. With a stable age-distribution, the sum of human capital across all working individuals in the economy ($H = \int h$) likewise grows at rate g_h per year. By (5), (7) and (8) output per person also grows at rate g_h.[9] Recall that $f'(s^*) > \gamma$. Therefore the growth rate is rising in the level of s; a higher level of schooling means each generation is taking a bigger step above the human capital of the previous generation. Conditional on years of schooling, the growth rate is falling in the level of N.[10] Lower N, or younger teachers, means these steps are being taken more frequently so growth *per year* is faster.

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[9] We are additionally assuming that the fraction of the population serving as school teachers is constant over time. Note that it does not matter whether some or all of the education sector is measured as part of GDP, as long as the measured fraction is fixed over time.

[10] Actually, $\partial g_h/\partial N$ is positive only if η is not too large and positive. But, when we calibrate the model later, we find that η must be negative in order to match the average growth rate of country GDP per capita.

From (9) and $g_A = 0$ (no technological change) the wage per unit of human capital w(t) is constant. What is the slope of the *cross-sectional* experience-earnings profile in this economy? Earnings are $w \cdot h$. Since w is the same for every worker, differences in earnings across individuals solely reflect differences in their human capital. Consider the cohorts entering and leaving the workforce. The former are age s with no experience and the latter are age T with (T − s) years of experience. But the younger cohort has better schooling. Using subscripts on $\bar{h}$ to denote schooling vintage, we have $\bar{h}_T / \bar{h}_s = e^{-g_h(T-s)}$. The earnings of T year olds relative to s year olds in a cross section is

$$\frac{\bar{h}_T e^{\eta + f(s) + \gamma(T-s)}}{\bar{h}_s e^{\eta + f(s)}} = e^{(\gamma - g_h)\cdot(T-s)} .$$

The slope of the cross-sectional experience-earnings profile is therefore $(\gamma - g_h)$%, reflecting both experience (γ) and rising school quality (at rate g_h). Since the country growth rate equals the rate at which schools are improving in the country, the implication for cross-country data is direct: If countries do not differ in the rate at which human capital accumulates on-the-job (γ), then each percent increase in country growth implies a one percent flatter experience-earnings profile. i.e. in this model, the slope of the experience-earnings profile should be $(\gamma - g_h)$ so that regressing it on g_h should yield a coefficient of -1 so long as γ is uncorrelated with g_h.

The preceding implications for Mincer coefficients on experience hold for a constant s and a constant A over time within each country. The implications change slightly if there are country-specific changes in school attainment s and technology A. Differences in s across cohorts will be controlled for by the schooling term in the Mincer regression for each country, so they should not affect the experience slopes. The level of A, meanwhile, affects the intercept of the experience-earning profile in each country, but not the slope. However, country differences in the growth rate of s and A imply that $g_Y \neq g_h$, so that not all country differences in growth rates stem from differences in growth rates of school quality. In these cases, regressing the slopes on the growth rate of output yields a coefficient of $-$ (expectation of g_h conditional on g_Y), which can be interpreted as (minus) the fraction of variation in country growth rates due to variation in the growth rate of school quality.[11]

Exogenous growth: $\phi < 1,\ g_A > 0$

When $\phi < 1$ the quality of schooling remains unchanged when the quantity of schooling attainment is constant the from generation to generation. Specifically,

$$h(t) = \overline{h}^{\,\phi} e^{\eta + f(s) + \gamma(t-s)} \quad \forall\, t \in (s, T] \text{ for all generations.}$$

where

$$\overline{h} = \exp\left[\frac{\eta + f(s) + \gamma(N-s)}{1-\phi}\right]$$

is constant from generation to generation. Thus teacher human capital and the quality of schools do not grow over time ($g_h = 0$). With a stable age-distribution of the population, the aggregate human capital stock H is also constant over time.

In the previous case schooling-driven growth, the stock of human capital grows and the wage per unit of human capital is constant. Here, with exogenous growth, the stock of human capital per person is constant and the wage rate per unit of human capital grows. By (9) w(t) grows at the rate $g_A > 0$. What do experience-earnings profiles look like under this exogenous growth version of the model? The earnings of T year olds relative to s year olds is

$$\frac{\overline{h}_T e^{\eta + f(s) + \gamma(T-s)}}{\overline{h}_s\, e^{\eta + f(s)}} = e^{\gamma\cdot(T-s)} .$$

The slope of the profile is γ, solely reflecting human capital accumulated on-the-job since school quality is constant over time. The contrast with schooling-driven growth is stark: there

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[11] Specifically, $\text{cov}(\gamma - g_h, g_y)/\text{var}(g_y)$.

is no connection between a country's rate of growth and the steepness of its experience-earnings profile.

How can exogenous, technology-driven growth be reconciled with the positive relationship between country schooling and country growth found by Barro (1991) and others? We see two possibilities. First, reverse causality, or a channel by which faster growth induces more schooling investment. From (10) we can see that the effective rate of discount for investing in schooling is the difference between the interest rate and the growth rate $(r - g_A)$. Faster growth in the wage per unit of human capital raises the absolute wage gain from acquiring human capital relative to the opportunity cost of acquiring it. Thus faster growth might induce more schooling.[12] The upshot is that this exogenous growth model is qualitatively consistent with the Barro fact. In section 3 below we explore whether this "growth to schooling" channel is *quantitatively* strong enough to explain Barro's coefficient.

A second possibility is that the Barro coefficient reflects a *transitional* growth effect rather than a steady-state growth effect of initial enrollment rates. i.e. initial enrollment rates may be correlated with subsequent growth because, when initial enrollment is high, it tends to be high relative to schooling attainment in the working population, foretelling growth in h and Y. As long as $\phi > 0$, school quality (teacher human capital) will also be changing along paths with changing school attainment. In the next section we employ UNESCO data on historical enrollment rates for many countries to estimate the size of the "schooling to *transitional* growth" channel for different values of ϕ.

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[12] Wright (1996) argues that faster exogenous growth is likely to influence the level of redistributive taxation through a similar channel.

3. Evidence on the Relationship Between Schooling and Growth

Barro (1991) finds that 1960 primary and secondary *enrollment rates* are positively correlated with 1960-1985 growth in per capita GDP, conditioning on 1960 per capita GDP. Column 1 of our Table 1 reproduces this finding using updated Summers-Heston (1991) Penn World Tables Mark 5.6 data.[13] Our measure of schooling equals 6 times a country's primary school enrollment rate, plus 6 times its secondary school enrollment rate, plus 5 times its higher education enrollment rate. This corresponds to the steady-state average years of schooling that these enrollment rates imply, with the durations based on World Bank conventions. The estimated coefficient on schooling in Column 1 implies that an increase in enrollment rates tantamount to one more year of schooling attainment is associated with an increase in average growth of .60% per year over 1960-1990.

Barro and Sala-i-Martin (1995) employ data on years of schooling *attainment* in a country's working-age population from Barro and Lee (1993) to test the hypothesis that schooling promotes growth. Column 2 of our Table 1 reproduces their finding that 1960 schooling attainment is positively correlated with subsequent growth, again with an updated dataset (Barro and Lee, 1996). An additional year of schooling is associated with .36% faster growth per year. Finally, Column 3 of Table 1 simultaneously includes years of schooling based on 1960 enrollment rates and the 1960 level of schooling in the working population. Growth remains highly correlated with enrollment rates. Conditional on 1960 enrollment rates, past education has no positive relation to growth.

Of course, the strong positive association between schooling and growth is consistent with schooling causally affecting growth, growth causally affecting schooling, or both growth and schooling being driven by other factors. One reason to question that schooling affects long-term growth rates is that schooling has risen dramatically world-wide in the last 30 years,

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[13] The data are described in Barro and Sala-i-Martin (1995). Our specification differs from Barro's (1991) in that we enter a single schooling variable (rather than primary, secondary, and post-secondary schooling separately) and omit other control variables (such as the number of coups).

yet the world-wide growth rate has declined. For the 93 countries examined in Table 1, schooling attainment implied by enrollment rates increased by one third from 1960 to 1975, while the average growth rate of per capita GDP fell from 2.9% per year over 1960 to 1975 to 1.1% over 1975 to 1990. The drop in growth is actually more pronounced in countries with above-average growth in schooling. The correlation between the change in schooling from 1960 to 1975 and the change in the growth rate from 1960-1975 to 1975-1990 is $-.25$. (This correlation is statistically significant at the .02 level.)

The timing between schooling and growth is arguably more supportive of causality running from expected growth to schooling. In particular, schooling enrollment in 1975 is more correlated with growth from 1960 to 1975 (correlation .51) than it is with growth from 1975 to 1990 (correlation .33).[14] Another way to present this point is to break a country's growth from 1975-1990 into a component predicted by its 1960-1975 growth and an orthogonal *unpredicted* component. The correlation between a country's schooling in 1975 and its predicted 1975-1990 growth is .51. The correlation between schooling and unpredicted growth is only .19. That growth is more correlated with recent schooling decisions than with earlier schooling decisions is sharply reflected in the results in Column 3 of Table 1, showing that growth is much more correlated with initial enrollment rates than with initial attainment.[15]

We now conduct four tests of whether the strong correlation between schooling and growth reflects schooling causing growth or growth causing schooling. First we report evidence on whether faster growing countries display flatter experience-earnings profiles. Second we instrument for cross-country differences in schooling with variables related to schooling yet possibly unaffected by growth. Third we calibrate an empirically plausible version of the schooling-driven growth model and ask if it is capable of delivering the

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[14] This is akin to Carroll and Weil (1994), who test whether savings causes growth or the other way around by seeing which comes first. They find that growth Granger-causes saving, but not the reverse.

[15] Under the "rising schooling causes transitional growth" hypothesis, the coefficient on attainment should (crudely speaking) be the negative of the coefficient on enrollment, since the gap between the two contributes to growth. Therefore, under this hypothesis the coefficient on attainment should be more negative.

quantitative relation between schooling and growth estimated in Table 1. Last we calibrate the model in which growth drives schooling and ask if it is consistent with Table 1.

Experience-earnings profiles for many countries

Schooling-driven growth has the prediction that faster growing countries have more rapidly improving schools. This means that faster-growing countries should exhibit flatter cross-sectional experience-earnings profiles.[16] More precisely, a country is predicted to have an experience-earnings profile with slope $\gamma - g_h$, where γ is the return to experience and g_h is the rate of improvement in school quality. Suppose that country differences in growth rates (g_Y) are uncorrelated with country differences in the return to experience (γ) and that all country differences in growth rates reflect differences in the rate of improvement of schools ($g_Y = g_h$). Then regressing the slope of a country's experience-earnings profile ($\gamma - g_h$) on the country's past growth rate (g_Y) should yield a coefficient of -1. More generally, when rising school quality explains only a fraction of observed growth, the coefficient should be the fraction of country variation in growth explained by the growth rate of school quality.

The canonical Mincer (1974) regression estimates the "returns" to experience and education using a cross-section of individuals (i's)

$$(11) \qquad \mathrm{Ln}(w_i) = \lambda_0 + \lambda_1 s_i + \lambda_2 \, \mathrm{exper}_i + \lambda_3 \, \mathrm{exper}_i^2 + \epsilon_i$$

where w is the wage, s is years of schooling, experience is (age $-$ s $-$ 6), and ϵ reflects measurement error, ability, compensating differentials, and other omitted variables. λ_1 is the Mincerian return to education and ($\lambda_2 + 2 \cdot \lambda_3 \cdot$ experience) is the Mincerian return to experience. We obtained estimates of (11) for 52 countries, largely from the work of

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[16] This is reminiscent of Carroll and Summers (1991), who point out that age-consumption profiles should be flatter in faster growing countries, contrary to what they find when they compare the U.S. and Japan.

Psacharopoulos (1994).[17] Underlying these estimates are about 5,200 persons per country, with a median sample size of 2,469. We concentrate on estimates for males since the degree to which "potential experience" (age $-$ s $-$ 6) deviates from actual experience may differ substantially across countries for women. For our 52 countries we obtained the growth rate of real per capita GDP from Summers and Heston Mark 5.6.

Figure 1 plots Mincerian returns to experience (the average percentage return from 0 to 20 years of experience) against the growth rate over the 20 years preceding the year of the country cross-section.[18] Regressing the slopes on the country growth rates yields a coefficient of .10 (s.e. .15).[19] We reject a null of -1 with a t-statistic of 7.5, strong evidence against a dominant role for rising school quality. More generally, there is no evidence that a faster growth rate affects the wages of the young relative to those of the old. This finding might be hard to reconcile, for example, with a vintage model wherein young workers have skills specific to the latest and best technology.

If the return to experience varies positively with a country's growth rate this will bias the coefficient positively (toward 0) from -1. It is sometimes estimated that workers with more years of schooling exhibit steeper experience-earnings profiles, say because schooling teaches students how to learn. If countries with greater schooling exhibit both more growth

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[17] Psacharopoulos, sometimes with co-authors, conducted studies for 23 of our 52 countries. Through references in Psacharopoulos (1994) we obtained estimates for another 20 countries. In Appendix A we list the 52 countries and their estimated returns to experience.

[18] Slopes are $[\exp(\lambda_0+\lambda_1 s+\lambda_2 20+\lambda_3 20^2+\epsilon)/\exp(\lambda_0+\lambda_1 s+\epsilon)]^{1/20} - 1 = \exp(\lambda_2+20\,\lambda_3) - 1$.

[19] The dependent variable in this regression is $\exp(\widehat{\lambda}_2 + 20\widehat{\lambda}_3)$-1, where $\widehat{\lambda}_2$ and $\widehat{\lambda}_3$ are the estimated Mincerian returns to experience and experience squared. So the error in this regression, under the null, can be interpreted as the deviation between $\exp(\widehat{\lambda}_2 + 20\widehat{\lambda}_3)$-1 and $\exp(\lambda_2 + 20\lambda_3)$-1 for each of the 52 countries. We assume that the measurement error in estimating the relative wage of older workers is unrelated to the growth rate. One reason this might be violated is if the return to schooling is overestimated (perhaps because schooling is positively correlated with ability) and countries with faster income growth exhibit higher growth in schooling. With growth in schooling older workers have less schooling than younger workers; so if the return to schooling is overstated then the return to experience must also be overstated to fit their relative wages. This would create a spurious positive correlation between a country's growth rate and its estimated return to experience. But empirically neither Barro and Sala-i-Martin (1995) nor Benhabib and Spiegel (1994) find a correlation between growth in income and growth in schooling for this sample period.

and more investment and learning on the job, this would create a positive correlation between a country's γ and its growth rate g_Y.

To incorporate this possibility, we let the return to experience $\gamma = \gamma_0 + \gamma_1 s$, where s is schooling in the country. We re-do the regression after netting an estimate of $\gamma_1 s$ from the slope of each country's experience-earnings profile. For γ_1 we use the value .875%. This is consistent with Lillard (1977), who finds that, controlling for IQ, workers with a college degree exhibit about 3.5% faster growth in earnings than average ability workers with a high school degree (6% per year compared to 2.5%). We view this value, .875, as erring on the high side. It is much larger than the value implied by more recent U.S. Current Population Survey data and larger than estimates that have been done for a small number of other countries.[20] Regressing the adjusted slope coefficients on the country growth rates yields a coefficient of $-.04$ (s.e. .26). We continue to reject a null of -1, now with a t-statistic of 3.6. In summary, the pattern of experience-earnings slopes and growth rates of GDP per capita across countries suggests a minority role for rising school quality in explaining country growth differences.

Instrumenting for cross-country differences in schooling

A natural attack on the issue of causality is to instrument for cross-country differences in schooling with variables that influence schooling, but are otherwise exogenous to a country's growth rate. In practice this is difficult. Schooling in our model is strongly related to life expectancy, since longer life expectancy means a longer time over which to reap the benefits of schooling investment (see equations 4 and 10). So a starting point is to instrument for cross-country schooling differences with differences in life expectancy.

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[20] Lillard's findings are based on the NBER-TH data reflecting the earnings from 1943 to 1970 of 4699 men who volunteered to be Air Force pilots during WWII. 1992 CPS data on earnings for full-time working men appear in Ehrenberg and Smith (1997). These show that workers who complete high school exhibit about 1 percent steeper profiles than high school dropouts and workers with some college exhibit .5 percent steeper profiles than workers with a high school degree. But workers with a college degree (or postgraduate studies) do not exhibit steeper profiles than high school graduates.

Table 2 reports the relation between schooling and life expectancy.[21] The first column relates schooling in 1960 (years implied by enrollment rates) to life expectancy in 1960 and 1960 per capita GDP. Life expectancy is for a person who has successfully reached age one. An extra year of life expectancy, given per capita GDP, is associated with .26 more years of schooling. Column of Table 2 repeats the exercise for 1985 with similar results. An extra year of life expectancy is associated with .27 more years of schooling. The final column of Table 2 relates the increase in schooling in each country from 1960 to 1985 to the change in life expectancy over 1960 to 1985. We find .13 extra years of schooling for each increased year of life expectancy, half the size of the coefficients for the 1960 and 1985 cross sections.

In Table 3, Column 2, we instrument for schooling with a country's life expectancy. There remains a very large and statistically significant relation between growth and schooling. Compared to the OLS results, repeated in Column 1, the impact of schooling is actually 40% larger. We are skeptical, however, that life expectancy is exogenous to growth. Factors which cause growth may also affect life expectancy, so that life expectancy too suffers from endogeneity problems.

Ideally we could instrument for schooling with factors that affect life expectancy but are unaffected by growth or any non-schooling factors which affect growth. Studies identify climate as an important determinant of longevity (Hartwig, 1959 and Cohen, 1963).[22] In Column 3 of Table 3 we instrument for schooling and initial GDP using six climate variables.[23] The climate variables are excellent predictors of life expectancy and schooling. They generate an R-squared of .70 for variations in life expectancy and .68 for variations in

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[21] The life expectancy data is from Barro and Lee (1993).

[22] Longevity studies for humans have largely focused on genealogy, physical, and behavioral characteristics. The studies we refer to for climate are mostly for nonhumans.

[23] The six variables are average rainfall, the ratio of rain in the heaviest month to the average, the natural log of the average high temperature in April (October for the Southern hemisphere), the difference between the highest monthly high temperature and the lowest monthly low, the altitude of the most populous city, and the ratio of country border made up of coast. The weather variables are based on the most populous available weather station; altitude is for the most populous city. We additionally instrumented with five dummy variables for whether a country is in a region subject to various diseases, such as malaria and yellow fever. This yields similar results to those in Table 3, with a slightly higher coefficient of .0095 for schooling (standard error .0021).

schooling. Looking at Column 3, there remains a very strong relation between schooling and growth. The impact is actually considerably larger than for the OLS regression.[24]

In sum, instrumenting for schooling, either with life expectancy or climate, does not overturn the Barro cross-country regression. The quantitative relation between schooling and growth is actually magnified. Of course, climate may be correlated with other factors that generate variations in schooling and growth, or that generate variations in growth, with schooling then responding to growth. Since we have more than one instrument, we can check whether their overidentifying restrictions are satisfied. The R-squared from regressing the residuals from Column 3 on the instruments equals .092. Multiplying by the number of observations yields a χ^2 test statistic with a p-value of greater than 10%, so we cannot reject exogeneity of the instruments at conventional significance levels.

Calibrating the "schooling causes long run growth" channel

We now calibrate the version of the model wherein schooling causes endogenous steady-state growth even with constant school attainment to compare its predictions to the Barro regression coefficient. With $\phi = 1$, the endogenous growth rate g_h in country j is

$$g_j = \frac{f(s_j) + \gamma(N - s_j) + \eta_j}{N} . \tag{12}$$

According to this version of the model $\gamma = g_h +$ (Mincerian return to education), where g_h equals observed growth. The average 1960-1990 growth rate of the Summers-Heston countries is 2.0%, and the average Mincerian return to experience estimated across our 52 countries is 3.8%, so we set $\gamma = .058$. We calibrate N, the age gap between students and teachers, as follows. In 1960 the average life expectancy in Summers-Heston countries was

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[24] Instrumenting with climate reduces the sample of countries from 93 down to 73. But the OLS regression for these 73 countries generates results similar to those reported for the 93 country sample in Column 1.

60.4. If all but six years are spent in school or at work, the average age gap between student and worker will be $(60.4 - 6)/2 = 27.2$ years.

For f(s) we posit

$$f(s) = \frac{\theta}{1-\psi} s^{1-\psi}. \tag{13}$$

We entertain $\psi > 0$, or diminishing returns to schooling, because optimal schooling investment is highly sensitive to parameter values when $\psi = 0$. Psacharopoulos (1994) reports estimates of Mincerian returns to schooling for 56 countries. We use his sample, as opposed to our 52-country sample, because we do not require that returns to experience also be reported, and because we need the mean years of schooling in the micro sample for each country, which Psacharopoulos reports. To estimate ψ in (13), we exploit the fact that estimated Mincerian returns to education, λ_1 in (11), equal $f'(s) = \theta/s^{\psi}$. We regress country *estimates* of Mincerian returns on country schooling levels for Psacharopoulos' 56-country sample:

$$\mathrm{Ln}(\widehat{\lambda}_1) = \mathrm{Ln}(\theta) - \psi\,\mathrm{Ln}(s) + [\mathrm{Ln}(\widehat{\lambda}_1) - \mathrm{Ln}(\lambda_1)].$$

We find $\widehat{\psi} = .58$ with a standard error of .15. That $\widehat{\psi} > 0$ means countries with higher schooling levels display lower Mincerian returns to education. For example, as years of enrollment in 1960 go from 2 to 6 to 10 (e.g. Central African Republic to Fiji to Iceland), the implied Mincerian return on schooling falls from 21.6% to 11.4% to 8.5%. These sharply diminishing returns depart from the custom in the labor literature of positing no diminishing returns.[25] For this reason we consider two lower values of the curvature parameter ψ, or three in all: .58 (our point estimate), .28 (our point estimate minus two standard errors), and 0 (no diminishing returns).

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[25] When estimated on micro data within countries, the typical finding is linear returns to education, or $\psi = 0$ (see Card, 1994). As Card argues, ability bias may drive these estimates toward linearity. The cross-country estimates are arguably less subject to ability bias and more likely to reflect differences in education subsidies and life expectancy.

For each value of ψ we set the value of parameter θ so that the mean of θ/s^{ψ} equals the mean Mincerian return across Psacharopoulos' 56 countries, which is .099. For $\psi = .58$, $\theta = .32$ achieves this objective; for $\psi = .28$, $\theta = .18$ does so; for $\psi = 0$ the required value of θ is, of course, .099. These estimated Mincerian returns to education may overstate θ. First, estimates of (11) based on cross-sections of individuals are biased upward if high-ability individuals (those with high ϵ) obtain more education. Second, Mincer's specification imposes a constant return to education. If $\psi > 0$ then the return to schooling is convex to the origin, so by Jensen's inequality linear estimates overstate θ. Overstating θ would mean overstating the strength of the "schooling to growth" channel.

Using these three sets of calibrated parameter values, we insert actual schooling levels in 1960 (implied by enrollment rates) into (12) and generate predicted growth rates for each country. We then regress these predicted growth rates on the actual schooling levels to see how the coefficient compares to that in the data.[26] The results are shown in Table 4. One more year of schooling produces at most .24% faster growth, compared to the empirical finding that one more year of schooling is associated with .60% faster growth (Table 1). As Table 4 shows, the channel is even weaker for lower values of ψ. We conclude that the "schooling to growth" channel is too weak to explain most of the correlation observed between country growth rates and country schooling levels. This conclusion is reinforced if the estimates of θ are upward biased for the reasons discussed above.[27]

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[26] The residual in this regression is the country-specific school quality term (η), which according to the model does not affect schooling levels and hence does not introduce simultaneity bias. Of course, we must ask what is driving country variation in enrollment. For the sake of the exercise suppose it is variation in tuition and life expectancy across countries that is orthogonal to variation in η.

[27] The channel from schooling to growth is stronger if teachers are younger than the average worker, but we know of no evidence suggesting that this is so. The channel is weaker if, as we suspect, variation in the schooling of teachers across countries is less extreme than the variation in schooling for the entire populations.

Calibrating the "rising schooling causes transitional growth" channel

As discussed earlier, the schooling coefficient might reflect the impact of rising school attainment on *transitional* growth. We address this possibility by constructing measures of each country's human capital stock for 1960 and 1990 based on the country's history of enrollment rates. We describe this briefly here (and more extensively in Appendix B).

Using country Census data on schooling attainment of age groups 25 to 54 or older in years as far back as 1946 and as recently as 1977 (see UNESCO, 1977 and 1983), we infer the attainment of 25 year olds for close to 35 years before the earliest survey. For the countries with the relevant data, we estimate the persistence of 25 year olds' attainment from 1960-1990 and 1930-1960, respectively. We find that the natural log of attainment is a little less persistent than a random walk with drift from 1960-1990, and very close to a random walk with drift from 1930-1960. Based on these estimated stochastic processes, for a panel of 87 countries we "fill in" estimates of the attainment of 25 year olds for the years going back before attainment data is available in each country. [We also report results for a 56 country sample for which attainment data reach back at least to 1940.] We then construct human capital stocks for individuals of each age between 25 and 59, using (3) and incorporating schooling, experience, and teacher human capital specific to each age. Finally, we calculate aggregate human capital stocks for each of the 87 countries in 1960 and 1990 by weighting each age's human capital stock by the proportion of that age group in the total population of the country in that year (using population data from United Nations, 1994).

For these calculations we first use the parameter values $\theta = .32$ and $\psi = .58$ to describe the returns to schooling. Returns to experience and experience-squared are chosen so that experience-earnings profiles mimic the average profile of our 52-country sample of Mincer estimates. Pinning down ϕ, the elasticity of human capital with respect to teacher human capital, is more difficult. We consider three values: 0, .5, and .690.[28] We view $\phi = .69$ as an upper bound because higher values drive the 1990 correlation between Ln(A) and Ln(Y per capita) below zero;[29] i.e. at $\phi = .69$ the correlation between the Solow residual and GDP per capita is zero, with higher values of ϕ producing negative correlations. We view it as implausible that poorer countries have higher levels of TFP than richer countries.

Using these estimates of human capital stocks for 1960 and 1990, we can estimate the extent to which the Barro schooling coefficient reflects the correlation between initial schooling and subsequent growth in human capital, as opposed to the correlation between initial schooling and subsequent TFP growth. Specifically, using (5) and (7) it is straightforward to show that

$$g_y = g_h + g_A \tag{14}$$

where y is GDP per capita, h is human capital per capita, and A is TFP. The elasticity of y with respect to A and with respect to h are each 2/3 in production function (5), but the open capital market assumption implies that "where A and H go, K follows." Hence the breakdown in (14) incorporates the induced accumulation of physical capital that comes with higher H and with higher A.

Using (14) and the linearity of OLS, we can additively decompose the coefficients from the Barro regression into the coefficients from regressing the growth in human capital and the growth in TFP, respectively, on Ln(GDP per capita) in 1960 and years of enrollment in 1960. Table 5 shows the results using our estimates of the growth rate of human capital from 1960-1990 for 87 countries. [For comparison purposes, the bottom of the table shows that the Barro schooling coefficient is .58% for this sample of 87 countries, not far from the .60% for

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[28] Note that, if there are constant returns to producing human capital, then Kendrick's (1976) estimate that roughly one-half of human capital investment consists of teacher time suggests setting $\phi = .5$.

[29] Ln(A) = Ln(TFP) = Ln(Y per capita) – (1/3)Ln(K per capita) – (2/3)Ln(H per capita). Y is GDP. K is physical capital, estimated using the Penn World Tables investment rates (starting with 1960 K's estimated using the methodology in Klenow and Rodríguez-Clare, 1997). H is our human capital series.

the 93 country sample.] Column 1 shows that, with $\phi = 0$ so that only student time feeds into human capital, the coefficient on schooling is actually negative, equaling $-.074\%$. Hence one cannot argue that 1960 enrollment is highly correlated with subsequent GDP growth through growth in the *quantity* of school attainment and experience. Column 2, with $\phi = .5$, displays a schooling coefficient that is still negative, but essentially zero. When we consider our upper bound value of $\phi = .69$, the schooling coefficient becomes positive at .061% (standard error .025%), but nevertheless falls short of the Barro coefficient by almost an order of magnitude. As the bottom of Table 5 indicates, the coefficient is even lower if we confine the regression to those 56 countries for which we have attainment data back to 1940 or earlier. Hence, even incorporating estimates of rising school quality (teachers equipped with more human capital), the correlation of 1960 enrollment with subsequent growth in human capital accounts for only 10% of the Barro coefficient.

Related, the bottom panel of Table 5 presents the ratio $\mathrm{cov}(g_h, g_y)/\mathrm{var}(g_y)$ for each value of ϕ. This ratio can be interpreted as the conditional increase in growth in human capital from knowing that a country exhibited one percent faster growth in per capita income from 1960 to 1990. Consistent with the upper panel results, we see that growth in human capital is not an important source of the cross-country growth differences in per income. Even for the upper value $\phi = .69$, growth in human capital contributes only about 9% of the faster growth.

As discussed above, this benchmark case with $\psi = .58$ reflects substantial curvature in the returns to schooling. For robustness, we look at two cases with less curvature, the case of $\psi = .28$ and the case of no curvature, or $\psi = 0$. For each ψ we report results for three values of ϕ: 0, .5, and the value for ϕ that drives the correlation between a country's per capita income and its TFP in 1990 to zero.

Results for $\psi = .28$ are presented in Table 6. When $\phi = 0$ there is no impact of 1960 enrollment rates on human capital growth, g_h, from 1960 to 1990. Unlike in Table 5, for $\phi = .5$ there is now a significant positive effect of 1960 schooling on g_h, equaling .091% (standard error .019%). This effect remains less than one-sixth the size of the Barro coefficient. Since $\psi = .28$ as opposed to .58, a larger value for ϕ can be considered without driving the correlation between per capita income and TFP negative. For the upper value of $\phi = .84$, there is a substantial impact of 1960 schooling on g_h, equaling .237% (standard error .016%). This represents 40% of the magnitude of the Barro coefficient.

Finally, the results for no curvature ($\psi = 0$) are given in Table 7. For $\phi = 0$ and .5 the respective estimates of the impact of schooling on g_h equal .066% (standard error .015%) and .133% (standard error .014%). Even the latter value remains far below the Barro coefficient. Furthermore, country differences in g_h contribute less than one-seventh of the country differences in income growth. It is now possible, however, to take ϕ up to as high as .98 without creating a negative correlation between country income and country TFP. For this uppermost value of $\phi = .98$, the estimated impact of schooling on g_h is substantial, equaling .340% (standard error .015%). This represents 60% of the magnitude of the coefficient on schooling in the cross-country income growth equation. Nevertheless, differences in g_h contribute less than one-third of differences in income growth across countries.

Our conclusion is that is difficult to account for very much of the observed relation between schooling and income growth purely from growth in human capital, even transitory growth in human capital. The exception is if there are no diminishing returns to the investment in schooling and we take the power on the previous generation's human capital, parameter ϕ, to be as large as possible. Then we can account for a majority of the schooling-growth relation with human capital growth. But the assumption of no diminishing returns is strongly contradicted by the cross-country evidence on schooling returns in Psacharopoulos (1994), and the extreme values for ϕ leave no role for technology and related factors in explaining the dramatic cross-country differences observed in income.

Calibrating the "growth causes schooling" channel

Our model provides a channel by which higher expected TFP growth could induce more schooling. We now calibrate the version of the model with exogenous TFP growth to see if this channel is up to the quantitative task of matching the Barro coefficient. We use the same methods as above for Table 4, with two minor modifications dictated by the move from endogenous to exogenous growth. First, instead of $\{\phi = 1, g_A = 0\}$ we have $\{\phi < 1, g_A > 0\}$ for each country. Variation in country g_A affects predicted schooling choices in equation (10). The second modification, which follows from the first, is that $\gamma =$ Mincerian return to experience $= 3.8\%$, not 5.8%. The three sets of calibrated values for ψ, θ, and r are (.58, .32, 8.3%), (.28, .18, 7.8%), and (0, .099, 6.4%), respectively.[30]

According to our model, schooling enrollment decisions respond to expected growth and expected lifespan. To generate predicted schooling levels for each country, we insert into (10) a forecast of 1960-1990 growth for g_A and actual 1960 life expectancies for T.[31] Our forecast of growth is based on 1960 per capita GDP, the years of schooling implied by 1960 enrollment rates, and 1960 life expectancy. For the first two sets of calibrated values, associated with $\psi = .58$ and $\psi = .28$, the variances of predicted schooling levels are 38% and 98% of the variance of actual schooling in 1960. That these numbers are less than 100% is reassuring since presumably not all variation in schooling levels is due to variation in expected growth and life expectancy. The same cannot be said for the third set of calibrated values, associated with $\psi = 0$. Without curvature in the returns to schooling, the model implies extreme sensitivity of schooling decisions to life expectancy and expected growth. Thus for the remainder we only consider the two cases with $\psi > 0$.

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[30] The real interest rate r is chosen to ensure that the mean level of schooling predicted by (10) (using actual 1960 life expectancies) matches the mean level of schooling implied by 1960 enrollment rates.

[31] For this exercise we set $(\mu - 1) = 1$, so that tuition is the same size as the opportunity cost of student time. We base this on Kendrick's (1976) evidence that instruction costs and the opportunity cost of student time are roughly equal in the U.S.. We also distinguish between working years of life versus life-expectancy. Based on observed employment/population ratios in the Summers-Heston sample, we estimate that expected working years increase by .6 years for each increased year of life expectancy.

We regress actual 1960-1990 growth rates on these predicted schooling levels, with the results shown in Column 1 of Table 8.[32] The coefficients are scaled down by the ratio of the variance of actual to predicted schooling. We estimate coefficients of .25% when $\psi = .58$ and .48% when $\psi = .28$. These figures exceed the biggest coefficients for the "schooling to growth" channel in Tables 5 and 6, .06% for $\psi = .58$ and .24% for $\psi = .28$. Yet the Column 1 figures in Table 8 fall short of the empirical coefficient of .60% (Table 1).

Of course, individuals may have more information for predicting growth than we are using to construct forecasts. (The $\bar{R}^2$ from the forecasting regression is .40.) Suppose alternatively that 50% of country variation in growth over 1960-1990 was foreseen in advance. E.g., if Hong Kong averaged 6% growth compared to 2% for the world as a whole over 1960-1990, suppose expected growth in Hong Kong in 1960 was 4%. We insert these growth forecasts and actual 1960 life expectancies into (10) to generate predicted schooling levels for each country. The variances of predicted 1960 schooling are again lower than that of actual 1960 schooling (24% for $\psi = .58$ and 90% for $\psi = .28$). Column 2 of Table 8 shows the scaled coefficients from regressions of actual 1960-1990 growth rates on these predicted schooling levels. The estimates are .31% and .61%, respectively. Given that the empirical estimate is .60% (Table 1), the .61% entry indicates that the "growth to schooling" channel is capable of explaining the empirical relationship between schooling and growth in the absence of any effect of schooling on the long-run growth rate.

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[32] The error term in this regression can be interpreted as classical measurement error in country growth rates.

4. Conclusion

Barro (1991) and others find a strong positive correlation between initial schooling enrollment and the subsequent growth rate of per capita GDP across countries. We consider a variety of evidence to try to determine whether this relationship owes more to causality running from schooling to growth or the other way around. Our tests are motivated by a model of schooling and growth with finite-lived individuals.

First, if a higher level of schooling causes faster growth through rising school quality, then faster-growing countries should have flatter cross-sectional experience-earnings profiles. We find no such pattern across 52 countries. Second, we show that the schooling–growth correlation is robust to instrumenting for schooling with country differences in life expectancy or climate. The validity of these instruments is an open question. Last, we calibrate two models, one where schooling drives growth and one where growth drives schooling, using evidence from the labor literature and historical attainment data from UNESCO (1977, 1983). We find the channel by which schooling might cause growth to be too weak to explain even half of Barro's coefficient. This remains true even when we take into consideration the transitional growth effects of rising school attainment in the data. The channel from expected growth to schooling, meanwhile, is capable of generating the Barro coefficient (even assuming much of realized growth is unexpected). Our conclusion is that the evidence favors a dominant role for the channel from growth to schooling.

Figure 1

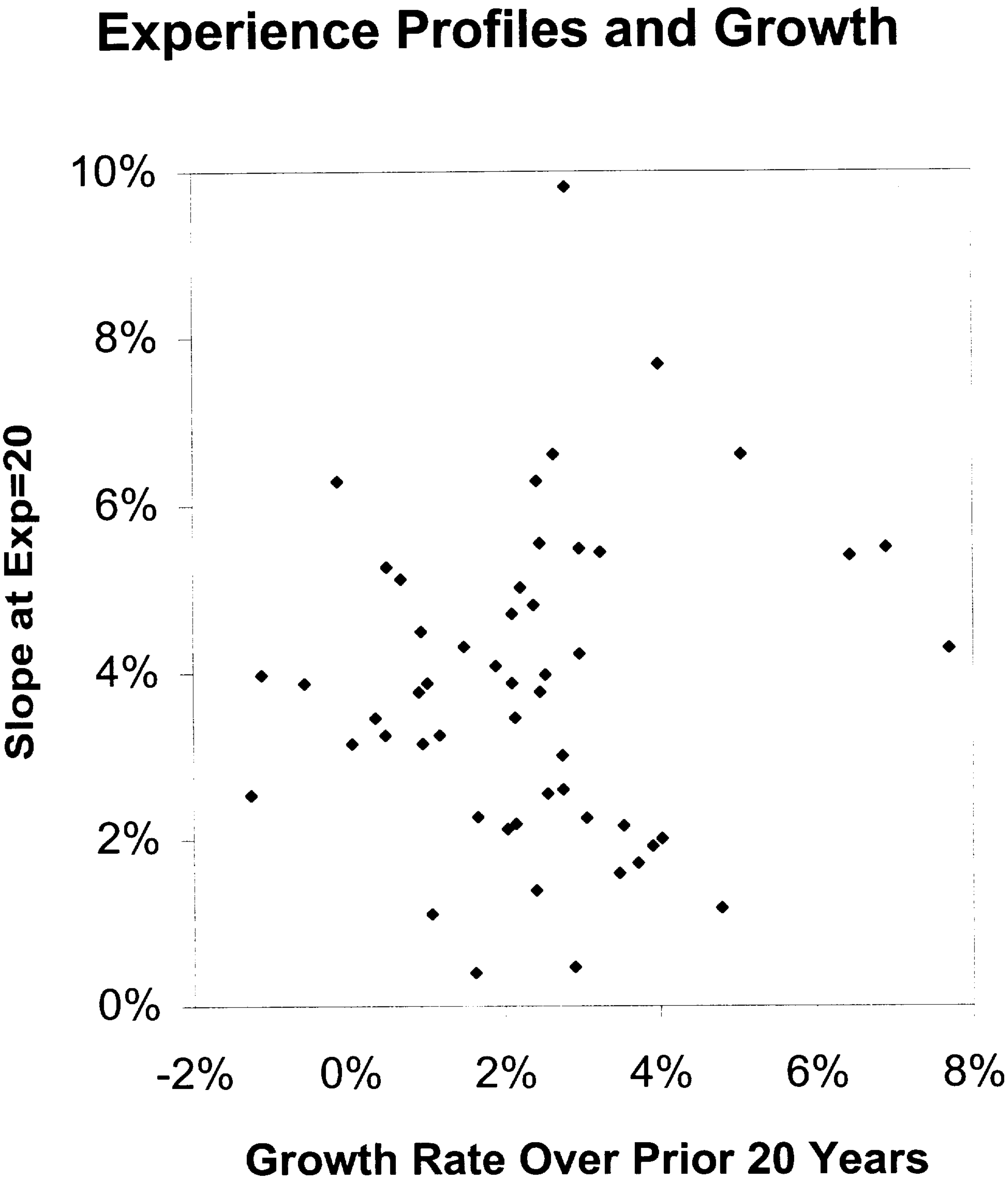
Experience Profiles and Growth
10%
8%
6%
4%
2%
0%
Slope at Exp=20
-2%
0%
2%
4%
6%
8%
Growth Rate Over Prior 20 Years

Table 1

Growth Regressed on Rates and Years of Schooling[*]

The Dependent Variable is the average annual growth rate of GDP from 1960 to 1990.

	(1)	(2)	(3)
Ln(GDP 1960)[†]	– 1.215 % (.279)	– .597 % (.348)	– 1.160 % (.322)
Schooling 1960 (Enrollments rates)	.598 % (.086)		.628 % (.123)
Average Years of Schooling, 1960		.364 % (.116)	– .058 % (.131)
$\bar{R}^2$	.36	.10	.32
Number of Countries	93	81	81

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[*] The data is from Summers-Heston (Penn World Tables, Mark 5.6) and from Barro and Lee (1996). Standard errors are in parentheses.

[†] GDP is short for *per capita* GDP.

Table 2

Schooling Investment

	DEPENDENT VARIABLE		
	(1) Schooling 1960	(2) Schooling 1985	(3) Δ Schooling 1960 – 1985
Ln(GDP 1960)	.297 (.241)		
Life Expectancy 1960	.256 (.021)		
Ln(GDP 1985)		.903 (.254)	
Life Expectancy 1985		.266 (.032)	
Δ Ln(GDP), 1960 – 1985			.972 (.269)
Δ Life Expectancy, 1960 – 1985			.126 (.034)
$\bar{R}^2$	.83	.86	.20
Number of Countries	102	106	92

Table 3

Cross-Country Regressions of Growth on Schooling

The Dependent Variable is the average annual growth rate from 1960 to 1990.

	(1)	(2)	(3)
Ln(GDP 1960)†	– 1.215 % (.279)	– 1.877 % (.375)	– 2.124 % (.795)
Schooling 1960	.598 % (.086)	.844 % (.125)	.928 % (.238)
$\bar{R}^2$	.36	.30	.17
Number of Countries	93	91	73
Instruments	None	Ln(GDP 1960), Life Expectancy	6 Climate Var's

Table 4

Calibrated "Schooling → Growth" Channel

The Dependent Variable is the growth rate predicted from (12) and 1960 Schooling.

The Independent Variable is 1960 Schooling.

Curvature	Coefficient
$\psi = .58$	.240 %
$\psi = .28$	.189 %
$\psi = .00$	.151 %
Number of Countries	93

Table 5

Growth in Human Capital Regressed on Schooling
($\psi = .58$)

The Dependent Variable is the average annual growth rate of human capital from 1960 to 1990.*

	(1) $\phi = 0$	(2) $\phi = .5$	(3)† $\phi = .690$
Ln(GDP 1960)	− .057 % (.083)	− .102 % (.087)	− .101 % (.084)
Schooling 1960 (Enrollments rates)	− .074 % (.025)	− .007 % (.026)	.061 % (.025)
$\bar{R}^2$	.28	.04	.06
Number of Countries	87	87	87
$\frac{\text{cov}(g_h, g_y)}{\text{var}(g_y)}$	− .032 (.029)	.030 (.026)	.088 (.024)
$\frac{\text{cov}(TFP_{90}, \text{Ln}(Y_{90}))}{\text{var}(\text{Ln } Y_{90})}$	.377 (.021)	.184 (.031)	− .0002 (.042)

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[*] For these 87 countries, the basic regression for growth in per capita income is:

$$g_y = \underset{(.29)}{-1.21\,\text{Ln}(Y_{60})} + \underset{(.088)}{.584\,S_{60}} \qquad \bar{R}^2 = .35\,.$$

[†] If we repeat Column 3, but only for those 56 countries with attainment back to 1940 we get:

$$g_y = \underset{(.105)}{-.091\,\text{Ln}(Y_{60})} + \underset{(.033)}{.019\,S_{60}} \qquad \bar{R}^2 = -.01\,.$$

Table 6

Growth in Human Capital Regressed on Schooling (ψ = .28)

The Dependent Variable is the average annual growth rate of human capital from 1960 to 1990.

	(1) $\phi = 0$	(2) $\phi = .5$	(3) $\phi = .840$
Ln(GDP 1960)	– .057 % (.064)	– .068 % (.062)	– .0004 % (.051)
Schooling 1960 (Enrollments rates)	.017 % (.019)	.091 % (.019)	.237 % (.016)
$\bar{R}^2$	– .01	.34	.88
Number of Countries	87	87	87

$\frac{\text{cov}(g_h, g_y)}{\text{var}(g_y)}$	.036 (.019)	.102 (.020)	.226 (.038)
$\frac{\text{cov}(TFP_{90}, \text{Ln}(Y_{90}))}{\text{var}(\text{Ln } Y_{90})}$	.394 (.019)	.260 (.026)	– .0004 (.042)

Table 7

Growth in Human Capital Regressed on Schooling
($\psi = 0$)

The Dependent Variable is the average annual growth rate of human capital from 1960 to 1990.

	(1) $\phi = 0$	(2) $\phi = .5$	(3) $\phi = .980$
Ln(GDP 1960)	− .043 % (.051)	− .032 % (.047)	.134 % (.050)
Schooling 1960 (Enrollments rates)	.066 % (.015)	.133 % (.014)	.340 % (.015)
$\bar{R}^2$	.29	.72	.95
Number of Countries	87	87	87
$\frac{\text{cov}(g_h, g_y)}{\text{var}(g_y)}$	.072 (.016)	.133 (.022)	.310 (.060)
$\frac{\text{cov}(TFP_{90}, \text{Ln}(Y_{90}))}{\text{var}(\text{Ln } Y_{90})}$	.407 (.019)	.307 (.023)	− .0006 (.045)

Table 8

Calibrated "Growth → Schooling" Channel

Dependent Variable: 1960-90 growth rate.

Right-hand-side Variables: Ln(GDP 1960) and 1960 schooling predicted by (10).

	(1) Expected Growth from Forecast	(2) Expected Growth = "50%" of Actual
$\psi = .58$	.251 %	.314 %
$\psi = .28$	.479 %	.608 %
Number of Countries	93	93

Appendix A: 52-country sample of Mincer regression coefficients

COUNTRY	EXP	EXP^2	S	YEAR	#OBS	REFERENCE
Argentina	.052	-.00070	.107	1989	2965	Psacharopoulos (1994)
Australia	.064	-.00090	.064	1982	8227	Psacharopoulos (1994)
Austria	.039	-.00067	.039	1987	229	Psacharopoulos (1994)
Bolivia	.046	-.00060	.073	1989	3823	Psacharopoulos (1994)
Botswana	.070	-.00087	.126	1979	492	Psacharopoulos (1994)
Brazil	.073	-.00100	.154	1989	69773	Psacharopoulos (1994)
Britain	.091	-.00150	.097	1972	6873	Psacharopoulos (1994)
Canada	.025	-.00046	.042	1981	4642	Psacharopoulos (1994)
Chile	.048	-.00050	.121	1989	26823	Psacharopoulos (1994)
China	.019	-.00000	.045	1985	145	Psacharopoulos (1994)
Colombia	.059	-.00060	.145	1989	16272	Psacharopoulos (1994)
Costa Rica	.042	-.00050	.105	1989	6400	Psacharopoulos (1994)
Cote d'Ivoire	.053	-.00008	.207	1985	1600	Psacharopoulos (1994)
Cyprus	.092	-.00140	.098	1984	3178	Psacharopoulos (1994)
Denmark	.033	-.00057	.047	1990	5289	Rosholm & Smith (1996)
Dominican Republic	.055	-.00080	.078	1989	436	Psacharopoulos (1994)
Ecuador	.054	-.00080	.098	1987	5604	Psacharopoulos (1994)
El Salvador	.041	-.00050	.096	1990	4094	Psacharopoulos (1994)
Greece	.039	-.00088	.027	1985	124	Psacharopoulos (1994)
Guatemala	.044	-.00060	.142	1989	8476	Psacharopoulos (1994)
Honduras	.058	-.00070	.172	1989	6575	Psacharopoulos (1994)
Hungary	.034	-.00059	.039	1987	775	Psacharopoulos (1994)
India	.041	-.00050	.062	1981	507	Psacharopoulos (1994)
Indonesia	.094	-.00100	.170	1981	1564	Psacharopoulos (1994)
Ireland	.061	-.00100	.079	1987	531	Callan & Reilly (1993)
Israel	.029	-.00046	.057	1979	1132	Psacharopoulos (1994)
Italy	.010	-.00027	.028	1987	197	Psacharopoulos (1994)
Jamaica	.083	-.00110	.280	1989	1172	Psacharopoulos (1994)
Kenya	.044	-.00200	.085	1980	1600	Armitage & Sabot (1987)
South Korea	.082	-.00140	.106	1986	4800	Psacharopoulos (1994)
Malaysia	.013	-.00004	.094	1979	605	Psacharopoulos (1994)
Mexico	.084	-.00100	.141	1984	3425	Psacharopoulos (1994)
Morocco	.068	-.00070	.095	1970	2422	Psacharopoulos (1994)
Netherlands	.035	-.00049	.066	1983	1888	Psacharopoulos (1994)
Nicaragua	.050	-.00080	.097	1978	962	Psacharopoulos (1994)
Pakistan	.106	-.00060	.097	1979	1568	Psacharopoulos (1994)
Panama	.066	-.00080	.126	1989	5436	Psacharopoulos (1994)
Paraguay	.058	-.00090	.103	1989	1084	Psacharopoulos (1994)
Peru	.053	-.00070	.085	1990	1625	Psacharopoulos (1994)
Philippines	.023	-.00060	.119	1988	4283	Psacharopoulos (1994)
Poland	.021	-.00036	.024	1986	5040	Psacharopoulos (1994)
Portugal	.025	-.00040	.094	1985	21823	Psacharopoulos (1994)
Singapore	.062	-.00100	.113	1974	1247	Psacharopoulos (1994)
Spain	.049	-.00060	.130	1990	635	Alba-Ramirez & San Segundo (1995)
Sweden	.049	-.00000	.026	1981	2996	Arai (1994)
Switzerland	.056	-.00069	.072	1987	304	Psacharopoulos (1994)
Tanzania	.041	-.00100	.067	1980	1522	Armitage & Sabot (1987)
Thailand	.071	-.00088	.091	1971	3151	Chiswick (1977)
Uruguay	.051	-.00070	.090	1989	6567	Psacharopoulos (1994)
USA	.032	-.00048	.093	1989	8118	Krueger & Pischke (1992)
Venezuela	.031	-.00030	.084	1989	1340	Psacharopoulos (1994)
West Germany	.045	-.00077	.077	1988	2496	Krueger & Pischke (1992)

Appendix B: Construction of Human Capital Stocks for 1960 and 1990

We construct estimates of the growth in human capital stocks from 1960 to 1990 by country as follows. We first construct an estimate of human capital for workers at each age from 25 to 59 for both 1960 and 1990. We then weight these age-specific human capitals into aggregates for 25 to 59 year olds using data on population weights by age from the United Nations (1994).

Our measure of human capital for an individual of age a at time t is based on the Mincerian model of human capital accumulation, generalized for an impact from human capital of the previous generation:

$$\mathrm{Ln}[h(a,t)] \;=\; \phi \mathrm{Ln}[h(a,t-25)] + \frac{\theta s^{1-\psi}}{1-\psi} + \gamma_1[a - s(a,t) - 6] + \gamma_2[a - s(a,t) - 6]^2 \,.$$

This formulation assumes that the relevant cohort for an individual's human capital is 25 years older (approximately the difference in the average age of workers and teachers across countries, as we discuss in the text). It also generalizes the text treatment by allowing for experience $(a - s - 6)$ to enter in quadratic form. We set $\psi = .58$. As described in the text, this reflects the lower return to schooling in countries with more years of schooling that Psacharopoulos (1994) finds, and we estimate, in his 56-country sample of estimates of the Mincer equation. We also present results for two smaller values for ψ: $\psi = .28$, which represents our point estimate for ψ minus two standard errors of the estimate, and $\psi = 0$. We set $\theta = .32$ to match the average return to schooling of 9.9% across the 56 countries. We choose the parameters γ_1 and γ_2 to yield the average experience-earnings profiles observed for our 52-country sample for which we have such profile slope estimates. For $\phi=0$, γ_1 and γ_2 are .0512 and $-.00071$, respectively. For $\phi > 0$ the parameter γ_1 must be revised upwards to maintain the same steepness of experience-earnings profiles, as discussed in the text.

Given these parameter choices, the only remaining input in the calculation is educational attainment. Because an individual's human capital is a function of the human capital in past cohorts (the teachers) when $\phi > 0$, it is important that we obtain information on schooling going back as far as possible. We construct country-specific time series for schooling attainment for 25 year olds for the years 1975 to 1990 from data on primary, secondary, and higher enrollment rates in the Summers-Heston data. For prior to 1975 we construct a series for educational attainment of 25 year olds based on country censuses of schooling attainment by age cohort conducted in various years between 1946 and 1977. These surveys are compiled by the United Nations and reported in the two UNESCO publications *Statistics of Educational Attainment and Illiteracy 1945-1974* and *Statistics of Educational Attainment and Illiteracy 1970-1980*. For 32 countries we use two or more surveys taken in that country in differing years.

The surveys provide the fraction of population of each age bracket achieving each of six possible levels of attainment: no schooling, some primary, completed primary, some secondary, completed secondary, and some post secondary. We assign respectively the values 0, 3, 6, 9, 12, and 14.5 years of schooling to these qualitative categories, in accord with World Bank estimates of the duration of these levels of education. The definition of age cohorts differs somewhat across surveys. The most common classification is according to the age groups 15-19, 20-24, 25-34, 35-44, 45-54, 55-64, and 65+. For the most part, we do not use age categories below age 25 because in general individuals in this category may not have completed their schooling. For countries with virtually no higher education we do use ages 20-24. We also do not use age category 65+. We then project back in time to construct a history of attainments of 25 year olds that generates the age distributions of schooling we observe at the dates of the census surveys. To take a concrete example, a 1951 survey for Columbia shows 2.00 years of schooling for persons aged 55 to 64. The midpoint of this bracket is age 59.5. A person aged 59.5 in 1951 was age 25 in mid-year 1915. Therefore we set attainment of a 25 year old in mid-1915 equal to 2.00 years. Similarly, the attainment of 2.40 years for 45 to 54 year olds in 1951 yields attainment of 2.40 years for a 25 year old in mid-1925, and so forth.

Many cells are missing in the UNESCO data. For instance for the 1952 Chilean survey we know how many persons received primary schooling only, and we do not know what fraction of these literally completed the schooling. By contrast, for the 1970 Chilean survey we do know. If two consecutive cells are missing in a survey, such as not knowing how many persons had some or completed secondary schooling, we do not use the survey. If only one cell is missing we attempt to interpolate based on later or previous survey information for that country. For instance, for Chile we can interpolate the fraction of 25-34 year olds in 1952 who had completed primary schooling based on the fraction of 45-54 year olds in 1970 who had completed. When this is not possible, we interpolate based on observed ratios in countries with similar schooling distributions using predicted values based on regressions.

Between the Summers-Heston enrollment rates and the UNESCO censuses we are able to construct attainment of 25 year olds for as many as 11 different dates ranging from 1990 back to as early as 1911. More exactly, we were able to construct attainment back to 1940 or before for 56 countries, to 1930 or before for 32 countries, and to 1920 or before for 21 countries. For each country we interpolated attainment for the years between our data points.

It remains necessary to project attainment back before our available data. For $\phi > 0$ we need to project attainment back arbitrarily far, though if ϕ is much less than one the weights on these previous attainments will decline rapidly. We use three separate equations for backcasting: One for 1960 and after, one for 1930 to 1960, and a third for prior to 1930. For 1960 and after we backcast using the equation $\mathrm{Ln}[s(25,t)] = 1.0216\ \mathrm{Ln}[s(25,t+1)] - .0706$. This equation is consistent with the results of regressing attainment of 25 year olds in 1960 on attainment of 25 year olds in 1990 for the countries where both series are available. Similarly, for 1930 to 1960 we use an equation $\mathrm{Ln}[s(25,t)] = 1.0047\ \mathrm{Ln}[s(25,t+1)] - .0226$, which is based on regressing 1930 attainment on 1960 attainment. The coefficient in this latter equation is not significantly different from one. Based on that, prior to 1930 we simply assume that attainment decreases by 1.77% per year. This is the average rate of increase for the years 1930 to 1960.

The outcome is that we are able to construct human capital stocks for 1960 and 1990 for 87 of the 93 countries used in the basic growth regression in Column 1 of Table 1. For 56 of these countries these stocks reflect information on enrollments going back at least as far as 1940.

References

Alba-Ramirez, Alfonso and Maria Jesus San Segundo (1995), "The Economic Returns to Education in Spain," **Economics of Education Review** 14 (2), 155-166.

Arai, Mahmood (1994), "An Empirical Analysis of Wage Dispersion and Efficiency Wages," **Scandinavian Journal of Economics** 96 (1), 31-50.

Armitage, Jane and Richard Sabot (1987), "Socioeconomic Background and the Returns to Schooling in Two Low-Income Economies," **Economica** 54 (213), 103-108.

Barro, Robert J. (1991), "Economic Growth in a Cross Section of Countries," **Quarterly Journal of Economics** 106 (2), 407-444.

Barro, Robert J. and Jong-Wha Lee (1993), "International Comparisons of Educational Attainment," **Journal of Monetary Economics** 32 (3), 363-394.

Barro, Robert J. and Jong-Wha Lee (1996), "International Measures of Schooling Years and Schooling Quality," **American Economic Review**, Papers and Proceedings 86 (2), 218-223.

Barro, Robert J., N. Gregory Mankiw, and Xavier Sala-i-Martin (1995), "Capital Mobility in Neoclassical Models of Growth," **American Economic Review** 85 (1), 103-115.

Barro, Robert J. and Xavier Sala-i-Martin (1995), **Economic Growth**, McGraw Hill.

Benhabib, Jess and Mark M. Spiegel (1994), "The Role of Human Capital in Economic Development: Evidence from Aggregate Cross-Country Data," **Journal of Monetary Economics** 34 (2), 143-174.

Card, David (1994), "Earnings, Schooling, and Ability Revisited," NBER Working Paper #4832.

Callan, Tim and Barry Reilly (1993), "Unions and the Wage Distribution in Ireland," **Economic and Social Review** 24 (4), 297-312.

Carroll, Christopher D. and Lawrence H. Summers (1991), "Consumption Growth Parallels Income Growth: Some New Evidence," B. Douglas Bernheim and John B. Shoven, eds., **National Saving and Economic Performance**, University of Chicago Press, 305-343.

Carroll, Christopher D. and David N. Weil (1994), "Saving and Growth: A Reinterpretation," **Carnegie-Rochester Conference Series on Public Policy** 40, 133-192.

Chiswick, Carmel U. (1977), "On Estimating Earnings Functions for LDCs" **Journal of Development Economics** 4 (1), 67-78.

Cohen, Bernice H. (1963), "Family Patterns of Mortality and Life Span," **Quarterly Review of Biology**, 38, 130-181.

Denison, Edward F. (1985), **Trends in American Economic Growth, 1929-1982**, Washington, D.C.: The Brookings Institution.

Easterly, William, Michael Kremer, Lant Pritchett, and Lawrence H. Summers (1993), "Good Policy or Good Luck? Country Growth Performance and Temporary Shocks," **Journal of Monetary Economics** 32 (3), 459-484.

Eaton, Jonathan and Samuel Kortum (1996), "Trade in Ideas: Patenting and Productivity in the OECD," **Journal of International Economics** 40, 251-278.

Ehrenberg, Ronald G., and Robert S. Smith (1997), **Modern Labor Economics**, Addison-Wesley.

Foster, Andrew D. and Mark R. Rosenzweig (1996), "Technical Change and Human Capital Returns and Investments: Evidence from the Green Revolution," **American Economic Review** 86 (4), 931-953.

Hartwig, W., (1959), "Lifespan of Cattle and Horses Under Various Climatic Conditions and the Reasons for Premature Culling," in **The Lifespan of Animals** (G. E. Wolstenhome and C. M. O'Connor, eds.), Little, Brown, and Company.

Jones, Charles I. (1997), "The Upcoming Slowdown in U.S. Economic Growth," mimeo., Stanford University.

Kendrick, John W. (1976), **The Formation and Stocks of Total Capital**, New York, Columbia University Press for the NBER.

Klenow, Peter J. and Andrés Rodríguez-Clare (1997), "The Neoclassical Revival in Growth Economics: Has It Gone Too Far?" forthcoming, **1997 NBER Macroeconomics Annual**.

Krueger, Alan B. and Jorn-Steffen Pischke (1992), "A Comparative Analysis of East and West German Labor Markets Before and After Unification," NBER Working Paper #4154.

Levine, Ross and David Renelt (1992), "A Sensitivity Analysis of Cross-Country Growth Regressions," **American Economic Review** 82 (4), 942-963.

Lillard, Lee A. (1977), "Inequality: Earnings vs. Human Wealth," **American Economic Review** 67, 42-53.

Lucas, Robert E. (1988), "On the Mechanics of Economic Development," **Journal of Monetary Economics** 22, 3-42.

Maddison, Angus (1982), **Phases of Capitalist Development**, Oxford University Press.

Mincer, Jacob (1974), **Schooling, Experience, and Earnings**, New York: Columbia University Press.

Mulligan, Casey B. and Xavier Sala-i-Martin (1995), "A Labor-Income-Based Measure of the Value of Human Capital: An Application to the States of the United States," NBER Working Paper #5018.

Psacharopoulos, George (1994), "Returns to Investment in Education: A Global Update," **World Development** 22, 1325-1343.

Rebelo, Sergio (1991), "Long Run Policy Analysis and Long Run Growth," **Journal of Political Economy** 99, 500-521.

Rosen, Sherwin (1976), "A Theory of Lifetime Earnings," **Journal of Political Economy** 84 (4), S45-S57.

Rosholm, Michael and Nina Smith (1996), "The Danish Gender Wage Gap in the 1980s: A Panel Data Study," **Oxford Economic Papers** 48 (2), 254-279.

Rudd, Jeremy (1996), "Empirical Evidence on Human Capital Spillovers," mimeo., Princeton University.

Summers, Robert and Alan Heston (1991), "The Penn World Table (Mark 5): An Expanded Set of International Comparisons," **Quarterly Journal of Economics** 106 (2), 327-368.

United Nations (1994), **The Sex and Age Distribution of the World Populations, the 1994 Revision**, United Nations, New York.

UNESCO (1983), **Statistics of Educational Attainment and Illiteracy, 1970-1980**, Paris, France.

UNESCO (1977), **Statistics of Educational Attainment and Illiteracy, 1945-1974**, Paris, France.

U.S. Department of Education (1996), **1996 Digest of Education Statistics**, U.S. Government Printing Office, Washington D.C.

Wright, Randall (1996) "Taxes, Redistribution, and Growth," **Journal of Public Economics** 62, 327-338.