Does Schooling Cause Growth?

By Mark Bils and Peter J. Klenow*

A number of economists find that growth and schooling are highly correlated across countries. A model is examined in which the ability to build on the human capital of one's elders plays an important role in linking growth to schooling. The model is calibrated to quantify the strength of the effect of schooling on growth by using evidence from the labor literature on Mincerian returns to education. The upshot is that the impact of schooling on growth explains less than one-third of the empirical cross-country relationship. The ability of reverse causality to explain this empirical relationship is also investigated. (*JEL* I2, J24, O4)

Robert J. Barro (1991), Jess Benhabib and Mark M. Spiegel (1994), Barro and Xavier Sala-i-Martin (1995), Sala-i-Martin (1997), and many others find schooling to be positively correlated with the growth rate of per capita GDP across countries. For example, we show below that greater schooling enrollment in 1960 consistent with one more year of attainment is associated with 0.30-percent faster annual growth over 1960–1990. This result is consistent with models, such as that of Barro et al. (1995), in which transitional differences in human-capital growth rates explain temporary differences in country growth rates.

We examine a model with finite-lived individuals in which human capital can grow with rising schooling attainment and thereby contribute to a country's growth rate. Each generation learns from previous generations; the ability to build on the human capital of one's elders plays an important role in the growth generated by rising time spent in school. We also incorporate into the model a positive externality from the level of human capital onto the level of technology in use.

We calibrate the model to quantify the strength of the effect of schooling on growth. To do so, we introduce a measure of the impact of schooling on human capital based on exploiting Mincerian returns to education and experience (Jacob Mincer, 1974) commonly estimated in the labor literature.[1] Our calibration requires that the impact of schooling on human capital be consistent with the average return to schooling observed in estimates of the Mincer equation conducted on micro data across 56 separate countries. We also require that the human-capital returns to schooling exhibit diminishing returns consistent with the observed higher returns to schooling in countries with low levels of education. We further discipline the calibration by requiring that average human-capital growth not be so high that technological regress must have occurred on average in the world over 1960–1990. Our principal finding is that the impact of schooling on growth probably explains less than one-third of the empirical cross-country relationship, and likely much less than one-third. This conclusion is robust to allowing a positive external benefit from human capital to technology.

If high rates of schooling are not generating higher growth, what accounts for the very strong relationship between schooling enrollments and subsequent income growth? One element is that countries with high enrollment

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[1] Our approach is very related to the work of Anne O. Krueger (1968), Dale W. Jorgenson (1995), and Alwyn Young (1995), each of whom measures growth in worker quality in a particular country based on the relative wages and changing employment shares of differing schooling- and age-groups. Our approach is more parametric, but can also be applied to many more countries.

rates in 1960 exhibit faster rates of growth in labor supply per capita from 1960 to 1990. This explains perhaps 30 percent of the projection of growth on schooling. A second possibility is that the strong empirical relation between schooling and growth reflects policies and other factors omitted from the analysis that are associated both with high levels of schooling and rapid growth in total factor productivity (TFP) from 1960 to 1990. For example, better enforcement of property rights or greater openness might induce both faster TFP growth and higher school enrollments. Finally, the relationship could reflect reverse causality, that is, schooling could be responding to the anticipated rate of growth for income.

To explore the potential for expected growth to influence schooling, we extend the model to incorporate a schooling decision. Our model builds on work by Gary S. Becker (1964), Mincer (1974), and Sherwin Rosen (1976). 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 earnings. Economic growth, even of the skill-neutral variety, increases the wage gains from schooling.[2] Thus an alternative explanation for the Barro et al. findings is that growth drives schooling, rather than schooling driving growth. We calibrate the model to quantify the potential importance of the channel from growth to schooling, again disciplined by estimates of empirical Mincer equations. Our calibration suggests that expected growth could have a large impact on desired schooling.

We conclude that the empirical relationship documented by Barro and others does not primarily reflect the impact of schooling on growth. We suggest that it may partly reflect the impact of growth on schooling. Alternatively, an important part of the relation between schooling and growth may be omitted factors that are related both to schooling rates in 1960 and to growth rates for the period 1960 to 1990.

The rest of the paper proceeds as follows. In Section I we lay out the model. In Section II we document that a higher level of schooling enrollment is associated with faster subsequent growth in GDP per capita (also GDP per worker, and GDP per worker net of physical capital accumulation). In Section III we calibrate the model and explore whether the channel from schooling to human-capital growth is capable of generating the empirical coefficient found in Section II. In Section IV we add the channel from schooling to the level of technology, to see whether the effect of schooling on human capital and technology combined can mimic the empirical relationship. In Section V we investigate whether the reverse channel from expected growth to schooling can do the same. In Section VI we conclude.

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

A. *The Channel from Schooling to Growth*

We start with production technologies since much of our estimation and calibration is based solely on them, with no assumptions needed about preferences or capital markets. Consider an economy with the production technology

$$Y(t) = K(t)^{\alpha}[A(t)H(t)]^{1-\alpha} \tag{1}$$

where Y is the flow of output, K is the stock of physical capital, A is a technology index, and H is the stock of human capital. The aggregate stock of human capital is the sum of the human-capital stocks of working cohorts in the economy. For exposition, suppose for the moment that all cohorts go to school from age 0 to age s (so that s is years of schooling attained) and work from age s to age T. Then we have

$$H(t) = \int_{s}^{T} h(a,t)L(a,t)\, da \tag{2}$$

where $L(a,t)$ is the number of workers in cohort a at time t and $h(a,t)$ is their level of human capital. Note the efficiency units assumption that different levels of human capital are perfectly substitutable. We generalize (2) to the case where s and T differ across cohorts.

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

We posit that individual human-capital stocks follow

$$(3) \quad h(a,t) = h(a+n,t)^{\phi} e^{f(s)+g(a-s)} \ \forall a > s.$$

The parameter $\phi \geq 0$ captures the influence of teacher human capital, with the cohort n years older being the teachers. When $\phi > 0$ the quality of schooling is increasing in the human capital of teachers.[3] The exponential portion of (3) incorporates the worker's years of schooling (s) and experience ($a - s$), with $f'(s) > 0$ and $g'(a - s) > 0$ being the percentage gains in human capital from each year. Note that the "teachers" that influence h are at school *and* on the job. In the special case of $\phi = 1$, h grows from cohort to cohort even if years of schooling attained are constant, à la Robert E. Lucas, Jr. (1988) and Sergio Rebelo (1991). If $\phi < 1$, then growth in h from cohort to cohort requires rising s and/or T.

When $\phi = 0$, $f(s) = \theta s$, and $g(a - s) = \gamma_1(a - s) + \gamma_2(a - s)^2$, equation (3) reduces to the common Mincer (1974) specification. This specification implies that the log of the individual's wage is linearly related to that individual's years of schooling, years of experience, and years of experience squared. We choose this exponential form precisely so that we can draw on the large volume of micro evidence on θ, γ_1, and γ_2 to quantify the impact of schooling on human capital and growth. This approach differs from that of N. Gregory Mankiw et al. (1992), who assume a human-capital production technology identical to that of other goods (consumption and physical capital). Although (3) is a departure from the prior literature, we view it as an improvement because it ensures that our estimates of human capital are consistent with the private returns to schooling and experience seen in micro data.[4]

In addition to the direct effect of human capital on output in (1), human capital may affect output by affecting A, the level of technology. Richard R. Nelson and Edmund S. Phelps (1966), Theodore W. Schultz (1975), Benhabib and Spiegel (1994), and many others propose that human capital speeds the adoption of technology. For instance, the growth rate of technology for country i may follow

$$(4)' \quad g_{A_i}(t) = -\eta \ln \frac{A_i(t)}{\bar{A}(t)} + \beta \ln h_i(t) + \xi_i(t)$$

where $\bar{A}$ is the exogenously growing "world technology frontier" and $h_i(t) = H_i(t)/L_i(t)$ is the average level of human capital in country i.[5] When $\eta > 0$, the closer the country's technology to the frontier the slower the country's growth rate. When $\beta > 0$, the higher the country's human capital the faster the country's growth rate. As stated, one motivation for $\beta > 0$ is that human capital may speed technology *adoption.* But another motivation is that human capital may be necessary for technology *use.* That is, in (4)′ human capital can be indexing the fraction of frontier technology which the country can use.[6] Evidence that human capital plays a role in adoption includes Finis Welch (1970), Ann Bartel and Frank Lichtenberg (1987), and Foster and Rosenzweig (1996). Empirical studies finding that human capital is complementary to technology use are plentiful, recent examples being Mark Doms et al. (1997), David H. Autor et al. (1998), and Eli Berman et al. (1998).

If one integrates (4)′ over time one finds that the level of technology in a country should be a positive function of its current and past human-capital stocks. Below we report that there is ample evidence that the level of technology [A constructed from equation (1)] and the level of human capital [constructed using equation (3)] are positively correlated across countries. Conditional on current human capital, however, we do not find a positive correlation between current A and past human capital. In terms of (4)′,

[3] We ignore nonlabor inputs because evidence suggests that teacher and student time constitute about 90 percent of all costs (see John W. Kendrick [1976] and U.S. Department of Education [1996]).

[4] Recent papers that have followed our approach include Charles I. Jones (1998), Boyan Jovanovic and Raphael Rob (1998), Jonathan Temple (1998), Daron Acemoglu and Fabrizio Zilibotti (1999), and Robert E. Hall and Jones (1999).

[5] $L_i(t)$ is the sum of $L_i(a, t)$ across cohorts.

[6] William Easterly et al. (1994), Jones (1998), and Francisco Caselli (1999) adopt this "use" formulation.

this could mean that η is very high so that transition dynamics are rapid and economies are close to their steady-state paths. This would suggest a simple use formulation, with a higher level of human capital allowing a higher level of technology use:

$$\ln A_i(t) = \beta \ln h_i(t) + \ln \bar{A}(t) + \xi_i(t). \tag{4}$$

$\Rightarrow$

$$g_{A_i}(t) = \beta g_{h_i}(t) + g_{\bar{A}}(t) + \varepsilon_i(t). \tag{5}$$

Equation (5) says that growth in human capital contributes to growth indirectly (through growth in A), not just directly [through H in equation (1)]. Note that, because we measure h to be consistent with Mincerian private-return estimates in (3), this indirect effect of human capital on technology represents an externality not captured by the individual worker. Externalities might arise because of learning from others who have adopted or because introduction of technology is based on the amount of human capital in the country as a whole (e.g., when there is a fixed cost component to transferring technology).

In Section III we estimate the effect of schooling on growth using equations (1) through (5), eschewing (4)′ in favor of (4) because the latter fits the data better. In conducting this growth accounting we can take schooling decisions as given (i.e., as data). To quantify possible reverse causality, however, we must model schooling decisions. For this purpose, we next specify market structure and preferences.

B. *The Channel from Growth to Schooling*

We consider a competitive open economy facing a constant world real interest rate r.[7] With the price of output in the world normalized to one each period, firm first order conditions from (1) are

$$\alpha Y(t)/K(t) = r + \delta \tag{6}$$

and

$$(1 - \alpha)Y(t)/H(t) = w(t) \tag{7}$$

where δ is the depreciation rate of physical capital and w is the wage rate *per unit of human capital.* Combining (1), (6), and (7), one can easily show that

$$w(t) \propto A(t) \tag{8}$$

which means the wage per unit of human capital grows at the rate g_A.

In this economy each individual is finite-lived and chooses a consumption profile and years of schooling to maximize

$$\int_0^T e^{-\rho t} \frac{c(t)^{1-1/\sigma}}{1 - 1/\sigma}\, dt + \int_0^s e^{-\rho t} \zeta\, dt. \tag{9}$$

Here c is consumption and ζ is flow utility from going to school. Schultz (1963) and others argue that attending class is less onerous than working, especially in developing countries. This benefit of going to school will create an income effect on the demand for schooling.[8]

The individual's budget constraint is

$$\int_s^T e^{-rt} w(t) h(t)\, dt \geq \int_0^T e^{-rt} c(t)\, dt + \int_0^s e^{-rt} \mu w(t) h(t)\, dt \tag{10}$$

[7] The common r assumption means that, in our model, the private rate of return to schooling will be equalized across countries. This is in contrast to the model of Barro et al. (1995), in which low schooling countries have high returns to human capital but cannot borrow to finance human-capital accumulation.

[8] We model a utility flow from going to school for concreteness, but there are other motivations for an income effect: higher education may improve one's ability to enjoy consumption throughout life (Schultz, 1963); higher income may relax borrowing constraints; and tuition may not rise fully with a country's income (say because goods are used in education production).

where $\mu > 0$ is the ratio of school tuition to the opportunity cost of student time.[9] Individuals go to school until age s and work from age s through age T.

From (3), (9), and (10), the first-order condition for an individual's schooling choice is

$$(11)\quad (1+\mu)w(s)h(s) = \zeta c(s)^{1/\sigma} + \int_s^T e^{-r(t-s)}[f'(s) - g'(t-s)]w(t)h(t)\,dt$$

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 sum of the utility flow from attending plus the present value of future earnings gains (the right-hand side). The gap between human capital gained from education and that gained from experience $[f'(s) - g'(t-s)]$ enters because staying in school means forgoing experience.

The privately optimal quantity of schooling is generally not an explicit function of the model's parameters. To illustrate concepts, however, consider a special case in which it is: $f(s) = \theta s$, $g(a-s) = \gamma(a-s)$, and $\zeta = 0$. (Later, when we calibrate the model, we consider $\zeta > 0$ and g and f functions with realistic curvature in s and $a - s$.) Using $h(t) = h(s)e^{\gamma(t-s)}\ \forall t > s$, $w(t) = w(s)e^{g_A(t-s)}$ from (8), and first-order condition (11), the privately optimal quantity of schooling is

$$(12)\quad s = T - \left[\frac{1}{r - g_A - \gamma}\right] \times \ln\left[\frac{\theta - \gamma}{\theta - \gamma - \mu(r - g_A - \gamma)}\right].$$

Equation (12) illustrates the channel by which higher expected growth in A can induce more schooling. The interest rate r and the growth rate g_A enter the schooling decision through their difference $(r - g_A)$, so comparative statics of the schooling decision with respect to g_A mirror those for r, with the opposite sign. Higher growth acts just like a lower market interest rate: by placing more weight on future human capital, it induces more schooling. The benefit of having human capital is proportional to the level of A while working. The cost of investing in human capital is proportional to the level of A while in school. Thus higher A in the future *relative* to today, which is to say higher growth in A, raises the private return to investing in schooling.

Other noteworthy implications of the model are as follows. A permanently higher *level* of technology A (equivalently, wage per unit of human capital) does not affect the optimal amount of schooling because it affects the marginal cost and benefit of schooling in the same proportion. Similarly, neither teacher human capital nor its contribution to learning (ϕ) affect the schooling decision. These results on A and teacher human capital hinge on $\zeta = 0$ (no utility benefit to attending class). Regardless of the level of ζ, a higher life expectancy (T) results in more schooling, since it affords a longer working period over which to reap the wage benefits of schooling. Likewise, a higher tuition ratio (μ) lowers schooling.

II. The Cross-Country Pattern of Schooling and Growth

Barro (1991) finds that 1960 primary- and secondary-school *enrollment rates* are positively correlated with 1960–1985 growth in real per capita GDP. Column (1) of our Table 1 reproduces this finding using updated Robert Summers and Alan Heston (1991) Penn World Tables Mark 5.6 data and Barro and Jong-Wha Lee (1993) enrollment rates.[10] Our measure of schooling equals six times a country's primary-school enrollment rate plus six times its

[9] We make tuition costs increasing in the opportunity cost of student time because, in the data, tuition rises with the level of education (see U.S. Department of Education, 1996).

[10] Our specification differs from Barro's (1991) in that we enter a single schooling variable (rather than primary, secondary, and tertiary schooling separately) and omit initial income as well as other control variables (such as the number of coups). If we condition on the natural log of 1960 per capita GDP, the coefficient on schooling is 0.598 percent (with a standard error of 0.094 percent) and the coefficient on initial income is −1.215 percent (standard error 0.291 percent).

TABLE 1—GROWTH REGRESSED ON RATES AND YEARS OF SCHOOLING

	(1)	(2)	(3)	(4)
Dependent variable	GDP per capita	GDP per worker	$Ah^{\dagger}$	Ah
Schooling 1960 (Enrollment rates)	0.300 percent (0.050)	0.213 percent (0.050)	0.229 percent (0.049)	0.476 percent (0.117)
Average years of schooling, 1960				−0.223 percent (0.118)
$\bar{R}^2$	0.23	0.13	0.15	0.22
Number of countries	93	93	85	81

Notes: The dependent variable is the average annual growth rate from 1960 to 1990 of the variable listed. White-corrected standard errors are in parentheses.
Sources: The data is from Summers-Heston (Penn World Tables, Mark 5.6, 1991) and from Barro and Lee (1996).
† A is a productivity index. h is human capital per person.

secondary-school enrollment rate plus five times its higher-education enrollment rate. This corresponds to the steady-state average years of schooling that these enrollment rates imply, with the durations of primary, secondary, and higher education based on World Bank (1991 p. 285) conventions. The estimated coefficient on schooling in column (1) implies that an increase in enrollment rates tantamount to one more year of attainment is associated with 0.30-percent per year faster growth over 1960–1990 (with a standard error of 0.05 percent).[11]

Our focus is on whether high enrollments in 1960 are associated with rapid subsequent growth because high enrollments generate rapid growth in human capital or productivity. Therefore, we proceed to net off the contribution of growth in labor supply and physical capital per capita to arrive at a measure of the combined growth in h and A for each country. We first deduct the contribution of growth in labor supply by examining growth in income per worker rather than per capita. (Measures of GDP per worker are also taken from the Penn World Tables.) The result, shown in column (2) of Table 1, is that an increase in enrollments sufficient to produce one more year of schooling is associated with 0.21-percent faster growth per year for 1960–1990 (with a standard error of 0.05 percent). Thus nearly 30 percent of the projection of growth in per capita income on 1960 schooling, reported in column (1), reflects faster growth in labor supply per capita in countries with higher 1960 schooling.

Now, using (1) we can isolate the combined growth in h and A for each country as

$$g_h + g_A = \frac{1}{1-\alpha}(g_y - \alpha g_k)$$

where h is human capital per person, A is a productivity index, y is GDP per worker, and k is physical capital per worker. We estimate k using investment rates from the Penn World Tables and the 1960 capital stocks estimated by Klenow and Andrés Rodríguez-Clare (1997).[12] We set physical capital's share (α) to one-third. The result of regressing $g_h + g_A$ on schooling in 1960 for the 85 countries with available data appears in the third column of Table 1. An additional year of schooling enrollment in 1960 is associated with an increase in $g_h + g_A$ per year for 1960 to 1990 of 0.23 percent (with a standard error of 0.05 percent). In Section III we

[11] Related, Eric A. Hansuhek and Dennis D. Kimko (2000) examine the relationship between the *quality* of schooling (measured by standardized math and science test scores) and subsequent economic growth. They find a significant relationship, even controlling for the quantity of schooling.

[12] Klenow and Rodríguez set a country's 1960 $K/Y = I/Y/(g + \delta + n)$, with the investment rate I/Y, the growth rate of $Y/L(g)$, and the population growth rate (n) equal to the country's averages over 1960–1970, and with $\delta = 0.07$.

break this impact into its g_h and g_A components for various specifications of the accumulation technology for human capital.

Barro and Sala-i-Martin (1995) employ data on years of schooling *attainment* in a country's working-age population to test the hypothesis that schooling promotes growth. Column (4) of Table 1 relates average annual growth from 1960 to 1990 to Barro and Lee's measure of 1960 schooling attainment, again with an updated data set (Barro and Lee, 1996), as well as to enrollment (years of schooling based on 1960 enrollment rates). Growth remains highly correlated with enrollment rates. Conditional on 1960 enrollment rates, past enrollments (as captured by attainment) have no positive relation to growth; in fact, attainment enters with a marginally statistically significant negative impact. We view this as suggestive that any causal impact of 1960 schooling on growth from 1960 to 1990 is more likely to reflect transitional growth in human capital or technology over the period, as opposed to a steady-state influence on growth (as, for instance, in AK models). If schooling creates sustained growth, then the schooling attainment in a country, reflecting past enrollment rates, should positively, rather than negatively, influence growth.

To repeat, an extra year of schooling enrollments in 1960 is associated with 0.23-percent faster annual 1960–1990 growth in human capital and technology combined. We proceed as follows to deduce how much of this impact reflects a causal effect from schooling to growth. In the next section we calculate to what degree countries with higher enrollments in 1960 exhibit faster subsequent growth in human capital. In Section IV we allow human capital to add to growth both directly and indirectly by spurring more advanced technology. In Section V we examine the ability of the reverse channel from expected growth to schooling to explain the strong correlation between 1960 enrollments and growth over 1960 to 1990.

III. Estimating the Impact of Schooling on Growth in Human Capital

In this section we quantify the growth in human capital from 1960 to 1990 for a cross section of countries. We consider various specifications of the production of human capital designed to be consistent with Mincer (1974) wage equations that have been estimated for many countries. We also allow schooling investments in one generation to improve the quality of education for subsequent generations. We then ask to what extent the faster growth in income for countries with high schooling enrollments in 1960 can be attributed to faster growth in human capital from 1960 to 1990.

A. *Calibrating the Production Function for Human Capital*

Based on equation (3) and $g(a - s - 6) = \gamma_1(a - s - 6) + \gamma_2(a - s - 6)^2$—a quadratic term in experience, as is standard in the empirical literature on wages—a worker of age a will possess a natural log of human capital given by

$$\ln[h(a)] = \phi \ln[h(a + n)] + f(s) + \gamma_1(a - s - 6) + \gamma_2(a - s - 6)^2. \tag{13}$$

A time subscript is implicit here. For as many countries as possible, we construct human-capital stocks for individuals of each age between 20 and 59, using (13) and incorporating schooling, experience, and teacher human capital specific to each age. We can then calculate average human-capital stocks for each country 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).

To make (13) operational requires data on schooling attainment going back as many years as possible. This is of particular importance if ϕ is positive, making the current generation's human capital depend on past generations' schooling. United Nations Education, Scientific, and Cultural Organization (UNESCO) (1977, 1983) report country census data on schooling attainment of age-groups 20 to 54 or older in years as far back as 1946 and as recently as 1977. We exploit this data to construct a time series for

schooling attainment of 20-year-olds for close to 40 years before the earliest survey.[13] This construction is described in much greater detail in Appendix A. For the countries with the relevant data, we estimate the persistence of attainment from 1955–1985 and 1925–1955, respectively. Based on this, for a panel of 85 countries we "fill in" estimates of the attainment of 20-year-olds for the years going back before attainment data is available in each country. We also report results for a 55-country sample for which attainment data reach back at least to 1935.

Constructing individual human capitals in (13) also requires parameter values for the returns to experience, γ_1 and γ_2, a parameterized functional form for the impact of schooling, $f(s)$, a value for the parameter ϕ that governs the intertemporal transmission of human capital, and (when $\phi > 0$) a value for the age difference between teachers and students, n.

We base the returns to experience and schooling on estimates of the sources of wage differences (Mincer equations) that have been examined with micro data for a large number of countries. The canonical Mincer regression estimates the "returns" to experience and education using a cross section of individuals (i's)

$$\text{(14)} \quad \ln(w_i) = \lambda_0 + \lambda_1 s_i + \lambda_2(\text{age} - s_i - 6) + \lambda_3(\text{age} - s_i - 6)^2 + \varepsilon_i$$

where w is the wage, s is years of schooling, (age $- s - 6$) is experience, and ε reflects measurement error, ability, and compensating differentials. In terms of (13), this specification sets $\phi = 0$ and makes the impact of schooling linear in s. We obtained estimates of (14) for 52 countries, largely from the work of George Psacharopoulos (1994).[14] In Appendix B we list the 52 countries and their estimated returns to schooling and experience. 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.

Our parameter choices for γ_1 and γ_2 reflect the average estimates for λ_2 and λ_3 across these 52 countries. These average estimates are 0.0512 and -0.00071, respectively.

For $f(s)$ we posit

$$\text{(15)} \qquad f(s) = \frac{\theta}{1 - \psi} s^{1-\psi}.$$

We entertain $\psi > 0$ because diminishing Mincerian returns to schooling appear to exist when we compare micro-Mincer estimates across countries.

To estimate ψ in (15), we exploit the fact that estimated Mincerian returns to education, λ_1 in (14), equal $f'(s) = \theta/s^{\psi}$. Psacharopoulos (1994) reports estimates of Mincerian returns to schooling, together with mean years of schooling in the sample, for 56 countries.[15] We regress country Mincerian return *estimates* on country schooling levels for Psacharopoulos' 56-country sample:

$$\ln(\hat{\lambda}_1) = \ln(\theta) - \psi \ln(s) + [\ln(\hat{\lambda}_1) - \ln(\lambda_1)].$$

We find $\hat{\psi} = 0.58$ with a standard error of 0.15. That $\hat{\psi} > 0$ 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., as in from the Central African Republic to Fiji to Iceland), the implied Mincerian return on schooling falls from 21.6 percent to 11.4 percent to 8.5

[13] For countries with nontrivial higher education, a number of 20-year-olds may have not completed their formal schooling. In these cases we base the attainment of 20-year-olds in year t on the reported attainment of 25-year-olds in year $t + 5$.

[14] 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. We found independent estimates for nine more countries.

[15] We use his sample, as opposed to our 52-country sample, because this exercise does not require that returns to experience also be reported, but does require the average years of attainment in each sample.

percent.[16] These sharply diminishing returns depart from the custom in the labor literature of positing no diminishing returns.[17] For this reason we consider two lower values of the curvature parameter ψ, or three in all: 0.58 (our point estimate), 0.28 (our point estimate minus two standard errors), and 0 (no diminishing returns). But we note that the case of no diminishing returns is nearly four standard errors below our estimate of ψ.

For each value of ψ we set the value of θ so that the mean of θ/s^{ψ} equals the mean Mincerian return across Psacharopoulos' 56 countries, which is 0.099. When $\psi = 0.58$, $\theta = 0.32$ achieves this objective; when $\psi = 0.28$, $\theta = 0.18$ does so; when $\psi = 0$ the required value of θ is, of course, 0.099. These estimated Mincerian returns to education may overstate θ. First, estimates of (14) 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. For curvature parameter $\psi > 0$, the return to schooling is convex to the origin; so by Jensen's inequality linear estimates overstate θ. Overstating θ would mean overstating the causal impact of enrollment in 1960 on g_h and growth in output.

We consider a range of values for ϕ, the elasticity of human capital with respect to teacher human capital. The standard Mincer specification sets $\phi = 0$. Note that values for ϕ much above zero greatly increase the total "return" to schooling. For instance, along a steady-state growth path, the return on schooling is magnified to the extent of $\frac{1}{1-\phi}$; so for $\phi = ½$ the Mincerian return to schooling is doubled. We pick an upper value for the range of ϕ as follows. For each value of ψ, we pick a value for ϕ sufficiently large that all growth in Ah from 1960 to 1990, on average for our sample of countries, can be attributed to growth in human capital. We view this as an upper bound on the plausible range for ϕ. Any higher value for ϕ would imply that 1960–1990 growth in output per worker, which for our sample of countries averaged nearly 1.1 percent per year net of the impact of growth in physical capital, was associated with a 30-year period of technological regress.

For $\phi > 0$ it is necessary to calibrate n, the age gap between students and teachers. We set $n = 25$. This is slightly less than the average age gap we calculate between student and worker for countries in the Summers-Heston data.[18]

B. *Results*

For each specification of the human-capital production function (values of ψ and ϕ) we regress the calculated annual growth rate in h for 1960 to 1990, which we denote as g_h, on years of schooling enrollment in 1960 for 85 countries with available data. Results appear in Table 2. Recall from Table 1 that one more year of schooling enrollment in 1960 is associated with 0.23-percent faster growth per year in Ah from 1960 to 1990. (For comparison purposes, the bottom of Table 2 shows that the corresponding coefficient for this sample of 85 countries is similar at 0.24 percent.)

We begin in the first panel of Table 2 with the case of curvature parameter $\psi = 0.58$. Row 1 shows that, with $\phi = 0$ so that only *own* schooling and experience feeds into human capital, the coefficient on schooling is actually negative, equaling -0.100 percent with a standard error of 0.015 percent. Hence one cannot argue that 1960 enrollment is highly correlated with subsequent GDP growth through growth in the

[16] Noting that India and China exhibit modest Mincerian returns despite low schooling attainment (see our Appendix B), we were concerned that this result might be driven by high Mincerian returns in small, low schooling-attainment countries such as Honduras. When we excluded the 12 countries with populations below 5 million, however, we obtained a similar coefficient of -0.53 (standard error 0.16).

[17] When estimated on micro data within countries, the typical finding is linear returns to education, or $\psi = 0$. See David 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.

[18] In 1960 the average life expectancy across our sample of countries was 60.5. If all but six years are spent in school or at work, the average age gap between student and worker will be $(60.5 - 6)/2 = 27.25$ years. We obtained life expectancy for a person who has successfully reached age one from Barro and Lee (1993).

TABLE 2—GROWTH IN HUMAN CAPITAL REGRESSED ON SCHOOLING

		Schooling 1960 (Enrollment rates)	$\bar{R}^2$	Mean g_h
$\psi = 0.58$	$\phi = 0$	−0.100 percent (0.015)	0.35	1.39 percent
	$\phi = 0.19$	−0.091 (0.015)	0.29	1.60
$\psi = 0.28$	$\phi = 0$	−0.007 (0.011)	−0.01	1.11
	$\phi = ⅓$	0.029 (0.012)	0.06	1.43
	$\phi = 0.46$	0.054 (0.012)	0.19	1.60
$\psi = 0$	$\phi = 0$	0.048 (0.009)	0.23	0.94
	$\phi = ⅓$	0.087 (0.009)	0.50	1.18
	$\phi = 0.67$	0.171 (0.009)	0.80	1.60

Notes: The dependent variable is the average annual growth rate of human capital from 1960 to 1990. $1 - \psi$ and ϕ are the respective exponents on years of schooling and teacher human capital in the human-capital production function. The number of countries in the sample equals 85. For these 85 countries, the regression for growth in human capital plus technology [Table 1, col. (2)] is: $g_h + g_A = \underset{(0.054)}{0.238}\, S_{60}$, $\bar{R}^2 = 0.18$.

quantity of school attainment and experience. (Limiting the analysis to a sample of 55 countries for which we can construct enrollment rates back at least to 1935 yields an even more negative impact on g_h of −0.137 percent with a standard error of 0.020 percent.)

It may appear surprising that countries with higher enrollment rates do not display faster human-capital growth from 1960 to 1990. It is important to recognize, however, that one more year of schooling enrollments in a country in 1960 is associated with a very modest increase in schooling attainment in the working population between 1960 and 1990 of only 0.042 additional years. This reflects the high persistence of cross-country differences in enrollment rates. (See Appendix A.) Because countries with high enrollment rates in 1960 also had relatively high enrollments pre-1960, these countries are largely just maintaining their relatively high attainments. Also, for $\psi = 0.58$ there are considerably diminishing returns to schooling. Consider two countries, each of which has higher enrollments in 1960 than in past years. Both countries will exhibit growth in human capital. But the country expanding on a relatively low level of enrollments will display somewhat faster growth in human capital. We see shortly that for $\psi = 0$, higher enrollment rates in 1960 are associated with higher g_h, though the magnitude is small.

The rightmost column of Table 2 reports that, for this specification, the average growth rate in human capital for the 85 countries for 1960 to 1990 equals 1.39 percent. By comparison, the average rate of growth for Ah equals 1.60 percent. Thus the specification in column 1, $\psi = 0.58$, $\phi = 0$, implies that over 85 percent of growth in Ah can be attributed to growth in human capital. More generally, we find for all specifications considered that growth in human capital is primarily responsible for average growth in Ah for 1960 to 1990.

Row 2 reports results for $\phi = 0.19$. For $\psi =$

0.58 this value is the upper bound on the plausible range for ϕ. That is, higher values for ϕ would imply that technology regressed on average for the 85 countries from 1960 to 1990. Even for this higher value of ϕ the schooling coefficient remains negative at -0.091 percent, and statistically significant. (The coefficient is yet more negative, equaling -0.131 percent with standard error 0.021 percent, if we confine the regression to those 55 countries for which we have attainment data back to 1935 or earlier.) Hence, even incorporating estimates of rising school quality reflecting rising human capital of teachers, the correlation of 1960 enrollment with subsequent growth in human capital accounts for none of the dramatic association of 1960 schooling with faster income growth from 1960 to 1990.

As discussed above, this benchmark case with $\psi = 0.58$ features steeply diminishing Mincerian returns to schooling. Results for $\psi = 0.28$ are presented in the second panel of Table 2. When $\phi = 0$, so that human capital of elders does not directly augment human capital of the young, we find no impact of 1960 enrollment rates on human capital growth, g_h, from 1960 to 1990. (The coefficient equals -0.007 percent with standard error 0.011 percent.) The next row presents results raising ϕ to ⅓. For $\phi = ⅓$ there is now a positive effect of 1960 schooling on g_h, equaling 0.029 percent (standard error 0.012 percent). Nevertheless, this effect remains only one-eighth the size of the projection of $g_h + g_A$ on 1960 schooling enrollments. By construction, this implies that all but one-eighth of this projection reflects faster growth in A in countries with high schooling rates in 1960. For $\psi = 0.28$, as opposed to 0.58, a larger value for ϕ can be considered without driving the average value of g_h above the average value of $g_h + g_A$. For the upper value of $\phi = 0.46$ the impact of 1960 schooling on g_h equals 0.054 percent (standard error 0.012 percent). This still represents less than one-fourth of the projection of $g_h + g_A$ on schooling, with more than three-fourths attributable to faster growth in technology. Note, however, that this arguably exaggerates the value of ϕ, the impact of elders' human capital, and the importance of growth in human capital as it leaves no role for advances in technology in average growth from 1960 to 1990.

Finally, results for no curvature ($\psi = 0$) are given in the bottom panel of Table 2. The case of $\phi = 0$ corresponds to a standard Mincer specification. The projection of g_h on the 1960 years of schooling enrollment generates a coefficient of 0.048 percent (with standard error of 0.009 percent). This is one-fifth of the size needed to explain the projection of $g_h + g_A$ on 1960 enrollments, implying that 80 percent of the explanation for faster growth can be attributed to faster growth in technology. For $\phi = ⅓$ the estimated impact of schooling on g_h equals 0.087 percent (standard error 0.009 percent), implying that country differences in g_h contribute over one-third of the differences in $g_h + g_A$ associated with schooling in 1960. For $\psi = 0$ it is possible to take ϕ up to as high as 0.67 without driving the average value for g_h above the average value for $g_h + g_A$. For this uppermost value of $\phi = 0.67$, the estimated impact of schooling on g_h is substantial, equaling 0.171 percent (standard error 0.009 percent). This, by contrast to the other specifications, implies that two-thirds of the country differences in $g_h + g_A$ associated with schooling in 1960 can be attributed to the g_h component.

We conclude that pure growth in human capital accounts for a minority of the observed relation between schooling and income growth, most probably less than one-third. 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 equal our imposed upper bound. Then we can account for a majority of the schooling-growth relation with human-capital growth. But note that this specification is extreme in a couple of respects. The lack of diminishing returns to schooling is strongly contradicted by the cross-country evidence on schooling returns in Psacharopoulos (1994). In fact, a value for ψ of 0 is nearly four standard errors below our point estimate of ψ. Secondly, the very high value for ϕ of 0.67 implies that *average* growth in human capital for the 85 countries accounts for all of *average* growth in Ah of 1.6 percent per year, allowing no role for improvements in technology from 1960 to 1990.[19]

[19] One might also object to the very high value for ϕ of 0.67 on the grounds that it requires an implausibly strong impact of parent and teacher human capital on the outcomes of students. For instance, researchers such as Hanushek (1986) and James J. Heckman et al. (1996) have difficulty correlating schooling outcomes with teacher inputs. Such evidence, however, may not capture all channels by which a person can be affected by the human capital of their elders.

To illustrate this point, suppose we only require that ψ be within *three* standard deviation of its estimate, so that $\psi = 0.13$, and that technological growth, on average, be strictly positive but very small, so that it contributes only one-tenth (0.2 percent per year) of the observed average growth in income per worker for these 85 countries. These conditions are sufficient to restrict the intergenerational parameter ϕ to equal 0.34. Furthermore, these restrictions imply that one additional year of schooling enrollment in 1960 is associated with 0.065 percent faster g_h for 1960 to 1990 (with standard error 0.011 percent). This explains only 30 percent of the magnitude of the projection of $g_h + g_A$ on 1960 enrollments reported in Table 1.[20]

IV. Estimating the Impact of Schooling on Growth in Technology

Higher school enrollment in 1960 may be associated with faster growth in A because growth in human capital facilitates adoption of technology. [See the discussion and references surrounding equations (4)′, (4), and (5) in the model section above.] If workers need more human capital to use more advanced technology, then growth in human capital can bring improvements in technology. Our human-capital stocks should reflect the private wage gain to the adopting worker. But if there are external effects to that adoption, it will show up as higher A where human capital is higher.

Suppose that, based on equation (4) above, we regress the log level of A in 1990 on the log level of human capital, h, in 1990 for our sample of 85 countries.[21] We measure human capital based on the parameter values $\psi = 0.28$ and $\phi = 1/3$. This is intermediate to the cases examined in Section III. This exercise yields an estimated elasticity of A with respect to h of 0.77 (standard error 0.13).[22] If one interprets this as an unbiased estimate of β in equation (4), then this is consistent with an external benefit three-quarters as large as the private benefit to human capital. Of course, A may be high in countries with high human capital because they are both caused by, say, government policies favoring investments of all types. If so, then the ordinary least-squares (OLS) estimate of the external effect is biased upward.[23]

Consider the very high (OLS) estimated elasticity of A with respect to h of 0.77. It is important to recognize that this elasticity implies that the combined direct and indirect (through A) impacts of growth in human capital on income growth would be extremely large for the 1960 to 1990 period. As reported in Table 2, for $\psi = 0.28$ and $\phi = 1/3$, the average g_h for 1960–1990 for the 85 countries equals 1.43 percent per year. The elasticity of 0.77 implies a combined impact of growth in h on $g_h + g_A$ of 2.53 percent per year. But the total growth in $g_h + g_A$ on average across the 85 countries equals only 1.60 percent per year. This discrepancy would require that technology, holding human capital constant, must have regressed at 0.93 percent per year. We view this as implausible.

[20] From Table 2, we see that for countries with high 1960 schooling to exhibit much higher g_h requires an important role for rising *quality* of schooling, reflecting rising human capital of teachers and a value for ϕ considerably above 0. In an earlier version of this paper (Bils and Klenow, 1998), we show that growth in the quality of schooling can imply relatively higher wages for younger cohorts, biasing the estimated Mincerian return on experience below its true return. This downward bias should be most pronounced for countries with the most rapid growth in their quality of schooling. If cross-country differences in growth partly reflect differences in the rate of growth of the quality of schooling, then we should observe flatter age-earnings profiles in countries which have displayed more rapid growth. We test this prediction by relating differences in the estimated return to experience for 52 countries to differences in their growth rates of per capita income. We find no evidence that faster growth affects the wages of the young relative to those of the old.

[21] Heckman and Klenow (1997) follow a similar strategy in order to gauge the potential for externalities from human capital.

[22] When we added lags of the human-capital stocks to this regression, none entered positively and significantly. In terms of our model section, the data favor specification (4) over (4)′. For this reason we maintain the interpretation that a higher level of human capital raises the level of technology rather than its transitional growth rate.

[23] The natural attack on this simultaneity problem is to instrument for country differences in human capital with variables that influence human capital but are otherwise exogenous to a country's level of technology. In practice it is very difficult to find cross-country variables that are both relevant predictors of schooling and arguably valid instruments. In an earlier draft (Bils and Klenow, 1998) we attempted to instrument for a country's human capital using life expectancy in the country or, alternatively, a set of variables depicting climate in the country. We found a very high elasticity of A with respect to instrumented country differences in h. We presented considerable evidence, however, that our instruments were not valid.

TABLE 3—GROWTH IN HUMAN CAPITAL, WITH INDUCED GROWTH IN TECHNOLOGY, REGRESSED ON SCHOOLING

		(1)	(2)	(3)
		Critical value for ϕ	Impact of 1960 schooling on g_h	Combined impact on $g_h + g_A$
$\psi = 0.58$	$\beta = 0$	0.19	−0.091 percent (0.015)	−0.091 percent (0.015)
	$\beta = 0.15$	0	−0.100 (0.015)	−0.115 (0.017)
$\psi = 0.28$	$\beta = 0$	0.46	0.054 (0.012)	0.054 (0.012)
	$\beta = ⅓$	0.11	0.002 (0.012)	0.003 (0.015)
	$\beta = 0.42$	0	−0.007 (0.011)	−0.010 (0.016)
$\psi = 0$	$\beta = 0$	0.67	0.171 (0.009)	0.171 (0.009)
	$\beta = ⅓$	0.35	0.090 (0.009)	0.120 (0.013)
	$\beta = 0.71$	0	0.048 (0.009)	0.082 (0.015)

Note: β = elasticity of A (technology) with respect to h (human capital); ϕ = the exponent on teacher human capital in human-capital production; $1 - \psi$ = the exponent on years of schooling in human-capital production.

We explore this connection further in Table 3. Here we vary the impact of human capital on technology while at the same time imposing that technology, holding h constant, did not regress on average for our 85 countries.[24] For each elasticity of A with respect to h, this requires putting an upper bound on the parameter ϕ such that the combined direct and indirect impact of growth in human capital on $g_h + g_A$ does not explain more than 100 percent of its average value across countries for 1960–1990 of 1.60 percent. We then ask how much of the faster growth observed in $g_h + g_A$ in countries with high 1960 schooling can possibly be attributed to the direct plus indirect (technology) effects of faster growth in human capital in those countries.

Table 3 again considers values for the curvature parameter ψ equal to 0.58, 0.28, and 0, starting in the top panel with $\psi = 0.58$. For comparison, the first row presents the case of h having no impact on A. This duplicates results from Table 2. The upper bound on ϕ, for $\psi = 0.58$, is 0.19. Note that for this benchmark case, countries with relatively high 1960 schooling have *slower* growth in human capital, with the coefficient equaling −0.091 percent. The second row assumes a positive elasticity β of A with respect to h equal to 0.15. This value for β is the largest we can entertain, while at the same time keeping the parameter ϕ that links human capital across generations nonnegative and keeping *average* residual technological growth nonnegative for the 85 countries. For this case as well, countries with higher 1960 schooling exhibit slower growth in human capital, the coefficient equaling −0.100 percent. Thus magnifying increases in human capital to capture an influence on technology (last column of Table 3) only makes this negative impact larger in magnitude.

The middle panel of Table 3 treats the case of $\psi = 0.28$. The first row repeats the case from Table 2 of $\beta = 0$, with ϕ set at the upper bound of 0.46. The impact of 1960 schooling on g_h

[24] Our approach is similar to an exercise of Becker's (1964 Ch. 6), who estimates the "room" for human-capital externalities in the level of residual TFP growth.

equals 0.054 percent, less than one-fourth of the extent that $g_h + g_A$ projects on 1960 schooling. The next row assumes that A exhibits an elasticity β of ⅓ with respect to h, so increases in h raise the level of technology. Note, however, that it is now necessary to reduce ϕ from 0.46 down to 0.11 in order that growth in human capital not explain more than 100 percent of average $g_h + g_A$. This reduces the impact of 1960 schooling on g_h from 0.054 percent all the way down to 0.002 percent. Even allowing for the indirect impact of g_h on g_A, the total impact of schooling on $g_h + g_A$ is now only 0.003 percent, and is not statistically different than zero. Thus allowing for a positive impact of human capital on technology, because it necessitates lowering the upper bound for ϕ, the impact of elders' human capital, actually reduces the potential ability of schooling differences to explain differences in $g_h + g_A$. The third row of the middle panel considers the largest elasticity of A with respect to h that is possible without driving the parameter ϕ negative. This reinforces the message from the second row. Taking the elasticity to 0.42, and driving ϕ down to 0, makes the measured impact of 1960 schooling on g_h slightly negative. Therefore, even though g_h indirectly raises g_A by 0.42 percent, the combined effect of schooling on $g_h + g_A$ is less than obtained for larger values of ϕ with less of the indirect channel through technology use.

The final panel of Table 3 repeats the exercise for $\psi = 0$ (no curvature). Comparing rows 1 and 2, if we allow g_A to increase by ⅓ percent for each percentage-point increase in g_h, then it becomes necessary to reduce the upper bound on ϕ from 0.67 to 0.35. This reduces the impact of 1960 schooling on g_h by almost one-half (from 0.171 percent to 0.090 percent). It more than offsets the indirect channel of g_h on g_A, reducing schooling's ability to explain country differences in $g_h + g_A$ from 0.171 percent to 0.120 percent. Raising the elasticity of A with respect to h to 0.71, the highest value possible without lowering ϕ below 0, again cuts the impact of schooling on g_h by almost one half to 0.048 percent, resulting in a still lower combined impact of schooling on $g_h + g_A$ of 0.082 percent.

In sum, allowing for a channel from human capital to technology does not alter our conclusion from Section III: differences in growth rates of human capital explain a relatively small fraction of the cross-country relationship between schooling and subsequent growth.

A. *Levels Accounting*

Our focus is on interpreting the strong correlation observed between 1960–1990 growth rates and 1960 levels of schooling. Klenow and Rodríguez-Clare (1997) and Hall and Jones (1999) also employ our approach of using the Mincerian return on schooling to measure human capital across countries, but focus primarily on the relative contributions of human and physical capital versus TFP in cross-country differences in income levels. These papers examine special cases of our human-capital technology: linearity in the Mincer specification ($\psi = 0$) in Klenow-Rodríguez, no intergenerational link in human capital ($\phi = 0$) in Hall-Jones, and no externality from human capital to technology ($\beta = 0$) in either. Both papers attribute greater importance to differences in TFP across countries than to differences in human capital.

We can examine the robustness of the Klenow-Rodríguez/Hall-Jones levels accounting exercise by varying the curvature parameter ψ and allowing for large external effects of schooling either through "teaching" ($\phi > 0$) or technology ($\beta > 0$). As in our calculations from Tables 2 and 3, we restrict the size of these external effects only by the requirement that the implied impact from growth in human and physical capital does not explain more than 100 percent of the average growth in income per worker for 1960 to 1990 for our sample of 85 countries. That is, that there is no technological regress on average for these countries.

The results for various parameter values appear in Table 4. They can be summarized as follows. Regardless of how we specify the production of human capital, we find that differences in physical capital contribute 46 percent of the differences in per capita income. More exactly, conditional on income per worker in 1990 being 1 percent higher than the mean across countries, one should expect ⅓ $\ln(K/L)$ to be 0.46 of 1 percent above the mean across countries. The remaining contribution of 54 percent is similarly attributed to the term ⅔ $\ln(Ah)$. How this 54 percent is attributed to

TABLE 4—CONTRIBUTIONS OF HUMAN CAPITAL AND TFP TO 1990 INCOME PER WORKER

		Fractional contribution to income per worker from†	
		(1)	(2)
		$\frac{2}{3}(1 + \beta)\ln(h)$	$\frac{2}{3}[\ln(A) - \beta\ln(h)]$
	$\beta = 0$, $\phi = 0$	0.169 (0.009)	0.368 (0.019)
$\psi = 0.58$	$\beta = 0$, $\phi = 0.19$	0.220 (0.012)	0.318 (0.021)
	$\beta = 0.15$, $\phi = 0$	0.195 (0.011)	0.342 (0.020)
	$\beta = 0$, $\phi = 0$	0.154 (0.008)	0.383 (0.018)
	$\beta = 0$, $\phi = 0.46$	0.276 (0.016)	0.262 (0.024)
$\psi = 0.28$	$\beta = \frac{1}{3}$, $\phi = 0.11$	0.232 (0.013)	0.305 (0.021)
	$\beta = 0.42$, $\phi = 0$	0.219 (0.012)	0.318 (0.021)
	$\beta = 0$, $\phi = 0.67$	0.142 (0.008)	0.395 (0.018)
	$\beta = 0$, $\phi = 0.67$	0.314 (0.020)	0.223 (0.027)
$\psi = 0$	$\beta = \frac{1}{3}$, $\phi = 0.35$	0.274 (0.016)	0.263 (0.024)
	$\beta = 0.71$, $\phi = 0$	0.243 (0.013)	0.294 (0.022)

Notes: β = elasticity of A (technology) with respect to h (human capital); ϕ = the exponent on teacher human capital in human-capital production; $1 - \psi$ = the exponent on years of schooling in human-capital production.

† The contribution of factor X to income per worker, $\ln(Y/L)$, is defined as $\text{cov}(\ln(Y/L), X)/\text{var}(\ln(Y/L))$, equaling the coefficient from regressing $\ln(Y/L)$ on X. Given that the three factors, $\frac{1}{3}\ln(K/L)$, $\frac{2}{3}(1 + \beta)\ln(h)$, and $\frac{2}{3}[\ln(A) - \beta\ln(h)]$ sum to $\ln(Y/L)$, the contributions of the three factors must sum to one. The contribution from physical capital, $\frac{1}{3}\ln(K/L)$, is estimated at 0.463 with standard error 0.014 across all these specifications for the production and impact of human capital.

human capital (h) and TFP (A) is not overly sensitive to the choice of the curvature parameter ψ. In particular, for the case of no external effects (ϕ and β both zero), the contribution of A is about 2.5 times that for h, regardless of the value of ψ.

Not surprisingly, raising the value of ϕ, the impact of elders' human capital, increases the relative contribution of h. For $\psi = 0.58$, the highest ϕ can be is only 0.19. For this case, the contribution of TFP remains 75 percent larger than that from human capital. For lower values of ψ, ϕ can be higher without average growth in human capital exceeding average growth in Ah. For $\psi = 0.28$, the maximal value for ϕ of 0.46 implies that differences in human capital are comparable in importance to differences in TFP. For $\psi = 0$, it is conceivable to raise ϕ to 0.67, at which point the differences in human capital contribute nearly 50 percent more than differences in TFP.

Similar to the growth exercises in Table 3, allowing for externalities from human capital to technology does not expand the importance of human capital, once we scale back the impact ϕ of elders' human capital to avoid implying technological regress.

As with our discussion of Table 2, we would argue that plausible parameter values would allow for some diminishing returns to schooling and at least very modest technology gains. Suppose we again only require that ψ be within *three* standard deviation of its estimate, so $\psi = 0.13$, and that technological growth contributes at least one-tenth (0.2 percent per year) of the observed average growth in income per worker for these 85 countries. These conditions, which restrict ϕ to 0.34, imply a contribution from human capital of 21.6 percent (standard error of 1.3 percent) and from TFP of 32.1 percent (standard error of 2.1 percent). So differences in TFP are about 50 percent more important than differences in human capital.

V. Estimating the Impact of Expected Growth on Schooling

As we stressed in Section I, our model contains a channel by which higher expected growth in A can induce more schooling. We now calibrate the

model to determine whether this channel is up to the quantitative task of matching the coefficient from the regression of 1960–1990 annual growth in *Ah* on 1960 enrollment [0.23 percent in column (3) of Table 1].

With diminishing Mincerian returns to both schooling ($\psi > 0$) and experience ($\gamma_2 < 0$) and with country-specific expected growth in A, first-order condition (11) from the model says that the privately optimal level of schooling in country j solves

$$(16)\quad 1 + \mu = \zeta(\text{annuity}_j) + \int_{s_j}^{T} e^{(g_{A_j} + \gamma_1 + \gamma_2(a - s_j) - r)(a - s_j)} \times [\theta s_j^{-\psi} - \gamma_1 - 2\gamma_2(a - s_j)]\, da.$$

Here the "annuity" is the annuity value of higher expected growth, that is, how much expected future growth boosts today's consumption relative to today's earnings.[25] Higher expected growth induces more schooling by lowering the effective discount rate and, when $\zeta > 0$, by raising wealth.

Using (16) we construct predicted schooling levels (s_j's) for 93 countries. We then regress actual 1960–1990 g_{Aj} on these predicted schooling levels. We allow the actual 1960 country schooling levels to deviate from the schooling predicted by (16) according to a country-specific error term ω_j. This error term reflects measurement error and omitted factors such as country-specific education subsidies. Suppose that the ω's are orthogonal to 1960–1990 g_A's so that predicted schooling from (16) and growth covary *only* because of the impact of expected growth on schooling. Then adding the ω's would raise the variance of schooling (to its observed variance) without affecting the covariance between schooling and growth, thereby reducing the coefficient obtained by projecting growth on constructed schooling. This is appropriate, however, as it is not meaningful to judge the ability of the reverse channel to generate the observed correlation between schooling and growth if predicted schooling is much less variable than observed schooling levels.[26]

To obtain s_j's and implement this procedure we need measures of expected growth, $E(g_{Aj})$, for each country. We consider three possibilities: that country j anticipated ¼, ⅓, or ½ of its *ex post* 1960–1990 g_{Aj} relative to the world average. That is, we set $E(g_{Aj}) = \frac{1}{4}g_{Aj} + \frac{3}{4}g_{A\text{avg}}$ etc. For example, if Hong Kong averaged 6-percent growth compared to 2-percent growth for the world as a whole over 1960–1990, we consider expected growth in Hong Kong in 1960 to be 3 percent, 3.33 percent, or 4 percent. This would imply that the variance of expected growth is 1/16, 1/9, or ¼ of the variance of realized growth. This seems reasonable in light of the R^2's reported in Table 1, for example, 0.24 for the regression of *Ah* growth on initial schooling enrollment alone.

The last step to obtain s_j's is to set parameter values. The parameter ψ governs the degree of diminishing Mincerian returns to schooling. As we described in Section IV, our point estimate is 0.58. In addition to $\psi = 0.58$ we consider $\psi = 0.28$, two standard deviations below our point estimate. We found that the model implies extreme sensitivity of schooling decisions to changes in parameter values when $\psi = 0$. For example, schooling rises fully one year for each one-year increase in life expectancy.[27] Related to this, if we proceed and set $\psi = 0$ in (16) we find that, despite the model's omission of factors such as country-specific education subsidies, predicted schooling levels vary more than

[25] Specifically, from (11) ζ multiplies $c(s)^{1/\sigma}/(w(s)h(s))$. We set $\sigma = 1$ because the empirical literature provides little guidance on whether it is above or below one. We assume that persistent level differences in per capita income have proportional effects on consumption and earnings, leaving $c(s)/(w(s)h(s))$ unaffected. Differences in expected growth, in contrast, should raise $c(s)$ relative to $w(s)h(s)$ by the annuity value of that growth, i.e., by the factor $1 + r \sum ((1 + g_A)^t - 1)/(1 + r)^t$. We sum over 30 years (growth from 1960–1990), and r is set to match mean predicted and actual schooling levels in 1960.

[26] Because it is orthogonal to g_{Aj}, we need not observe ω_j. We can instead regress g_{Aj} on s_j from (16) (which omits ω_j) and then scale the coefficient down by the variance of s_j relative to the variance of actual 1960 schooling. This is equivalent to including an orthogonal ω_j.

[27] In an earlier version of this paper (Bils and Klenow, 1998) we estimated using cross-country data that schooling rises by only about ⅛ to ¼ of a year for each one-year increase in life expectancy.

actual schooling levels. Thus we report results only for $\psi = 0.58$ and $\psi = 0.28$, for which the variances of predicted schooling fall well short of the variance of actual schooling in 1960.

We use $\theta = 0.323$ when $\psi = 0.58$ and $\theta = 0.176$ when $\psi = 0.28$. These values ensure that the average Mincerian return implied for Psacharopoulos' 56-country sample matches the actual average of 9.9 percent. We set $\gamma_1 = 0.0512$ and $\gamma_2 = -0.00071$, the average Mincerian coefficients on experience and experience-squared across the 52-country sample for which we have such estimates. We set $\mu = 0.5$ so that tuition costs are one-half as large 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 United States, and the idea that students pay one-half of instruction costs. We set life expectancy T equal to its 1960 average over our 93-country sample of 54.5. (We subtract six years from the literal 60.5 average so that, as in the model, schooling begins at age 0.)

We set the wealth effect parameter ζ based on Robert Haveman and Barbara Wolfe's (1995) survey of micro estimates of the effect of family income on schooling attainment. They report a range of elasticities of log years of attainment with respect to log family income of 0.02 to 0.20. We set ζ so that the elasticity in the model (evaluated at the 6.2 years implied by mean 1960 schooling enrollment) is at the upper end of this range, or 0.20. We do this because, as we shall see, the wealth effect turns out to be too weak to generate much of the estimated coefficient of growth on schooling.

Finally, depending on the case (the value for curvature ψ, the share of growth expected, and wealth effect excluded or included), we set the real interest rate r to as low as 0.093 or as high as 0.105 to ensure that average predicted 1960 schooling enrollment matches the actual average of 6.2 for the 93 countries.

Using these parameter values we can calculate the responses of optimal schooling in (16) to changes in expected growth, life expectancy, and the Mincerian return on schooling. Starting at 6.2 years of schooling, a 1-percent higher expected growth rate induces 1.4 more years of schooling when $\psi = 0.58$ and 2.5 more years when $\psi = 0.28$. One more year of life expectancy induces 0.03 and 0.04 more years of schooling, respectively, under the two values of ψ. And a 1-percent-point higher Mincerian return to schooling engenders 1.1 and 1.9 more years in the two cases. Are these responses reasonable? A few studies, Robert J. Willis and Rosen (1979), Richard Freeman (1986), and David Meltzer (1995), have estimated the response of schooling to its Mincerian rate of return. They obtain estimates in the 0.3 to 0.7 range, compared to our calibrated model values of 1 to 2. Thus, even with substantial curvature, our model implies large schooling responses compared to the limited estimates in the literature.

The top panel of Table 5 reports coefficients from regressing 1960–1990 growth rates of A on predicted schooling levels from (16) for the case of curvature $\psi = 0.58$. (All entries in Table 5 are coefficients scaled down to incorporate the ω error terms.) In the first row, with no wealth effect ($\zeta = 0$), the coefficients are 0.10 percent, 0.14 percent, and 0.20 percent. The coefficients are increasing in the fraction of subsequent growth which is anticipated. The more that growth is foreseen, the bigger its effect on schooling and the larger the role of reverse causality. Excluding the ω's, the variance ratios (variances of predicted schooling relative to that of actual schooling) rise from 3 percent to 12 percent across the three columns. The second row in Table 5 repeats the exercise except with a wealth effect ($\zeta > 0$). With this additional effect of expected growth on schooling, the coefficients are higher but very modestly so (less than 0.02 percent higher). All of the coefficients in the top panel of Table 5 fall short of the empirical coefficient of 0.23 percent, but they suggest that more than one-third of the empirical relationship could reflect reverse causality.

The bottom panel of Table 5 reports coefficients for the case of $\psi = 0.28$. Since diminishing Mincerian returns to schooling mitigate the impact of expected growth on schooling, less diminishing returns (a smaller ψ) means a larger reverse channel. With no wealth effect, the coefficients are 0.21 percent, 0.28 percent, and 0.41 percent (with variance ratios of 13 percent, 23 percent, and 52 percent when the ω's are omitted). Again, even a large wealth effect makes a minor contribution, boosting the coefficients less than 0.02 percent.

Table 5 shows that, for plausible parameter values, the reverse causality channel is strong

TABLE 5—CALIBRATED REVERSE CAUSALITY CHANNEL

		(1) Expected growth $= \frac{1}{4} g_{Aj} + \frac{3}{4} g_{Aavg}$	(2) Expected growth $= \frac{1}{3} g_{Aj} + \frac{2}{3} g_{Aavg}$	(3) Expected growth $= \frac{1}{2} g_{Aj} + \frac{1}{2} g_{Aavg}$
$\psi = 0.58$	No wealth effect ($\zeta = 0$)	0.101 percent	0.135 percent	0.201 percent
	With a wealth effect ($\zeta > 0$)	0.119	0.151	0.214
$\psi = 0.28$	No wealth effect ($\zeta = 0$)	0.208	0.276	0.406
	With a wealth effect ($\zeta > 0$)	0.227	0.293	0.420

Notes: Dependent variable: Average annual 1960–1990 growth rate of A.

Right-hand-side variables: 1960 schooling predicted by the model. Schooling s predicted by the model solves $1 + \mu = \zeta(\text{annuity}) + \int_s^T e^{(g_A + \gamma_1 + \gamma_2(a-s) - r)(a-s)}[\theta s^{-\psi} - \gamma_1 - 2\gamma_2(a - s)]\, da$.

$1 - \psi =$ the exponent on years of schooling in human-capital production.

Other parameter values: $\theta = 0.323$ or 0.176, depending on ψ (so that Mincerian return averages 9.9 percent average across 56 countries).

$\gamma_1 = 0.0512$, $\gamma_2 = -0.00071$ (average coefficients in Mincerian returns to experience across 52 countries).

$\mu = 0.5$ (student-paid instruction costs relative to the opportunity cost of student time).

$r = 0.093$ to 0.105 (ensures predicted 1960 schooling matches the actual average of 6.2 for 93 countries).

$T = 54.5$ (average life expectancy 60.5 from Barro and Lee [1993] minus the six years before school).

$\zeta =$ (value which generates an income elasticity of schooling of 0.20 as in Haveman and Wolfe, 1995).

$g_{Aavg} = 0.0151 =$ the average growth rate across the 93 countries from 1960–1990.

Coefficients are scaled by the variance of predicted schooling relative to the variance of 1960 schooling.

enough to generate the empirical coefficient of 0.23 percent in the absence of any effect of schooling on the growth rate. The qualifier on these Table 5 results is that they reflect a demand for schooling that is considerably more responsive to schooling's Mincerian return than implied by several micro studies.

VI. 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. Using evidence from the labor literature and historical attainment data from UNESCO (1977, 1983), we calibrate a model to determine how much of this relationship reflects causality running from schooling to growth. We find that the channel from schooling to growth is too weak to plausibly explain more than one-third of the observed relation between schooling and growth. This remains true even when we take into consideration the effect of schooling on technology adoption. Thus our primary conclusion is that the bulk of the empirical relationship documented by Barro and others should not be interpreted as reflecting the impact of schooling on growth.

We also calibrate a model channel from expected growth to schooling. We find that this channel is capable of generating much of the empirical coefficient (even assuming most of realized growth is unexpected). Another important consideration, however, is that part of the relation between schooling and growth may reflect omitted factors that are related both to schooling rates in 1960 and to growth rates for the period 1960 to 1990. Identifying the nature and importance of any such factors is a subject for further study.

Appendix A: 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 20 to 59 for both 1960 and 1990. We then weight these age-specific human capitals into aggregates for 20- to 59-year-olds using data on population weights by age from the United Nations (1994).

As discussed in Section III, 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:

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

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). We set $\psi = 0.58$. 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: $\psi = 0.28$, which represents our point estimate for ψ minus two standard errors of the estimate, and $\psi = 0$. We then set θ to match the average return to schooling of 9.9 percent across the 56 countries. We choose the parameters γ_1 and γ_2 to yield the average experience-earnings profiles observed for a 52-country sample for which we have profile slope estimates (Appendix B). This requires respective values for γ_1 and γ_2 of 0.0512 and -0.00071. (For $\phi > 0$ the parameter γ_1 must be revised upwards modestly to maintain the steepness of experience-earnings profiles in the presence of rising school quality.)

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 20-year-olds for the years 1970 to 1990 from data on primary, secondary, and higher enrollment rates in the Barro-Lee (1993) data. For prior to 1970 we construct a series for educational attainment 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 (1977, 1983), *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 (1991) 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+. We do not use age categories below age 20 or above age 65. (For countries with nontrivial higher education, a number of 20-year-olds may have not completed their formal schooling. In these cases we measure the attainment of 20-year-olds in year t by the attainment of 25-year-olds in year $t + 5$.) We then project back in time to construct a history of attainments of 20-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 20 in midyear 1910. Therefore we

set attainment of a 20-year-old in mid-1910 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 20-year-old in mid-1920, 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 Barro-Lee enrollment rates and the UNESCO censuses we are able to construct attainment of 20-year-olds for as many as 12 different dates ranging from 1990 back to as early as 1906. More exactly, we were able to construct attainment back to 1935 or before for 55 countries, to 1925 or before for 32 countries, and to 1915 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 1955 and after, one for 1925 to 1955, and a third for prior to 1925. For 1955 and after we backcast using the equation $\ln[s(20, t)] = 1.0216 \ln[s(20, t + 1)] - 0.0706$. This equation is consistent with the results of regressing attainment of 20-year-olds in 1955 on attainment of 20-year-olds in 1985 for the countries where both series are available. Similarly, for 1925 to 1955 we use an equation $\ln[s(20, t)] = 1.0047 \ln[s(20, t + 1)] - 0.0226$, which is based on regressing 1925 attainment on 1955 attainment. The coefficient in this latter equation is not significantly different from one. Based on that, prior to 1925 we simply assume that attainment decreases by 1.77 percent per year. This is the average rate of increase for the years 1925 to 1955.

The outcome is that we are able to construct human-capital stocks for 1960 and 1990 for 85 of the 93 countries used in the basic growth regression in column (1) of Table 1. For 55 of these countries these stocks reflect information on enrollments going back at least as far as 1940.

Appendix B

Table B1—52-Country Sample of Mincer Regression Coefficients

Country	Experience	Experience^2	Schooling	Year	Number of observations	Reference
Argentina	0.052	−0.00070	0.107	1989	2965	P
Australia	0.064	−0.00090	0.064	1982	8227	P
Austria	0.039	−0.00067	0.039	1987	229	P
Bolivia	0.046	−0.00060	0.073	1989	3823	P
Botswana	0.070	−0.00087	0.126	1979	492	P
Brazil	0.073	−0.00100	0.154	1989	69773	P
Britain	0.091	−0.00150	0.097	1972	6873	P
Canada	0.025	−0.00046	0.042	1981	4642	P
Chile	0.048	−0.00050	0.121	1989	26823	P
China	0.019	−0.00000	0.045	1985	145	P
Colombia	0.059	−0.00060	0.145	1989	16272	P
Costa Rica	0.042	−0.00050	0.105	1989	6400	P
Côte d'Ivoire	0.053	−0.00008	0.207	1985	1600	P
Cyprus	0.092	−0.00140	0.098	1984	3178	P
Denmark	0.033	−0.00057	0.047	1990	5289	R&S
Dominican Republic	0.055	−0.00080	0.078	1989	436	P
Ecuador	0.054	−0.00080	0.098	1987	5604	P
El Salvador	0.041	−0.00050	0.096	1990	4094	P
Greece	0.039	−0.00088	0.027	1985	124	P
Guatemala	0.044	−0.00060	0.142	1989	8476	P
Honduras	0.058	−0.00070	0.172	1989	6575	P
Hungary	0.034	−0.00059	0.039	1987	775	P
India	0.041	−0.00050	0.062	1981	507	P
Indonesia	0.094	−0.00100	0.170	1981	1564	P
Ireland	0.061	−0.00100	0.079	1987	531	C&R
Israel	0.029	−0.00046	0.057	1979	1132	P
Italy	0.010	−0.00027	0.028	1987	197	P
Jamaica	0.083	−0.00110	0.280	1989	1172	P
Kenya	0.044	−0.00200	0.085	1980	1600	A&S
South Korea	0.082	−0.00140	0.106	1986	4800	P
Malaysia	0.013	−0.00004	0.094	1979	605	P
Mexico	0.084	−0.00100	0.141	1984	3425	P
Morocco	0.068	−0.00070	0.095	1970	2422	P
Netherlands	0.035	−0.00049	0.066	1983	1888	P
Nicaragua	0.050	−0.00080	0.097	1978	962	P
Pakistan	0.106	−0.00060	0.097	1979	1568	P
Panama	0.066	−0.00080	0.126	1989	5436	P
Paraguay	0.058	−0.00090	0.103	1989	1084	P
Peru	0.053	−0.00070	0.085	1990	1625	P
Philippines	0.023	−0.00060	0.119	1988	4283	P
Poland	0.021	−0.00036	0.024	1986	5040	P
Portugal	0.025	−0.00040	0.094	1985	21823	P
Singapore	0.062	−0.00100	0.113	1974	1247	P
Spain	0.049	−0.00060	0.130	1990	635	AR&S
Sweden	0.049	−0.00000	0.026	1981	2996	A
Switzerland	0.056	−0.00069	0.072	1987	304	P
Tanzania	0.041	−0.00100	0.067	1980	1522	A&S
Thailand	0.071	−0.00088	0.091	1971	3151	C
Uruguay	0.051	−0.00070	0.090	1989	6567	P
United States	0.032	−0.00048	0.093	1989	8118	K&P
Venezuela	0.031	−0.00030	0.084	1989	1340	P
West Germany	0.045	−0.00077	0.077	1988	2496	K&P

Sources: A = Mahmood Arai (1994)
A&S = Jane Armitage and Richard Sabot (1987)
AR&S = Alfonso Alba-Ramirez and Maria Jesus San Segundo (1995)
C = Carmel U. Chiswick (1977)
C&R = Tim Callan and Barry Reilly (1993)
K&P = Alan B. Krueger and Jörn-Steffen Pischke (1992)
P = Psacharopoulos (1994)
R&S = Michael Rosholm and Nina Smith (1996).

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