Human Capital, Ideas, and Economic Growth

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June 14, 1996 – Version 1.00
Preliminary—Comments Welcome

Abstract

This paper presents a simple model of human capital, ideas, and economic growth that integrates contributions from several different strands of the growth literature. The model generates a regression specification that is very similar to that employed by Mankiw, Romer and Weil (1992), but the economics underlying the specification is very different. In particular, the model emphasizes the importance of ideas and technology transfer in addition to capital accumulation. The model suggests that cross-country data on educational attainment is most appropriately interpreted from the macro standpoint as something like an investment rate rather than as a capital stock. Finally, this setup helps to resolve a puzzle recently highlighted by the empirical growth literature concerning human capital and economic growth by following Bils and Klenow (1996) in emphasizing a relationship between wages and educational attainment that is consistent with Mincerian wage regressions.

I would like to thank the Center for Economic Policy Research at Stanford and the National Science Foundation (SBR-9510916) for financial support.

Prepared for the VIII Villa Mondragone International Economic Seminar on Finance, Research, Education, and Growth in Rome on June 25-27, 1996.

1 Introduction

This paper develops and analyzes empirically a simple model of human capital, ideas, and economic growth that integrates contributions from several different strands of the growth literature. These strands, and a discussion of what I try to emphasize in the paper, are outlined below.

- *Romer (1990) and the Research-Based New Growth Theory.* The recent advances in new growth theory emphasize the importance of ideas, nonrivalry, and imperfect competition for understanding the engine of economic growth. Romer (1993) argues that these issues may also be important for understanding economic development. Nelson and Phelps (1966) provide a way of thinking about technology transfer that incorporates both human capital and advantages to "backwardness."

- *Mankiw et al. (1992) (MRW).* MRW show that a simple neoclassical model can explain up to 80% of the cross-country variation in the log of per capita GDP, especially if it incorporates differences in human capital investment across countries.

- *Barro and Lee (1993) and Bils and Klenow (1996).* Barro and Lee provide an extensive panel data set on educational attainment for a large number of countries. Bils and Klenow argue for including educational attainment in a model in a way that is consistent with Mincerian wage regressions.

- *Benhabib and Spiegel (1994), Islam (1995), Pritchett (1996), and Judson (1996).* These papers document in various ways a puzzle involving the relationship between human capital and economic growth. The puzzle appears when one looks at a growth-accounting approach that involves variables like the Barro and Lee (1993) human capital stocks.

> In either simple or multivariate regressions of the growth rate of output on the growth rate of the human capital stock, the human capital stock appears with a negative coefficient.

Weitzman (1996) suggests that a useful analogy for understanding the research process is a child's chemistry set: research proceeds by taking various elements (various ideas) and joining them together. Most combinations are useless, but a few combinations are extremely valuable. In this paper, I consider the various elements of the growth literature just outlined and combine them together in a particular —and hopefully valuable!—way.

Several insights emerge from this combination. First, even though the model emphasizes the importance of ideas and research, one can derive an empirical specification from the model that is nearly identical to the regression estmated by Mankiw et al. (1992). The MRW level regressions are a very useful way to organize one's thinking about why different countries achieve different levels of income, but the specification says very little, I think, about the importance of a "neoclassical" growth model versus a growth model based on imperfect competition and ideas.[1]

Second, many authors have interpreted the Barro and Lee (1993) data on educational attainment as measuring the stock of human capital per person in an economy. In the model presented here, the most natural interpretation of the Barro and Lee (1993) educational attainment data is as something like a rate of investment in human capital rather than as a human capital stock. More precisely, these data correspond to the fraction of an individual's time endowment that is spent accumulating skills. Unlike the physical capital stock or the capital stock per person, this variable is constant along a balanced growth path. This has implications for how these data are used in growth accounting exercises.

[1] Barro and Sala-i-Martin (1995) and Bernard and Jones (1996) make a similar point with respect to the convergence literature.

Third, the empirical estimation of the level regression derived from the model verifies several of the results found by Mankiw et al. (1992). However, the fit of the model is far from perfect, suggesting that an important feature of the technology transfer process is not captured by the model that is presented. I discuss some avenues for future research that I am pursuing in order to address this issue.

Finally, the setup considered here provides one possible resolution of the human capital puzzle mentioned earlier. In particular, the formulation of the model suggests that it is not the growth rate of the educational attainment variable that belongs in the specification, but rather the change in the level. Regressions that follow this approach look remarkably similar to the MRW-style level regressions in which the educational attainment variables show up strongly.

The paper is organized as follows. Section 2 presents the basic model, integrating several strands of the growth literature. Section 3 considers the empirical applications of the model, and Section 4 concludes.

2 The Model

2.1 Production

Three kinds of goods are produced in the economy: a consumption good ("output"), a human capital good ("experience" or "skill"), and new varieties of intermediate capital goods ("ideas").[2]

Output Y is produced by competitive firms using labor L_Y and a collection of intermediate capital goods x_i. The amount of human capital per person in the firm determines the range of intermediate capital goods that the firm can use. That is, human capital in this model is interpreted as skill or experience in using advanced intermediate goods. The production

[2] The model in this section draws heavily on Jones (1996).

function for a firm employing workers of average skill h is

$$Y(t) = L_Y(t)^{1-\alpha} \int_0^{h(t)} x_i(t)^{\alpha}\, di, \tag{1}$$

where $0 < \alpha < 1$, so that a firm with skill level h faces constant returns to scale in production. This kind of specification differs from that used in Romer (1990) in that the range of goods that can be used by a firm has both a nonrivalrous and a rivalrous component: the intermediate good must have been invented, and the workers in the firm must have learned to use the intermediate good.[3] Because there are constant returns to scale, given h, and because individuals in this economy are identical, we can focus on a single, competitive representative firm.

As an alternative to producing output, individuals can spend their time acquiring skills. That is, they can learn to use more advanced intermediate capital goods. Activities such as on-the-job training, education, and apprenticeships are all examples of skill acquisition. Individuals accumulate human capital according to

$$\dot{h}(t) = \mu e^{\theta u(t)} h(t) \left(\frac{A(t)}{h(t)}\right)^{\gamma}. \tag{2}$$

In this equation, $u(t)$ is the fraction of an individual's labor endowment spent accumulating human capital, μ is an arbitrary positive constant, and $A(t)$ represents the technological frontier, i.e. the total measure of intermediate goods that have been invented to date.

Equation (2) can be motivated in several ways. The equation is similar to the specification employed by Lucas (1988), particularly if the last term is ignored. Lucas favored a specification that was linear in h so that the model generated endogenous growth. The last term of equation (2) imposes curvature on the model, rendering it less than linear in h. With $\gamma > 0$, the

[3] Similar specifications have been employed by Ciccone (1996) and Easterly, King, Levine and Rebelo (1994).

equation incorporates an advantage to "backwardness" as in Gerschenkron (1952). The curvature implies that it is easier to learn to use intermediate goods that are further from the frontier; goods close to the frontier are harder to master. More generally, the notion that time spent acquiring skills and "backwardness" interact to affect the level of productivity in an economy dates back at least to Nelson and Phelps (1966).

Another motivation for the specification in (2) is that it is consistent with microeconomic evidence on the relationship between wages and schooling or experience. According to Mincer (1974), an additional year of schooling or an additional year of experience should increase wages proportionally. That is, the relationship between wages and schooling or experience is a semi-log form. Equation (2) shares this property, as we will see shortly. Bils and Klenow (1996) emphasize this microeconomic regularity in building a model of human capital and growth.[4]

In order for individuals to learn to use an intermediate good, the design for the intermediate good must have been invented. In thinking about the production of "ideas" in this economy, it is useful for the moment to interpret the model as one of a large, advanced closed economy. Later, we will discuss the model's implications for idea flows across countries. The production function for ideas is given by

$$\begin{aligned} \dot{A}(t) &= \tilde{\delta} h(t)^{\beta} L_A(t) \\ &\equiv \delta h(t)^{\beta} L_A(t) A(t)^{\phi}. \end{aligned} \tag{3}$$

This production function follows the modification in Jones (1995) of the Romer (1990) specification. Units of labor L_A produce ideas based on their skill, with elasticity $\beta > 0$. The productivity of a skill-adjusted unit of labor, $\tilde{\delta}$, is an increasing function of the existing stock of ideas ($\phi > 0$).

[4]Their specification is one in which e^{rN} explictly enters the production function for final output, where N is years of schooling.

This incorporates an intertemporal knowledge spillover into the model.[5]

A feature of this equation not in Jones (1995) is that the skills of individuals augment their ability to produce ideas, apart from knowledge spillovers. One can interpret the difference as follows: h^β captures the effects of past knowledge on future production of ideas that can be "internalized" while A^ϕ captures the knowledge spillovers that are external in society. The effect of education increasing an individual's abilities, either in research or in the production of output, is potentially internalized either by markets or by forward-looking individuals. On the other hand, the invention of the laser and just-in-time production presumably generate spillovers into future research that the inventors are unable to capture.

2.2 Factor Accumulation

Capital K is accumulated by foregoing consumption and is measured in units of the output good:

$$\dot{K}(t) = s_K(t)Y(t) - dK(t), \tag{4}$$

where s_K is the investment share of output (the rest going to consumption) and $d > 0$ is some constant exponential rate of depreciation.

Units of an intermediate capital good x_i are created one-for-one with units of raw capital. To simplify the setup, we assume this transformation is effortless and can also be undone effortlessly. Thus,

$$\int_0^{h(t)} x_i(t)\ di = K(t). \tag{5}$$

Intermediate goods are treated symmetrically throughout the model, so that $x_i(t) = x(t)$ for all i. This fact, together with equation (5) and the production function in (1) implies that the aggregate production technology for

[5] Other effects, such as a duplication externality, can be included as well. See Jones (1995) and Jones and Williams (1996).

this economy takes the familiar Cobb-Douglas form

$$Y = K^{\alpha}(hL_Y)^{1-\alpha}, \tag{6}$$

where we have suppressed time subscripts (which we will continue to do when the meaning is clear).

The fundamental factor of production in this model is labor, and we have already described its various uses. The total quantity of labor in the economy is given by $L(t)$, which is assumed to grow exogenously at rate $n > 0$.[6] The labor market clearing condition is

$$L_Y + L_h + L_A = L, \tag{7}$$

where $L_h \equiv uL$.

To summarize, the structure of the model is the following. An individual accumulates skills h which represent the range of intermediate goods that the individual has learned to use. The individual then spends time either producing the consumption/capital good Y, accumulating additional skills, or searching for new designs of intermediate goods. Individuals accumulate capital to smooth consumption, and the population of the economy grows exogenously at rate n.

2.3 The Allocation of Resources

The resource allocation decisions in this economy involve the allocation of labor over time and the division of output into consumption and investment over time. Romer (1990) describes how the market can be used to allocate resources in this economy only in the presence of imperfect competition, and a similar approach could be taken here. Intermediate goods firms own the exclusive rights to sell their particular varieties and operate in a monopolistically competitive environment. Researchers prospect for new ideas and

[6]In terms of human capital, we assume that new units of labor are automatically endowed with the average skill level in the economy.

are rewarded for their efforts with the present discounted value of the flow of profits that can be earned in the intermediate goods sector.

An allocation decision that is not present in Romer (1990) is the decision of how much time to spend learning to produce with new varieties of intermediate capital goods. One can model this decision as being taken by forward-looking individuals who either recognize or do not recognize that learning to use a new variety has dynamic effects on future skill acquisition. In the second case, the amount of time spent accumulating skills will typically be suboptimal.

In this paper, we choose not to spend additional time developing the market allocation of resources. Instead, we will assume that these allocations—i.e. s_K, u, L_A/L, and L_Y/L—are exogenously given. This can be justified, for example, by appealing to taxes and institutions outside the model that impinge on the forward-looking setup to deliver allocations that are (at least asymptotically) constant. We take these allocations as given and then ask what the steady state of the model looks like.

2.4 Steady State Analysis

The steady state of the model is most easily described by considering the production function for ideas. Rewriting equation (3) in terms of growth rates,

$$\frac{\dot{A}}{A} = \delta \left(\frac{h}{A}\right)^{\beta} \frac{L_A}{A^{1-\beta-\phi}}. \tag{8}$$

In steady state, the growth rates of A and h are constant and equal.[7] Therefore, the ratio h/A is constant, and a balanced growth path requires the numerator and denominator of the last term in equation (8) to grow at the same rate. Therefore,

$$g_A = \frac{n}{1-\beta-\phi}, \tag{9}$$

[7] The steady state of the model is stable, as can be shown by examining the dynamics of the model.

where the notation g_x will be used to denote the constant growth rate of placeholder x, and we have used the fact that the share of labor devoted to research is constant.

Equation (9) is the human capital-augmented version of a result in Jones (1995). A balanced growth path for the model with a growing population exists only if $\beta+\phi<1$. This condition implies that the differential equation governing the production of ideas is less than linear and leads to a "semi-endogenous" growth model. Although technological progress is endogenized, the model exhibits no long-run per capita growth unless the population is growing over time.

Analysis of the production function in equation (6) and the capital accumulation equation in (4) reveals that along the balanced growth path

$$g_y = g_k = g_h = g_A \equiv g, \tag{10}$$

where $y \equiv Y/L_Y$ and $k \equiv K/L_Y$.[8] Because of the labor-augmenting nature of technological change in the model, per capita (or per worker) growth rates are all equal to the rate of technological progress.

Further analysis of these equations allows us to solve for the level of output per worker in the final goods sector:

$$y^*(t) = \left(\frac{s_K}{n+g+d}\right)^{\alpha/(1-\alpha)} \left(\frac{h}{A}\right)^* A^*(t), \tag{11}$$

where we have used the superscript asterisk (*) to denote the balanced growth path.

Moreover, from the production function for skills in equation (2), the ratio of skills to ideas along a balanced growth path is given by[9]

$$\left(\frac{h}{A}\right)^* = \left(\frac{\mu}{g}e^{\theta u}\right)^{1/\gamma}. \tag{12}$$

[8] It turns out to be convenient to think about output per worker in the final goods sector rather than output per member of the labor force. For example, much international data doesn't include time spent in education in the labor force data.

[9] We require $\mu < ge^{-\theta}$ to guarantee that h/A is less than unity.

Combining these last two equations,

$$y^*(t) = \left(\frac{s_K}{n+g+d}\right)^{\alpha/(1-\alpha)} \left(\frac{\mu}{g} e^{\theta u}\right)^{1/\gamma}. \tag{13}$$

This last equation makes clear the appeal of entering time spent accumulating skill in an exponential form. Increases in the level of u will have proportional effects on labor productivity and wages, thus matching evidence from Mincerian wage regressions.

2.5 Comparisons to Previous Work

1. Jones (1995) and Romer (1990). The model illustrates how one can add human capital to the model of Jones (1995) without changing the basic results. In the extended model, standard policies such as investment tax credits, subsidies to R&D, or subsidies to skill acquisition — at least to the extent that we think of them as permanent increases in the rate of investment, the share of labor devoted to R&D, or the amount of time spent accumulating skill — have *level* effects but no long-run growth effects in the model. This results from fundamental lack of linearity in the production equation for ideas, and as in Jones (1995), this lack of linearity is a necessary condition for the existence of a balanced growth path in the presence of population growth.

This result can be overturned, but only by making arbitrary assumptions about the strength of externalities in appropriate places. For example, one could set $\gamma = 0$ and have human capital be an input into the production of ideas but not into the production of output (so that designs can be used immediately after they are created). Segerstrom (1995) follows this approach, and the linearity of the human capital equation generates endogenous growth, as in Lucas (1988). However, the linearity of the human capital accumulation equation is then somewhat arbitrary, and the endogenous growth arises from human capital accumulation, not from research.

2. Jovanovic (1995) and "Scale Effects". Jovanovic (1995) emphasizes the importance of adoption costs relative to research costs. He argues that if there are costs proportional to the size of the population that must be paid in order to implement ideas that these costs will asymptotically swamp any fixed cost of creating the ideas. This approach might call into question the significance of "scale effects" and the importance of thinking about the nonrivalrous nature of ideas.

The model in this paper incorporates both an adoption cost (skill acquisition) and the nonrivalrous nature of ideas. However, the model still contains a "scale effect" and it is still important to recognize the nonrivalrous nature of ideas.

Consider first the issue of "scale effects." Suppose there are two nearly-identical economies of the kind described in this paper. The economies are not allowed to interact or share ideas (for example, they are on opposite sides of the universe). The only difference between the two economies is that one has a much larger population than the other. Starting from the same initial conditions, it is obvious that the larger economy must grow more rapidly in the short-run, and this transition effect leads the larger economy to be richer in the long-run, when both economies are growing at the same rate. This can be seen most easily by considering the production function for ideas in equation (3).

Is this kind of "scale effect" relevant to the countries of the planet earth? Clearly, an issue that complicates matters is the fact that countries in the world share ideas. Moreover, casual empiricism suggests that scale is at most one among many important factors. For example, China is much poorer than Hong Kong. In the next section, I will discuss interpreting this model in the context of a multi-country setting, and the particular version considered will not exhibit scale effects. However, a more detailed model in Jones (1996) still exhibits scale effects in a multi-country setting.

What about the importance of the nonrivalrous nature of ideas—does this become negligible in the presence of adoption costs that grow with the population? The answer to this question is surely in the negative, and the argument follows Romer (1990). With a nonrival input, all factors cannot be paid their marginal product, so that imperfect competition must be introduced into the model. Intermediate goods will be priced above marginal cost, with a markup that depends, for example, on the elasticity of substitution between intermediate goods. None of this changes as a result of adding another rivalrous factor (the training of labor) to the model.

3. Mankiw et al. (1992). The result derived in equation (13) is very similar to the result derived by Mankiw et al. (1992) for the human capital-augmented Solow model. A country is richer along its balanced growth path the higher is its investment rate in physical capital s_K, the higher is its investment rate in human capital u, the lower is its rate of population growth n, and the higher is its level of technology A.

However, the model underlying this result is very different. The MRW approach builds on a Solow model with exogenous technological progress. There is no research, no nonrivalry, no imperfect competition, and no learning to use newly-invented technologies. This suggests that macro evidence of the kind presented in their paper cannot distinguish between a "neoclassical" growth model and an R&D-based growth model. Additional evidence must be brought to bear in order to make this distinction.

2.6 Interpreting the Model with Many Countries

Up until now, we have been interpreting the model primarily as one of a large, advanced closed economy that grows by pushing out the technological frontier. In order to apply this model to a cross-section of countries, we must discuss the important issues of how ideas flow between economies and which economies decide to engage in research. To push our model as far as possible, we will make another simplifying assumption, motivated in part by what we have already developed. We assume that the world consists of a large number of relatively small economies. This is really the opposite of the assumption we have maintained so far, so it allows us to explore a different extreme. The economies will be small in the sense that the effect of an individual economy's research on the state of the world technological frontier is small, and in fact we will ignore this effect empirically. From an individual economy's perspective, the world technological frontier is expanding exogenously at rate $g \equiv g_A$ given by equation (9). We also assume that the amount of research undertaken in any single economy is small.

Under this assumption, the skill-acquisition equation (2) becomes a technology transfer equation. In order to use a technology that has been invented somewhere in the world, a country must learn the skills associated with that technology. Although from the standpoint of the *invention* of ideas, knowledge is nonrivalrous but partially excludable, from the international standpoint of technology transfer, it may be a useful starting point to assume that technology is a public good. That is, a developing country sees a new technology being used in the OECD, and that technology is like a public good. Provided the developing country can learn to use the technology, it need not pay for the invention itself.[10]

In the next section, we will discuss the empirical implications of the model. One can interpret the empirical results as describing how far the simplifying assumptions made in this model can go in terms of explaining the cross-section distribution of income.

[10]This approach implies large international knowledge spillovers of the kind explored recently by Coe, Helpman and Hoffmaister (1995). Eaton and Kortum (1995) provide a more detailed analysis of how ideas might be transferred across advanced economies.

3 Empirical Applications

Three empirical applications of the model are considered. First, we address an important question of interpretation that has been overlooked by the empirical growth literature. The question is how to map data on educational attainment into our growth models. Second, we consider the empirical estimation of equation (13), as in Mankiw et al. (1992), emphasizing our underlying model's focus on research and technology transfer. Finally, we analyze a question recently raised in empirical growth literature concerning the relationship between human capital and growth. As phrased in the title of Pritchett (1996), "Where has all the education gone?".

3.1 Years of Schooling: Stocks or Flows?

How to measure human capital has been one of the difficult questions faced by the empirical growth literature. Various authors have employed data on literacy rates, school enrollment rates, and public expenditures on education. Recently, however, Barro and Lee (1993) have assembled data on average educational attainment (i.e. years of schooling) per adult in the population for a large number of countries at five year intervals going back to 1960.[11] This data has been used in a number of recent studies, including Islam (1995), Barro (1996), Pritchett (1996), and Judson (1996). In these studies, the practice has been to interpret the average educational attainment data as a measure of the stock of human capital per person in the economy.[12] This practice presumably is carried over from the labor economics literature

[11] More sophisticated approaches exist as well. For example, Judson (1996) computes a value of the human capital stock by weighting years of educational attainment by the cost of various levels of education. Jorgenson and Fraumeni (1992) and Mulligan and Sala-i-Martin (1994) use wage differentials between educated and uneducated labor to infer values of stocks of human capital.

[12] This practice extends beyond the Barro and Lee data set. For example, Benhabib and Spiegel (1994) interpret alternative measures related to educational attainment as stocks of human capital.

in which individuals accumulate "stocks" of human capital that augment their wages for a lifetime.

From the standpoint of the macroeconomic analysis of income and growth, however, I believe this interpretation is incorrect. Instead, the educational attainment data is more appropriately interpreted as a flow variable similar to an investment rate rather than as a capital stock. Educational attainment per person is plausibly thought of as a constant, at least asymptotically. For example, one might think that average educational attainment in the U.S. will eventually level off at something like 14 years of schooling per person. In contrast, the physical capital stock per person grows over time (e.g. because of technological progress). The most natural mapping of the educational attainment data into models of economic growth is as the time an individual spends accumulating human capital. Taken as a fraction of an individual's total time endowment, this data corresponds to the variable u in the model outlined in the previous section.

It is difficult to judge how much of a problem interpreting educational attainment as a stock of human capital is in the empirical growth literature. In cross-country growth regressions such as Barro (1996), it is plausible to reinterpret the log of average educational attainment as (the log of) an investment rate. The regression variable then proxies (perhaps with other variables) for the steady state level of income as in Mankiw et al. (1992) and makes sense in terms of "conditional convergence." On the other hand, in growth-accounting regressions such as those employed by Benhabib and Spiegel (1994) and Pritchett (1996) the interpretation may be more difficult. In these papers, the estimation is motivated by log-differentiating the production function. That is, output growth is regressed on the growth rates of the physical capital stock, the human capital stock, and the labor force. Asymptotically, however, the human capital stock should stop growing if it is measured by the average educational attainment of the labor force, and it is unclear how to interpret the results of the regression in this context.

3.2 Level Regressions

With this as background, we can now proceed to estimating equation (13). First, however, consider the equation in logarithmic form:

$$\begin{aligned} \log y^*(t) = & \log \quad A^*(t) + \frac{1}{\gamma}\log\frac{\mu}{g} + \frac{\alpha}{1-\alpha}\log s_K \\ & - \quad \frac{\alpha}{1-\alpha}\log(n+g+d) + \frac{\theta}{\gamma}u \end{aligned} \tag{14}$$

As specified, the equation does not contain an error term. We will introduce one in two ways. First, we will assume that all countries are on their steady state balanced growth paths. To the extent that they are not, this will be captured by an error term. Second, according to the model, all differences in labor productivity are accounted for by physical investment rates, population growth rates, and time spent learning about the technologies available in the world. To the extent that the model is misspecified, we will find large residuals. We will exploit this argument below as a "test" of the model.

In general, there is no reason to suppose that these sources of the error term are uncorrelated with the variables on the right-hand-side of equation (14). However, we will proceed with ordinary least squares to see what kind of relationships the data and the model together suggest.

The data used to estimate equation (14) are primarily taken from the Penn World Tables Mark 5.6 of the Summers and Heston (1991) data set. For $\log y^*$ we use the log of real GDP per worker for 1990.[13] For s_K we use the average investment rate from 1980 to 1990.

[13]Recall that according to the model, the appropriate variable is output per wokrer in the final goods sector. Because time spent in school is not counted in the labor force, this is a reasonable measure. Also, we are ignoring labor employed in research. Since the measured shares of labor in research are quite small, even in advanced countries, this is probably inconsequential.

To measure u, one would ideally prefer a measure that includes on the job training as well as time spent in the formal education sector. However, this data does not seem to be available for a large number of countries. Therefore, we measure u using the average educational attainment variable from Barro and Lee (1993), including primary, secondary, and tertiary education. Data is reported at five year intervals from 1960 to 1985, and we use the average of the 1980 and 1985 observations.

To compute u, one needs to divide educational attainment by the average time endowment of individuals in years. Instead of picking an arbitrary number, we instead simply use educational attainment as the independent variable so that the average time endowment is included in the coefficient.[14] We will use the notation N for the average educational attainment in years.

Table 1 reports the results of estimating equation (14). As the regression is very similar to the one implemented by Mankiw et al. (1992), the basic results are familiar. In a large sample of countries, a simple specification involving physical investment rates, population growth rates, and a human capital investment rate can explain a large fraction of the variation in (log) output per worker across countries. Here, the $\bar{R}^2$ is 0.713. In addition, the estimate of α, the elasticity of the production function with respect to physical capital, is 0.344, which agrees quite well with evidence from income shares and other empirical studies.

Interpreting the coefficient on u is more complicated. In terms of the parameters of the model, the coefficient is θ/γ divided by the average time endowment (lifetime) of an individual. A more direct interpretation is the econometric one: an increase in average educational attainment of one year raises output per worker by approximately twenty percent. In terms of standard deviations, a one standard deviation increase in average educational attainment is associated with an increase in $\log Y/L$ of 0.56 standard devia-

[14]Notice that the levels specification cannot separately identify θ and γ anyway.

Table 1: Level Regression, 1990

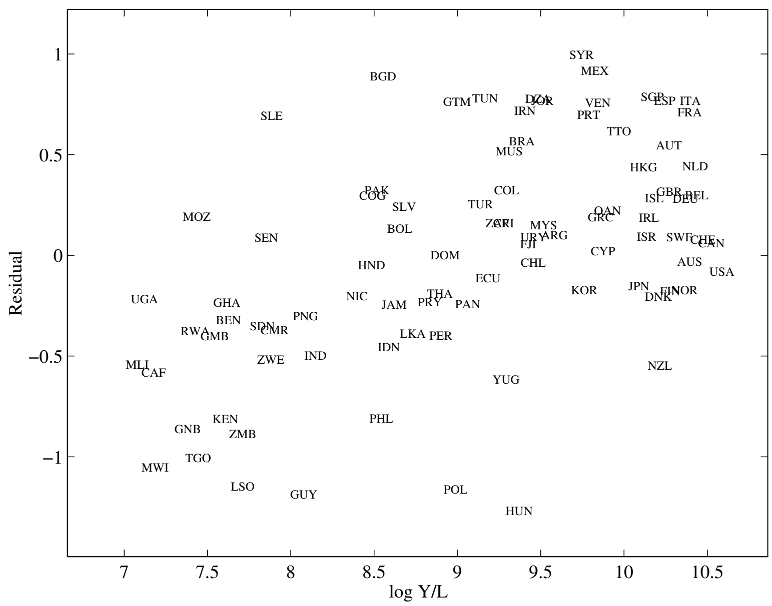
Variable	Unconstrained		Constrained	
Constant	7.402	(1.294)	7.785	(0.135)
$\log s_K$	0.519	(0.118)	...	...
$\log(n+g+d)$	-0.688	(0.567)	...	...
$\log s_K/(n+g+d)$	...	...	0.525	(0.118)
N	0.191	(0.031)	0.195	(0.029)
α	...	...	0.344	(0.051)
p-value	...	...	.76	...
$\bar{R}^2$	.710	...	.713	...

Note: NumObs=90. The p-value corresponds to the test of whether or not the coefficients on $\log s_K$ and $\log(n+g+d)$ are the same. White heteroskedasticity-robust standard errors are reported in parentheses.

tions. Finally, the coefficient suggests that if Cameroon were to increase its educational attainment from 2.00 years per person to the U.S. level of 11.84 years per person, its output per worker would rise from \$2,490 to \$16,963 (compared to a U.S. level of \$36,754). Of course, these numbers are only meant to be suggestive, as the causality of the relationship is not firmly established, but clearly the educational attainment variable is economically as well as statistically significant.

Another way to analyze these results is to think of them as a test of the model proposed in the previous section. To the extent that we have accounted successfully for the important sources of income differentials across countries, the residuals from this estimation should be small. The $\bar{R}^2$ of 0.713 is somewhat favorable, but it masks important differences in residuals across countries. These residuals are plotted in Figure 1.

Figure 1: Residuals from Equation (14) versus $\log Y/L$



The general upward slope in the figure suggests that countries that are rich are richer than the model would predict, and countries that are poor are poorer than the model would predict. In other words, there is a systematic difference in incomes across countries that the model does not capture. To see the magnitude of this difference, notice that the residual varies from about -1 for poor countries to about +1 for rich countries. That is, it is not uncommon to find countries that are either 2.7 times poorer or 2.7 times richer than the model would predict.

This suggests that, while capturing significant differences in income across countries, the model still omits important determinants.[15] An avenue I am exploring in Jones (1996) is that circumstances beyond learning to use new technologies affect whether new ideas are implemented. In par-

[15]Given the fact that N and s_K are probably correlated with whatever it is that we are missing, the amount of variation that remains to be explained is likely even larger.

ticular, ideas are likely to be put into place only when an investor expects to earn a sufficiently large profit on the idea. Even in a society in which educational attainment is fairly high, if entrepreneurs are not allowed to capture rents from their efforts, new ideas may not be taken advantage of. It remains to be seen whether a model that incorporates these additional effects can make progress in explaining the cross-sectional distribution of income.

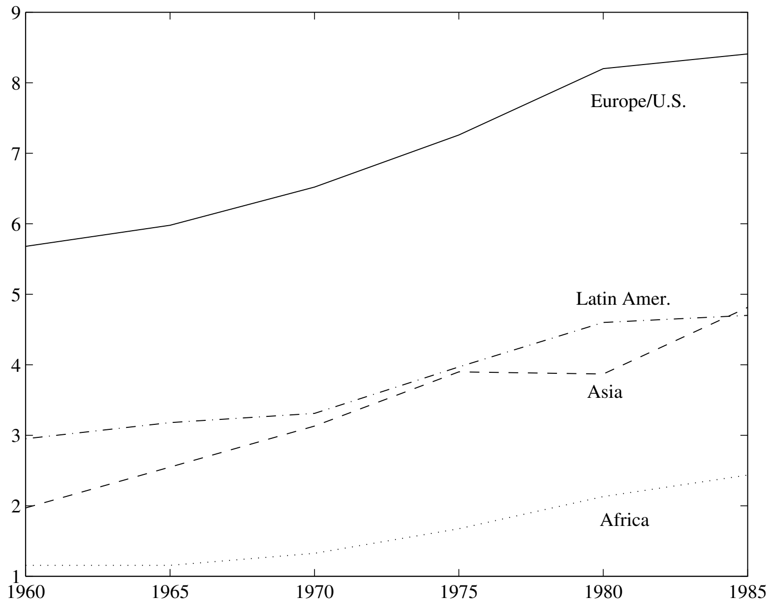
3.3 "Where has all the education gone?"

Several recent studies in the empirical growth literature have emphasized the following finding: although levels of various measures of human capital have explanatory power in growth regressions, the *growth rate* of the stock of human capital has very little explanatory power and often enters regressions negatively instead of positively. These studies include Benhabib and Spiegel (1994), Islam (1995), and Pritchett (1996). This leads the authors to ask, quite naturally, why the countries that have increased their human capital more rapidly have not performed better. Why haven't these investments paid of in the aggregate? Benhabib and Spiegel (1994) and Islam (1995) answer the question by arguing for a different empirical specification, one in which the *level* of human capital enters instead of the growth rate of the human capital stock. However, in many ways, this simply ignores the problem.

Intuitively, the problem arises because several very poor countries with very low levels of educational attainment have increased these low levels by a large percentage amount: e.g. from 1 year to 2 years, or 100%. In contrast, rich countries have increased their levels by one or two years as well, but starting from a much higher base. This is shown by plotting the educational attainment data by continent in Figure 2.

One possible resolution of this puzzle is that it is not the percentage

Figure 2: Educational Attainment in Years by Continent



change in educational attainment that matters, but rather the change in levels. In fact, this is exactly what a model based on the Mincerian microfoundations suggests, as shown in the previous section.[16]

Table 2 illustrates the puzzle by including the logarithm of average educational attainment in the regression. The specification is first estimated in levels for 1990 and 1960, treating both years as steady state observations. As reported in the table, the results are very similar to those in Table 1. The last regression of the table is the differenced specification; all variables are the 1990 level minus the 1960 level, and the negative coefficient on the change in the log of average educational attainment replicates the traditional

[16]I do not deserve any of the credit for making this point. I first heard the suggestion from the participants of an N.B.E.R. conference on human capital and economic growth in February, 1996, at Stanford. As I recall, Kevin Murphy, Alwyn Young, and Pete Klenow emphasized this in discussing Pritchett (1996). Independently, Julie Schaffner made a similar suggestion to me.

Table 2: Regressions Using the *Log* of Educational Attainment

Variable	Level, 1960		Level, 1990		Difference 1990–1960	
Constant	5.350	(0.580)	5.814	(0.783)	0.621	(0.085)
$\log s_K/(n+g+d)$	0.425	(0.149)	0.437	(0.168)	0.394	(0.095)
$\log N$	1.032	(0.184)	0.500	(0.137)	-0.050	(0.128)
α	0.298	(0.073)	0.304	(0.081)	0.282	(0.049)
$\bar{R}^2$	.668		.522		.141	

Note: NumObs=78. White heteroskedasticity-robust standard errors are reported in parentheses. For the 1990 regression, s_K and n are computed as averages from 1986 to 1990 and the Barro-Lee data for 1985 is used. For the 1960 regression, s_K and n are computed as averages from 1960 to 1964 and the Barro-Lee data for 1960 and 1965 is averaged.

puzzle. The partial correlation is displayed graphically in Figure 3.

In contrast, Table 3 and Figure 4 illustrate that there is no longer a puzzle when the *level* of average educational attainment is used, as suggested by the Mincerian approach used in the model here. Even in the specification using the 1990-1960 differenced data, the *level* of educational attainment enters positively and significantly with a coefficient that is quite close to the coefficient in the level specifications. This positive partial correlation is illustrated graphically in Figure 4.

Table 3: Regressions Using the *Level* of Educational Attainment

Variable	Level, 1960		Level, 1990		Difference 1990–1960	
Constant	5.512	(0.538)	5.950	(0.650)	0.301	(0.123)
$\log s_K/(n+g+d)$	0.506	(0.128)	0.377	(0.138)	0.353	(0.095)
N	0.191	(0.031)	0.189	(0.031)	0.159	(0.064)
α	0.336	(0.056)	0.274	(0.073)	0.261	(0.052)
$\bar{R}^2$	.678		.571		.205	

See notes to Table 2.

Figure 3: The "Puzzle" using Logs

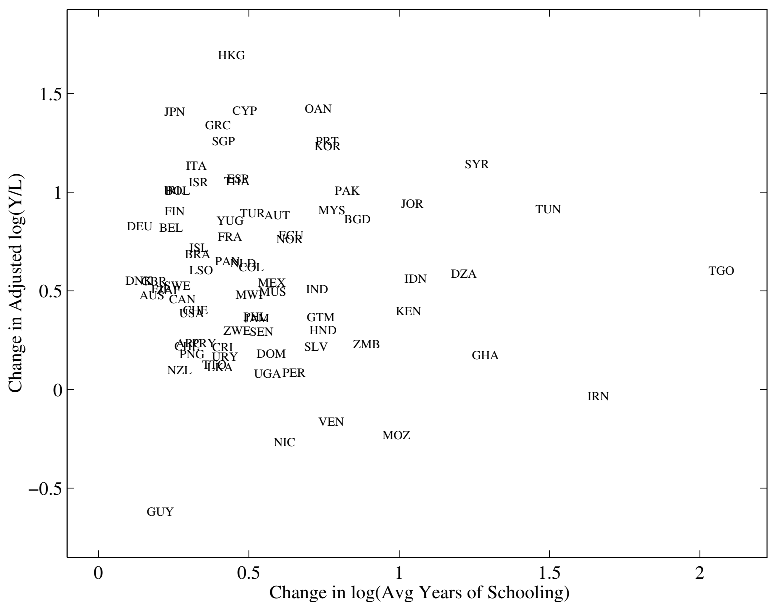
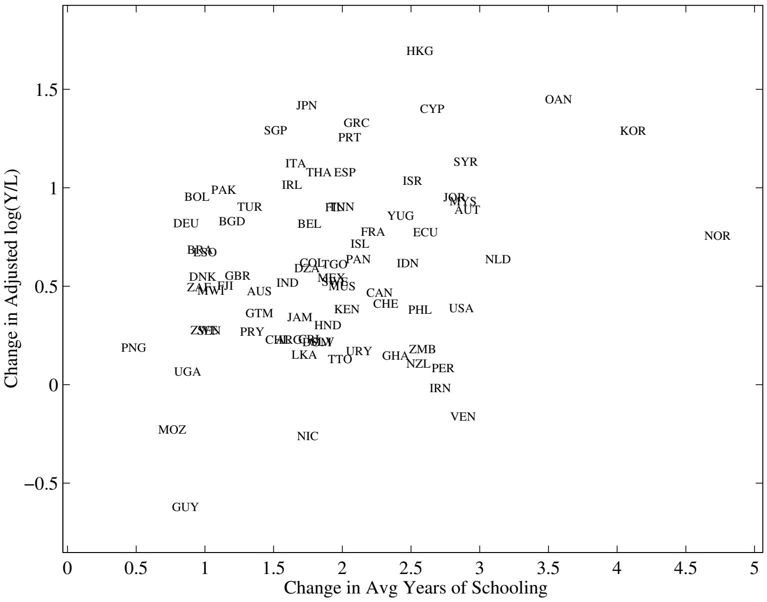


Figure 4: The Resolution: No Logs



4 Conclusion

Combining insights from Romer (1990), Mankiw et al. (1992), Nelson and Phelps (1966), and others to obtain a model that emphasizes the importance of technology transfer in understanding cross-country differences in income seems to be a promising avenue worthy of further research. The analysis presented here suggests that a model emphasizing research and ideas can generate the relatively successful cross-country regression pursued by MRW. But it also highlights the failings of this simple framework: it is not uncommon to find economies 2.7 times poorer or 2.7 times richer than what the model predicts.

The paper also suggests several insights related to human capital. First, the educational attainment data assembled by Barro and Lee (1993) and other similar data series are most accurately interpreted as something analogous to an investment rate rather than as a capital stock. This interpretation is consistent with the observation that educational attainment is asymptotically bounded; it does not grow without bound over time like the physical capital stock per worker.

Finally, the model follows the lead of Bils and Klenow (1996) by including educational attainment in the model in a way that is consistent with Mincerian wage regressions. This framework provides a natural resolution to a recently documented empirical puzzle. Benhabib and Spiegel (1994), Islam (1995), and Pritchett (1996) report negative coefficients of human capital growth rates in growth accounting regressions. The specification suggested here implies that it is not the growth rate of educational attainment that belongs in these regressions but rather the change in the level. Empirical analysis of this specification reveals a relatively stable coefficient on educational attainment regardless of whether the specification is estimated in levels or differences.

References

Barro, Robert J., "Democracy and Growth," *Journal of Economic Growth*, March 1996, *1*, 1–27.

—— **and Jongwha Lee**, "International Comparisons of Educational Attainment," *Journal of Monetary Economics*, December 1993, *32*, 363–394.

—— **and Xavier Sala-i-Martin**, "Technological Diffusion, Convergence, and Growth," 1995. NBER Working Paper #5151.

Benhabib, Jess and Mark M. Spiegel, "The Role of Human Capital in Economic Development: Evidence from Aggregate Cross-Country Data," *Journal of Monetary Economics*, 1994, *34*, 143–173.

Bernard, Andrew B. and Charles I. Jones, "Technology and Convergence," *Economic Journal*, July 1996, pp. xxx–xxx.

Bils, Mark and Peter Klenow, "Does Schooling Cause Growth or the Other Way Around?," 1996. University of Chicago GSB mimeo.

Ciccone, Antonio, "Rapid Catch-Up, Fast Convergence, and Persistent Underdevelopment," 1996. University of Pompeu Fabra mimeo.

Coe, David T., Elhanan Helpman, and Alexander W. Hoffmaister, "North-South R&D Spillovers," 1995. Centre for Economic Policy Research Discussion Paper No. 1133.

Easterly, William, Robert King, Ross Levine, and Sergio Rebelo, "Policy, Technology Adoption and Growth," 1994. NBER Working Paper #4681.

Eaton, Jonathan and Samuel S. Kortum, "Trade in Ideas: Patenting and Productivity in the OECD," 1995. NBER Working Paper No. 5049.

Gerschenkron, Alexander, "Economic Backwardness in Historical Perspective," in Bert F. Hoselitz, ed., *The Progress of Underdeveloped Areas*, Chicago, IL: University of Chicago Press, 1952.

Islam, Nazrul, "Growth Empirics: A Panel Data Approach," *Quarterly Journal of Economics*, November 1995, *110*, 1127–1170.

Jones, Charles I., "R&D-Based Models of Economic Growth," *Journal of Political Economy*, August 1995, *103*, 759–784.

——, "A Simple Model of Growth and Development," 1996. Stanford mimeo (in progress).

—— **and John C. Williams**, "Too Much of a Good Thing? The Economics of Investment in R&D," 1996. Stanford Economics Working Paper.

Jorgenson, Dale W. and Barbara M. Fraumeni, "The Output of the Education Sector," in Zvi Griliches, ed., *Output Measurement in the Services Sector*, Chicago: The University of Chicago Press, 1992, pp. 303–338.

Jovanovic, Boyan, "Research, Schooling, Training, and Learning by Doing in the Theory of Growth," 1995. New York University mimeo.

Judson, Ruth, "Do Low Human Capital Coefficients Make Sense?," 1996. Board of Governors of the Federal Reserve Working Paper 96-13.

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

Mankiw, N. Gregory, David Romer, and David Weil, "A Contribution to the Empirics of Economic Growth," *Quarterly Journal of Economics*, May 1992, *107*, 407–438.

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

Mulligan, Casey B. and Xavier Sala-i-Martin, "Measures of the Aggregate Value of Human Capital," 1994. University of Chicago mimeo.

Nelson, Richard R. and Edmund S. Phelps, "Investment in Humans, Technological Diffusion, and Economic Growth," *American Economic Association Papers and Proceedings*, May 1966, *56*, 69–75.

Pritchett, Lant, "Where Has All the Eduation Gone?," March 1996. The World Bank, Policy Research Working Paper #1581.

Romer, Paul, "Idea Gaps and Object Gaps in Economic Development," *Journal of Monetary Economics*, 1993, pp. 543–573.

Romer, Paul M., "Endogenous Technological Change," *Journal of Political Economy*, October 1990, *96*, S71–S102.

Segerstrom, Paul S., "Endogenous Growth Without Scale Effects," 1995. Michigan State University mimeo.

Summers, Robert and Alan Heston, "The Penn World Table (Mark 5): An Expanded Set of International Comparisons: 1950–1988," *Quarterly Journal of Economics*, May 1991, *106*, 327–368.

Weitzman, Martin L., "Recombinant Growth," 1996. Harvard University mimeo.