Education and Economic Growth

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Abstract

This paper provides a survey of work on the link between education and economic growth. It shows that data from the early 20th century are coherent with conclusions about education and economic growth derived from the much more recent past. It also presents an analysis of the role of education in facilitating the use of best-practice technology.

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1 Introduction

There are two very basic reasons for expecting to find some link between education and economic growth. First of all at the most general level it is intuitively plausible that living standards have risen so much over the last millennium and in particular since 1800 because of education. Progress of the sort enjoyed in Europe was not observed in the illiterate societies that have gradually merged into the world economy over the last two hundred years. To the most casual observer it must seem that there is a link between scientific advance and the way in which education has facilitated the development of knowledge. Of course the Curies and the Newtons of this world are few and far between. But people with only very limited education often find it difficult to function at all in advanced societies. Education is needed for people to benefit from scientific advance as well as to contribute to it.

Secondly, at a more specific level, a wide range of econometric studies indicates that the incomes individuals can command depend on their level of education. If people with education earn more than those without, shouldn't the same be true of countries? If not the rate of change of output per hour worked, at least the level of output per hour worked in a country, ought to depend on the educational attainment of the population. If spending on education delivers returns of some sort, in much the same way as spending on fixed capital, then it is sensible to talk of investing in human capital, as the counterpart to investing in fixed capital. The process of education can be analysed as an investment decision.

2 History

Some education has been available since ancient times. In England there is a fairly large number of schools which can trace their origins back to the days of Queen Elizabeth (although rather few much older than the reign of King Edward VI). Nevertheless, the expansion of education is largely something which has happened in the last 200 years. In the United Kingdom elementary education did not become compulsory until 1870. Very limited free secondary education was introduced in 1907 and it was not until 1944 that universal free secondary education was introduced. Only a small minority benefited from tertiary education until almost the end of the twentieth century. Unlike with primary and secondary education there is, however, a lively debate about what level of access is desirable.

Easterlin (1981) points out that in 1850 very few people outside North-Western Europe and North America had any formal education. Even in 1940 that was still true in Africa and in much of Asia and Latin America. The spread of formal school seems to have preceded the beginning of modern economic growth. It is also true that, in some countries, there have been sudden increases in schooling which are not followed by surges in economic development. Furthermore Easterlin suggests some evidence that the type of schooling is very important. Education in Spain was tightly controlled by the Church and focused on oral instruction in religion and a few manual skills. Illiteracy remained rife despite the level of school attendance. He argues that it was the combination of education and protestant Christianity which was responsible for the economic success of countries in North-Western Europe and their offshoots, at a time when there was little economic development elsewhere. The link between secular education and the Reformation can be deduced from the observation above that few schools in the United Kingdom predate this.

Figure 1 shows the expansion of primary education measured as the enrolment rate per 10000 population drawn from data provided by Easterlin. As an indicator of educational attainment this measure is obviously unsatisfactory, but historical data are limited. The lead of the North European countries is obvious, and they held this lead throughout the 19th century.

As to a link between education and economic performance, again over this historic period there are severe data limitations. However in figure 2 we plot GDP *per capita* in 1913 from figures provided by Maddison (1991) against the primary school enrolment rates of 1882[1]. Whatever concerns one might have about drawing inferences from a plot of seven points, the picture is very clear, that high levels of GDP *per capita* are associated with high levels of primary school enrolment some thirty years earlier. The

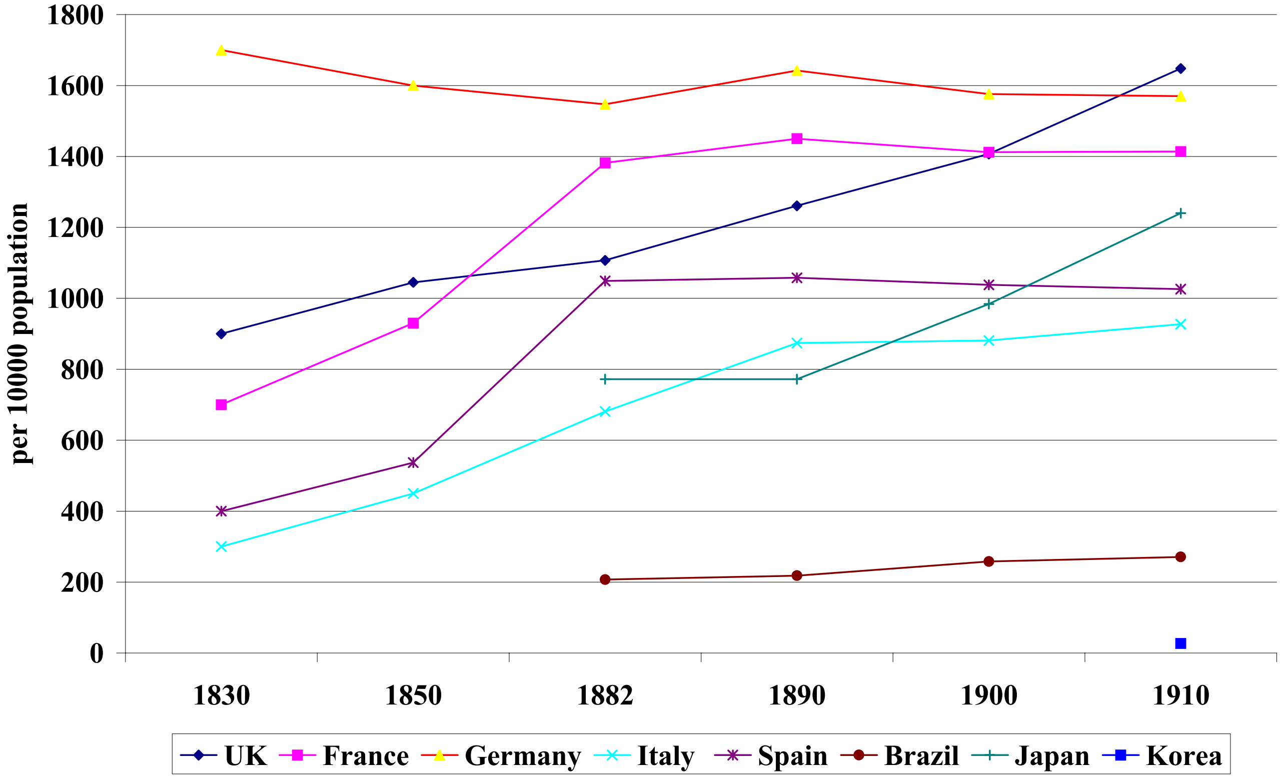

Figure 1: Primary School Enrolment Rates

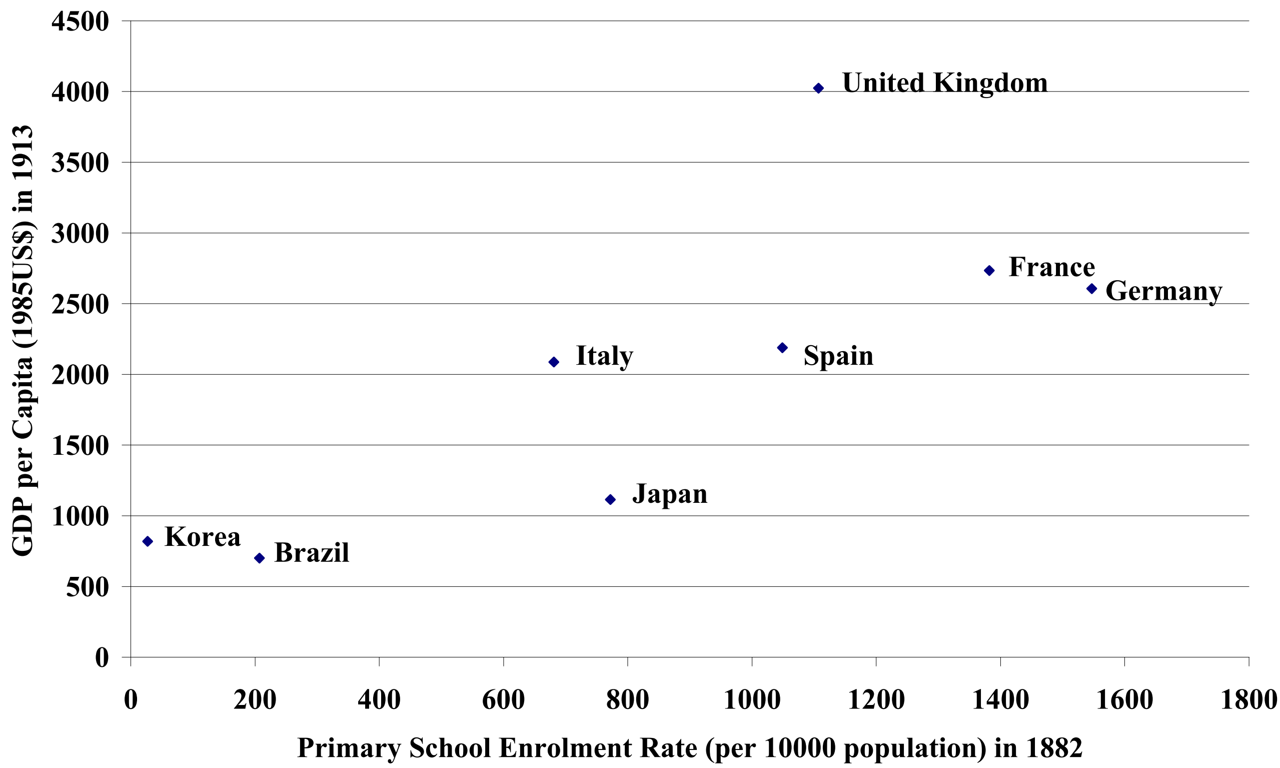

Figure 2: Education and GDP *per capita*

UK appears to be something of an outlier, with an income level higher than its school enrolment might lead one to expect. Since both levels of education and levels of GDP *per capita* in any particular year are closely related to those in earlier and later years, any conclusions drawn from the graph do not, of course, answer the question whether the high level of GDP in France, Germany and the UK is a consequence or a cause of the high level of education. The need to resolve this question of causation in a satisfactory manner has been one of the major problems faced by studies linking education and economic performance.

While any deductions from the graph can hardly be regarded as conclusive, it is nevertheless possible, by fitting a regression line, to analyse them in a manner which allows for some sort of comparability with later findings. The result of such an analysis yields the following result (with standard errors in parenthesis):

$$\ln \textit{GDP per capita} = \underset{(0.12)}{0.35} \ln \textit{Enrolment Rate} + \underset{(0.77)}{5.23} \qquad (1)$$
$$R^2 = 0.59$$

Thus this suggests that a 1% increase in the enrolment rate raises GDP by 0.35%. Or, to put it in perspective, suppose that an increase in the enrolment rate of 20 % raises the average number of years of education of the labour force from 5 to 6. This is an increase of 0.18 log units which raises GDP by 6.5%; the equation is logarithmic and only approximately linear in percentages. For a less-well educated population an increase from 2 to 3 years achieved by an increase in the enrolment rate of 50% or 0.41 log units would raise GDP by 15.4%. The equation has to be regarded very much as a reduced form. Countries with high GDP and high levels of education also have high capital stocks; thus this regression attributes to education effects which, in a fully specified model, would be attributed to the capital stock. Nevertheless, we preserve the results for future reference.

3 Returns to Education

Any analysis of the determination of economic growth has to have some connection with the micro-economic underpinning mentioned above. Because education delivers economic benefits to individuals, we should expect to see effects of education on groupings of individuals (nations). We therefore by providing only a brief survey of accounts of the effects of education on individuals.

A classic study was provided by Mincer (1974). He looked at individual earnings as a function of years of education and also other factors such as age and experience. He found that for white males not working on farms, an extra year of education raised the earnings of an individual by about 7%. However earnings appeared to be an increasing linear and decreasing quadratic function of years of work. When allowance was made for this, the return to a year's schooling increased to 10.1%. The introduction of a quadratic effect in schooling and a cross-product term between education and experience suggested a more complicated pattern of returns but pointed to the early stages of education being more valuable than the later stages. The figures of 7% or 10.1% obviously overstates the return to society from investing in extra education for an individual. It ignores the cost of providing the education, the loss of earnings resulting from time spent being educated and the fact that the benefits of education may decay with age and certainly disappear once an individual retires from the labour force. Secondly, the analysis might be taken to infer that everyone is homogenous. The benefits of extra education are obviously different for different individuals. People can be supposed to finish their education at the point at which the anticipated return of extra education to them is just balanced by the extra costs. Given this assumption the figure measures the average return per year of education up to the point at which the marginal return to education just equals the marginal benefit identified by the individual. With the reasonable assumption of declining marginal effects of education, it follows that this figure must be higher than the incremental benefit of an extra year's education.[2]

Psacharopoulos (1994) provides an international survey of rates of return to education.. The figures cover seventy-eight countries. They show returns to primary education ranging from 42% p.a. in Botswana to only 3.3% p.a. in the former Yugoslavia and 2% p.a. in Yemen. The largest return for secondary education was 47.6% p.a. in Zimbabwe, falling to only 2.3% in the former Yugoslavia. The range for tertiary education was somewhat narrower, between -4.3% p.a. in Zimbabwe and 24% p.a. in Yemen. It is not clear that much can be learned from these individual data, but aggregates, either by region or by income level can average out some of the variability in the individual returns. Thus Psacharopoulos quotes the following returns by income level

Income Band		Social Rate of Return (% p.a.)		
Income is measured in 1985 US$	Mean Income	Primary	Secondary	Higher
Low Income (< $610)	$299	23.4	15.2	10.6
Lower middle income ($610-$2449)	$1402	18.2	13.4	11.4
Upper Middle Income ($2500-$7619)	$4184	14.3	10.6	9.5
High Income (> $7619)	$13100	n.a.	10.3	8.2
World	$2020	20.0	13.5	10.7

Table 1: Rates of Return to Education

These show that social returns decrease with the amount of education received by individuals and also that they decrease with the income of the country concerned (and thus, it may be assumed with the abundance of educated labour).

The Mincerian returns show a similar phenomenon This suggests that, if we are to look at the influence of education on economic growth through its effects on the education of individuals, we should look to one extra year's education to raise labour income by about 10%, but by only about 6.5% in advanced countries. In broad terms

Income Band (1985 US$)	Mean Income	Years' education	Mincerian Return
Low Income (< $610)	$299	6.4	11.2
Lower middle income ($610-$2449)	$1402	8.4	11.7
Upper Middle Income ($2500-$7619)	$4184	9.9	7.8
High Income (> $7619)	$13100	10.9	6.6
World	$2020	8.7	10.1

Table 2: Mincerian Returns to Education

these figures are similar to the effects identified in section 2.

4 Growth Accounting: the Basic Framework

Perhaps the simplest framework in which to look at the effects of education on economic growth is offered by the growth accounting framework. The basic model is that output is a function of factor inputs as described by Solow (1956). For ease of exposition it is assumed that there are two inputs, labour, L, and capital, K, with only one aggregate output, Y. The model extends happily to the case where there are multiple inputs and outputs provided the production function is homothetic. This has the implication that Divisia quantity indices of the inputs and outputs can be constructed, aggregating the inputs and outputs so as to reduce the problem to the structure below shown as explained by Samuleson & Swamy (1974). A represents "total factor productivity". As will become clear, the model is not closed because growth of A is assumed to be exogenous.

$$Y = AF(K, L)$$

Differentiating

$$\frac{\dot{Y}}{Y} = F_K \frac{K}{Y}\frac{\dot{K}}{K} + F_L \frac{L}{Y}\frac{\dot{L}}{L} + \frac{\dot{A}}{A}$$

If the factors of production are rewarded by their marginal products, then $F_K \frac{K}{Y}$ is the share of profits in the economy and $F_L \frac{L}{Y}$ is the share of labour. With a homothetic production function these shares sum to one, so that, if we denote $F_K \frac{K}{Y} = \alpha$ then $F_L \frac{L}{Y} = 1 - a$ and

$$\frac{\dot{Y}}{Y} = \alpha \frac{\dot{K}}{K} + (1 - \alpha)\frac{\dot{L}}{L} + \frac{\dot{A}}{A}$$

It should be noted that there is no requirement for α to be time-invariant. If the underlying production function is Cobb-Douglas, that is, however, the case.

Suppose there are different types of labour indexed by years of education, so that L_t is the input of labour with t years of education combined in some form to give an aggregate labour equivalent.

$$L = L(L_0, L_2, ...L_T)$$

Then we have

$$\frac{\dot{Y}}{Y} = F_K \frac{K}{Y}\frac{\dot{K}}{K} + F_L \sum \frac{\partial L}{\partial L_i}\frac{L_i}{Y}\frac{\dot{L}_i}{L_i} + \frac{\dot{A}}{A} \tag{2}$$

Here the marginal product of each type of labour is given as $\frac{dF}{dL}\frac{\partial L}{\partial L_i} = w_i$ if each type of labour is paid its marginal product and the labour aggregator is also homothetic. This means that

$$\frac{\dot{Y}}{Y} = F_K \frac{K}{Y}\frac{\dot{K}}{K} + \sum w_i \frac{L_i}{Y}\frac{\dot{L}_i}{L_i} + \frac{\dot{A}}{A}$$

It follows that the contribution of expansion of each type of labour is given as its rate of growth multiplied by the share of earnings of this type of labour in the total product.

The growth accounting framework can be used to indicate the implications of the figures of section 3 for economic growth. If a country increases the average number of years of education of its workforce by one, and one assumes that educated and uneducated labour are perfect substitutes for each other, so that it does not matter whether everybody's education has increased by the same amount, or whether some people have expanded their education by more, and others less than one year then the effective labour supply is increased by the same amount. The increase in output resulting from this is the increase in effective labour multiplied by the share of labour in the overall product. It is quite likely that countries with high levels of education will also have more capital per worker; indeed if the amount of capital per effective worker is the same before and after the increase in educational attainment, then they will have to. As a result the overall percentage increase in output is likely to be the same as the increase in the effective labour force; using the Mincerian return for the world this is 10.1% per extra year of education. But if the share of labour in the product is only 2/3 (e.g. Mankiw *et al*, 1992), then one extra year's education contributes only 6.7% to output growth and the remainder is due the capital stock rising *pari passu.*

There are many practical examples of this calculation. For example Matthews *et al* imply that between 1856 and 1973 an improved level of education contributed 0.3%

(% p.a.)	Labour Quality Improvement	Contribution to Growth	Growth of Output *per capita*
Canada	0.74	0.50	2.93
France	0.73	0.49	3.04
Germany	0.41	0.28	2.91
Italy	0.19	0.12	3.74
Japan	1.16	0.79	5.39
United Kingdom	0.38	0.26	2.15
United States	0.59	0.40	2.07

Table 3: Growth of Labour Quality and its Contribution to Overall Economic Growth, 1960-1989

p.a. to the growth of output in the United Kingdom (with overall growth of 1.9% p.a.). Dougherty & Jorgenson (1997) provide the figures shown in table 3 for the contribution of improved labour quality to labour input in the G7 countries. Using the growth accounting framework, their contribution to overall economic growth can be found by multiplying by the share of labour. The figures shown in table 3 are calculated assuming a labour share of 2/3. It should be noted that labour quality is a wider variable than education; it reflects all factors leading to growth in the number of well-paid relative to badly-paid workers.

A defect of the model is, however, the fact that growth in total factor productivity is exogenous. If the rate of growth of total factor productivity is itself dependent on the level or the rate of change of educational attainment, then growth accounting will understate the true contribution of education to economic growth.

5 Educated Labour as a Factor of Production

There have been a number of studies comparing output per worker (or initially because of data constraints output *per capita*) in a number of different countries based on variants of this approach. Perhaps the best known was by Mankiw *et al* (1992). Instead of relying on the sort of growth accounting exercise described above, they assumed that there were two types of labour, educated and uneducated. The proportion of educated labour was indicated by the proportion of the labour force with secondary education. Thus, by contrast to the studies above, they assumed that the production function took the form

$$Y = K^{\alpha} H^{\beta} (AL)^{1-\alpha-\beta} \tag{3}$$

where H is the stock of human capital.

To develop this further, we denote the fraction of income invested in physical capital by s_k and the fraction invested in human capital by s_h. L and A are assumed to grow at rates of n and g respectively and these are assumed to be the same everywhere. δ is assumed to be the rate of depreciation of both physical and human capital. The rates of change of the stocks of physical and human capital per unit of effective labour are given by

$$\begin{aligned} \dot{k} &= s_k y - (n+g+\delta)k \\ \dot{h} &= s_h y - (n+g+\delta)\, h \end{aligned}$$

where $y = Y/AL$, $k = K/AL$ and $h = H/AL$ are quantities per effective unit of labour.

We can from these expressions calculate the steady-state values of k and h. We typically observe indicators of the *level* of human capital but the *rate* of saving. It is therefore sensible to derive an equation for output per person employed in terms of the level of human capital, h^* but the gross rate of accumulation of physical capital, s_k

$$\begin{aligned} \ln \frac{Y}{L} &= \ln A + gt + \frac{\alpha}{1-\alpha-\beta} \ln(s_k) - \frac{\alpha+\beta}{1-\alpha-\beta} \ln(n+g+\delta) \\ &\quad + \frac{\beta}{1-\alpha-\beta} \ln(s_h) \end{aligned} \tag{4}$$

Mankiw *et al* explain differences in output per person in 98 countries which do not produce oil in 1985. They measure the rate of accumulation of human capital by the fraction of the working age population in secondary school. They find they can accept the restrictions that the coefficients on $\ln(s_k)$, $\ln(n+g+\delta)$ and $\ln(s_h)$ sum to zero[3] with a p-value of 0.41. The implied value of α is 0.31 and of $\beta = 0.28$. They note that these figures are consistent with the idea that the proportion of income paid to capital is about 1/3 of the total and also that figures of the United States based on the relationship between the minimum wage and the average wage suggest that β is between 1/3 and 1/2. Thus, although these calculations are in many ways rough and ready they give an answer which is plausible. The authors also pre sent results showing that if the human capital variable is omitted from the estimation (i.e. $\beta = 0$) then the estimate of

α which emerges is 0.6. This is quite inconsistent with the observation that the share of output accruing to capital is 1/3. Although the sample is split between developing countries and the OECD countries the authors do not use any statistical test to explore whether they can accept the hypothesis that the coefficients are common to the OECD and the developing countries.

There are a number of reasons for being unhappy about this approach. First of all, the analysis assumes *faut de mieux* that the production function is Cobb-Doublas. In other words the elasticity of substitution between capital and each of the two types of labour is one, as is the elasticity of substitution between the two types of labour. Without information on wage rates it is not possible to test this. But *a priori* one might expect a higher elasticity of substitution between the two types of labour than between labour and capital . There could also be concerns about the use of 1985 data to infer steady state values and the assumption that the ratios of physical and, more particularly human capital to effective labour have reached their steady states. The model has the same property as those discussed earlier; when the proportion of people with secondary education stops rising (as it eventually must), then growth in output per capita can be generated only by rising capital intensity. The decline in the rate of return which follows from this will eventually mean that growth comes to a halt.

Nevertheless, it is impossible to avoid the urge to make a comparison between the coefficients quoted by Mankiw *et al* and those found in equation (1). If we assume that the enrolment data are proportional to saving in the form of human capital, then they play the role of s_h in equation (4). If saving in physical capital is uncorrelated with saving in human capital, then, with the values of α and β suggested by Mankiw *et al*, in an equation explaining output levels by enrolment rates alone, we should anticipate a coefficient of 0.75. To the extent that s_h and s_k are positively correlated, then we should expect a larger coefficient, with a maximum value being given by $\frac{\alpha+\beta}{1-\alpha-\beta} = 1.5$. These figures are markedly higher than the value of 0.35 found in equation (1). It is nevertheless difficult to relate the two figures, or to derive a sensible estimate of the return to education from these estimates. The equation suggests here that a country with no secondary education will have zero output; equation (1) had the same implication about primary school education. Thus both equations are unlikely to be informative about the effects of expanding education (secondary in this case) from a very low base. While it made some sense to convert the primary school enrolment rates into years of education, even though schooling in backward countries is often interrupted, it is much harder to do this with secondary school enrolment figures because we do not know what primary school enrolment rates are linked with them. The simple assumption that everyone has primary school education before anyone embarks on secondary school education is plainly incorrect.

It is likely, nevertheless, that an increase in secondary school enrolment of 1% has a smaller proportional effect on the average level of education of the labour force than does an increase in the primary school enrolment rate of the same proportion, making the gap between the figures presented here and that of equation (1) smaller. It is, however, not obvious how far this effect reduces the gap.

6 Education and Endogenous Growth

There are a number of ways in which the change in total factor productivity can be rendered endogenous. They tend to involve a departure from the production function above with its types of labour with different degrees of education. Instead Lucas (1988), for example, assumes that, in addition to the stock of physical capital, there is a meta-physical variable called human capital, h. A fraction u is devoted to production while the remainder is devoted to accumulation of human capital. The average level of human capital in the economy determines the level of total factor productivity. Lower case variables are used to indicate *per capita* variables.

$$y = Ah_a^{\gamma} f(k, uh)$$

Here human capital plays two roles. First of all, if f has constant returns to scale, then as human and physical capital increase in step, so does $f(k, uh)$. But if $\gamma > 0$ then there are, overall increasing returns to scale. Output increases more than in proportion to increases in the supplies of factors of production. In particular increases in the stock of human capital should have a marked effect on the rate of growth of output.

The rate of growth of human capital is given as

$$\frac{\dot{h}}{h} = \pi(1 - u)$$

These equations stand in sharp contrast to that provided by Mankiw *et al.* They assumed that the returns to the two factors of production, human capital and physical capital were less than one. The implication was that, even if the stock of human and physical capital rise without limit, overall output growth declines asymptotically to the rate set by the growth of the exogenous term, A. By contrast in Lucas' model output depends only on produced factors and provided the stock of these increases output can grow without limit. Note that if the rate of accumulation of human capital were instead of the form

$$\frac{\dot{h}}{h} = \pi(1-u)h^{-\zeta}$$

then the accumulation of human capital would eventually decrease and if $\zeta > \gamma$ then output too would be bounded. The rate of growth can be increased by choosing to invest more labour in the expansion of human capital. However, if the whole of labour were invested in adding to human capital (expanding knowledge) then no final output would actually be produced. The selected rate of accumulation of human capital will depend on the balance between current and future output.

In both this model and, the previous one, an increase in educational attainment- assuming this is related to human capital- must lead to an increase in output. Lucas' model implies that human capital may increase even without any increase in educational attainment. Although the human capital of individuals may decay over time, there is a public body of knowledge and accumulation of human capital can add to this. Thus, even when educational attainment has stopped increasing, human capital can continue to increase and thus continuing growth is possible.

A similar model developed by Romer (1990) assumes that the growth of productivity depends on the existing stock of ideas and the number of people devoting their time to the accumulation of new ideas.

In the previous model, by contrast, once the whole of the labour force had been educated to the maximum viable standard[4], growth would be possible only through the accumulation of physical capital or from exogenous total factor productivity growth. Unless the elasticity of substitution between labour and capital is greater than one, without exogenous total factor productivity growth, expansion of output *per capita* would eventually come to an end. It is worthy of note that, in some advanced countries such as Germany, there is pressure to reduce the maximum duration of education.

While this is perfectly consistent with continuing improvement in average educational standards for years to come, it does nevertheless suggest that the period in which the educational quality of the labour force has steadily increased is now drawing to a close.

Thus the growth accounting model implies that we can now see a point at which human capital will cease to grow and therefore stop its contribution to economic growth.

7 The Level and the Growth Rate

Within the empirical literature there is much, and in some sense unresolved, debate whether, after adjusting for other factors, a high level of education leads to a rapid growth rate, as Lucas' model suggests, or whether a high growth rate can be expected only if the stock of educated capital is expanded, rather as the augmented Solow model implies. The confusion has been augmented by the fact that some researchers instead claim to find that growth in output is unaffected by expansion of education although it is by the existing stock (Benhabib & Spiegel 1994). It should be noted that this is implied by neither model but needs to be explained by the catch-up phenomenon - that countries are catching up with each other, but that differences in steady states will arise from differences in educational attainment. Put like this the influence of the education on the rate of growth can be regarded as describing a situation in which the steady state is defined by the Solow model. In such models growth is given by

$$\Delta \ln(\frac{Y}{N}) = \theta_0 + \theta_1 \ln(\frac{Y_0}{N_0}) + \theta_2 \frac{I}{Y} + \theta_3 H \tag{5}$$

The term in θ_1 indicates a catch-up effect and should be expected to be negative. Nevertheless, the presence of the other terms means that output per person does not automatically catch up to some uniform value. Instead the value which is reached depends on the investment ratio and also on the educational standing of the country. The second term reflects the return to capital; θ_2 cannot be interpreted as a return to capital because the dependent variable is measured on a *per capita* basis.

Barro (1997), working with what is essentially equation (5) suggests that one extra year of education (for men) raises the growth rate by 1.2% p.a. In fact he suggests a total impact of education on growth of even more than this, because in his framework countries with low incomes *per capita* tend to catch up with those with high incomes. The rate of catch-up depends positively on the number of years of education, reflecting the view that a high level of education makes it easier to absorb best-practice technology. The overall effect is described by Topel (1999) as a huge rate of return. Sianesi & van Reenen (2003) agree that the effect of such a change is implausibly large.

In fact, while there may be questions about the mechanisms, the rate of return implied by such an investment is perfectly reasonable. If a country decides to increase the level of education of its labour force by one year, the first impact is that the labour force falls because the youngest cohort starts work a year later than would otherwise be the case. The level of education of the labour force changes very slowly as the better educated young gradually displace the poorly-educated old. Looking at an expansion of secondary/tertiary education from four to five years, we find that the rate of return to the extra education measured by balancing the output foregone in the early years against the extra output produced in the later years is 14% p.a. This is indeed a high, but not implausibly high, rate of return. However, the equation developed by Barro (1997) does not have any explicit role for co-operating capital. The expansion of output resulting from extra education would certainly take place alongside an expansion of the capital stock and, in assessing the benefit of extra education, an adjustment must be made for this. If one assumes that 1/3 of the increase in output is due to accumulation of extra capital, then the rate of return of the investment in incremental education falls to 6.5% p.a.

Topel develops this point, arguing that if one year of education raises human capital by 13% (rather than the 10.1% identified in table 2), and if countries tend to catch up with the technological leader at a rate of about 3% p.a.[5], then the effects of one extra year of education should accrue only slowly; Topel argues that the impact of one extra year's education on growth will be given by $0.03 \times 13\% = 0.4\%$ p.a. He argues that the figure of 1.2% p.a. at 3 times this is "vastly too big for the model they purport to estimate"; we have already noted that the rate of return implied by the model is inherently reasonable. This is, of course, not to say that Barro's figure is itself correct, but simply to point out that it is a mistake to dismiss it out of hand as implausible.

There is nevertheless an important methodological point. The model he estimates is a regression equation in which the change in output over ten or twenty-year periods is a function of a number of variables including educational attainment but also including the initial level of output. Thus the effect of education on growth is conditional on the initial level of output and eventually an increase in education leads to higher output and not faster growth. This dampening effect has the consequence of reducing further the return to education below the figures described above.

Oulton (1997) looks at the role of human capital to explain growth in total factor productivity, thus removing the effects of possible interactions with the stock of physical capital. He finds that a 1% increase in human capital per worker in 1965, measured using a 1996 version of Barro and Lee's data set, raises the rate of growth of total factor productivity by 0.0365%. Or, to put it another way round, an increase in years of education from five years to six years raises growth by 0.73% p.a. The effect is therefore smaller than that identified by Barro; it is, however, calculated after taking account of the effects of any parallel increase in the capital stock and the difference is therefore less than might appear.

Benhabib & Spiegel (1994) work with a differenced version of equation (3) but also include lagged GDP *per capita* as an explanatory variable. They do not find any significant effect for human capital-measured in the same way as Barro[6]. They then suggest an alternative model based on the work by Nelson & Phelps (1966). Suppose that in the United States where more or less everyone has secondary education, $Y_{US} = A_{US} L_{US}^{\alpha} K_{US}^{1-\alpha}$ and that in other countries $Y_{Other} = A_{Other} L_{Other}^{\alpha} K_{Other}^{1-\alpha}$. If in the other countries there are H_{Other} people with secondary education and $A_{Other} = A_{US}(H_{Other}/L_{Other})^{\gamma}$ then we find $Y_{Other} = A_{US}(H_{Other}/L_{Other})^{\gamma} L_{Other}^{\alpha} K_{Other}^{1-\alpha} = A_{US} {H_{Other}}^{\gamma} L_{Other}^{\alpha-\gamma} K_{Other}^{1-\alpha}$. The function of secondary education is, however, rather specific as compared to the general role ascribed to human capital. Given a technological frontier defined by the United States, absence of secondary education is a factor leading to production which is in some sense inefficient since the follower country does not utilise all of the available technology (Nelson & Phelps, 1966; Kneller & Stevens, 2002).

If, however, the level of human capital is a factor which influences the rate of adoption of American technology, then it will influence the growth rate through its influence on the rate at which productivity catches up with levels in the United States.

$$\frac{\dot{A}_{Other}}{A_{Other}} = \phi \left(\frac{H_{Other}}{L_{Other}} \right) \frac{A_{US}}{A_{Other}}$$

and the rate of growth of log output (rather than productivity) will be given by the sum of the rate of growth of productivity and the rates of growth of the two inputs weighted by the coefficients on them in the production function. On this basis Benhabib & Spiegel estimate a regression equation in which growth in GDP is explained by growth in the labour force and the capital stock but by the average level of education. Looking at 78 countries over the period 1965-1985, they find evidence to support their view from a further regression which includes an interactive term in the product of human capital and the ratio of *per capita* GDP in the highest income country to that in the country in question. The effect identified is, nevertheless, very small, with an extra year's education raising output by only 0.35% over twenty years, for a country whose initial *per capita* income level is half that of the highest income country. Thus they imply a rate of return which suggests that education is scarcely worth bothering with.

Krueger & Lindahl (2001) follow a different tack. In estimation, they split countries into three groups based on education levels. They find a statistically significant positive link between education and growth only for the countries with the lowest level of education. They then explore a quadratic relationship between economic growth and years of education. They find that for low levels of education, education contributes positively to growth, while for high levels of education it depresses the rate of growth. The marginal effect of education on economic growth is positive for countries where the average worker spends less than 7.5 years in education. Above this marginal education has a negative effect; the average level of education in the OECD is 8.4 years, so incremental education is expected to depress the growth rate in OECD countries. They point out that these findings are also consistent with results provided by Barro (1997).

Another approach is to directly estimate the effect of human capital on the distance of a follower country from the technical frontier in income and human capital levels (Kneller & Stevens, 2002). This overcomes, to some extent, the problems with measurement error that are exacerbated by first-differencing. Any change in variables negatively related to distance from the frontier will lead to higher growth. We consider this approach in more detail in section 11 below.

The evidence on whether the effect of human capital on economic growth is a level or a growth effect is inconclusive. It should, however, be noted that the fact remains that educated people are paid more than uneducated people. With the reasonable assumption that people's marginal product is measured by their wage rate, the most basic model (2) implies that an expansion of the number of educated people will lead to growth of output. This observation has such generality that it is difficult to come to any conclusion except that the absence of such an effect has to be regarded as a fundamental flaw of empirical work. Or rather, a fundamental criticism of the way in which the empirical work is carried out. The point about the studies mentioned above is that the effects of growth of education were not statistically significantly different from zero. Just because the hypothesis that the effect of expansion of education is zero can be accepted statistically does not mean that it is a sensible restriction to impose. A more sensible restriction would be that the effect of education is that given by a coherent theoretical model. Greater emphasis should be put on the values taken by the other coefficients when a coherent restriction is imposed on the effect of growth of the educated labour force than when a zero coefficient is put on it.

8 What sort of Education?

The study mentioned by Mankiw, Romer & Weil (1992) defined the role of education by the proportion of the workforce with secondary education. This is obviously only one of a number of possible indicators and there have to be concerns that other equally plausible indicators might have delivered less satisfactory results. The role of different types of education is explored by Wolff & Gittleman (1993). They estimated regression equations which explained growth in output *per capita* on the basis of the share of GDP invested, the initial level of GDP *per capita* and groups of six possible indicators of educational standing. These were enrolment rates in each of primary, secondary and tertiary education and attainment rates, i.e. the fraction of the workforce with each of these types of education at a date close to the start date from which economic growth was measured.

Thus the equation was of the form

$$\Delta \ln(\frac{Y}{N}) = \theta_0 + \theta_1 \ln(\frac{Y_0}{N_0}) + \theta_2 \frac{I}{Y} + \sum_{i=1}^{k} \psi_i E_i \tag{6}$$

Although the underlying model in principle should be used to explain growth in labour productivity, *faut de mieux*, in common with many other such studies growth in output per person is used instead, so no account is taken of the effects of variation in the ratio of hours worked to population in different countries. Wolff and Gittleman look at the world economy but also separate the industrial and upper middle income countries, as defined by the World Bank, from the lower middle income and poor countries. They find that among the upper income group, where there is much more variation in tertiary education than in primary or secondary education, that tertiary education is the only statistically significant variable. On the other hand, for the poor countries primary education is statistically significant while differences in tertiary education, which show rather little variation, are not. There has to be some concern that they find enrolment in

	S^{BL}_{65}	S^{BL}_{85}	S^{K}_{65}	S^{K}_{65}	ΔS^{BL}	ΔS^{K}
S^{BL}_{65}	1					
S^{BL}_{85}	0.97	1				
S^{K}_{65}	0.91	0.92	1			
S^{K}_{85}	0.81	0.86	0.88	1		
ΔS^{BL}	0.23	0.46	0.36	0.51	1	
ΔS^{K}	-0.12	-0.03	-0.17	0.33	0.34	1

The sample size is 68 . BL indicates Barro-Lee data and K indicates Kyriacou data. The subscript indicates the year.

Table 4: Correlations between Measures of Schooling

education at the start of the period considered a better indicator of subsequent economic growth than was the educational attainment of the workforce.

9 Data Concerns

The construction of the data sets needed for the range of empirical studies has been a substantial undertaking for the various researchers involved. There are obviously questions over the GDP figures used, and particularly so for relatively poor countries where non-market activity is likely to be more important than in advanced countries. However Krueger & Lindahl (2001) draw attention to the problems raised by the accuracy of the measures of education. They discuss two sources of data, those provided by Barro & Lee (1993) and by Kyriacou (1991). They find the correlation matrix between the two measures in 1965 and 1985, and the changes between them shown in table 4.

This table shows that the individual measures are more closely correlated with themselves across time than they are with each other at the same time. Other points worth noting are that the Barro-Lee data show the increment to education being positively correlated with the initial level while Kyriacou's measure shows it negatively correlated with the initial level. Not surprisingly the effect of measurement errors is augmented when the connection between the changes in education using the two measures is studied; the correlation falls to a low level.

If measurement error is additive, i.e. if the published data reflect the true data plus a measurement error which is uncorrelated with the true data, then it follows that the less volatile series is the more reliable series, and also that a minimum variance estimate can be produced as a combination of the two based on the results of a regression of the one on the other (Smith, Weale & Satchell 1998). Data on variances and co-variances also provided by Krueger & Lindahl (2001) suggest that Kyriacou's figures ought to be preferred to those of Barro and Lee. But the change in education between 1965 and 1985 estimated by Kyriacou has a larger variance than that estimated by Barro and Lee suggesting a more complex error pattern.

It is, of course not possible to establish the variance of the measurement error simply from the existence of two different estimates of the same thing, both with measurement errors of unknown variance. And the general result that measurement error in a variable biases an estimate of a regression coefficient on it towards zero applies only to univariate regression. Nevertheless, given the obvious disparity between two measures of the change in years of education, it seems likely that there are substantial measurement errors present and, unless there are strong correlations between this variable and the others in a regression equation, it is likely that a regression coefficient on the change in education as measured by either of these variables will be depressed towards zero; the standard error associated with it will also be larger than would be observed were the variable measured precisely. Thus the failure to find a link between expansion of education and economic growth may easily be attributed to measurement error. Kruger and Lindahl argue that the effect of this is compounded when the change in the capital stock is included as an explanatory variable. Then the coefficient on the growth of capital is restricted to a value of 0.35 (approximating the share of capital internationally) then expansion of education appears to be an important factor behind economic growth. One extra year's education appears to raise GDP per capita by 8%. This, bearing in mind that it is a partial effect, with the capital stock fixed, corresponds to an effect of education on labour income of about 12%, and is therefore rather high. On the other hand the t-statistic of the estimate is less than two, and on that basis, it is clear that the estimate is consistent with a much lower (or much higher) true value.

10 Panel Modelling

The models and analysis we have described so far tend to look at growth in a cross-section of countries and explain it in terms of initial levels of education, average saving during the period and, as we have discussed above, possibly growth in educational attainment during the period. The regressions have been either cross-section regressions, with growth rates in a number of countries explained by initial circumstances and sometimes capital accumulation during the period, or pooled regressions in which observations for the same country in different periods are different periods are combined in the same way as observations for different countries.

Islam (1995) sets out, for the first time, the problem of analysing growth rates as a panel regression problem in standard format. He finds that positive effects of human capital in cross-section regressions turn into negative, but insignificant, effects once panel methods are used. He hints, as Benhabib and Spiegel have suggested, that human capital may affect economic growth through its influence on the catch-up term. The catch-up is much more rapid than that identified by the earlier approaches.

Lee *et al* (1996) argue that it is a mistake to take the standard Solow model a reference point. This model has the implication that eventually all countries tend to the same growth rate; its extensions suggest that factors such as education influence the relative income levels of different countries but not their long-run growth rates of *per capita* income. Starting from a position in which different countries may have different rates of technical progress (represented by country-specific trends and period-by-period country specific shocks) and also different rates of labour force growth they point out the usual model is a poor approximation to this. They reject the hypothesis of a common technological growth rate and also find a much faster rate of convergence. They do not explicitly look for effects of education but their results are nevertheless important in a discussion of the effects of education and growth because of the methodological issues they raise.

Two points should be made. First of all, if the degree of convergence forced on countries is weaker, because they are allowed different trend growth rates, then it is not surprising that the rate at which they converge to their more individual growth paths is faster than if they are required all to converge to the same path. Secondly, since the only indicator variable they use is employment, it is not surprising that they find a degree of heterogeneity; other authors have reduced this by controlling for other effects. Over the time period analysed (1965-1989) it must be difficult to distinguish the effects of different steady-state growth paths from the effects of slow convergence to a single growth rate. But the smaller the number of control variables, the more likely it seems that statistically distinct growth paths will be found.

Recent work at the OECD has led to the construction of an annual data set of educational attainment for OECD countries to allow these issues to be addressed. The education data were combined with existing data on output, savings and labour input so as to make possible a pooled time-series/cross section analysis. The starting point for the study by Bassanini *et al* (2001) is equation (3), but with a more general expression to take account of factors other than physical and human capital and labour input.

With $Y = K^{\alpha}H^{\beta}(AL)^{1-\alpha-\beta}$ and $\alpha + \beta < 1$, they express labour productivity, A, as a function of institutional and other variables which may influence it, and also allow for the fact that labour productivity may grow over time. This general specification leads to steady-state output as a function of the steady state savings rate, the level of human capital (measured in years of education) and the other influences on productivity. Since the world is not in a steady state, the equation has to be modified to include short-term dynamics to yield a function for the growth in output as a function of savings rates, the change to savings rates, the level and change to human capital and the levels and changes of the various other indicators of interest including inflation variability, government consumption and trade exposure. The analysis therefore addresses the question whether economic growth is influenced by the change in education as well as the level. Pooled Mean Group estimation (Pesaran *et al*, 1999) is used to provide estimates of both short-run and long-run coefficients. Using this method, the short-run responses are allowed to vary country by country, while the hypothesis that the long-run responses are the same across all countries is imposed. The analysis suggests, depending on the precise form adopted, that one extra year of education for the workforce raises output by 4-7 per cent; the speed of convergence conditional on the stock of human capital remaining fixed is 12% p.a. rather than the more usual figures of around 5% p.a. but in keeping with the rate quoted by Lee *et al* (1997); once again, this greater speed of convergence is probably a consequence of allowing greater country-heterogeneity than was permitted by the earlier estimation methods. However, given the insignificant negative coefficients on the change to human capital, there is little point in assessing the effects of change in education on economic growth.

11 Education and Inefficiency

The model put forward by Nelson & Phelps (1966) (see section 7) suggests that education, or rather the lack of it, is important as an explanation of why countries might fail to use the best-practice technology. The situation they describe is one where there is a single technological frontier on which efficient economies can perform. Those without adequate education are doomed to produce inefficiently, in the interior of the production possibility set rather than on its frontier. This framework is explored by Kneller & Stevens (2002) using stochastic frontier analysisThe basic model stems from the production function given by equation (3) but with two stochastic terms introduced

$$Y_{it} = f(K_{it,}L_{it}, H_{it}) \exp(-\eta_{it}) \exp(\varepsilon_{it})$$

where Y_{it} is output of country, K_{it} is the capital stock, L_{it} is the labour input (adjusted for hours worked per week) and H_{it} is human capital. $\varepsilon\tilde{} N(0, \sigma_\varepsilon^2)$ reflects the random disturbances which are needed to account for the fact that regression lines do not fit perfectly. η_{it} reflects economic inefficiency ($0 < \eta_{it} < 1$). A country which is fully efficient ($\eta_{it} = 1$) is able to produce on the frontier; otherwise it produces inefficiently with the degree of inefficiency measured by the size of η_{it}. The inefficiency effect is measured by a truncated normal distribution (Battese & Coelli 1995) and the mean level of inefficiency is denoted by

$$\mu_{ijt} = \delta_0 + \sum_{k=1}^{\kappa} \delta_k z_{k,it}$$

where $z_{k,it}$ is a set of economic, geographic and social factors which influence technical efficiency.

The problem is that the η_{it} are not directly observed; one observes only $\nu_{it} = \eta_{it} + \varepsilon_{it}$. We can, however, define the efficiency predictor using the conditional expectation of $\exp(-\eta_{it})$ given the random variable ε_{it} :

$$\begin{aligned} EE_{it} &= E\left[\exp(-\eta_{it})|\nu_{it}\right] \\ &= \left\{\exp(-\theta_{it} + \frac{1}{2}\tilde{\sigma}^2\right\} \times \left\{\Phi\left(\frac{\theta_{it}}{\tilde{\sigma}} - \tilde{\sigma}\right) / \Phi\left(\frac{\theta_{it}}{\tilde{\sigma}}\right)\right\} \end{aligned}$$

where $\Phi(.)$ denotes the distribution function of the standard normal variable,

$$\theta_{it} = (1-\gamma)\left\{\delta_0 + \sum_{m=1}^{M} \delta_m E_m\right\} - \gamma\nu_{it},\ \tilde{\sigma}^2 = \gamma(1-\gamma)\sigma^2,\ \text{and } \gamma = \frac{\sigma^2}{\sigma_\varepsilon^2 + \sigma^2}. \quad (7)$$

An operational predictor for the efficiency of country i at time t is found by replacing the unknown parameters in equation (7) with the maximum likelihood predictors. The log-likelihood function for this model is presented by Battese & Coelli (1993) as are the its first derivatives. In this model the variance of the efficiency term, η_{it} relative to the variance of the overall error, ν_{it}, measured by γ, tells us how far the overall variation in output, after adjusting for factor inputs, is due to inefficiency rather than pure stochastic variability. If $\gamma = 0$, then a standard non-frontier methodology is correct, while if $\gamma = 1$

then all of the variation has to be attributed to differing degrees of inefficiency. A statistically significant value of γ different from 0 indicates that the traditional regression approach is misspecified.

The production function is assumed to be determined by the factor inputs of labour, capital and human capital as discussed above. Regional dummies are included to represent the idea that different technologies are appropriate to countries in different regions. Time dummies are also introduced to explain differences in productivity growth in 1974-1987 relative to 1960-1973.

Inefficiency is represented as a function of many of the variables which are often placed in straightforward regression equations. It depends on log human capital, openness (*swopen,* as measured by Sachs & Warner, 1995), whether countries are landlocked, their latitudes, inter-country risk, as assessed by Knack & Keefer (1995), the fraction of the population from ethnic minorities and the product of openness and log human capital. The results of the estimation are shown in table 5.

Because the model is non-linear, there is no simple way of interpreting the coefficients on the efficiency terms. However, using the result obtained in Battese & Broca (1997), we can calculate the effect at mean level of efficiency. The effect is

$$\delta_m C_{it}$$

where

$$C_{it} = 1 - \frac{1}{\sigma}\left[\frac{\phi\left(\frac{\overline{\theta}_{it}}{\sigma} - \sigma\right)}{\Phi\left(\frac{\overline{\theta}_{it}}{\sigma} - \sigma\right)} - \frac{\phi\left(\frac{\overline{\theta}_{it}}{\sigma}\right)}{\Phi\left(\frac{\overline{\theta}_{it}}{\sigma}\right)}\right]$$

Thus, at mean values of θ, for an closed economy an increase in years of education of 1% reduces inefficiency by 0.02%, but the same increase reduceces inefficiency by 0.34% in an open economy. An increase in education from seven to eight years is an increase of 14%; thus this suggests an increase in output for an open economy of 5% of GDP. This is coherent with the range of figures from micro-economic studies and thoroughly plausible. The determination of the frontier is less satisfactory. The effect of human capital is small but incorrectly signed, which may be due to the presence of h in the part of the model that explains efficiency. The coefficient on capital is considerably larger than is consistent with observed factor shares while that on labour is correspondingly lower.

The overall conclusion one can draw from this study is that education does seem to be a factor accounting for inefficiency, or a failure to use the available technology to

	coefficient	standard-error	t-ratio
Frontier			
Constant	1.673	0.106	15.745
k	0.776	0.007	112.461
l	0.226	0.007	30.592
h	-0.036	0.016	2.232
t(60-73)	-0.001	0.001	0.800
t(74-87)	-0.015	0.001	9.865
C_1	0.026	0.029	0.918
C_2	-0.132	0.024	5.423
C_3	-0.459	0.0319	14.374
C_4	-0.224	0.044	5.140
C_5	-0.167	0.027	6.200
Efficiency terms			
Constant	-0.011	0.169	0.065
h	-0.025	0.027	0.907
Swopen	0.620	0.102	6.093
landlock	0.183	0.044	4.195
latitude	-0.007	0.001	4.773
tropical	0.169	0.067	2.522
ICRGE	-0.0536	0.012	4.633
eth. frac	0.006	0.001	6.209
swopen*h	-0.420	0.073	5.733
σ^2	0.170	0.019	8.838
γ	0.916	0.012	78.057
log likelihood function			59.900
LR test of the one-sided error			657.948

Table 5: Parameters of the Inefficiency Model

the best advantage but, at the same time, only open economies can benefit from the effects of education in reducing efficiency. That seems to be true even if education is also assumed to influence the position of the frontier.

12 Conclusions

It is difficult to be left completely satisfied by the wide range of studies looking at the effects of education on economic growth. Micro-economic analysis provides estimates of the effect of education on individual incomes, and researchers tend to feel most comfortable with those macro-economic studies which provide estimates of rates of return similar to those found in micro-economic studies, in the range of 6-12% p.a.. Since results which suggested much higher or much lower returns would lack credibility, there has probably been an element of selection bias in the findings which are published. Thus the most that can be concluded from the various studies is that there has been no conclusive evidence suggesting that the returns to education are very different from this. There is, however, some evidence to support the view that education is needed as a means of allowing countries to make good use of available technology with the implication, observed in Mincerian returns, that returns to education diminish with levels of development.

Notes

[1] The figure for Korea is in fact that of 1910.

[2] There is a separate worry about measures of this sort. They measure the return to the individual, but is education a means of helping people to increase their earning because it helps them to stand out from the crowd?

[3] With n as the average rate of growth of the population aged 15-64 between 1960 amd 1985 and $g + \delta$ set to 0.05.

[4] Since people have finite working lives and each year of education deprives them of a year of work, then, even if increasing education always increases people's earning power once they are working, there is an upper limit to the duration of education which is economically viable.

[5] Topel does not give any indication as to the basis for his assumption of a 3% convergence rate.

[6] There are a number of alternative explanations of their finding. Temple (1999) has shown that this result may be due to the presence of outliers. Another explanation, suggested by Temple (2001) is the assumption that the productivity effect of an additional year of schooling is constant may be unduly restrictive. We deal with the third, measurement error, in section 9 below (Krueger & Lindhal, 2001).

References

Barro, R. (1997), *Determinants of Economic Growth: a Cross-Country Study*, MIT Press, Cambridge, U.S.A.

Barro, R. & Lee, J.-W. (1993), 'International Comparisons of Educational Attainment', *Journal of Monetary Economics* **32**, 363–394.

Battese, G. & Broca, S. (1997), 'Functional Forms of Stochastic Frontier Productino Functions and Models for Technical Inefficiency Effects: a Comparative Study for Wheat Farmers in Pakistan', *Journal of Productivity Analysis* **8**, 395–414.

Battese, G. & Coelli, T. (1993), A Stochastic Frontier Production FUnction Incorporating a model for Technical Inefficiency Effects. Working Papers in Econometrics and Applied Statistics, No 69. Department of Econometrics. University of New England.

Battese, G. & Coelli, T. (1995), 'A Model for Technical Efficiency Effects in a Stochastic Frontier Production Function for Panel Data', *Empirical Economics* **20**, 325–332.

Benhabib, J. & Spiegel, M. (1994), 'The Role of Human Capital in Economic Development: Evidence from Aggregate Cross-country Data', *Journal of Monetary Economics* **43**, 143–174.

Dougherty, C. & Jorgenson, D. (1997), 'There is no Silver Bullet: Investment and Growth in the G7', *National Institute Economic Review* (162), 57–74.

Easterlin, R. (1981), 'Why isn't the Whole World Developed?', *Journal of Economic History* **41**, 1–19.

Islam, N. (1995), 'Growth Empirics: a Panel Data Approach', *Quarterly Journal of Economics* **110**, 1127–1170.

Knack, S. & Keefer, P. (1995), 'Institutions and Economic Performance: Cross-country Tests using Alternative Institutional Measures', *Economics and Politics* **7**, 207–227.

Kneller, R. & Stevens, P. (2002), The Role of Efficiency as an Explanation of International Income Differences. National Institute Discussion Paper No 206.

Krueger, A. & Lindahl, M. (2001), 'Education for Growth: Why and for Whom?', *Journal of Economic Literature* **39**, 1101–1136.

Kyriacou, G. (1991), Level and Growth Effects of Human Capital. C.V. Starr Centre, New York University.

Lucas, R. (1988), 'On the Mechanics of Economic Development', *Journal of Monetary Economics* **22**.

Maddison, A. (1991), *Dynamic Forces of Capitalist Development*, Oxford University Press, Oxford.

Mankiw, G., Romer, D. & Weil, D. (1992), 'A Contribution to the Empirics of Economic Growth', *Quarterly Journal of Economics* **107**, 407–437.

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

Nelson, R. & Phelps, E. (1966), 'Investment in Humans, Technical Diffusion and Economic Growth', *American Economic Review* **56**, 69–75.

Oulton, N. (1997), 'Total Factor Productivity Growth and the Role of Externalities', *National Institute Economic Review* (162), 99–111.

Psacharopoulos, G. (1994), 'Returns to education: a global update', *World Development* **22**, 1325–1343.

Romer, P. (1990), 'Endogenous Technical Change', *Journal of Political Economy* **89**, S71–S102.

Samuleson, P. & Swamy, S. (1974), 'Invariant Economic Index Numbers and Canonical Duality: survey and Synthesis', *American Economic Review* **64**, 566–593.

Sianesi, B. & van Reenen, J. (2003), 'The Returns to Education: Macroeconomics', **17**, 157=200.

Smith, R., Weale, M. & Satchell, S. (1998), 'Measurement Error with Accounting Constraints: Point and Interval Estimation for Latent Data with an Application to UK Gross Domestic Product', *Review of Economic Studies* **65**.

Solow, R. (1956), 'A Contribution to the Theory of Economic Growth', *Quarterly Journal of Economics* **70**, 65–95.

Temple, J. (1999), 'A Positive Effect of Human Capital on Growth', *Economics Letters* **65**, 131–4.

Temple, J. (2001), 'Generalisations that aren't? Evidence on Education and Growth', *European Economic Review* **45**, 905–18.

Topel, R. (1999), The Labour Market and Economic Growth, *in* O. Ashenfelter & D. Card, eds, 'The Handbook of Labour Economics', North Holland, Amsterdam, p. Ch. 44.

Wolff, E. & Gittleman, M. (1993), The Role of Education in Productivity Convergence: Does Higher Education Matter, *in* A. Szimai, B. van Ark and D. Pilat, ed., 'Explaining Economic Growth', Elsevier Science Publishers, Amsterdam.