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Schooling Quality and Economic Growth

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Abstract

Many studies of the determinants of economic growth rates across countries use a measure of schooling quantity, such as mean secondary school enrolment rates, to proxy for the rate of human capital accumulation. This approach ignores the contribution of schooling quality. We augment the growth model of Mankiw, Romer and Weil (1992) to include schooling quality, derive the relevant steady state income and growth rate equations, and then estimate the model. We find that differences in schooling quality across countries are probably more important than differences in schooling quantity in explaining variations in economic growth rates.

JEL Classification Numbers: O40, E13.

Schooling Quality and Economic Growth

1. Introduction

Many countries make very large educational investments, presumably because schooling is an important means whereby individuals accumulate human capital. But how does schooling matter? Is the accumulation of human capital simply an increasing function of the time spent at school, or are the types of tasks undertaken, the quality of the instruction given, and the academic atmosphere encouraged at school also important? These are difficult questions to investigate empirically, partly because human capital is difficult to measure (Mulligan and Sala-i-Martin 1995) and partly because students are not homogeneous with respect to their innate abilities and their family and other background characteristics. Furthermore, schools are not uniform in the educational experiences they provide. Accordingly, some students acquire more schooling and/or achieve higher measurable outcomes than others, whilst some schools achieve consistently superior results, on aggregate, than others. Such variability is also evident across countries.

This paper investigates whether, across countries, schooling quality is important in the relationship between human capital accumulation and economic growth. Most previous studies have used only a quantity measure of schooling, such as mean secondary school enrolment rates or mean years of schooling completed, as a proxy for the accumulation of human capital. A typical though not universal finding is that the quantity of schooling is positively and significantly associated with mean rates of economic growth[1]. These conclusions have led to calls for greater investments in schooling, especially in developing countries. However, perhaps equal attention should also be directed at improving the quality of schooling rather than simply encouraging students to acquire more schooling.

We investigate this issue by replicating the empirical approach taken by Mankiw, Romer and Weil (1992), but include in the analysis a measure of schooling quality across countries. Our objective is to determine whether, and if so in which direction, schooling quality affects the empirical results. It is true that this model and the associated empirical approach have attracted some recent criticism (Islam 1995 and Caselli, Esquivel and Lefort 1996), although we also note the existence of counter-arguments (Knowles, Lorgelly and Dorian Owen 1998). Our objective is not to enter into this debate, but rather solely to determine whether a measure of schooling quality across countries, when included in a commonly used and well understood neoclassical model of economic growth, has a significant impact on the estimation results.

An important issue concerns how to most appropriately measure schooling quality. An ideal metric would capture value added from schooling (Johnes 1992), given agreement on what outcomes of schooling are important and on how their value is to be determined. The notion of value added is an important but often neglected one, especially in popular discussions of the learning outcomes from schooling. For example, if students from school A achieve better outcomes than their counterparts from school B then the former school is commonly regarded

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[1] See, for example, Barro (1991), Mankiw, Romer and Weil (1992) and Levine and Renelt (1992). A study which finds that the quantity of schooling is inversely related to rates of economic growth across countries is Pritchett (1997).

as a better or higher quality school than the latter. However, this result may have simply been due to the students from school A possessing a higher level of innate ability. A better estimate of schooling quality would be gained by considering the value of the marginal learning outcomes produced by each school. Unfortunately, such information is not readily available. In this paper we use mean cross-country scores on tests of mathematics and science as the best available proxies for schooling quality across countries.

One criticism of test scores as measures of schooling quality is that they indicate, in the main, the degree to which only subject specific knowledge and reasoning abilities have been transmitted to students. Many would argue that other outcomes, such as the development of appropriate values, the ability to think creatively and abstractly, and a respect for diverse lifestyles and views, are equally important outcomes of a quality education. However, whilst the retention of factual knowledge and the ability to reason logically may not be sufficient outcomes, we believe that they are necessary ones. Furthermore, schools which are most successful at imparting knowledge and reasoning skills to their students are also likely to be those who successfully foster the development of the other desirable characteristics. High quality schools probably do not, in the aggregate, produce highly knowledgable but socially and culturally incompetent graduates. If this is so then mean cross-country test scores will be reasonable proxies for the quality of schooling across those countries[2].

[2] Individual test scores may be less satisfactory as indicators of individual productivity. Factors such as discrimination, disease, trauma or just plain bad luck may prevent individuals with high test scores from translating their school success into labour market success. However, on aggregate, it is reasonable to expect that a significantly higher national mean test score will translate, other things being equal, into a higher level of national productivity.

In other studies, schooling quality is often defined in terms of the quantity or quality of various school inputs. For instance, schools with lower student-teacher ratios, more highly paid teachers, or higher expenditures per student are often assumed to be of higher quality, and vice versa. However, whilst resources into schooling and schooling quality may be positively correlated, they need not be (Hanushek 1986). In our view this approach confuses inputs into schooling with outputs from schooling. We believe that mean cross country test scores are better measures of student learning outcomes from schooling, and hence of the quality of schooling.

Another common approach is to define higher quality schools as those whose graduates achieve higher labour market returns after graduation (Card and Krueger 1992). The idea here is that test scores are an imperfect measure of the value of school outputs and that, in any case, attention is better focused on longer term outcomes such as earnings. However, earnings represent (in a competitive market) the marginal labour market returns to aggregate human capital and so may not be good indicators of the value of the marginal product from schooling. Hence, using earnings as a proxy for schooling quality is also problematic because of differences in the innate abilities of students, and because of the many influences which exist pre and post schooling and which may impact on the accumulation of human capital and hence later earnings, such as parental education levels, on-the-job training, and so on.

The remainder of this paper is organised as follows. In the next section we outline the model of Mankiw et al. (1992) and briefly summarise their main empirical results. In section 3 we introduce a term for schooling quality into the model and derive the corresponding steady state income and growth rate equations. We then present data on schooling quality across a sample of countries and estimate the model. In section 4 we undertake a preliminary investigation of whether the inclusion of data on cross-country changes in the quality of schooling across two periods has any impact on changes in cross-country growth rates. Finally, section 5 concludes.

2. Schooling, Incomes and Economic Growth in Mankiw, Romer and Weil (1992)

The model of Mankiw et al. (1992) is well known[3] and so in this section we merely outline the main features of the model and summarise the results. The authors begin with the following production function, where *Y*, *K*, *H*, *A* and *L* are defined as the levels of real output, physical capital, human capital, technology and labour, respectively.

$$Y(t)=K(t)^{a}\, H(t)^{b}\, [A(t)L(t)]^{1-a-b} \qquad a>0,\ b>0,\ a+b=1 \qquad (1)$$

Physical and human capital accumulate as per (2) and (3) respectively, where s_k (s_h) is the physical capital (human capital) savings rate and δ is the (exogenous) depreciation rate.

$$dK(t)/dt = [s_k Y(t)] - dK(t) \qquad (2)$$

$$dH(t)/dt = [s_h Y(t)] - dH(t) \qquad (3)$$

[3] See Romer (1996).

By resorting to appropriate assumptions concerning the exogenous growth paths of technology and labour, the authors derive (4) for the steady state level of real income per effective worker.

$$ln\ y^* = -\ [(a+b)\ /\ (1-a-b)]ln(n+g+d) + [a/(1-a-b)]lns_K + [b/(1-a-b)]lns_h \quad (4)$$

Mankiw et al. also derive (5) for the growth rate of real income per effective worker as a function of the determinants of the steady state and the income level in the initial period ($y(0)$). Equation (5) is used to test the convergence hypothesis. If the coefficient on the initial level of income is negative (positive) then over the sample period and other things being equal, real per capita incomes in the initially poorer countries of the sample caught up or converged (diverged) on those of the initially richer countries, with λ being the average speed of convergence (divergence).

$$ln\ y(t) - ln\ y(0) \cong (1-e^{-lt})[a/1-a-b]ln\ s_k + (1-e^{-lt})[b\ /1-a-b]ln\ s_h\ -$$
$$(1-e^{-lt})[a+b/1-a-b]ln\ (n+g+d) - (1-e^{-lt})\ ln\ y(0) \quad (5)$$

The authors estimate (4) and (5) for the period 1960 to 1985 for three samples of countries. The first contains the 98 non oil-exporting nations for which they have data. The second includes only the 75 non oil-exporting nations for which the data is relatively more reliable. The third includes only the 22 member nations of the OECD. The authors use data on physical capital investment rates and population growth rates from Summers and Heston (1988), the latter adjusted to account for the proportion of the population in each country aged

15-64 years[4]. With regard to the human capital savings rate (s_h), the authors construct a proxy, which they call *SCHOOL*, and which measures approximately the mean percentage of the population of each country that was enrolled in secondary school from 1960 to 1985.

In estimates of (4) and for the two larger samples, the coefficients on the physical capital savings rate and the population growth rate are of the expected sign and statistically significant. For the OECD sample neither is significantly associated with mean real incomes at usual confidence limits. In contrast, the coefficients on *SCHOOL* in all three samples are of the expected sign and are statistically significant. Mankiw et. al. conclude that the physical capital investment rate, the working population growth rate and the school enrolment rate together explain nearly 80 percent of the cross-country variation in incomes in the two larger samples, and that the implied shares of income invested in physical and human capital are close to those observed in most countries.

The authors then estimate the growth rate equation (5) in three stages. Firstly, they test for unconditional convergence and establish that there is no tendency across their two largest samples for the poorest countries to systematically grow more quickly than the richest. However, unconditional convergence is found for the OECD countries, not surprising given their relative homogeneity with respect to those factors which determine the steady state. They next add the physical investment and population growth rates to the right hand side of the regression and establish that there exists a strong tendency for conditional convergence across all three samples, again most strongly for the OECD countries. Finally, the addition of *SCHOOL* further

[4] From here on, we refer to the growth rate of the working age population as simply the population growth rate.

improves the fit of the regression for all samples. These four variables together explain up to 65% of the variation in growth rates.

Given these findings, the authors conclude that;

> "...the Solow model is consistent with the international evidence if one acknowledges the importance of human as well as physical capital. The augmented Solow model says that differences in savings, education and population growth should explain cross-country differences in income per capita. Our examination of the data indicates that these three variables do explain most of the international variation...we expect that differences in tax policies, education policies, tastes for children and political stability will end up among the ultimate determinants of cross-country differences" (p.433).

Tax policy influences the savings rate and hence, in a closed economy, the physical capital investment rate. Tastes for children influence the population growth rate and political stability influences, among other things, the rate of technological advance. Of particular interest to us is the impact of education policy which, in general, may be classified as a quantity and/or quality effect. Education policy may impact on the quantity of schooling by, for instance, influencing the compulsory minimum school leaving age, and may impact on the quality of schooling by, for instance, impacting on the curriculum taught at school, the training and experience of teachers, and the incentives they face. Whilst most attention in empirical studies to date has been focused on the importance of the quantity of schooling, such as school enrolment rates, differences in schooling quality may also be important determinants of cross-country differences in economic growth rates.

In the next section we introduce a term for schooling quality into the model of Mankiw et al. (1992) and then state the corresponding equations for the steady-state level of per capita income and for the economic growth rate. We then present data on schooling quality across a sample of countries and re-estimate the convergence equation to determine whether schooling quality matters for economic growth.

3. The Impact of Schooling Quality on Economic Growth

This section investigates whether the addition of mean cross-country scores on tests of mathematics and science, as proxies for schooling quality, affects the empirical results from the model of Mankiw et al. (1992) which has been augmented by the addition of a variable for schooling quality. In (3) the multiplicative term $s_h Y(t)$ represents national expenditure on the accumulation of human capital, much of which is used for the provision of schooling. Hence, in general, greater educational expenditures are used either for the provision of an increased quantity of school resources such as more computers and desks in classrooms, larger library and recreational facilities and increased teaching staff, or for the provision of higher quality resources such as faster computers. As we argued earlier, more and/or better resources are inputs into the schooling process rather than measures of the value of outputs from schooling and so, in our view, national expenditures on schooling across countries are reasonable indicators of the quantity of schooling in those countries. This view is consistent with the empirical approach taken in Mankiw et al. (1992) and other studies, where school enrolment rates or average years of schooling completed, both quantity measures, are commonly used proxies for human capital accumulation rates.

However, this approach ignores the quality of schooling. Suppose that, in the manner of Lucas (1988), the accumulation of human capital is a function of both the quantity of schooling and the productivity of time spent at school, or the quality of schooling. Then the accumulation of human capital may be modelled as (6), where Q_h is a measure of mean national schooling quality.

$$dH(t)/dt = [s_h Y(t)]Q_h - dH(t) \qquad (6)$$

In (6) human capital accumulates only if gross additions exceed losses through depreciation. Gross additions are now expressed as a function of both the quantity of schooling, proxied by national expenditures on schooling, and the quality of schooling. Assuming that all other features of the model remain unchanged, the steady state level of per capita income is now given by (7), in which income per capita is a function of the shares of output going to physical capital creation (s_k) and schooling (s_h), the quality of schooling (Q_h), the depreciation rate (d) and the rates of technological advance and population growth (g and n).

$$ln[Y/L]^* = lnA(0) + gt + a/(1-a-b)\, ln\, s_k + b/(1-a-b)\, ln s_h + b/(1-a-b)\, ln Q_h$$

$$- (a+b)/(1-a-b)\, ln(n+g+d) + e \qquad (7)$$

Also, conditional convergence to the steady state is now given by (8), where average growth rates are again a function of the determinants of the steady-state level of income, which now include the quality of schooling, and the initial level of income.

$$lny(t) - lny(0) = (1-e^{-lt})(a/1-a-b)\, ln(s_k) + (1-e^{-lt})(b/1-a-b)\, ln(s_h)$$

$$+ (1-e^{-lt})(b/1-a-b)\, ln(Q_h) - (1-e^{-lt})(a+b/1-a-b)\, ln(n+g+d)$$

$$- (1-e^{-lt})\, ln(y(0)) \qquad (8)$$

Our objective now is to estimate (7) and (8). To do so we need, other than the usual data, measures of schooling quality across countries. Table 1 presents national standardised test scores published as part of the Third International Mathematics and Science Study (TIMSS) by the International Association for the Evaluation of Educational Achievement (Beaton et. al. 1996a and 1996b). These studies tested the mathematics and science knowledge of more than half a million students in over 40 countries in the mid 1990's. Mathematics curriculum dimensions tested were fractions and number sense; measurement; proportionality; data representation, analysis and probability; geometry; and algebra. Science curriculum dimensions tested were earth science; life science; physics; chemistry; and environmental issues and the nature of science. The study produced data on the mathematics and science achievements of year 4 students in 26 countries, year 8 students in 40 countries (41 school systems, as the Flemish and French systems in Belgium reported separately), and year 12 students in 21 countries. Student performances on the tests in each participating country were graded according to strictly defined criteria and national standardised mean test scores were calculated[5]. Table 1 also includes the rank of each country by school year and test.

5 See Beaton (1996a) for details on the testing procedures, etc.

Table 1: Cross-Country Test Scores by Year and Subject from the Third International Mathematics and Science Study

Country	4Math:Rk	4Sci:Rk	8Math:Rk	8Sci:Rk	12Math:Rk	12Sci:Rk
Australia	546:11	562:5	530:16	545:12	522:8	527:7
Austria	559:7	565:3	539:12	558:8	518:11	520:9
Belgium (Fl)			565:5	550:11		
Belgium (Fr)			526:19	471:36		
Bulgaria			540:11	565:4		
Canada	532:13	549:9	527:17	531:18	519:10	532:5
Colombia			385:40	411:40		
Cyprus	502:18	475:23	474:36	463:38	446:20	448:20
Czech Rep	567:6	557:6	564:6	574:2	466:18	487:13
Denmark			502:27	478:34	547:3	509:11
England	513:17	551:8	506:25	552:10		
France			538:13	498:28	523:7	487:13
Germany			509:23	531:19	495:13	497:12
Greece	492:21	497:21	484:33	497:29		
Hong Kong	587:4	533:14	588:4	522:24		
Hungary	548:10	532:15	537:14	554:9	483:14	471:18
Iceland	474:24	505:19	487:31	494:30	534:5	549:3
Iran	429:25	416:25	428:38	470:37		
Ireland	550:9	539:12	527:18	538:14		
Israel	531:14	505:20	522:20	524:23		
Italy			476:15	475:17		
Japan	597:3	574:2	605:3	571:3		
Korea	611:2	597:1	607:2	565:4		
Kuwait	400:	401:26	392:39	430:39		
Latvia	525:15	512:18	493:30	485:32		
Lithuania			477:35	476:35	469:17	461:19
Nether.	577:5	557:7	541:9	560:6	560:1	558:2
NZ	499:20	531:16	508:24	525:21	522:8	529:6
Norway	502:19	530:17	503:26	527:20	528:6	544:4
Portugal	475:23	480:22	454:37	480:33		
Romania			482:34	486:31		
Russia			535:15	538:15	471:16	481:15
Scotland	520:16	536:13	498:29	517:26		
Singapore	625:1	547:10	643:1	607:1		
Slovak R			547:7	544:13		
Slovenia	552:8	546:11	541:9	560:7	512:12	517:10
Sth Africa			354:41	326:41	356:21	349:21
Spain					487:32	517:27
Sweden			519:22	535:16	552:2	559:1
Switz			545:8	522:25	540:4	523:8
Thailand	490:22	473:24	522:21	525:22		
USA	545:12	565:4	500:28	534:17	461:19	480:16
n	26	26	41	41	21	21
Range	400-625	401-597	354-643	326-607	356-560	349-559
Mean	529	524	513	516	500	500

Notes: '4Math:Rk' in column two refers to 4th grade mathematics test scores and rank. Likewise for columns 3-7. Blank cells indicate that the relevant country did not participate in that test. 'Mean Score' is the international mean test score for the countries who participated in that test. 'Range' reports the lowest and highest mean test scores for that test. 'Korea' refers to the Republic of Korea, 'Iran' to the Islamic Republic of Iran, 'Russia' to the Russian Federation and NZ to New Zealand. The Flemish and French educational systems in Belgium participated separately.

Our sample period is 1960-1985, yet we propose to use test scores from the mid 1990's to proxy for schooling quality. Whilst it is possible that the mean quality of schools across countries was different in absolute terms over the period 1960-85 compared to the mid 1990's, we assume that the relativities across countries did not changed, and so the use of test scores from Table 1 as proxies for mean schooling quality for the period 1960-1985 should only impact on the regression constant. Also, as we are using a neoclassical growth model which assumes market dominated production, we omitted from our sample those countries which were formerly member states of the USSR. We also omitted Kuwait and Iran, who generate much of their income from the extraction and export of oil, and Scotland. This leaves us with a sample of 28, mostly OECD countries. The estimation results in Mankiw et. al. for the income equation (4) for the OECD sample were relatively poor, with neither the physical capital savings rate nor the population growth rate being statistically significant. We confirmed these results for our sample. Regressions of (7), not reported here, produced adjusted R^2 values of zero. Hence from here on, we report our estimation results for the conditional convergence equation (8) only. Data on physical capital investment rates, population growth rates, etc are from the Penn World tables (v5.6)[6]. The estimation results are presented in Table 2.

The results in Table 2 indicate that schooling quality is significantly and positively associated with mean economic growth rates for this sample of countries and over this sample period. The result in column one indicates that there is a strong tendency towards unconditional

[6] See http://datacentre.chass.utoronto.ca/pwt/index.html

convergence, with initial incomes alone accounting for 43% of the variation in mean growth rates across the sample period. When savings and population growth rates are added (column two), convergence (now conditional) remains strong. The coefficient on the physical capital savings rate is of the expected sign and is statistically significant whilst that on the population growth rate is of the expected sign but is not statistically significant. Also, the fit of the regression is substantially improved by the addition of these two explanatory variables, with the adjusted R^2 increasing from .43 to .53. When we add data on secondary school enrolment rates (column three), the previous results are little changed. The coefficient on *SCHOOL* is of the expected sign and is statistically significant at the 10% level whilst the fit of the regression is further improved (adjusted R^2 increases from .53 to .57). However, when we add our proxies for schooling quality, the results change markedly. In column four we add year 8 mathematics test scores (*8math*) and the adjusted R^2 increases from .57 to .71. Conditional convergence is still a strong feature, but now the coefficient on the savings rate is insignificantly different from zero at usual confidence limits. Also, the coefficient on *SCHOOL* is now essentially zero whilst that on *8math* is of the expected sign and is highly statistically significant. Hence the addition of year 8 mathematics test scores has a substantial positive impact on the estimation results from this model. The regression whose results are presented in column five uses year 8 science test scores (*8sci*) as proxies for schooling quality instead of year 8 maths scores. In this case the fit of the regression is also improved compared to that of column three, the coefficient on the test score variable is of the expected sign and statistically significant at the 10% level, whilst that on *SCHOOL* is again essentially zero. On this occasion, however, the coefficient on the savings rate is once again close to significant at the 5% level. The savings rate thus loses much of its explanatory power only with the addition of mathematics test scores.

Table 2: Estimation Results for Equation (8)
Dependent Variable log difference GDP per worker (1960-85)

Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
ln(y60)	-.37	-.42	-.46	-.41	-.43
	(-4.63)	(-5.17)	(-5.71)	(-5.89)	(-5.56)
ln(s_k)		.62	.50	.31	.46
		(2.56)	(2.08)	(1.48)	(2.03)
ln(n+g+d)		-.14	-.14	-.23	-.10
		(-.38)	(-.39)	(-.80)	(-.29)
ln(SCHOOL)			.28	.005	.04
			(1.82)	(.03)	(.24)
ln(8math)				3.04	
				(3.47)	
ln(8sci)					2.46
					(2.11)
Adj R^2	.43	.53	.57	.71	.62

Notes: t-statistics are in parentheses. y60 is the initial level of income per worker. s_k is the mean physical capital investment rate as a proportion of GDP. n+g+δ is the sum of the growth rates of workers and technology plus the depreciation rate. SCHOOL is the secondary school enrolment rate. 8math (8sci) is the year mathematics (science) test score. ln(•) refers to the natural logarithm. The regression constants have been omitted to save space.

Hence we conclude that the addition of test scores, as proxies for schooling quality, has a substantial positive impact on the estimation results. Mathematics scores are particularly important, and their inclusion results in the savings rate variable losing much of its explanatory power. Finally, we note that in regressions which include both the quantity and the quality of schooling, the latter is a more important determinant of mean economic growth rates than the former.

In this section we have shown that, with the growth model of Mankiw et al. (1992) which includes schooling quality as an additional explanatory variable, the quantity of schooling is essentially unrelated to mean cross-country growth rates when schooling quality is controlled for. On the other hand, schooling quality is significantly and positively associated with mean growth rates, and when test scores are included on the right hand side, the fit of the regressions improves substantially. Our results indicate that cross country differences in schooling quality are an important source of differences in economic growth rates across countries and hence should not be ignored. However, including proxies for schooling quality in analyses of the determinants of cross-country growth rates appears to be the exception rather than the rule[7].

Our results may help to explain some recent findings suggesting that schooling is unrelated to economic growth[8]. By using a measure of human capital accumulation that captures only the quantity of schooling, these studies have ignored the impact of schooling quality differentials across countries. Our results also indicate that when schooling quality is controlled for, physical capital savings rates lose much of their explanatory power in the

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7 To the best of our knowledge, the only empirical study of the impact of schooling quality on economic growth is Hanushek and Kim (1995).

8 Barro and Sala-i-Martin (1995) and Benhabib and Spiegel (1994), for example, find that changes in schooling quantity have insignificant effects on GDP growth. Krueger and Lindahl (1999) find that these results are in large part due to measurement error. However, no author, as far as we know, has investigated whether these results could also be due to the omission of schooling quality.

convergence regressions. This is a puzzling result and further research is needed to determine whether it is robust to a larger sample size or an alternate theoretical specification.

In the next section we undertake a preliminary investigation of whether changes in schooling quality across countries help to explain cross-country changes in economic growth rates across two periods.

4. The Impact of Changes in Schooling Quality on Changes in Economic Growth Rates

Hamilton and Monteagudo (1998, from here on referred to as HM) use the model and data of Mankiw et al. (1992) to investigate whether changes in mean cross country growth rates can be explained by changes in the physical and human capital accumulation rates and in the population growth rates across two periods, from 1960-70 to 1975-1985. The authors assume that the shares of income going to physical and human capital remain unchanged across the two periods but that the rate of technological advance, the population growth rate, the shares of output going to the accumulation of physical and human capital, and the depreciation rate may have changed, and hence may have caused changes to economic growth rates, across these two periods.

HM derive (9) and estimate for the full sample of 98 countries used in Mankiw et. al, where v=1,2 refers to period one (1960-70) and period two (1975-85) respectively and the dependent variable is the change in the growth rate across the two periods, ie the growth rate in period two ($q_i^{(2)}$) less the growth rate in period one ($q_i^{(1)}$), n^* is the natural logarithm of the growth rate of workers plus five percent, $y(t^{(v)})$ refers to the natural logarithm of the initial level of real GDP per worker at the beginning of each period, ie 1960 for v=1 and 1975 for v=2, and the subscript *i* denotes each country in the sample.

$$q_i^{(2)} - q_i^{(1)} = c + \sum_{v=1} [a_v \ln(s^{(v)}_{k,i}) + b_v \ln(s^{(v)}_{h,i}) + c_v n^{*(v)}_i + d_v y_i(t^{(v)}] + \varepsilon_i \qquad (9)$$

The authors find that the coefficients on the accumulation of physical capital across the two periods are of the expected sign and statistically significant. That is, a higher rate of physical capital accumulation in period two relative to period one is associated with a higher rate of economic growth in period two relative to period one. Similarly, the coefficients on the population growth rate are of the expected sign though neither is statistically significant at the 5% level. The coefficients on the initial levels of income are also of the expected sign and significant, ie a higher initial level of output in period two relative to period one is associated with a lower growth rate in period two relative to period one. However, the results for their proxies for the accumulation of human capital are contrary to expectation. According to HM;

> "The variable for which the results contrast most sharply with the theoretical prediction is the proxy for human capital investment, s_h - an increase in the fraction of resources devoted to education is correlated with slower, not faster, economic growth, with each of the individual coefficients again statistically significant" (p.500).

In HM, as was the case in Mankiw et al., output is defined as real per capita GDP whilst human capital accumulation is proxied for empirical estimation by mean secondary school enrolment rates. Given these definitions it seems likely, *a priori*, that an inverse relationship may exist between changes in these two variables. If a greater proportion of workers in any given period cease work, or reduce their working hours, so as to acquire more years of schooling then, other things being equal, real per capita GDP may also fall. If this ‘absence effect’ exists then the specification of HM biases their results towards finding an inverse relationship between changes in their proxy for the rate of human capital accumulation and changes in mean economic growth rates. Possibly offsetting this ‘absence effect’ is the likelihood that graduating workers will be more productive when they re-enter the workforce. If this 'graduation effect’ outweighs the 'absence effect’ then the net impact will be positive. However, the marginal labour market product from additional years of schooling may have diminished over the last 30 years (Loeb and Bound 1996). Hence the results of HM with regard to human capital accumulation in the form of schooling quantity may in part be a function of their sample period.

Also, HM use the same data as Mankiw et al., in particular, secondary school enrolment rates as proxies for human capital accumulation rates, and hence they also ignore the role of schooling quality in the accumulation of human capital. Hence we now investigate whether changes in schooling quality help to explain changes in mean economic growth rates across countries from period 1 (1960-1970) to period 2 (1975-1985). Our objective is to estimate (10), which is the differenced form of (9), but including in the regression a proxy for changes in schooling quality across these two periods[9].

$$q_i^{(2)} - q_i^{(1)} = c + a_1 Dlns_{k,i} + a_2 Dlns_{h,i} + a_3 Dlnn_i + a_4 Dlny_i + e_i \qquad (10)$$

9 This exercise will be illustrative rather than definitive because of severe data limitations.

We assume that the year 8 test scores in Table 1 are reasonable indicators of cross-country schooling quality for the period 1975-1985. However, test scores for the period 1960-1970 are only available for science, are based on a different scale to that used for the most recent tests, and exist for only ten countries of our sample of 28[10]. This is a very small sample but we have no other data on test scores for the earlier period. To overcome the scale problem, we constructed a relative score for each of the ten countries for each period, defined as the country test score for year 8 science divided by the international mean score. The relative scores from the earlier tests are our proxies for schooling quality for the period 1960-70 whilst the relative test scores for the same 10 countries from the latest tests are our proxies for schooling quality for the period 1975-85. The regression results are presented in Table 3. We firstly estimated (10) excluding changes in schooling quality (column 1) and then re-estimated including changes in schooling quality (column 2).

[10] These earlier data are from the First International Study of Science Education. The ten countries in our sample are Australia, Belgium, UK, Germany, Japan, Netherlands, New Zealand, Sweden, Thailand and USA. See Comber and Keeves (1973) and, for an earlier study of mathematics achievement but for even fewer countries, see Husen (1967).

Table 3: Estimation Results for Equation (10)
Dependent Variable: Change in Growth Rate (1960-1970) to (1975-85).

	(1)	(2)
$\Delta \ln(y_i)$	-.06	-.06
	(-7.85)	(-6.48)
$\Delta \ln(s_{k,I})$	.07	.07
	(3.89)	(3.70)
$\Delta \ln(n_i)$	.04	.04
	(1.38)	(1.40)
$\Delta \ln(SCHOOL_i)$	.02	.001
	(.95)	(.03)
$\Delta \ln(score_i)$	.01	(.64)
Adjusted R^2	.88	.87

Notes: t statistics are in parentheses. The regression constant has been omitted to save space. The variables are as defined in the text. ln(•) refers to the natural logarithm.

The results of column 1 indicate that, even for this small sample, higher investment rates in period two relative to period one were associated with higher growth rates, whilst higher initial incomes in period two were associated with lower growth rates. However, the signs of the coefficients on changes in the population growth rate and on changes in school enrolment rates are positive but statistically insignificant. These four variables together account for 88% of the variations in changes in mean growth rates for this sample of countries across the two periods.

In column 2, the coefficient estimates for the physical capital investment rates, the initial income levels, and the population growth rates are basically unchanged. The coefficient on schooling quality is positive but statistically insignificant, whilst its inclusion has substantially reduced the size and significance, but has not reversed the sign, of the coefficient on secondary schooling enrolment rates. These results are consistent with those of Table 3 for the larger sample.

Whilst these results should be treated with great caution, they indicate that changes in schooling quantity and quality may not be inversely associated with changes in economic growth rates. HM ask the following question. "...what can a country do to make itself better off, and how much of a difference will it make?" (p.496). These results, combined with our earlier results, suggest that at least some countries can make themselves better off by accumulating more human capital, and that increasing the quality of schooling may be more important in achieving this end than increasing the quantity of schooling[11].

5. Concluding Comments

This paper has investigated the impact of schooling quality on the empirical results from the neoclassical growth model of Mankiw, Romer and Weil (1992). Our results indicate that schooling quality, as proxied by cross country scores on tests of mathematics and science knowledge, are positively and significantly associated with mean economic growth rates, and that the inclusion of schooling quality substantially improves the goodness of fit of the convergence regressions. The mathematics test scores have a particularly strong impact on the

[11] Over 60% of MRW's sample of 98 countries are developing, and many of these are amongst the poorest countries in the world. Perhaps human capital accumulation is a necessary but not sufficient condition for development, and must be accompanied by appropriate social and institutional developments.

results, and especially on the coefficient estimates for the physical capital savings rates and the secondary school enrolment rates. Hence studies which include a measure of schooling quantity only as a proxy for the human capital accumulation rate may be ignoring an important additional factor in the relationship between human capital and economic growth.

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