# *Schooling Quality and Economic Growth*



by

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# DECLARATION

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All errors in this thesis are mine alone.

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## ABSTRACT

An important challenge to the study of economics is to better understand the causes of economic growth. Many models of economic growth include the stock of human capital as an important factor of production, and model the accumulation of human capital as a process akin to that for physical capital. That is, human capital accumulates as a result of investments of time and money in schooling. Accordingly, in many empirical analyses of the determinants of mean cross-country growth rates, human capital is often proxied by measures such as mean school enrolment rates of, or mean years of schooling acquired by, the working age population.

However, this approach ignores the fact that the creation of human capital via schooling is a social activity involving interactions amongst large numbers of people. Therefore schooling quality, which we define as the productivity of time spent studying, is likely to be highly variable, both within and across countries. Such variability may be an important determinant of cross-country variations in economic growth rates.

This thesis investigates whether cross-country variations in schooling quality affect the empirical results in studies of economic growth based on an augmented model of Solow (1956). We find that schooling quality across countries is positively and statistically significantly associated with mean economic growth rates in regressions which control for physical capital investment rates, population growth rates and secondary school enrolment rates.

We also investigate which student background variables are likely to impact on cross-country test scores, and find that home characteristics such as the education levels of parents as well as school characteristics such as hours of homework and the non-teaching duties of teachers are statistically significant determinants of the cross-country variations in test scores.

Finally, we investigate whether differences in cross-country schooling quality by gender are important in an augmented Solow model of economic growth which includes years of schooling and separate test scores for males and females. Our preliminary results suggest that years of schooling of females (males) are positively (negatively) and significantly associated with mean per capita incomes across countries, whilst schooling quality by gender is statistically insignificant. However, years of schooling and schooling quality of females (males) are negatively (positively) and significantly associated with mean cross-country growth rates.

We conclude that schooling quality matters for economic growth, and that studies of cross-country incomes and growth rates should not ignore variations in schooling quality across countries as a potentially useful additional explanatory variable.

# CHAPTER 1

# INTRODUCTION

*"Human capital accumulation is a social activity, involving groups of people in a way that has no counterpart in the accumulation of physical capital" (Lucas, 1988, p.19)*

There are great disparities in the material standards of living of the richest and poorest countries. Table 1.1 below presents some illustrative data which indicates that, for instance, real per capita GDP in the richest country (USA) in 1990 was approximately fifty times that in the poorest country (Bangladesh), and over twenty times that in the next poorest (India), in 1987. These disparities have been brought about, in part, by differences across countries in mean long run growth rates of real GDP per capita. For example, the mean growth rate in the USA between 1870 and 1990 was over twenty times that of Bangladesh and nearly three times that of India between 1900 and 1987. If such differences in growth rates persist into the future, the already large gaps in the material standard of living between the richest and poorest countries will simply continue to widen.[1] An important challenge to the study of economics is thus to better understand the causes of economic growth. This concern is driven by the notion that with such understanding comes the possibility of improving the living conditions for all, and especially for those whose prosperity is lowest. As Table 1.1 illustrates, seemingly small differences in growth rates which persist for long periods can have large impacts on average standards of living. Clearly, economists will make an enormous contribution to the social welfare of the currently poorest nations in particular if, other things being equal, they can direct economic policy so as to even marginally increase long run rates of economic growth.[2]

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1 On this point, see Pritchett (1996).

2 Undesirable external effects of economic growth, such as environmental degradation, may reduce the net welfare gains from economic growth. In this thesis, we assume that economic growth results in net additions to social welfare.

**Table 1.1 Real Per Capita Incomes and Economic Growth Rates**

| *Country* | *Period* | *BegGDP* | *EndGDP* | *Growth Rate* |
|---|---|---|---|---|
| USA | 1870-1990 | 2244 | 18258 | 1.75 |
| Canada | 1870-1990 | 1330 | 17070 | 2.13 |
| Japan | 1890-1990 | 842 | 16144 | 2.95 |
| Switzerland | 1910-1990 | 2979 | 15650 | 2.07 |
| Norway | 1870-1990 | 1190 | 15418 | 2.13 |
| Sweden | 1870-1990 | 1401 | 14804 | 1.96 |
| West Germany | 1870-1990 | 1223 | 14288 | 2.05 |
| France | 1870-1990 | 1582 | 14245 | 1.83 |
| Denmark | 1870-1990 | 1543 | 14086 | 1.84 |
| Finland | 1870-1990 | 933 | 14012 | 2.26 |
| UK | 1870-1990 | 2693 | 13589 | 1.35 |
| Australia | 1870-1990 | 3143 | 13514 | 1.22 |
| Belgium | 1870-1990 | 2009 | 13320 | 1.58 |
| Italy | 1870-1990 | 1216 | 13215 | 1.99 |
| Netherlands | 1910-1990 | 2965 | 13078 | 1.86 |
| Austria | 1870-1990 | 1442 | 12976 | 1.83 |
| Taiwan | 1900-1987 | 434 | 4744 | 2.75 |
| South Korea | 1900-1987 | 549 | 4143 | 2.32 |
| Brazil | 1900-1987 | 436 | 3417 | 2.37 |
| Chile | 1900-1987 | 956 | 3393 | 1.46 |
| Argentina | 1900-1987 | 1284 | 3302 | 1.09 |
| Colombia | 1900-1987 | 610 | 3027 | 1.84 |
| Mexico | 1900-1987 | 649 | 2667 | 1.62 |
| Peru | 1900-1987 | 624 | 2380 | 1.54 |
| Thailand | 1900-1987 | 626 | 2294 | 1.49 |
| China | 1900-1987 | 401 | 1748 | 1.69 |
| Phillipines | 1900-1987 | 718 | 1519 | 0.86 |
| Indonesia | 1900-1987 | 499 | 1200 | 1.01 |
| Pakistan | 1900-1987 | 413 | 885 | 0.88 |
| India | 1900-1987 | 378 | 662 | 0.64 |
| Bangladesh | 1900-1987 | 349 | 375 | 0.08 |

**Source:** Barro and Sala-i-Martin (1995) and author's calculations. *BegGDP* is real GDP per capita at the beginning of the period. *EndGDP* is real GDP per capita at the end of the period. *Growth Rate* is the mean annual economic growth rate over the relevant period.

However, considerable debate exists within the economics literature on how to most appropriately model economic growth. On the one hand are the economic growth models based on Solow (1956) and Swan (1956) which assume competitive markets, production techniques which double output as inputs such as capital and labour double, and an exogenously determined and freely available production technology.[3] These models result in per capita incomes eventually growing at the exogenous rate of technological advance. Whilst economic policy in these models may affect per capita incomes by, for example, changing the savings rate, economic policy can not affect the steady-state growth rate.[4]

A different class of economic model evolved during the 1980's, following the work of Romer (1983, 1986) and Lucas (1988), which attempts to better explain the process of economic growth.[5] These models explicitly acknowledge the importance of human inputs such as knowledge and skills. Some models generate positive steady-state growth over time by incorporating monopolistically competitive firms whose profits motivate the discovery of new knowledge. Others incorporate external effects from the research activities of firms (or from the accumulation of human capital by individuals) which increase the productivity of other firms (or of other individuals) such that increasing returns to scale exist in production, ie productive output increases more than proportionally to the increase in inputs. In these models, the long run growth rate is an endogenously determined function of relevant parameters within the model.

Mankiw, Romer and Weil (1992) take a different approach by augmenting the Solow model with human capital.[6] They argue that the modeling approach of Solow is appropriate but that the contribution of human capital to production must also be captured, especially given estimates that human capital accounts for over 50 percent of the total

[3] Solow (1956) shall, from here on, be referred to as Solow.
[4] The two types of effects may be difficult to distinguish if the transition to a new steady state takes many years or decades.
[5] Lucas (1988) shall, from here on, be referred to as Lucas.
[6] Mankiw, Romer and Weil (1992) shall, from here on, be referred to as MRW.

capital stock in developed countries. The model of MRW thus does not rely on increasing returns to scale or the existence of externalities to research and development, or education, to explain cross-country differences in standards of living and economic growth rates.

This thesis does not seek to add to the debate about which approach to the modeling of economic growth is most appropriate. Rather, the objective here is to determine whether a measure of human capital accumulation which includes the quality of schooling affects the empirical results from regressions based on an augmented Solow model of economic growth.

Human capital may be defined as the ability, skills and knowledge of workers which allows them to create or add market value. It is acquired throughout one's lifetime, typically at a diminishing rate over time and probably in three stages. To begin with, in-home and pre-school activities are important determinants of one's subsequent productive ability.[7] Secondly, schools and universities are important educational institutions which facilitate and promote the further accumulation of human capital. Finally, human capital accumulation may continue into one's working life via on-the-job training and learning-by-doing.

Whilst human capital may be relatively easy to define, it is much more difficult to quantify. As far as we know, there is no universally accepted measure of human capital.[8] This presents difficulties when the contribution of human capital to standards of living and economic growth rates is to be estimated. A common approach is to model the determination of (log) weekly wages by an earnings function like equation (1.1) below,

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7 A number of studies have established the importance of the education level of the mother for the subsequent schooling achievement and labour market success of the student. The link between these two variables is probably in-home education. See, for instance, Murnane, Maynard and Ohls (1981). For a discussion of related issues, see Chapter Five of this thesis.

8 A number of proxies have been developed, some of which are discussed in Chapter 3. Mulligan and Sala-i-Martin (1995) is a recent attempt at addressing this problem.

where *lnwky* refers to the natural logarithm of weekly income.

$$lnwky = \beta_0 + \beta_1 yos + \beta_2 exp + \beta_3 exp^2 \qquad (1.1)$$

In equation (1.1) human capital acquired through schooling is proxied by years of schooling (*yos*) whilst that acquired via on-the-job training and learning-by-doing is proxied by years of labour market experience (*exp*). When applied to cross-sectional data, $\beta_0$ is an estimate of the return to unskilled labour, $\beta_1$ is an estimate of the return per year of schooling whilst $(\beta_2+2\beta_3)$ is an estimate of the return to labour market experience.

Specifications like equation (1.1) implicitly assume that more years of schooling, that is, a greater quantity of schooling, is synonymous with more human capital. However, human capital accumulation will also be greater, other things being equal, the greater the productivity of time spent at school, that is, the higher the quality of schooling. If, across countries, the quality of schooling is simply proportional to the quantity of schooling, then a measure such as years of schooling will be a good proxy for human capital accumulation. Such measures will be erroneous in an absolute, but not in a relative, sense.[9] In this case schooling quality will simply be a factor of proportionality and thus will only affect the constant term in cross-country growth regressions.

However, schooling quality varies greatly across countries, and so cross-country estimates of human capital accumulation which rely solely on the quantity of schooling will be erroneous in terms of the human capital relativities they imply. The upshot of this is that, if schooling quality matters, then results from empirical studies which have used measures of schooling quantity only, as proxies for human capital, may be seriously biased.[10]

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9 See MRW, p.419, on this point.

10 A similar point can be made by noting that the variable *yos* in equation (1.1) is bounded from above given finite lives and a positive opportunity cost of schooling. This implies that the impact of schooling quantity on earnings will be similarly bounded. But if schools become better at facilitating the accumulation of human capital then for any given quantity of schooling, other

Whilst many might agree that differences in schooling quality may be a potentially important source of cross-country differences in rates of human capital accumulation, and hence in economic growth rates, relatively few theoretical or empirical studies include a schooling quality variable.[11] For example, MRW simply use a measure of schooling quantity across countries, namely secondary school enrolment rates, as a proxy for human capital accumulation and so ignore the potential contribution of differences in schooling quality. This is also the case in the endogenous growth model of Lucas, where the proportional rate of accumulation of human capital is modelled as a function of the proportion of non-leisure time spent studying, but where the productivity of time spent studying is assumed constant. The objective of this thesis, then, is to determine whether the inclusion of a measure of cross-country schooling quality affects the empirical results from regressions based on an augmented Solow model of economic growth.

The remainder of this thesis is structured as follows. In Chapter 2 we discuss the meaning of schooling quality and then review the literature on the measurement of schooling quality, on the impact of student achievement at school on earnings, and on the contribution of schooling quality to economic growth. In Chapter 3 we examine in some detail the growth models of Solow, Lucas and MRW. The model of Solow does not include human capital as a factor of production but is the foundation upon which the models of Lucas and MRW are based. In these latter two models, economic growth is driven, in full or in part, by the accumulation of human capital by individuals. Lucas provides a theoretical justification for focusing on the quality of schooling, even though he settles on a specification in which schooling quality is assumed constant. MRW augment the Solow model with human capital and so provide an empirical framework for

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things being equal, average weekly earnings will increase. So whilst the quantity of schooling may be bounded from above, weekly earnings may continue to increase as long as schooling quality continues to increase.

11 One exception is Hanushek and Kim (1995), who also seek to determine the contribution of schooling quality to per capita incomes and growth rates across countries. They use older data on schooling quality, and a different theoretical approach, to that used in this thesis.

determining whether the inclusion of a proxy for schooling quality affects the empirical results from cross-country regressions.

In Chapter 4 we augment the Solow model so as to capture the contribution of schooling quantity and schooling quality to per capita incomes and growth rates. We then construct a measure of schooling quality across a sample of countries and investigate whether the inclusion of schooling quality affects the empirical results. In Chapter 5 we investigate which student, school and national economic characteristics are significant determinants of schooling quality across countries. In Chapter 6 we investigate whether cross-country differences in schooling quality by gender affect the results from growth regressions which use only the average quantity of male and female schooling as proxies for, respectively, the stocks of male and female human capital. Finally, Chapter 7 concludes.

# CHAPTER 2

# SCHOOLING QUALITY AND ITS CONTRIBUTION TO PER CAPITA INCOMES AND ECONOMIC GROWTH: A REVIEW OF THE LITERATURE

## 2.1 Introduction

The literature concerning the contribution of schooling to individual and social well being is large and goes back many decades. Before we review some of this research, it is important to define what we mean by schooling quality. For the purposes of this thesis, schooling quality is defined as the value added by schooling to students in the form of knowledge and reasoning ability.

We acknowledge that a high quality education involves more than just the transmission of knowledge and reasoning ability. Outcomes such as the development of appropriate values, the ability to think creatively and abstractly, a respect for diverse lifestyles and views, and other outcomes may each be regarded as equally essential components of a high 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 abilities to their students are likely to also be those who most successfully foster the development of the other desirable characteristics. High quality schools probably do not, in aggregate, produce highly knowledgeable but socially and culturally incompetent graduates. If this is so then the knowledge and reasoning ability acquired by students from schooling will be a reasonable proxy for the quality of that schooling.

Therefore, one way to estimate the quality of schooling across countries is via mean country scores on standardised tests of the mathematics, science and reading abilities of students.[12] However, such test scores alone do not indicate value-added. For instance, students from school A may achieve higher test scores than students from school B, and whilst it may be common in such situations for school A to be regarded as a higher quality school than school B, the higher test scores may have simply been due to a greater stock of pre-school knowledge, or to a higher level of innate ability, on the part of students from school A. Rather, value added should ideally be measured as the marginal additions to student knowledge and reasoning abilities which result from their attendance at school. Hence to more properly estimate value added, students would need to complete pre and post school examinations. Unfortunately, such information is not commonly available.

For empirical purposes, one may reasonably use test scores as a measure of schooling quality as long as family and other characteristics are controlled for. For example, students from high income households, or students with more highly educated parents, are likely to have greater pre-school knowledge or a higher level of natural ability and so, other things being equal, would be expected to achieve higher test scores. Only when such background characteristics are controlled for may mean test scores be reasonably used as indicators of schooling quality across countries.

However, not all researchers define schooling quality in terms of outcomes such as test scores. It is common in the economics literature for the quality of schooling to be synonymous with the quality or quantity of school inputs. For instance, schooling quality is often assumed to be greater if the student-teacher ratio is lower, or if teachers are more highly paid, or if expenditures per student are higher, and so on. In our view, this confuses the quality or quantity of school inputs with the quality of school outputs, and whilst it may be reasonable to assume that the two are positively correlated, some studies suggest that they are not.

[12] 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.

An example of a study in which schooling quality is synonymous with the quantity of school inputs is Loeb and Bound (1996), which investigates the impact which measurable school characteristics have on student achievement in the U.S.A.. They note that:

> "Schools differ markedly in their quality and their ability to promote student achievement. Yet, simple measures of school inputs, such as student-teacher ratios, generally have not been found to capture the quality of schooling differences that influence student outcomes" (p.653).

The implication is that school inputs, at least those inputs which are readily identifiable, are not strongly correlated with test scores and hence are not, in general, good proxies for schooling quality. The authors then state that:

> "The 1966 Coleman report...showed little schooling quality effect on student test scores once family backgrounds were accounted for" (p653).

Presumably the authors meant that measurable school characteristics (rather than schooling quality ) had little effect on student test scores. Yet the authors then go on to use student-teacher ratios and term length as proxies for the quality of schooling. As we stated earlier, these are inputs into the schooling process and not measures of the quality of schooling *per se*.

This is not a semantic distinction. One objective of schooling is to maximise student learning. If the quality of schooling is thought to be simply a positive function of the quantity or quality of school inputs then an appropriate policy response might be to simply devote more resources to schooling. Yet, as we have already noted, some research suggests that there is no systematic positive relationship between resources devoted to schooling and student outcomes. If this is the case then the distinction between the inputs into, and the output from, schooling is an important one.

With these prefatory remarks in mind, we now review some of the literature on the measurement of schooling quality and the relationship between school inputs and student achievement. We then focus on two broad strands in the literature. The first concerns the relationship between educational attainment and earnings in later life whilst the second concerns the contribution of schooling quality to economic growth across countries.[13]

## 2.2 The Measurement of Schooling Quality

An example of a study which defines the output of schooling as student achievement on tests is Murnane, Maynard and Ohls (1981). They seek to determine the impact of home resources on student scores in a test of vocabulary. They find that the formal schooling of the mother is positively associated with student achievement, that this effect operates through the mechanism of child care rather than genetically transmitted endowment, and that the material goods available in the home have no consistent effect on student achievement.[14] The authors thus find that the quality of schooling, in the form of student test scores, is partly a function of particular background characteristics of the student.

Hanushek (1986) surveys the findings of research into the relationship between measurable school and teacher characteristics and student achievement on standardised tests, which he refers to as the quality of schooling. He concludes, in part, that:

> "Schools differ dramatically in 'quality', but not because of the rudimentary factors that many researchers (and policy makers) have looked to for explanation of these differences. For instance, differences in quality do not seem to reflect variations in expenditures, class sizes or other commonly measured attributes of schools and teachers. Instead, they appear to result from differences in teacher 'skills' that defy detailed description, but that possibly can be observed directly" (p.1142).

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13 Some papers have multiple objectives and are thus difficult to categorise. Welch (1966), for instance, seeks to determine the impact of schooling quality, in the form of certain school inputs, on lifetime earnings, but also discusses the measurement of schooling quality. Hence the categorisation of particular papers in the following sections is somewhat arbitrary.

14 See Chapter 5, section 4 of this thesis for a brief discussion of the debate concerning the relative importance of schooling versus innate ability for student achievement and national productivity.

The finding that student achievement is not systematically related to measurable school inputs is controversial. For instance, Sander (1993), partly in response to the findings of Hanushek (1986), examines the determinants of educational attainment in Illinios, USA, for the 1989-90 school year. Sander defines educational attainment in terms of student test scores on the American College Testing Program Assessment (ACT scores), high school graduation rates and the percentage in a high school planning to attend college. He finds, in apparent contrast to Hanushek, that an increase in mean teacher salaries increases ACT scores and the percentage who go to college, whilst an increase in the student-teacher ratio significantly reduces the graduation rate and the percentage who go to college.

An important study of cross-country educational attainment is Barro and Lee (1993). Many empirical studies of economic growth include human capital as an explanatory variable, yet data on cross-country human capital accumulation is very limited. The authors addressed this problem by constructing a data base for 129 countries from 1960 to 1985 describing the mean proportions of males and females which had attained no schooling, primary, secondary or higher level schooling. Whilst this study is a valuable source of data for cross-country studies of economic growth, human capital accumulation is defined in terms of the quantity of schooling only.

The authors address this problem in Lee and Barro (1997) where they investigate the determinants of educational quality for a large number of countries. The authors begin by rejecting the use of labour market performance as an indicator of the quality of schooling because of the likely effects of external factors, and settle on the use of student test scores and school repetition and drop-out rates. They then investigate the impact of family characteristics and financial resources on these measures of the schooling quality.

The study by Barro and Lee (1997) is one of the few which examines schooling quality across countries and so provides measures of human capital accumulation which are suitable for empirical research into the determinants of cross-country economic growth. The authors find that family characteristics are important and that school characteristics such as the student-teacher ratio, the average teacher salary and the length of the school year are positively associated with student performance. In contrast to Hanushek (1986), the authors conclude that:

> "....differences in schooling quality across countries are substantial and can be explained in part by a set of quantifiable explanatory variables" (p.30).

One of the few papers which explicitly mentions value-added as the appropriate notion with which to measure the quality of schooling is Johnes (1992). The author surveys past work which attempts to measure the performance of higher education institutions. After stressing that inputs matter just as much as outputs, Johnes notes that:

> "...the measurement of value-added is, of course, crucial to the study of economics, and is in the present context of far greater relevance than the somewhat less arduous task of measuring output" (p.20).

The author goes on to consider the use of degree quality, student drop-out rates and research productivity as performance indicators, and rejects all three. It seems that, in the absence of standardised cross-institutional testing of the knowledge and reasoning abilities of university graduates, the measurement of university quality is a difficult task.

Another line of research is by Peltzman (1993, 1996) who notes the declining performance of American school students on standardised international tests and asks whether this is due to political factors. Peltzman concludes that the growth of teacher unionisation, the growing resource allocating power of state governments rather than local school boards, and the preference of influential employers for the educational services of private schools rather than public schools may all have contributed to the declining performance of American public schools. If this is so then, presumably, other countries against which the American performance has deteriorated either do not have the same politically potent groups or their behavior is very different to those within the United States.

Glewwe (1996) investigates whether developing countries should invest in more schooling or whether they should increase the quality of existing schools. He notes that the use of 'rates of return' analysis to investments in education in developing countries typically concludes with a recommendation to invest heavily in primary education in particular. Glewwe then uses data for Ghana to distinguish between the returns to years of schooling and the returns to cognitive skills. He argues that:

> "...using estimates of returns to years of schooling to guide government investments in education...can be inappropriate and even completely misleading. Estimates of returns to government investments intended to raise the quality of existing schools are necessary to make efficient investments in education" (p.268).

Glewwe concludes that in countries with low schooling quality, investments to improve that quality have higher rates of return than investments to increase schooling quantity.

The controversy regarding the impact of school inputs on student achievement is clearly highlighted by Hanushek (1996a, 1998), Card and Krueger (1996) and Krueger (1998). Hanushek (1996) again concludes that variations in school resources are not systematically related to variations in student outcomes such as test scores. He begins by showing that aggregate real spending on schooling per student has increased substantially in the USA over the last 30 years whilst schooling quality over this time period, as measured by student test scores, has been constant at best. He then turns to micro-level evidence on specific school inputs and outputs and concludes that:

"...there is overwhelming evidence that some teachers and some schools are better than others ....... such dramatic differences in performance are simply not determined by the training of teachers, the number of teachers in the classroom, the salaries of teachers, or the overall level of spending"(p.18).

On the basis of these conclusions, Hanushek advocates the adoption of improved incentives for performance based on measurable student outcomes. Hanushek (1998) makes a similar case, although this paper also highlights the likely impact which schooling quality has on economic growth rates.[15]

An alternate perspective on the relationship between school inputs and student outcomes is provided by Card and Krueger (1996) and Krueger (1998). Card and Krueger (1996) draw attention to recent meta analyses which suggest that greater school resources do in fact result in higher test scores and that, in any case, it is more appropriate to focus on whether school resources affect long term outcomes such as the educational attainment and earnings of students, rather than simply their test scores, because test scores are an imperfect measure of the value of school outputs.[16] The authors find:

"...that school resources tend to be positively associated with earnings and educational attainment, but that the relationship is not always robust to specific features of the data set or empirical specification" (p.33).

In support of their conclusion, the authors describe the 'natural experiment' provided by the vastly different levels of school resources provided to students of (predominantly white) North Carolina and (predominantly black) South Carolina during the segregation era. The authors ask;

15 See his endnote 2. We review some of the research into this issue later in this Chapter, and conduct some further research in Chapter 4.

16 Meta analyses are specialised statistical techniques designed to combine the estimation results of a number of studies on, in this case, the impact of school resources on student achievement. The objective is to assess the magnitude and significance of the established relationships taken as a whole.

> "Did these differences in school resources lead to corresponding differences in educational attainment and earnings? Did the economic outcomes of succeeding cohorts converge as school resources converged? Based on our analysis of 1960, 1970 and 1980 micro data, the answers to these two questions seem to be 'yes' and 'yes'" (p.33).

Krueger (1998) reaches similar conclusions.

Is a measure of educational attainment alone, such as years of schooling, a reasonable indicator of the human capital accumulated from schooling, as Card and Krueger argue? Whilst it may be the case that, other things being equal, more schooling is better than less, one of the objectives of this thesis is to highlight the fact that all other things are not equal. In particular, the productivity of time spent at school both within and, as we show in Chapter 4, across countries varies greatly, and these productivity differences may be significant determinants of cross-country differences in growth rates. Simply focusing on the quantity of schooling deflects attention away from the potential importance of differences in schooling quality as a determinant of differences in human capital accumulation. Measuring the contribution of schooling in terms of labour market returns is also problematic because of the many potential influences which occur post schooling, such as on-the-job training.

Betts (1998) and Murnane and Levy (1998) both assert that student achievement in public schools in the USA is falling at a time of increased per student real expenditures. They then go on to argue that this is due, at least in part, to the absence of accepted and enforced educational standards. Betts argues for the introduction of exit exams which students must pass before dropping out of school, for higher grading standards to encourage additional student effort at school, and for increased homework as a means of establishing higher expectations. Higher standards are also recommended for teachers and school administrators. Murnane and Levy argue that better information is required, for parents in particular, on the extent to which the achievements of students match the requirements of the labour market. This requires regular monitoring of student achievement, the provision of ongoing training for teachers and a recognition of the fact that:

> "the nation has an achievement problem not because achievement levels have fallen but because job requirements are rising much faster than achievement levels have improved" (p.117).

The final paper examined in this section is Murnane and Levy (1996) which describes the educational outcomes in fifteen schools in Texas, USA. Due to legal actions, these schools were each granted $300,000 over and above their normal financial allocation. The authors claim that, four years after the increased funding, student achievement and attendance rates at thirteen of the schools had not improved at all. However, significant improvements were observed at the remaining two schools. The authors note that if one adopted the approach of Hanushek, such evidence would be regarded as support for the hypothesis that school resources are not systematically related to student achievement. However, because the gains in the two schools were so great, a meta analysis of the evidence would conclude in support of the position of Card and Krueger, that school resources are positively related to student achievement. The authors go on to conclude that:

> "Money is the answer to the problem in education with the caveat that it's spent and invested wisely" (p.96).

In summary, the literature on the measurement of schooling quality and the relationship between school inputs and student achievement is wide ranging and divided. On one side are studies which conclude that there is no systematic relationship between the two, and that simply devoting more resources to the problem of declining student achievement is wasteful. On the other side are studies which conclude that school resources are positively associated with student achievement. These authors would presumably support increased educational expenditures. Other than the paper of Murnane and Levy (1996), there seems little prospect for an emerging consensus on this question.

The next section reviews some of the research into the impact of school characteristics on individual earnings. Our interest lies not so much with the research results on the ultimate returns to schooling, but rather with the manner in which these studies define the quality of schooling.

### 2.3 The Impact of School Characteristics on Individual Earnings

An early attempt at measuring the returns to education and the determinants of schooling quality in the United States is Welch (1966), which estimates the relationship between the pecuniary returns to schooling and teacher salaries, total current expenditures per student, student-staff ratios and student enrolments. Welch argues that schooling quality differentials are reflected in differential labour market returns for a given quantity of schooling, but ignores the impact of post schooling factors such as on-the-job training. Welch finds that the pecuniary returns to schooling are a positive function of the quantity of schooling, and that schooling quality is a positive function of teacher salaries and school size.

For reasons already discussed, we believe that a more appropriate method of measuring national schooling quality is via mean scores on tests of knowledge and reasoning ability. Rivlin (1966), responding to the paper by Welch, makes a similar point:

> "Perhaps we should ask ourselves why we want to look at the quality variables. The Welch data are suggestive of policy conclusions such as: to improve quality, raise teachers' salaries, and consolidate rural schools. But if we are going to examine this type of question should we not choose a more current measure of the output of the school system (achievement test scores, for example) to go with our measures of current input?" (p.396)

Morgan and Sirageldin (1968) investigate the relationship between annual state expenditures on primary and secondary education and the labour market returns of students. After controlling for other determinants of earnings, they find a strong positive relationship, with an average rate of return to expenditure on schooling of more than 15 percent. According to the authors, their findings:

> "...can be interpreted as an estimate of the pay off to individuals from added annual expenditures which presumably increase the quality of education" (p.1069).

Johnson and Stafford (1973) estimate the marginal social rate of return to both schooling quantity and schooling quality. Schooling quality is defined as a positive function of average real per pupil expenditures on primary schooling. The authors find large but diminishing rates of return and advocate:

> "...increased educational quality (ie increased per student primary school expenditures) in school districts with lower per pupil expenditures so as to equalise the returns to years and annual expenditure per student" (p.139, term in parenthesis ours).

Behrman and Birdsall (1983) attempt to capture the impact of schooling quality on earnings. However, quality is not defined as merely real per student educational expenditures. To begin with, the authors note that:

> "In most...estimates (of the returns to schooling), schooling is represented merely by 'quantity' in terms of years or grades of schooling. But if there are substantial variations in the 'quality' of schooling...failure to control for the quality of schooling in earnings function estimates may cause biases in the estimated returns to schooling...probably in the upward direction" (p.928, term in parenthesis ours).

The authors then define schooling quality as a positive function of the average years of schooling of teachers and find that the social rate of return to schooling quality substantially exceeds that to schooling quantity.

We find this definition puzzling. On the one hand the authors claim that the quantity of schooling alone is a poor measure of the human capital of students because it ignores the quality of schooling, whilst simultaneously they propose that the quality of teachers can be adequately measured by their average quantity of schooling, with no reference to the quality of that schooling.

Nechyba (1990) investigates the importance of the quality of schooling in explaining the racial wage gap in the USA and finds, in part, that the inferior quality of black schools during the segregation era is a significant factor in explaining the income differentials between blacks and whites. Nechyba defines schooling quality in terms of official school inputs. After discussing the historical significance of differential class size, teacher quality, length of school year and value of school property, the author settles on the ratio of black to white per pupil teacher salaries as his schooling quality variable. If teacher salaries are a positive function of teacher qualifications then this definition of schooling quality is similar to that used by Behrman and Birdsall (1983).

Murnane, Willett and Levy (1995) examine the impact of the cognitive skills of students on their earnings. The authors find that basic cognitive skills, in the form of mathematics skills at graduation from high school, had a larger impact on the earnings of 24 year olds in 1986 than in 1978, and that the impact was more pronounced six years after graduation than it was just two years after graduation. This is one of the few studies of the determinants of earnings which uses student test scores as an explanatory variable in the earnings function.

In 1996 the *Review of Economics and Statistics* (RES) published a number of papers in a symposium on the quality of schooling and educational outcomes which address the effect of school inputs on later earnings. The impetus for the symposium were the papers of Card and Krueger (1992) and Betts (1995) which come to apparently conflicting conclusions regarding the impact of school quality on later earnings. In a footnote to the symposium introduction, Moffitt (1996) highlights the importance of distinguishing between inputs into schooling and outputs from schooling, a point which we have repeatedly stressed in this Chapter.

> "...in the view of many analysts (the issue) is not whether the quality of schooling truly affects achievement and earnings-that seems highly likely-but rather *whether the proxies for inputs used in empirical work adequately represent quality...*" (p.559, italics ours).

Card and Krueger (1992) identify the impact of schooling quality on aggregate earnings by examining the differences in earnings of adults who live in the same state but who were born and (presumably) grew up in different states with different average schooling quality. Their proxies for schooling quality are the student-teacher ratio, the average term length and the relative pay of teachers. They find that:

> "...men who were educated in states with higher quality schools have a higher return to additional years of schooling. Rates of return are also higher for individuals from states with better educated teachers..." (p.1).

Betts (1995) investigates the same relationship but with micro based data on the actual schools attended by individuals. Schooling quality is proxied by three variables: the student-teacher ratio, the salary of beginning, degree qualified teachers and the percentage of teachers with a masters degree or higher. Betts finds:

> "...that while there are significant differences between the labour market performance of students who attended different schools, these differences are not significantly related to standard measures of the quality of schooling" (p.232).

We now summarise the papers in the symposium, which address these apparently conflicting results. Once again our interest is as much with the approach of researchers to the definition and measurement of schooling quality as it is with the conclusions regarding the relationship between schooling and earnings.

Heckman, Layne-Farrar and Todd (1996) ask whether higher schooling quality, in the form of lower student-teacher ratios, longer term length and higher teacher salaries, is positively associated with labour market returns. They answer in the affirmative but conclude that the above factors are not adequate proxies for schooling quality, at least at the primary and secondary levels. The authors also produce evidence against the efficiency units model of labour services, used in aggregate analyses and growth accounting, where each unit of labour with a given quantity of schooling is assumed equally productive. Rather, they argue that:

> "A model of heterogeneous skills in which regional labour market shocks affect the price of unskilled labour provides a more accurate description of the data on individual earnings" (p.562).

Loeb and Bound (1996) also investigate the apparent conflict between the findings on the effect of school resources on student test scores and those on the effects of school resources on later earnings. The authors argue that one possible explanation is that the former studies use contemporaneous data whilst the latter studies use historical data. Another possible explanation is that the former typically use micro level data, matching students to particular schools or classrooms, whereas the latter studies typically use aggregate data, matching workers to the average inputs in the school district or state in which they grew up. The authors then use aggregate historical data on school inputs to predict the scholastic achievement of people born in the 1920's, the 1930's and the 1940's, and find that school inputs, at least in these three decades, did indeed have powerful influences on student learning. The authors conclude that:

"...the differences between the two literatures arises, at least partly, from differences in the nature of the data used: either differences in the historical period covered or the extent of aggregation involved in measuring school inputs" (p.654).

Consistent with the conclusions of Loeb and Bound (1996) concerning the impact of data aggregation is Hanushek, Rivkin and Taylor (1996). They investigate the effect of data aggregation on the estimated impact of school resources on student achievement, measured by standardised test scores and years of post-secondary schooling, and conclude that:

"When important state differences in school policy are omitted ...... aggregation implies clear upward bias of estimated school resource effects ...... these results provide further support to the view that additional expenditures alone are unlikely to improve student outcomes" (p.611).

Grogger (1996) also investigates the aggregation issue, but with regard to later earnings rather than student achievement. Using micro and macro level data sets, he finds that estimates using the macro data generally yield larger effects of school expenditures than do estimates using the micro data, and concludes that whilst the impact of school expenditures on later earnings is positive, the magnitude of the impact is small.

Betts (1996) wonders whether the lack of schooling input effects on earnings is due to the use of data on only younger workers, whereas the effects of schooling inputs may only appear much later in their working lives. He examines the occupations in which young men have chosen to work rather than their earnings, uses census data on the full age distribution to estimate later earnings of these men, and then relates schooling inputs to later earnings via an occupational channel. Betts concludes that:

"...age dependence is not the main explanation for the divergent results in the literature on the link between school resources and earnings" (p.651).

Altonji and Dunn (1996a) examines data on the schooling and labour market experience of siblings, some of which attended different schools, to control for fixed family effects. The authors use four input measures of schooling quality, they being the student-teacher ratio, expenditures per student, mean salary of beginning teachers with a Bachelor of Arts, and a composite measure of the quality of schooling which comprises the first and third factors above plus the student-counsellor and books-student ratios. They find that the effects of schooling quality on earnings increase when fixed family effects are controlled for but find, contrary to much of the literature, no consistent evidence that their measures of the quality of schooling effect the marginal return to an additional year of schooling.

Behrman, Rosenzweig and Taubman (1996) examine the impact of university quality on the earnings of twins who attended different institutions. In this study, however, controlling for fixed family effects lowers the estimated effect of university inputs. The authors define university quality in terms of total expenditures per student, the number of full time students enrolled, the number of students per faculty member, whether the institution awards PhDs, whether a public or private institution, and the mean salaries of full professors. The authors conclude that students with higher family or individual fixed effects attend school longer and attend higher quality universities.

In conclusion, then, the research into the impact of school resources on labour market returns suggests that the initially large positive effects of school resources on earnings have diminished over time, that the estimation results are sensitive to the level of data aggregation, and that family background is a consistently significant determinant of individual earnings. It is also clear that a number of different definitions and measures of the quality of schooling have been used.

Relative to the literature on the impact of the quality of schooling on earnings, that on the impact of schooling quality on economic growth is small. We examine this next.

## 2.4 The Impact of Schooling Quality on Economic Growth

Most recent studies of the determinants of economic growth use measures of schooling quantity as a proxy for human capital. In MRW, for example, mean secondary school enrolment rates are found to be positively and significantly associated with per capita incomes and growth rates. However, few studies have examined the impact of schooling quality on economic growth rates across countries.

Jorgenson and Fraumeni (1992) measure the impact of investment in education on USA growth rates. We have argued above that per student real expenditures are a measure of the inputs into schooling rather than a measure of schooling quality. Nevertheless, as we have seen, real expenditures per student are a commonly used proxy for schooling quality in the economics literature. Jorgenson and Fraumeni find that investment in education is positively associated with greater lifetime earnings and that, along with investments in non human capital, accounts for a majority of the growth of the USA economy during the postwar period.

Baily (1981) investigates possible causes for the US productivity slowdown of the 1970's. One possibility is that the quality of new entrants into the labour force was lower relative to that of earlier periods. If this was the case then the flows of effective labour services may have grown more slowly, or even fallen, during this period. Baily discusses the declining scores on the Scholastic Aptitude Test observed since 1963 but argues that such scores are not sufficiently reliable measures of labour quality. Instead, he conducts a simple simulation experiment which suggests that the quality of labour for the cohort born in the 1960's would have to have been approximately one half that for the cohort born in the 1940's to explain much of the productivity slowdown of the 1970's, an implausibly low figure.

Bishop (1989) re-examines the issues raised in Baily (1981) and reaches similar conclusions for the 1960's and the 1970's, but finds that the major impact of the decline in test scores on productivity was experienced in the 1980's. According to Bishop:

> "The rate of growth of labour quality was .240 percent per year lower between 1980 and 1987 than it would have been if test scores had continued to grow at the rate that prevailed between 1942 and 1966. The drag on productivity growth will continue well into the 21st century" (p.192).

Bishop stresses the point that test scores are a good indicator of the general intellectual achievement of students, a summary term for developed cognitive abilities, competencies and knowledge which contribute to productivity in most jobs, and so provides support for our position that test scores are likely to be better measures of schooling quality than variables which simply measure inputs into schooling.

One of the few studies that we know of into the impact of schooling quality on economic growth is Hanushek and Kim (1995). They combine international scores on standardised tests of mathematics and science across countries and use these to develop a measure of labour force quality in each country. They find that these measures have:

> "...a consistent, stable and strong influence on economic growth....one standard deviation in mathematics and science skills translates into one percentage point in average annual real growth. This growth effect is larger than would be obtained from over eight years in average schooling" (p.29).

The study of Hanushek and Kim has direct relevance to this thesis because, whilst their theoretical approach is different, their data is similar to ours although from an earlier vintage of surveys.

One potential criticism of using mean cross country test scores as proxies for schooling quality is that test scores are likely to be biased because of the influence of home education. If parental education levels are positively and statistically significantly associated with child achievement at school then test scores are likely to overstate the quality of schooling in more relative to less developed countries. However, our statistical tests (see Chapter 4) are in terms of economic growth rates, not levels of per capita incomes, and so test scores will be biased only if parental education levels are correlated with growth rates across countries. In a simple OLS regression for our sample of countries we find that there is no such correlation at usual confidence limits and so we conclude that mean test scores will not be biased proxies for schooling quality in cross country growth regressions[17].

## 2.5 Concluding Comments

It is generally agreed that human capital is an important determinant of individual and aggregate well being and that schooling makes an important contribution to the accumulation of human capital. It also seems clear that the productivity of investments in human capital accumulation, what we call schooling quality, may be an important determinant of human capital accumulation, and hence of economic growth rates. However, there are considerable differences in the literature concerning the most appropriate measure of schooling quality and about whether increased resources devoted to schools result in increased student achievement.

We believe that schooling quality is most appropriately defined as a positive function of the value added by schools to students, in the form of knowledge, reasoning ability and other traits considered valuable in the labour market and in society more

[17] In the OLS regression $\ln(\text{ParentEd}) = a_1 + a_2 \ln(\text{gnp/c}) + e_1$, $a_2 = .213$ (t-stat = 9.79). In a similar regression but on mean growth rates rather than mean per capita incomes, $a_2 = -.095$ (t stat = -1.26).

broadly. However, in the absence of data on value-added by schools, schooling quality across countries may be reasonably estimated by student test scores on standardised tests of knowledge and reasoning ability whilst controlling for relevant background characteristics. No study that we know of has investigated the impact of including cross-country mean test scores on the results from a well known empirical study of per capita incomes and mean growth rates. We do so in Chapter 4 where we introduce test scores into the augmented Solow model of MRW which includes human capital as a factor of production.

An important theoretical model which stresses the importance of human capital to economic growth and development, and which models a process of human capital accumulation, is Lucas. In the next Chapter we examine the models of Solow, Lucas and MRW in some detail.

# CHAPTER 3

# A REVIEW OF THE ECONOMIC GROWTH MODELS OF SOLOW, LUCAS AND MRW

## 3.1 Introduction

This Chapter examines in some detail the economic growth models of Solow, Lucas and MRW.[18] The model of Solow does not include human capital as an input into production, but is the foundation upon which the models of Lucas and MRW are based. The model of Lucas is similar to that of Solow but goes further because it endogenises the human capital accumulation process and because it includes in the production function a human capital externality, both of which result in an increasing returns to scale production function. MRW, on the other hand, reject the use of an increasing returns to scale production function. Rather, they simply augment the Solow model with human capital as an additional factor of production and investigate whether this addition improves the results from cross-country regressions of per capita real incomes and growth rates.

The models of Lucas and MRW both emphasise the importance of human capital as a determinant of incomes and growth rates and so are both important reference points for this thesis. We begin in section 3.2 with a detailed examination of the Solow model. Section 3.3 then reviews the model of Lucas whilst section 3.4 reviews that of MRW. Section 3.5 concludes.

[18] Much of the discussion which follows is based on Sala-i-Martin (1990), Barro and Sala-i-Martin (1995) and D.Romer (1996).

## 3.2 The Economic Growth Model of Solow

### 3.2.1 Main Features

The Solow model assumes a closed economy. Physical capital is the only asset which can be accumulated and production takes place using inputs of capital and labour in varying proportions. The rate of technological advance is exogenously determined and the savings rate is fixed. In this highly simplified world the economy converges to a balanced growth path, that is a steady-state, where each variable in the model grows at the same constant rate. In the steady-state, the capital-labour ratio is constant. In the absence of technological advance, the economic growth rate, defined as the growth rate of real per capita GDP, is zero. The Solow model does allow for positive economic growth as the economy converges to its steady-state. However, it does not allow for positive economic growth in the steady state as this would require a continually increasing capital-labour ratio. We now examine the Solow model in more detail.

### 3.2.2 The Model of Solow in Detail

In modeling the growth of output, Solow focuses on physical capital, labour and technology. The general form of the production function is given by equation (3.1), where ($Y$) is output, ($K$) is physical capital, ($L$) is labour, ($A$) is the level of technology and $t$ denotes time.

$$Y(t)=F[K(t), A(t), L(t)] \tag{3.1}$$

It will be convenient for the analysis that follows to consider a specific functional form, the Cobb-Douglas production function, as follows:

$$Y(t)=K(t)^{\alpha}\,[A(t)\,L(t)]^{1-\alpha} \qquad 0<\alpha<1 \tag{3.2}$$

Equation (3.2) displays constant returns to scale and satisfies other important properties which Solow assumes of equation (3.1).[19] Solow also assumes that output can be freely transformed from consumption goods to physical capital, and vice versa, and that a constant share of output ($s$) is devoted to physical capital investment per time period.[20] Finally, Solow assumes a constant and exogenous population growth rate ($n$) which is synonymous with the growth rate of the labour force, and assumes a constant rate of technological advance ($g$) and physical capital depreciation ($\delta$). The equations of motion for population and technology, respectively, are equations (3.3) and (3.4).

$$L(t)=L(0)\ e^{nt} \tag{3.3}$$

$$A(t)=A(0)\ e^{gt} \tag{3.4}$$

Within this simplified world, the only asset which may be accumulated is physical capital, whose accumulation equation is (3.5).

$$dK(t)/dt = sY(t) - \delta K(t) \tag{3.5}$$

Equation (3.5) states that additions to the physical capital stock are made over time only if gross investment ($sY(t)$) is greater than depreciation of existing capital ($\delta K(t)$). As labour and technology evolve at exogenously determined constant rates, it is the accumulation of physical capital which determines the behaviour of this economy. If we define the

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[19] Equation (3.2) may be expressed in intensive form as $y(t)=f(t)^{\alpha}$ where $y=Y/AL$ and $k=K/AL$. Hence $dy/dk=\alpha k^{\alpha-1}>0$ whilst $d^2y/dk^2=\alpha(\alpha-1)k^{\alpha-2}<0$, given $0<\alpha<1$. Finally, the function satisfies the Inada conditions, i.e. dy/dk approaches infinity (zero) as k approaches zero (infinity).

[20] The share of output, s, is assumed to be fixed and determined exogenously, although the same conclusions can be reached by setting up a model in which the evolution of the capital stock is derived from interactions of maximising households and firms in competitive markets. In this case s is no longer exogenous and need not be constant.

effective capital-labour ratio, $k(t)$, as $K(t)/[A(t)L(t)]$ then equation (3.6) expresses the accumulation of $k(t)$ over time.

$$dk(t)/dt = [dK(t)/dt \,.[A(t)L(t)] - K(t)\; d[A(t)L(t)]/dt] \;/\; [A(t)L(t)]^2 \qquad (3.6)$$

Further manipulation of equation (3.6) results in equation (3.7) where $y(t) \equiv Y(t)/[A(t)L(t)] = k(t)^{\alpha}$.

$$dk(t)/dt = sy(t) - (\delta + n + g)\, k(t) \qquad (3.7)$$

Equation (3.7) is the key equation in the Solow model. It states that the rate of change of the capital stock per unit of effective labour ($dk(t)/dt$) is the difference between actual investment per unit of effective labour ($sy(t)$) and break-even investment per unit of effective labour, ie that required to keep pace with depreciation and the growth rate of effective labour ($(n+g+\delta)k(t)$). The difference between these two is net investment. We plot these two components of equation (3.7) in Figure 3.1 below. As $n$, $g$ and $\delta$ are exogenously determined constants, $(n+g+\delta)k(t)$ is linear. Also, because $\alpha<1$ by assumption, the production function displays diminishing returns to capital and hence $sy(t) = sk(t)^{\alpha}$ is increasing at a decreasing rate. This, and other assumed characteristics of the production function (see footnote 18), imply that $k^*$ in Figure 3.1 is the only capital-effective labour ratio at which $k(t)$ is constant.

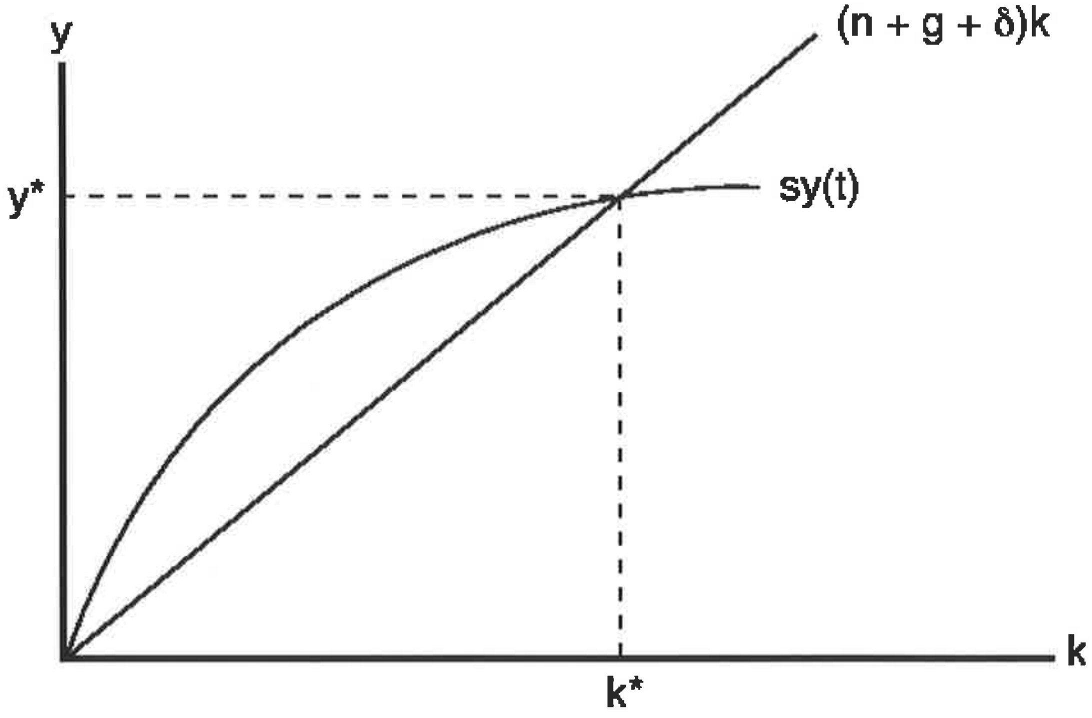


**Figure 3.1: Diagrammatic Representation of the Solow Model of Economic Growth**

Assuming that $k(t) \neq k^*$ then, irrespective of where the economy starts off, $k(t)$ will converge to $k^*$. If initially $k(t)<k^*$ then net investment is positive, $dk(t)/dt>0$ and hence $k(t)$ will increase towards $k^*$. If, on the other hand, $k(t)>k^*$ in the initial period then net investment is negative and hence $k(t)$ will decrease towards $k^*$. Only when $k(t) = k^*$ will $dk(t)/dt = 0$. Thus, $k^*$ is the only possible steady-state capital-effective labour ratio consistent with positive output. When $k(t) = k^*$ the physical capital stock $(K)$ and the quantity of effective labour $(AL)$ will both grow at rate $(n+g)$. With assumed constant returns to scale in production, output $(Y)$ must also grow at this rate. Hence physical capital and output per capita ($K/L$ and $Y/L$ respectively) will grow at rate $g$. Because inputs and outputs grow at the same rate, whether expressed in absolute terms or in per capita terms, the economy is said to converge to a balanced growth path as $k(t)$ approaches $k^*$.

Suppose $k(t)=k^*$. What will be the final outcome of a permanent change in the savings rate, say from $s_1$ to $s_2$?[21] If $s_2>s_1$ then $s_2y(t)>s_1y(t)$ for all positive $k$. We illustrate the consequences of this change in Figure 3.2 below. Assume the economy is in the steady state prior to the increase in the savings rate. With $k(t)=k_1^*$ and the new gross savings function $s_2y(t)$, actual investment now exceeds break-even investment. Hence the capital-effective labour ratio will increase over time until $k(t)=k_2^*$, at which point all variables will be growing in absolute terms at rate $(n+g)$, whilst in per effective labour terms at rate $(g)$.

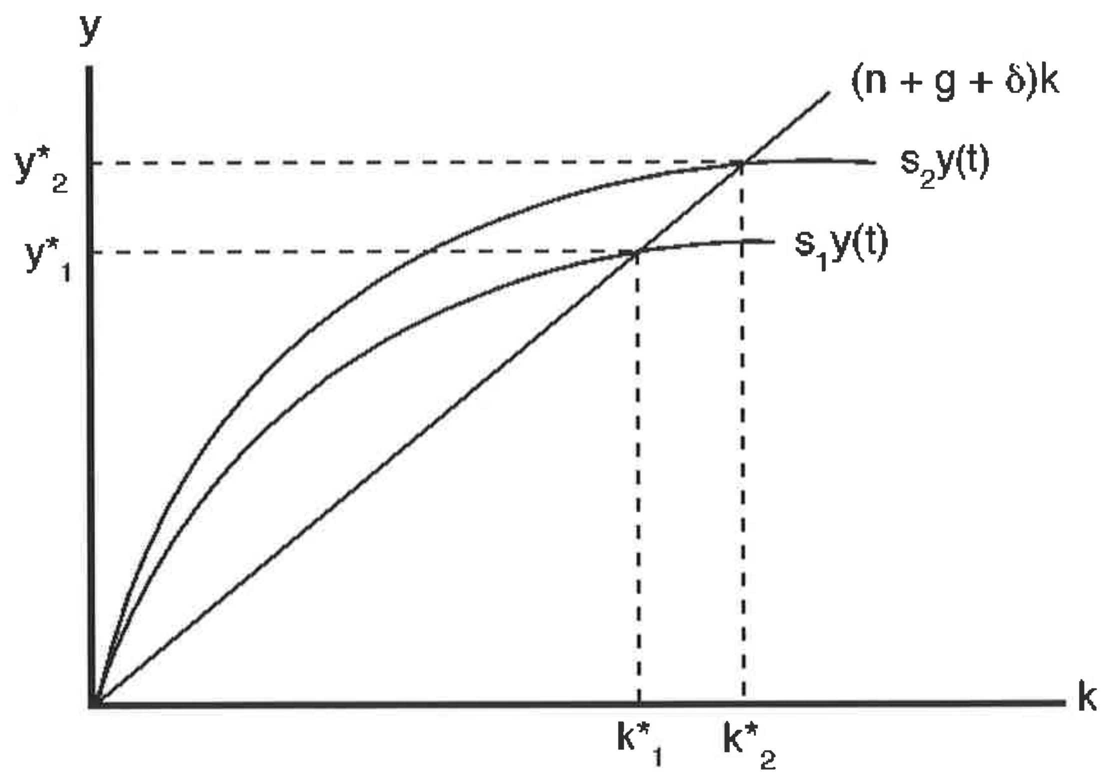


**Figure 3.2: The Impact of an Increase in the Savings Rate in the Solow Model of Economic Growth**

[21] We focus on the impact of a change in the savings rate because this is the only parameter in this model which may respond, at least in the short term, to economic policy. Government may impact on the savings rate via, for instance, its tax treatment of income generated by savings. Government policy is less likely to affect the other parameters in the model, namely the population growth rate and the physical capital depreciation rate.

Note that in the transition from the old to the new steady state the economy displays a growth rate of per capita output which is greater than $g$. This is so because the growth rate of per capita output will, in this period, equal $g$ plus the growth rate of per capita physical capital. However, as $k(t)$ approaches $k_2^*$, the growth rate of k will approach zero and so the growth rate of $(Y/L)$ will approach $g$ once again. Hence in this model, a permanent increase in the savings rate will result in only a temporary increase in the growth rate of per capita output as the economy moves to the new steady state, whilst the level of per capita output in the new steady state will be permanently greater. Similar but opposite conclusions hold for a permanent decrease in the savings rate.

Thus, in the Solow model, a permanent change in the savings rate will result in a permanent change in the levels of the variables but will result in only a temporary change in their growth rates as the economy moves from the initial steady state to the new steady state.[22] As the growth rate of $Y/L$ is $g$ in the steady state, it is clear that only a change in the (exogenous) rate of technological advance is capable of permanently changing the economic growth rate in this model. Note, however, that economic policy may still have a significant impact on the growth rate. If the speed of adjustment from the old to the new steady state is low, the 'temporarily' higher growth rate will be long lasting.

We can estimate both the speed of adjustment and the magnitude of the change in per capita output in this model. These can then be compared with real world observations to determine whether the Solow model provides a satisfactory explanation of cross-country differences in standards of living.

### (i) Speed of Adjustment

Given a permanent increase in the savings rate ($s$), how long does it take for $k_1^*$ to reach $k_2^*$ in Figure 3.2 above? The equation of motion for $k(t)$ is given by equation (3.7).

[22] Similar results will hold for permanent changes in the level of technology (A), or the population growth rate (n) or the depreciation rate (δ).

By taking a first-order Taylor-series approximation of equation (3.7) around $k^*$ we derive equation (3.8).

$$dk(t)/dt \cong [\delta(dk(t)/dt) / \delta k(t) \text{ evaluated at } k(t)=k^*] \,.\, (k(t)-k^*) \qquad (3.8)$$

Since $dk(t)/dt = sf(k(t)) - (n+g+\delta)k(t)$, we can re-write equation (3.8) as equation (3.9).

$$[\delta(dk(t)/dt)/\delta k(t) \text{ evaluated at } k(t) = k^*] = sf'(k^*) - (n+g+\delta) \qquad (3.9)$$

Note that at $k^*$, $sf(k^*)=(n+g+\delta)k^*$. That is, $s=[(n+g+\delta)k^*]/f(k^*)$. Hence we have equation (3.10).

$$[\delta(dk(t)/dt)/\delta k(t) \text{ evaluated at } k(t) = k^*] = [n+g+\delta]k^*f'(k^*)] / f(k^*) - (n+g+\delta) \qquad (3.10)$$

If $y(t)=f(k(t))$ then the elasticity of output with respect to $k(t)$, $\varepsilon_k$ , is given by equation (3.11).

$$\varepsilon_k = [dy(t)/dk(t)] \,.\, [k(t)/y(t)]$$
$$= f'(k(t)) \,.\, [k(t) / f(k(t))] \qquad (3.11)$$

Using equation (3.11) for $k(t)=k^*$ to simplify equation (3.10) yields equation (3.12).

$$[\delta(dk(t)/dt) / \delta k(t) \text{ given } k(t)=k^*] = [\varepsilon_k(k^*)-1] \, (n+g+\delta) \qquad (3.12)$$

Finally, substituting equation (3.12) into equation (3.8) yields equation (3.13).

$$dk(t)/dt \cong -[1-\varepsilon_k(k^*)]\ (n+g+\delta)\ (k(t)-k^*) \qquad (3.13)$$

Equation (3.13) indicates that, close to the steady state, $k(t)$ approaches $k^*$ at a rate which is proportional to its distance from $k^*$, $(k(t)-k^*)$. The speed of adjustment is thus the value of $[1-\varepsilon_k(k^*)](n+g+\delta)$. If the population growth rate is about 1-2% per annum, as it is in many developed countries, and if the rate of technological advance and physical capital depreciation are together about 5%, then $(n+g+\delta)$ is approximately 6-7% per annum.[23] Furthermore, in many countries, the share of total output which goes to physical capital is approximately one third. With these parameter assumptions, the Solow model implies a speed of adjustment of approximately 4% per annum.[24] Hence $k(t)$ moves half the distance towards $k^*$, as does $y(t)$ towards $y^*$, approximately every 18 years.[25] Thus the Solow model predicts a relatively slow adjustment of $k(t)$, and hence $y(t)$, following a policy induced change such as an increased savings rate.[26]

**(ii) Magnitude of the Change**

The total impact on steady-state output of a permanently higher savings rate is given by equation (3.14) where $y^*=f(k^*)$.

$$\delta y^*/\delta s = f'(k^*)\ (\delta k^*/\delta s) \qquad (3.14)$$

To determine the magnitude of the change, we need to calculate $\delta k^*/\delta s$. When $k(t)=k^*$, $dk(t)/dt = 0$. Hence from equation (3.7), in the steady state, equation (3.15) holds.

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[23] See MRW p.413, footnote 6, for a justification of these assumptions concerning the rate of technological advance and the rate of depreciation.

[24] Assuming that physical capital earns its marginal product, the amount of output going to capital will be $k^*f'(k^*)$ in the steady state. Thus the steady-state share of output going to capital will be $[k^*f'(k^*)]/f(k^*)=\varepsilon_k(k^*)$. Hence $[1-\varepsilon_k(k^*)]$ is approximately 2/3, and so $[1-\varepsilon_k(k^*)](n+g+\delta)$ is approximately .04.

[25] According to the so-called 'rule of 70', a variable growing at a constant annual rate r will double in value approximately every 70/r years. In this case, the variable is the income gap (y-y*) which closes at an annual rate of 4%. Hence the income gap takes approximately 70/4≅18 years to halve.

[26] Barro and Sala-i-Martin (1995) argue that a rate of adjustment of this magnitude is much higher than rates typically observed across countries. This may be so because real economies are subjected to numerous shocks over time, which may retard their speed of adjustment. In our example, we are considering a permanent increase in the savings rate for an economy already on the balanced growth rate path.

$$sf(k^*) = (n+g+\delta)k^* \tag{3.15}$$

By taking derivatives of both sides of equation (3.15) with respect to the savings rate *(s)*, we derive equation (3.16).

$$sf'(k^*)\,[\delta k^*/\delta s] + f(k^*) = (n+g+\delta)\,\delta k^*/\delta s \tag{3.16}$$

Re-arranging equation (3.16) yields equation (3.17).

$$\delta k^*/\delta s = f(k^*) \,/\, [(n+g+\delta) - sf'(k^*)] \tag{3.17}$$

Substituting equation (3.17) into equation (3.14) yields equation (3.18).

$$\delta y^*/\delta s = [f'(k^*)f(k^*)] \,/\, [(n+g+\delta) - sf'(k^*)] \tag{3.18}$$

We convert this expression to an elasticity by multiplying both sides by $s/y^*$, keeping in mind that $y^*=f(k^*)$, and so derive equation (3.19).

$$(s/y^*)\,(\delta y^*/\delta s) = s \,/\, f(k^*)\,.\,[[f'(k^*)f(k^*)] \,/\, (n+g+\delta) - sf'(k^*)] \tag{3.19}$$

From equation (3.15) we know that $s=[(n+g+\delta)k^*] \,/\, f(k^*)$. Thus equation (3.19) can be written as equation (3.20).

$$(s/y^*)(\delta y^*/\delta s) = \{[k^*f'(k^*)] \,/\, f(k^*)\} \,/\, \{1-[k^*f'(k^*)\,]/f(k^*)\} \tag{3.20}$$

Finally, we note that the numerator of equation (3.20) is $\varepsilon_k(k^*)$, and so we derive equation (3.21).

$$(s/y^*)(\delta y^*/\delta s) = \varepsilon_k(k^*) \,/\, [1-\varepsilon_k(k^*)] \qquad (3.21)$$

If we again assume that capital's share of total output is approximately one third then the elasticity of output with respect to the savings rate is 1/2. This means that a permanent increase in the savings rate of 10% will increase the steady-state level of per capita output by approximately 5% relative to what it would have been with the initial savings rate. The Solow model is thus not optimistic about the magnitude of the long term impact of a plausible change in the savings rate. Moreover, given our earlier results, it would take approximately 18 years for the economy to move half way to the new steady state.

### 3.2.3 Concluding Comments on the Solow Model

The Solow model has made important contributions to the way we think about economic growth. For instance, it highlights the distinction between parameters which affect the steady-state growth rate and those which merely affect the level of income. The former parameters change growth rates along balanced paths to the steady state, whilst the latter parameters simply raise or lower the balanced path without changing the growth rate.

The only parameter in the Solow model which can affect the steady-state growth rate is the rate of technological advance. As we have already noted, if the rate of technological advance increases, then so too will the steady-state growth rate. On the other hand a parameter which is commonly thought of as being capable of affecting the economic growth rate but which, in the Solow model at least, affects only the level of income is the savings rate. A permanent increase in the savings rate will increase the capital-labour ratio and hence temporarily increase the growth rate of income above its steady-state level. However, the capital-labour ratio will eventually be such that the new savings rate will be just sufficient to maintain it. Hence whilst the per capita income level will be greater when this point is reached, the growth rate of per capita income will once again only equal the rate of technological advance.

Another contribution of the Solow model is the important and testable prediction that per capita incomes in like economies should converge. This is known as the conditional convergence hypothesis.[27] The idea is that, other things being equal, poorer countries should grow more quickly than richer countries because they are further from their steady state. This prediction has been supported by some empirical studies.[28]

However, the Solow model has a number of shortcomings. Firstly, only the accumulation of physical capital is endogenous in this model. Changes in this variable are capable of changing per capita incomes in the steady state, but will only affect transitional growth rates. We have shown that for plausible assumptions concerning the population growth rate ($n$), the rate of technological advance ($g$), and the depreciation rate ($\delta$), and for a plausible change in the savings rate ($s$), the magnitude of the change in the steady-state level of income per capita is relatively small.

The Solow model is thus not capable of explaining the great disparities which exist across countries, both in observed incomes per capita and in economic growth rates. For instance, mean output per worker in the USA in the mid 1990's was approximately ten times greater than it was in India (see Table 1.1). If the elasticity of output with respect to physical capital ($\varepsilon_k$) is approximately 1/3 then, according to the Solow model, physical capital per worker in the USA must have been $10^{1/\varepsilon k}$ or one thousand times greater than it

27 Details of this hypothesis are discussed in section 3.4.

28 See, for instance, the convergence regression results in MRW on the members countries of the OECD, and those in Barro and Sala-i-Martin (1992) on the states of the U.S.A..

was in India. However, such differences are not consistent with observed differences in physical capital stocks.

The only plausible explanation in the Solow model for these large differences in per capita incomes is that countries possess very different levels of technology *(A)*. Whilst differences in savings rates result in differences in transitional growth rates and only modest differences in steady-state levels of per capita income, differences in technology levels could explain the observed disparities in cross-country incomes. However, the level of technology *(A)* and its growth rate *(g)* are assumed to be exogenously determined. Hence whilst the Solow model may provide an explanation of economic growth in the transition from an initial steady state to a new steady state, it assumes, rather than explains, an economic growth rate of *g* for an economy in the steady state.

The Solow model could thus be classified as an 'exogenous' growth model because it contains no variables which can affect the steady-state growth rate and which are determined within the model. Once an economy has reached its steady state then, other things being equal, economic growth continues indefinitely at the rate of technological advance. However, no insights are provided by the model into which factors contribute to the process of technological advance or as to how the rate of technological advance may be increased. This feature of the Solow model has been criticised by Arrow (1962) who argues that:

> "...a view of economic growth that depends so heavily on an exogenous variable, let alone one so difficult to measure as the quantity of knowledge, is hardly intellectually satisfactory. From a quantitative, empirical point of view, we are left with time as an explanatory variable. Now trend projections, however necessary they may be in practice, are basically a confession of ignorance, and, what is worse from a practical viewpoint, are not policy variables" (p.155).

Lucas seeks to address some of the shortcomings of the Solow model by including the stock of human capital, and a human capital externality, in the Solow production function, and by modeling the process of human capital accumulation. We now examine the model of Lucas.

## 3.3 The Economic Growth Model of Lucas

### 3.3.1 Main features

In an attempt to better understand the processes which drive economic growth, some economists have constructed growth models which allow for a positive steady-state growth rate and which endogenise the possible determinants of economic growth. Known as endogenous growth models, these focus on increasing returns to scale in production, or externalities from the research activities of firms or the accumulation of human capital by individuals, as possible 'engines' of a positive steady-state growth rate. One such model, which focuses on the accumulation of human capital, is that of Lucas.

Lucas notes that technology is the only factor in the Solow model which is capable of accounting for observed cross-country disparities in incomes and growth rates. However, Lucas argues that technology is specific to humans rather than to any one country, and so whilst the growth rate of, for instance, Japan has been much greater than that of the USA, it makes little sense to argue that this is because Japanese technology has been greater than that of the USA. Lucas thus politely rejects the Solow explanation of differences in growth rates by stating that:

> "...while it is not exactly wrong to describe the differences (in growth rates) by an exogenous, exponential term like A(t) neither is it useful to do so" (p. 15, term in parenthesis ours).

Rather, he turns his attention to modeling the process of human capital accumulation and to determining the consequences of such accumulation for the productivity of nations.

Why does Lucas focus on the accumulation of human capital as the driving force for economic growth? He observes that in the eighteenth and nineteenth century histories of the Americas, Australia, South and East Africa, large differences in the returns to labour caused massive migrations to these countries which led to rapidly diminishing returns to labour. These effects are exactly what would be predicted by a land-labour Solow model where labour is the only mobile factor. However, Lucas argues that in the twentieth century, with the immigration of labour largely cut off, the movement of capital has not been as wide spread, and that which has occurred has not performed the same income equalising function, as did the movement of labour in the two prior centuries. In this way, Lucas argues that human capital may be the driving force behind economic growth and the convergence of real per capita incomes across similar countries.

In the Lucas model, individuals are assumed to devote a fraction of their non leisure time to current production and the remaining fraction to the current period accumulation of human capital via study. Lucas defines the skill (or human capital) weighted hours devoted to production in the current period as the effective workforce, and this term replaces labour in the Solow production function.

The feature in the Lucas model of greatest relevance to this thesis is the manner in which human capital accumulation is modelled. Lucas assumes that the proportional rate of human capital accumulation is simply a linear function of the amount of time devoted to study. That is:

> "...if no effort is devoted to human capital accumulation...then none accumulates. If all effort is devoted to this purpose...(human capital) grows at its maximal rate...In between these extremes, there are no diminishing returns to the stock (of human capital): a given percentage increase in (human capital) requires the same effort, no matter what level of (human capital) has already been attained" (Lucas, p.19).

Lucas thus ignores the possibility that the productivity of time spent studying may vary. Another important feature of the Lucas model is the existence of an externality to the mean level of human capital in the economy. The idea here is that an individual with a given level of human capital will be more productive the greater the human capital of his colleagues, which will itself be greater, other things being equal, the higher the mean level of human capital in the economy.

Apart from these innovations, the model is very similar to that of Solow. Rather than assuming a constant savings rate, Lucas sets up the current-value Hamiltonian and derives the first order conditions given the existence of two control variables (consumption and the proportion of time devoted to production) and two state variables (the stocks of human and physical capital). He then shows that because of the existence of a human capital externality, the growth rate of human capital in a competitive equilibrium is less than the optimal rate. This is because the private return to human capital accumulation is less than the social return, and so individuals do not accumulate capital at the socially efficient rate. On the other hand if the externality is internalised, the competitive equilibrium gives the optimal growth rate. Hence, in the Lucas model, there is a role for economic policy in maximising the economic growth rate by, for example, subsidising the cost of human capital accumulation via schooling.

### 3.3.2 The Basic Structure of the Lucas Model

Lucas begins with the following production function.

$$Y(t) = AK(t)^{\beta}\,[u(t)h(t)N(t)]^{1-\beta}\,h_a(t)^{\gamma} \qquad 1>\beta>0 \text{ and } \gamma>0 \qquad (3.22)$$

The level of technology *(A)* is assumed constant. Each of $N$ workers is assumed to possess a skill level $h$ such that $0<h<\infty$, and is assumed to devote the fraction $u$ of their non-leisure time to current production where $1\geq u\geq 0$. Thus $u(t)h(t)N(t)$ is the total effective labour available for production in the current period. Ignoring the final term on the right hand side of equation (3.22) for a moment, this part of the production function exhibits increasing returns to the factors $K$, $h$ and $N$ and so would alone generate a positive steady-state growth rate endogenously.[29] However, Lucas also includes the term $h_a$ which is defined as the average level of human capital in the economy and captures the idea that workers are more productive when their colleagues are, on average, more highly skilled. This external effect raises the degree of homogeneity of the production function to $(2-\beta+\gamma)$.

Lucas proposes the following equation of motion for the level of human capital ($h$).

$$dh(t)/dt = h(t)^{\psi} F(1\text{-}u(t)) \qquad (3.23)$$

The term (1-$u(t)$) is the proportion of non leisure time devoted by individuals in the current period to the accumulation of human capital via study. Lucas assumes that F(0)=0 whilst F'>0.[30] The parameter $\psi$ in equation (3.23) is especially important. Equation (3.23) implies that:

$$[dh(t)/dt] \,/\, h(t) = h(t)^{\psi-1} F(1\text{-}u(t)) \qquad (3.24)$$

If $\psi<1$ then the proportional growth rate of human capital will tend to zero as $h$ grows, even if $u=0$. Hence for human capital accumulation to drive the growth process, equation (3.24) must exhibit at least constant returns to the existing level of human capital. Lucas assumes, following Uzawa (1965), that $\psi=1$.

The function F is also important and of particular relevance for this thesis as it represents the productivity of time spent studying, i.e. schooling quality. For the sake of simplicity, Lucas assumes that F is equal to a constant ($\phi$). However, it is plausible that F

---

29 $Y(t)=AK(t)^{\beta}[u(t)h(t)N(t)]^{1-\beta}$ is homogeneous of degree $\beta+(1-\beta)+(1-\beta)=2-\beta>1$ (for $\beta<1$) in K, h and N.

30 That is, if u=1, no time is devoted to human capital accumulation and hence none accumulates. As u decreases, the rate of human capital accumulation increases monotonically.

is a function of characteristics which may be country specific, such that for a given stock of human capital and for a given proportion of non-leisure time spent studying, cross-country human capital accumulation, and thus economic growth rates, may vary.[31]

Given these assumptions, the human capital accumulation equation in the Lucas model is (3.25).

$$dh(t)/dt = h(t)\ \phi\,(1-u(t)) \tag{3.25}$$

According to equation (3.25), a given percentage increase in the stock of human capital requires the same input of study time irrespective of the existing level of human capital, whilst the productivity of time spent studying ($\phi$) is assumed to be constant.

Apart from equations (3.22) and (3.25), the Lucas model is similar to that of Solow. Physical capital accumulates according to equation (3.26), where $C$ is consumption and all other variables are as previously defined.

$$dK(t)/dt = AK(t)^{\beta}\,[u(t)h(t)N(t)]^{1-\beta}\,h_a(t)^{\gamma} - C(t) \tag{3.26}$$

Lucas assumes that individuals choose a stream of consumption ($C$) and the proportion of non leisure time spent working ($u$) so as to maximise the Hamiltonian equation (3.27), where, for the sake of simplicity, $N$ is assumed constant and has been normalised to one.

$$H(\bullet) = e^{-\rho t}[(c(t)^{1-\sigma} - 1)/(1-\sigma)] + \theta_1[AK(t)^{\beta}(u(t)h(t))^{1-\beta}\,h_a(t)^{\gamma} - C(t)] + \theta_2[h(t)\phi(1-u(t))] \tag{3.27}$$

31 We examine whether cross-country differences in schooling quality affect the results from regressions of cross-country economic growth rates in Chapter 4.

The variables $\theta_1$ and $\theta_2$ are the shadow prices of physical and human capital, respectively, and the instantaneous utility function is, by assumption, constant relative risk aversion utility with discount rate $\rho$. Because of the assumed externality to the mean stock of human capital, the market or equilibrium solution will differ from the optimal solution. As our interest lies primarily with the manner in which Lucas models the human capital accumulation process, we leave the detailed solution of this model to Appendix 3A.

### 3.3.3 Concluding Comments on the Lucas Model

For the purposes of this thesis, the Lucas model is important because it proposes a process of human capital accumulation in which the productivity of time spent studying, although assumed to be an exogenously determined constant, is at least explicit. Lucas thus provides a theoretical justification for focusing on schooling quality as a potential source of differences in cross-country rates of economic growth. In the next Chapter, we investigate whether schooling quality does vary across countries, and whether such variations help to explain cross-country differences in rates of economic growth.

MRW also seek to address some of the shortcomings of the Solow model. However, MRW reject the use of an increasing returns to scale production function. Rather, they simply augment the Solow model with human capital and investigate whether their model is better able to account for observed disparities in cross-country standards of living and economic growth rates. We now examine the model of MRW.

## 3.4 The Economic Growth Model of MRW

### 3.4.1 Main Features

The model of MRW is basically a Solow model of economic growth. However, MRW treat capital *(K)* in the Solow model as strictly physical capital and then augment the model, consistent with the approach of Lucas, with human capital *(H)*. If the share of output going to human capital is approximately that which goes to physical capital then the magnitude of the observed differences in incomes per capita, as illustrated in Table 1.1, could be explained by differences in the accumulation of both types of capital across countries of a factor of thirty.[32] Differences of this order of magnitude correspond more closely with observed differences in 'broad' capital per worker across countries. However, whilst the model of MRW is better able to explain cross-country differences in real per capita GDP, the steady-state economic growth rate remains a function of the exogenous rate of technological advance.

For empirical purposes MRW use a proxy for the rate of human capital accumulation which measures approximately the mean percentage of the working age population that is enrolled in secondary school over the sample period. On the basis of estimation results for a large sample of countries, and for particular subsets of this sample, MRW conclude that their model satisfactorily explains a large proportion of observed cross-country differences in standards of living. We now examine the details of the MRW model.

### 3.4.2 The Model of MRW in Detail

MRW begin by postulating the following production function, where all variables are as previously defined.

$$Y(t)=K(t)^{\alpha} H(t)^{\beta} [A(t)L(t)]^{1-\alpha-\beta} \qquad \alpha>0,\ \beta>0,\ \alpha+\beta=1 \qquad (3.28)$$

Equation (3.28) displays constant returns to scale and contains two endogenous variables, *K* and *H*, which are assumed to accumulate over time, according to equations (3.29) and (3.30) respectively.

[32] If $\varepsilon_k=\varepsilon_h=1/3$ then $10^{1/(2/3)}=10^{1.5}\cong 30$.

$$dK(t)/dt = s_K Y(t) - \delta K(t) \quad (3.29)$$

$$dH(t)/dt = s_H Y(t) - \delta H(t) \quad (3.30)$$

The accumulation of physical and human capital will both be positive if, in each case, gross investment exceeds depreciation. The parameters $s_K$ and $s_H$ are the shares of output devoted to physical and human capital accumulation respectively. Both physical and human capital are assumed to depreciate at a constant rate $\delta$. As was the case with the Solow model, labour $(L)$ and technology $(A)$ are assumed to grow at constant exogenous rates ($n$ and $g$ respectively).

Once again, we may express equation (3.28) in terms of effective units of labour as follows, where $y \equiv Y/AL$, $k \equiv K/AL$ and $h \equiv H/AL$.

$$y(t) = k(t)^{\alpha} h(t)^{\beta} \quad (3.31)$$

Equation (3.29) is similar to equation (3.5) and hence we simply restate the dynamic equation for physical capital per unit of effective labour as equation (3.32).

$$dk(t)/dt = s_K k(t)^{\alpha} h(t)^{\beta} - (n+g+\delta)k(t) \quad (3.32)$$

We are interested in characterising the steady state, ie when $Y$, $K$ and $L$ are all growing at the same rate, with $dk(t)/dt = 0$. This implies that $s_K k(t)^{\alpha} h(t)^{\beta} = (n+g+\delta)k(t)$ in equation (3.32). That is:

$$k(t) = k(h(t)) = [s_K/(n+g+\delta)]^{1/1-\alpha}\, h(t)^{\beta/1-\alpha} \quad (3.33)$$

Noting that $dk(t)/dh(t)>0$ whilst $d^2k(t)/dh(t)^2<0$, Figure 3.3 below illustrates the combinations of $h(t)$ and $k(t)$ which satisfy $dk(t)/dt=0$.

Since $dk(t)/dt$ is increasing in $h(t)$ then for any initial combination of human and physical capital, more (less) human capital results in more (less) physical capital over time. The arrows in Figure 3.3 indicate the direction of movement from any initial combination of human and physical capital which do not satisfy $dk(t)/dt=0$.

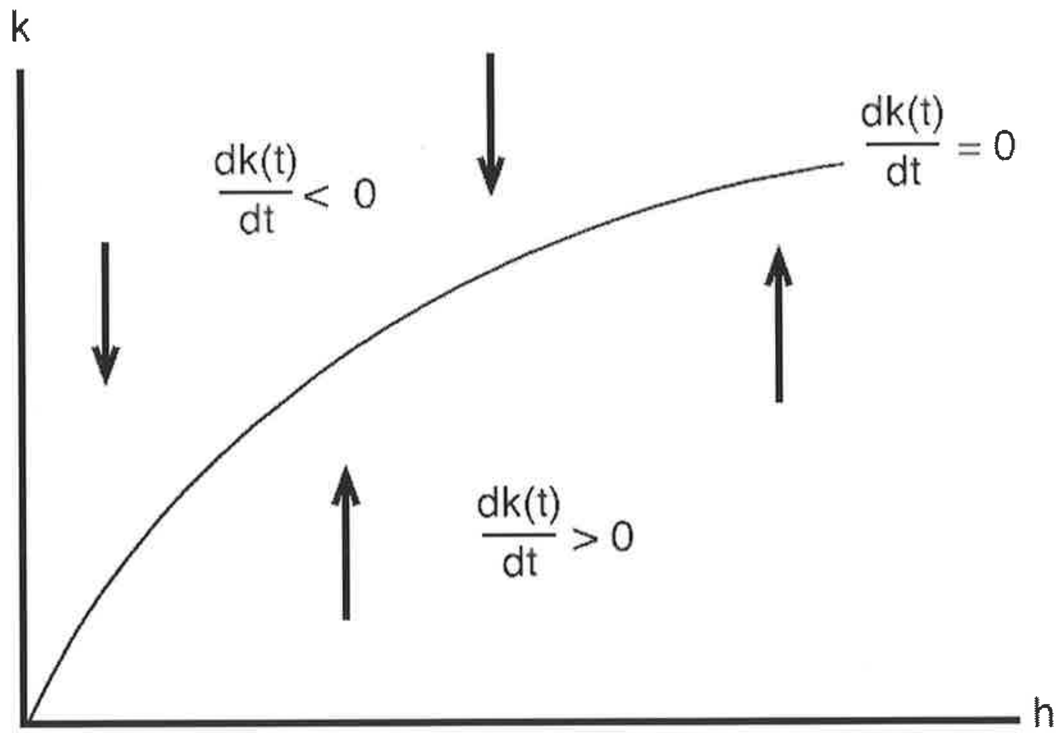


**Figure 3.3: The Dynamics of Physical Capital in the Augmented Solow Model of MRW**

We similarly derive the equation of motion for human capital as (3.34).

$$dh(t) / dt = s_H k(t)^{\alpha} h(t)^{\beta} - (n+g+\delta)h(t) \tag{3.34}$$

Equation (3.34) indicates that the growth rate of human capital per unit of effective worker is, as was the case for physical capital, the difference between the gross human capital investment rate and the sum of the population growth, technological growth and depreciation rates. Once again, $dh(t)/dt=0$ when $s_H k(t)^{\alpha} h(t)^{\beta}=(n+g+\delta)h(t)$. That is, $dh(t)/dt=0$ when equation (3.35) is satisfied.

$$k(t) = k(h(t)) = \{(n+g+\delta)/s_H\}^{1/\alpha} h(t)^{(1-\beta)/\alpha} \tag{3.35}$$

On this occasion, $dk(t)/dh(t)>0$ and $d^2k(t)/dh(t)^2>0$. The dynamics of human capital accumulation are illustrated in Figure 3.4 below. Since $\beta<1$, $dh(t)/dt$ is increasing in $k(t)$. Hence for any initial combination of human and physical capital, more (less) physical capital results in more (less) human capital. The arrows in Figure 3.4 indicate the direction of movement from any initial combination of physical and human capital which do not satisfy $dh(t)/dt = 0$. Whatever the initial values of $K$, $H$, $A$ and $L$, equations (3.32) and (3.34) determine the subsequent evolution of the physical and human capital stocks. We illustrate this process by combining Figure 3.3 and Figure 3.4 in Figure 3.5 below.

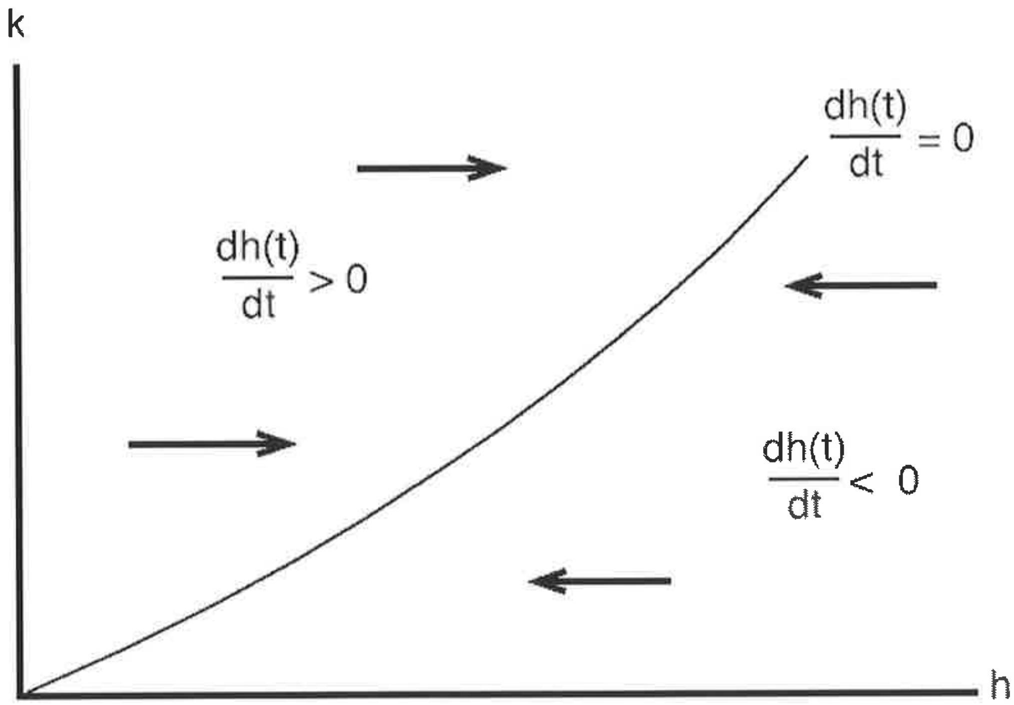


**Figure 3.4: The Dynamics of Human Capital in the Augmented Solow Model of MRW**

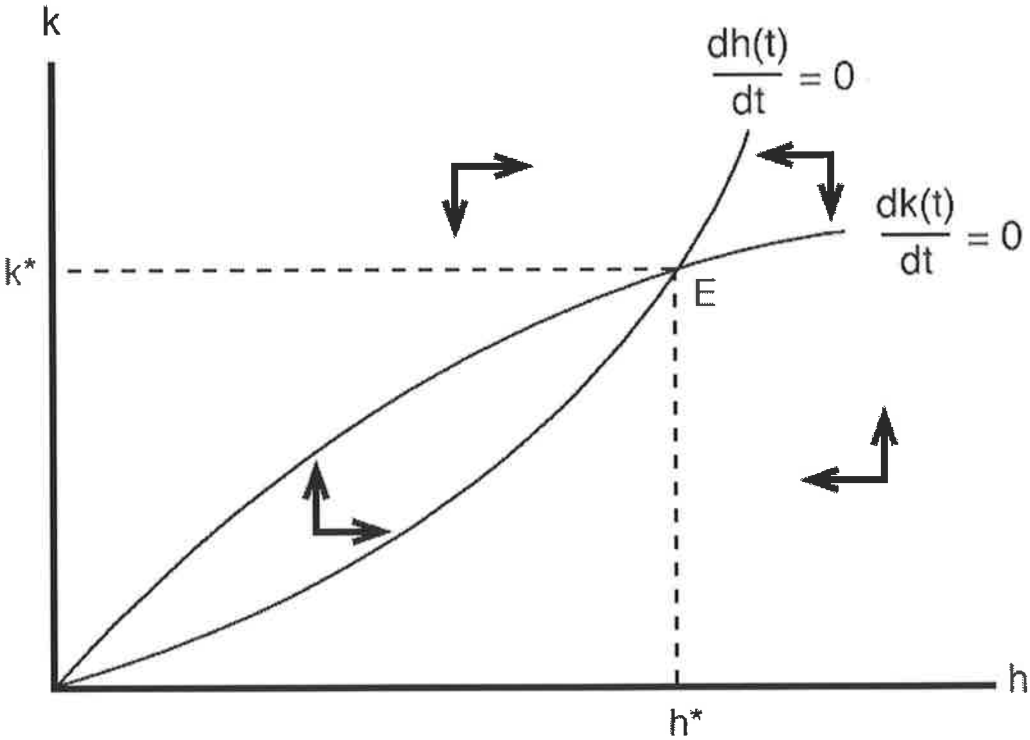


**Figure 3.5: The Joint Dynamics of Physical and Human Capital in the Augmented Solow Model of MRW**

In Figure 3.5 the economy converges to a stable steady state at point $E$ where $K$, $H$ and $Y$ are growing at rate $(n+g)$, $K/L$, $H/L$ and $Y/L$ are growing at rate $(g)$ and $k^*$, $h^*$ and $y^*$ are constant. Hence, as was the case with the Solow model, the long run growth rate of per capita incomes in this economy is determined by the exogenous rate of technological advance.

Also, the impact of a permanent change in the savings rate (or of a permanent change in the population growth rate or the depreciation rate) is almost identical to that of the Solow model. If $s_K$ increases, for instance, then the locus of points where $dk(t)/dt = 0$ in Figure 3.5 will rise. In the transition period, the growth rate of output per capita will exceed the rate of technological advance $(g)$ because both $k$ and $h$ will be increasing. When the new steady state is reached, however, the growth rate of per capita output will once again equal $g$. So, as was the case with the model of Solow, the model of MRW is not capable of explaining differences in steady-state growth rates across countries.

However, the model of MRW is capable of explaining cross-country differences in per capita incomes. If we assume that the economy is at, or is sufficiently close to, $E$ in Figure 3.5 then we can solve for $y^*$ as follows. At $E$, equation (3.36) holds.

$$\{(n+g+\delta)/s_H\}^{1/\alpha}\, h(t)^{(1-\beta)/\alpha} = \{s_K/(n+g+\delta)\}^{1/(1-\alpha)}\, h(t)^{\beta/(1-\alpha)} \qquad (3.36)$$

Manipulating equation (3.36), we get equations (3.37) and (3.38) for the steady-state stocks of physical and human capital respectively ($k^*$ and $h^*$).

$$k^* = \{(s_K{}^{1-\beta} s_H{}^{\beta}) \,/\, (n+g+\delta)\}^{1/(1-\alpha-\beta)} \qquad (3.37)$$

$$h^* = \{(s_K{}^{\alpha} s_H{}^{1-\alpha}) \,/\, (n+g+\delta)\}^{1/(1-\alpha-\beta)} \qquad (3.38)$$

By substituting these into the production function (equation (3.31)), we get equation (3.39) for the steady-state level of per capita income ($y^*$).

$$y^* = \{(s_K^{1-\beta} s_H^{\beta}) / (n+g+\delta)\}^{\alpha/(1-\alpha-\beta)} \{(s_K^{\alpha} s_H^{1-\alpha}) / (n+g+\delta)\}^{\beta/(1-\alpha-\beta)} \qquad (3.39)$$

Taking natural logarithms of equation (3.39) and simplifying, we get equation (3.40).

$$\ln y^* = -[(\alpha+\beta)/(1-\alpha-\beta)]\ln(n+g+\delta) + [\alpha/(1-\alpha-\beta)]\ln s_K + [\beta/(1-\alpha-\beta)]\ln s_H \qquad (3.40)$$

We can use equation (3.40) to derive the implications of this model for the steady-state incomes of two countries with identical production functions and levels of technology. We again assume that the share of output going to physical capital $(\alpha)$ is 1/3 and also that the share of output going to human capital $(\beta)$ is 1/3.[33] Now suppose that the two countries differ with respect to the proportions of output devoted to physical and human capital accumulation and with respect to the population growth rates, such that $2s_{K1} = s_{K2}$, $2s_{H1} = s_{H2}$, and $(n_1+g+\delta) = 0.7(n_2+g+\delta)$. Then, from equation (3.40):

$$\ln y^*_2 - \ln y^*_1 = -[(\alpha+\beta)/(1-\alpha-\beta)][\ln(n_2+g+\delta) - \ln(n_1+g+\delta)] + [\alpha/(1-\alpha-\beta)][\ln(s_{K2})-\ln(s_{K1})]$$
$$+ [\beta/(1-\alpha-\beta)][\ln(s_{H2}) - \ln(s_{H1})] \cong 2.10$$

As $e^{2.1} \cong 8$, the augmented Solow model of MRW with these parameter assumptions implies that steady-state output per capita in country 2 will be just over eight times greater that that in country 1. On the other hand, by assuming that $\beta$=0.44, per capita output in country 2 turns out to be over 33 times that of country 1. Hence plausible

[33] Unskilled workers typically earn between 1/3 and 1/2 of average wages. Hence 1/2 to 2/3 of average wages represents the return to human capital, i.e. $1/2(1-\alpha)<\beta<2/3(1-\alpha)$. With $\alpha \cong 1/3$ then $1/3<\beta<4/9$. Hence a reasonable lower (upper) bound for $\beta$ is .33 (.44).

assumptions concerning cross-country differences in the shares of output devoted to physical and human capital accumulation and concerning population growth rates result in lower and upper bound estimates of differences in per capita outputs which are consistent with those observed across countries, as indicated by the data in Table 1.1.

MRW also discuss the prediction of the Solow model concerning conditional convergence. They derive the following expression for the growth of income, which indicates that per capita income is a function of the determinants of the steady state and the initial level of per capita income.

$$ln\, y(t) - ln\, y(0) \cong (1-e^{-\lambda t})[\alpha/1-\alpha-\beta]\, ln\, s_k + (1-e^{-\lambda t})[\beta/1-\alpha-\beta]\, ln\, s_h - (1-e^{-\lambda t})[\alpha+\beta/1-\alpha-\beta]\, ln\, (n+g+\delta) - (1-e^{-\lambda t})\, ln\, y(0) \qquad (3.41)$$

MRW then estimate equation (3.41) using data for a sample of 98 countries, and for two subsets of this sample. They conclude that whilst per capita incomes across the larger subsets of countries do not converge in an absolute sense, the data does indicate the existence of conditional convergence, that is per capita incomes converging to their steady-state levels once parameter differences across countries are controlled for.[34]

### 3.4.3 Concluding Comments on the Model of MRW

Whilst the augmented Solow model of MRW has quantitative implications regarding per capita real incomes which accord more closely with observation, it offers no insights into the process by which individuals accumulate human capital, as does the model of Lucas. The model of MRW simply assumes that the same proportion of output ($s_H$) is devoted to human capital accumulation per time period. Nevertheless, MRW is important for the purposes of this thesis because it provides an empirical framework for

[34] This result, and others, are discussed in greater detail in Chapter 4.

determining whether the productivity of time spent studying, or schooling quality, is an important determinant of per capita incomes and economic growth rates across countries.

### 3.5 Concluding Comments

The models of Solow, Lucas and MRW attempt to explain the process of economic growth across countries. The Solow model ignores human capital and fails to satisfactorily account for observed differences in standards of living and in economic growth rates. Lucas models the process by which human capital is accumulated, highlights the potential importance of cross-country differences in schooling quality, and allows for a positive steady-state growth rate even in the absence of technological advance. Furthermore, in the Lucas model, there is a role for economic policy in maximising economic growth if there exist positive externalities to mean human capital in the economy.

The model of MRW includes human capital as an additional factor in the production function and, in so doing, is better able to account for disparities across countries in per capita incomes and economic growth rates than the Solow model. However, the model of MRW does not explain the process by which human capital is accumulated, thereby ignoring the potential impact of schooling quality, and can not account for a steady-state growth rate at anything other than the rate of technological advance.

This thesis is primarily interested in the impact which schooling quality has on the empirical results from an augmented Solow model of economic growth. The models of MRW and Lucas both assume that, other things being equal, more time spent at school results in the accumulation of more human capital. Lucas assumes (for the sake of simplicity) that a given proportion of time spent studying has the same impact on the rate of human capital accumulation for all individuals and irrespective of how much human capital they have previously acquired. MRW assume that, over the sample period, those countries in which a greater average proportion of the population were enrolled in secondary school are those with a higher rate of human capital accumulation. The implication from both models is that a measure of the mean quantity of schooling is a sufficient proxy for the rate of human capital accumulation across countries.

As stated earlier, this approach ignores the quality of schooling. Individuals study at different schools. The instruction provided by schools, especially across countries, is likely to be qualitatively very different. These differences may have significant impacts on rates of human capital accumulation, and hence on economic growth rates. If the quality of schooling matters then ignoring this aspect of the human capital accumulation process could bias downwards estimates of the contribution of human capital to per capita incomes and economic growth rates.

MRW acknowledge that their measure of human capital accumulation is imperfect, in part because it fails to capture the heterogeneity of teachers and schools.[35] Other studies which measure human capital accumulation in a similar way also acknowledge the shortcomings of this approach. For example, Barro and Lee (1993) define the accumulation of human capital as simply the years of primary, secondary or higher schooling attained by individuals but acknowledge that their data does not account for the quality of the education attained and that this is an important omission. Thus it is necessary to account for the quality of schooling when estimating the accumulation of human capital and the contribution of human capital to economic growth.

In the following Chapter, we present data which we argue can reasonably be used as proxies for schooling quality across countries. We then augment the model of MRW so as to include schooling quality, and derive the steady-state equations for per capita

[35] They argue, however, that if secondary school enrolment rates are proportional to the actual rate of human capital accumulation, using enrolment rates will only alter the constant term.

income and for the mean growth rate. We then estimate the growth rate equation for a sample of countries to determine whether the inclusion of schooling quality affects the estimation results from this model.

# APPENDIX 3.1
# The Solution to the Lucas Model

We derive the market solution first and then only state the corresponding optimal solution.

**(i) The Market Solution**

In this case individuals choose $C(t)$ and $u(t)$ given equations (3.25) and (3.26) so as to maximise equation (3.27), with $h_a$ given. Our objective is to determine the steady-state growth rates of consumption, physical and human capital. We begin with the first order conditions:

$$\delta H/\delta C = 0 \Rightarrow e^{-\rho t} C^{-\sigma} = \theta_1 \qquad (3A.1)$$

$$\delta H/\delta u = 0 \Rightarrow \theta_1[AK(t)^{\beta}h(t)^{1-\beta}(1-\beta)u(t)^{-\beta}h_a(t)^{\gamma}] - \theta_2 h(t)\phi = 0 \qquad (3A.2)$$

$$\delta\theta_1/\delta t = -\delta H/\delta K \Rightarrow \delta\theta_1/\delta t = -\theta_1[\beta AK(t)^{\beta-1}(u(t)h(t))^{1-\beta}h_a(t)^{\gamma}] \qquad (3A.3)$$

$$\delta\theta_2/\delta t = -\ \delta H/\delta h \Rightarrow \delta\theta_2/\delta t = -\theta_1[AK(t)^{\beta}u(t)^{1-\beta}(1-\beta)h(t)^{-\beta}h_a(t)^{\gamma}] - \theta_2[\phi(1-u(t))] \qquad (3A.4)$$

Market clearing requires that $h_a(t)=h(t)$ for all $t$. By taking natural logarithms and then derivatives of equation (3A.1) we get:

$$[d\theta_1/dt]/\theta_1 = -[\rho+\sigma(dC(t)/dt)\ /\ C(t)] \qquad (3A.5)$$

Now using equation (3A.3) to substitute for the left hand side of (3A.5) and then re-arranging we get an expression for the proportional growth rate of consumption, $G_C$, as follows:

$$[dC(t)/dt]/C(t) \equiv G_C = \sigma^{-1}[\beta AK(t)^{\beta-1}u(t)^{1-\beta}h(t)^{1-\beta+\gamma}-\rho] > 0 \quad (3A.6)$$

Similarly, with regard to $K(t)$, we use equation (3.26) to get an expression for the growth rate of physical capital, $G_K$, as follows:

$$[dK(t)/dt] / K(t) \equiv G_K = AK(t)^{\beta-1}u(t)^{1-\beta}h(t)^{1-\beta+\gamma} - C(t)/K(t) \quad (3A.7)$$

We know from equation (3A.6) that:

$$[G_C\sigma+\rho]/\beta = AK(t)^{\beta-1}u(t)^{1-\beta}h(t)^{1-\beta+\gamma} \quad (3A.8)$$

Hence:

$$C(t)/K(t) = [G_C\sigma+\rho]/\beta - G_K \quad (3A.9)$$

Taking logs and derivatives of equation (3A.9) we get:

$$G_C = G_K \quad (3A.10)$$

Hence in the steady state, consumption and capita grow at the same positive rate. With regard to human capital, we once again use equation (3A.6) to get:

$$[G_C\sigma+\rho]/\beta A = K(t)^{\beta-1}u(t)^{1-\beta}h(t)^{1-\beta+\gamma} \quad (3A.11)$$

Again taking logs and derivatives of both sides of equation (3A.10) we get:

$$0 = (\beta-1)G_K + (1-\beta+\gamma)G_H \qquad (3A.12)$$

where $G_H \equiv [dh(t)/dt]/h(t)$. Hence:

$$G_H = [(1-\beta)G_K]/(1-\beta+\gamma) \qquad (3A.13)$$

In the presence of a human capital externality ($\gamma>0$), the proportionate growth rate of human capital is less than that of physical capital and consumption in the steady state. In the absence of the externality, i.e. when $\gamma=0$, $G_H=G_K=G_C$. That is, in this model, a positive steady-state growth rate exists even with no technological advance.

All that remains now is to express $G_H$ in terms of parameters only, so as to determine whether the steady-state growth rate is, in part, a function of schooling quality. Using equation (3A.2) we get:

$$\theta_1 / \theta_2 = \phi / [AK(t)^{\beta}h(t)^{-\beta+\gamma}(1-\beta)u(t)^{-\beta}] \qquad (3A.14)$$

Taking logs and derivatives of both sides of equation (3A.14) yields:

$$[d\theta_2/dt]/\theta_2 = [d\theta_1/dt]/\theta_1 + \beta G_K + (\gamma+\beta)G_H \qquad (3A.15)$$

Now using equations (3A.3) and (3A.6) we know that:

$$[d\theta_1/dt] / \theta_1 = - [G_C\sigma+\rho] \qquad (3A.16)$$

We just need an expression for $[d\theta_2/dt]/\theta_2$. From equation (3A.4) we have:

$$[d\theta_2/dt]/\theta_2 = - \theta_1/\theta_2 [AK(t)^{\beta}u(t)^{1-\beta}(1-\beta)h(t)^{-\beta}h_a(t)^{\gamma}] - \phi[1-u(t)] \qquad (3A.17)$$

Using equation (3A.1) to get an expression for $\theta_1/\theta_2$, we get, after simplifying:

$$[d\theta_2/dt]/\theta_2 = -\phi \qquad (3A.18)$$

Using equations (3A.15), (3A.16), (3A.18) and (3A.13) we finally get an expression for the steady-state growth rate of human capital, and therefore of the economy.[36]

$$G_H = [(\phi - \rho)(1-\beta)] \, / \, [\sigma(1+\gamma-\beta)-\gamma] > 0 \qquad (3A.19)$$

If there is no externality ($\gamma$=0) then $G_H = (\phi-\rho)/\sigma$ and $\delta G_H/\delta\phi > 0$. With the discount rate ($\rho$) and the coefficient of relative risk aversion ($\sigma$) exogenously determined, the productivity of the formal education sector ($\phi$) is the only possible engine of growth in this model, even though Lucas assumes this to be constant. That is, the steady-state economic growth rate is a positive function of the productivity of time spent studying, or schooling quality.[37]

### (ii) The Planners Solution

Lucas shows that economic policies which affect the decisions of individuals to accumulate human capital can also affect the steady-state growth rate by deriving the growth rate of human capital assuming that the externality is internalised. In this case, he ends up with the following expression for the steady-state growth rate of human capital,

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[36] This equation is identical to equation (26) in Lucas, remembering that we have assumed a constant population, which means that the population growth rate ($\lambda$ in Lucas) is zero.

[37] The next Chapter tests empirically whether this is the case.

and thus of the economy.[38]

$$G_H^* = \sigma^{-1}\{[\phi-(1-\beta)\rho] / (1-\gamma-\beta)\} \tag{3A.20}$$

If the externality is positive ($\gamma=0$) then the 'efficient' growth rate is greater than the 'equilibrium' growth rate. That is, $G_H^* > G_H$. This is so because the private returns to education are less than the social returns and so, from a social perspective, investments in human capital accumulation in a competitive economy are insufficient. Thus in this model, if the externality to the mean level of human capital is positive, there is a role for public policy in maximising the rate of human capital accumulation and hence the economic growth rate by, for instance, subsidising schooling.

[38] This equation is identical to equation (24) in Lucas, again remembering that we have assumed a constant population.

# CHAPTER 4

# THE IMPACT OF SCHOOLING QUALITY ON ECONOMIC GROWTH IN THE AUGMENTED SOLOW MODEL OF MRW

## 4.1 Introduction

Many countries make very large educational investments, presumably because schooling makes an important contribution to the accumulation of human capital. But how does schooling matter? Do students accumulate human capital by simply attending 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 answer partly because human capital is difficult to measure, and partly because students are not homogeneous with respect to characteristics such as innate ability, family and other background characteristics. Furthermore, schools do not provide a uniform educational experience to all students. Accordingly, within countries, some students acquire more schooling and/or achieve higher measurable educational outcomes than others whilst some schools achieve superior results, in aggregate, than others. Such variability is also evident across countries.

This Chapter tries to answer the following question. Is schooling quality important in the relationship between human capital accumulation and economic growth? Many previous studies have used only quantity measures of human capital accumulation, such as school enrolment rates or years of schooling completed, and have typically concluded that the quantity of schooling is positively and significantly associated with cross-country levels of per capita income and rates of economic growth.[39] These conclusions have led to calls for greater investments in human capital accumulation in the form of more schooling, especially in developing countries.

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[39] See, for example, Barro (1991), Romer (1990), MRW (1992) and Levine and Renelt (1992).

However, the quality of schooling may also be an important determinant of per capita incomes and economic growth rates. If this is the case then attention should also be directed at improving the quality of existing schools rather than simply encouraging students to acquire more schooling. In this Chapter we address this issue by replicating the empirical approach taken by MRW, but include in the analysis a measure of schooling quality. The objective is to determine whether the inclusion of schooling quality affects the empirical results from the augmented Solow model of MRW.

In Chapter 3 we highlighted the major shortcomings of the augmented Solow model of MRW. That is, the model is incapable of accounting for steady-state growth at anything other than the rate of technological advance, and the model sheds no light on the process whereby human capital is accumulated by individuals, as does the model of Lucas. We nevertheless focus on the MRW model because in the Lucas model (a steady state model), the education productivity parameter does not feature in the long run growth equation. Also, the model of MRW is capable of accounting for observed disparities in per capita incomes across countries (for plausible assumptions concerning parameter values) and for observed out-of-steady-state dynamics as countries converge to their respective steady states (see the next section), has been much used and is well known. Hence we believe that the augmented Solow model of MRW is a reasonable one with which to determine whether schooling quality matters for economic growth[40].

The remainder of this Chapter is organised as follows. In section 4.2 we outline the empirical approach taken by MRW and summarise their main results. In section 4.3 we present data on schooling quality across a sample of countries. We then introduce a term for schooling quality into the augmented Solow model of MRW, derive the

[40] Related but more recent studies such as Islam (1995), Caselli, Esquival and Lefort (1996) and Lee, Pesaran and Smith (1998) use panel data and conclude, in part, that the results in MRW are biased due to their failure to account for fixed country effects and because of the likely endogeneity of investment rates. However, these shortcomings are not relevant to this thesis because our objective is to determine the sensitivity of the MRW results to the inclusion of proxies for schooling quality. In any case, to the best of our knowledge, no test score panel data exists.

corresponding equations for the steady-state level of per capita income and for the average growth rate over the sample period, and re-estimate. We then test whether our results are robust to an alternate measure of schooling quantity to that used by MRW. Finally, section 4.4 concludes.

## 4.2 The Quantity of Schooling and Economic Growth in MRW

The mechanics of the augmented Solow model of MRW were analysed in detail in Chapter 3. In this section, we focus on their main empirical results. MRW begin by estimating the standard Solow model which excludes human capital as a factor of production. We noted previously that the steady state in the Solow model is defined by an equality between gross investment in physical capital and its rate of depreciation, i.e. when $sf(k^*) = (n+g+\delta)k^*$, where the asterisk refers to the steady state. Solving for k* whilst noting that $f(k^*) = k^{*\alpha}$ yields equation (4.1).

$$k^* = [s/(n+g+\delta)]^{1/(1-\alpha)} \tag{4.1}$$

Substituting equation (4.1) into the Solow production function and taking natural logarithms yields equation (4.2) for the steady-state level of income per adult, where all variables are as defined in Chapter 3.

$$ln(Y/L)^* = a + (\alpha/1\text{-}\alpha)ln(s) - (\alpha/1\text{-}\alpha)ln(n+g+\delta) + \varepsilon \tag{4.2}$$

MRW use data on real GDP per capita from Summers and Heston (1988), adjusted to account for the proportion of the population in each country aged 15-64 years, to estimate equation (4.2).[41] These proportions are taken from the World Bank World Tables

[41] From here on, when we refer to the population growth rate, we mean that of the population aged 15-64 years.

and the 1988 World Development Report. Their data on savings rates and population growth rates are also taken from Summers and Heston (1988).

For empirical purposes, MRW concentrate on three samples of countries. The first includes the 98 non-oil-exporting nations for which data is available. The second includes only the 75 non-oil-exporting nations for which, according to Summers and Heston, the data is relatively more reliable. The third includes only the 22 member nations of the OECD.[42]

MRW's estimation results for equation (4.2) are reported in Table 4.1 below. For the two larger groups of countries the results indicate that savings rates are positively and significantly associated with real per capita GDP whilst population growth rates are negatively and significantly associated with real per capita GDP. However, these results imply that capital's share of income ($\alpha$) is approximately 60% for the two larger samples, which is much greater than that observed in the national accounts of most countries.

**Table 4.1**
**Estimation Results for Equation (4.2)**
**Dependent Variable: Log GDP per Worker (1985)**

| *Sample* | *Non-Oil* | *Intermediate* | *OECD* |
|---|---|---|---|
| Observations | 98 | 75 | 22 |
| ln(I/GDP) | 1.42<br>(10.14) | 1.31<br>(7.71) | 0.50<br>(1.16) |
| ln(n+g+δ) | -1.97<br>(-3.52) | -2.01<br>(-3.79) | -0.76<br>(-0.90) |
| Adjusted $R^2$ | 0.59 | 0.59 | 0.01 |
| s.e.e | 0.69 | 0.61 | 0.38 |
| Implied $\alpha$ | 0.60 | 0.59 | 0.36 |

**Notes:** t-statistics are in parentheses. The regression constants have been omitted to save space. I/GDP is investment as a proportion of GDP. n+g+δ is the sum of the population and technology growth rates plus the depreciation rate. The investment rate and the population growth rate are averages for the period 1960-85. MRW assume that the rate of technology growth plus the depreciation rate is equal to 5% for all countries over the sample period. ln(•) refers to the natural logarithm.

42 The data used in MRW is included here as Appendix 4.1.

For the OECD sample neither of the explanatory variables is statistically significant and the adjusted $R^2$ indicates that this model explains virtually none of the cross-country variation in per capita incomes. MRW suggest that this is probably because the OECD countries are a long way from their respective steady states as a result of the disruptions caused by World War II. On the basis of these results, MRW argue that the standard Solow model needs to be augmented to more accurately reflect the accumulation of all forms of capital, not just physical capital. They therefore introduce human capital into the Solow model (see equation (3.28)) and derive equations for the steady-state ratios of physical and human capital to effective labour, (4.3) and (4.4) respectively, where $s_k$ ($s_h$) is the mean proportion of GDP devoted to physical capital (human capital) accumulation[43].

$$k^* = \{(s_k^{1-\beta} s_h^{\beta}) / (n+g+\delta)\}^{1/(1-\alpha-\beta)} \tag{4.3}$$

$$h^* = \{(s_k^{\alpha} s_h^{1-\alpha}) / (n+g+\delta)\}^{1/(1-\alpha-\beta)} \tag{4.4}$$

By substituting equations (4.3) and (4.4) into the augmented Solow production function and taking natural logarithms, MRW derive equation (4.5) for the steady-state level of income per adult.

$$ln[Y/L]^* = lnA(0) + gt - [(\alpha+\beta)/(1-\alpha-\beta)]ln(n+g+\delta) + [\alpha/(1-\alpha-\beta)]ln(s_k) + [\beta/(1-\alpha-\beta)]ln(s_h) \tag{4.5}$$

[43] An issue here is whether one should use human capital data which measures flows of investment in schooling or schooling stocks. MRW actually derive 2 steady state income equations, one with the human capital investment rate ($s_h$) and another with the steady state stock of human capital. According to MRW, "...when testing augmented Solow models, a primary question is whether the available data on human capital corresponds more closely to....($s_h$) or (h)" (p.418). MRW estimate the investment rate version and this presumably reflects the available data at that time. On the other hand Barro and Sala-i-Martin (1995) use the stock of schooling as their human capital variable, although they add to their basic regression male and female school enrolment rates which, they argue, "...have been used frequently by previous researchers who did not have access to data on stocks of school attainment" (9.437). The results obtained using these two types of human capital data are quite comparable. In any case, our objective is to test the sensitivity of the MRW results to the inclusion of a proxy for schooling quality, not to defend the use of flow versus stock data.

MRW estimate equation (4.5) by constructing a proxy for $s_h$, which they call SCHOOL, which measures approximately the mean percentage of the population of each country that was enrolled in secondary school from 1960 to 1985. The estimation results for equation (4.5) are reported in Table 4.2 below. SCHOOL enters significantly in all three samples, reduces the coefficient on physical capital investment and improves the fit of all three regressions compared to those of Table 4.1. MRW conclude that the physical capital investment rate, the adult population growth rate and the school enrolment rate together explain nearly 80 percent of the cross-country variation in incomes per adult in the non-oil and intermediate samples, and that the implied shares of income invested in physical and human capital are now much closer to those observed in most countries. Once again the results for the OECD sample are less satisfactory with neither the savings rate nor the population growth rate being statistically significant, whilst the implied share of income going to physical capital ($\alpha$) is now less than expected.

MRW finally turn their attention to the issue of convergence of incomes per capita. By approximating around the steady state they derive equation (4.6) for the average growth rate, where *lny(0)* is the natural logarithm of real GDP per capita in 1960, *lny(t)* is the natural logarithm of real GDP per capita at time t, $\lambda$ is the rate of convergence to the steady state and all other variables are as previously defined.

$$lny(t) - lny(0) = (1-e^{-\lambda t})(\alpha/1-\alpha-\beta)ln(s_k) + (1-e^{-\lambda t})(\beta/1-\alpha-\beta)ln(s_h) - (1-e^{-\lambda t})(\alpha+\beta/1-\alpha-\beta)ln(n+g+\delta) - (1-e^{-\lambda t})lny(0) \quad (4.6)$$

**Table 4.2**
**Estimation Results for Equation (4.5)**
**Dependent Variable: Log GDP per Worker (1985)**

| *Sample* | *Non-Oil* | *Intermediate* | *OECD* |
|---|---|---|---|
| Observations | 98 | 75 | 22 |
| ln(I/GDP) | 0.69 | 0.70 | 0.28 |
| | (5.31) | (4.67) | (0.72) |
| ln(n+g+δ) | -1.73 | -1.50 | -1.07 |
| | (-4.22) | (-3.75) | (-1.43) |
| ln(SCHOOL) | 0.66 | 0.73 | 0.76 |
| | (9.43) | (7.30) | (2.62) |
| Adjusted $R^2$ | 0.78 | 0.77 | 0.24 |
| s.e.e | 0.51 | 0.45 | 0.33 |
| Implied α | 0.31 | 0.29 | 0.14 |
| Implied β | 0.28 | 0.30 | 0.37 |

**Notes**: t-statistics are in parentheses. The regression constants have been omitted to save space. I/GDP is investment as a proportion of GDP. n+g+δ is the sum of the population and technology growth rates plus the depreciation rate. The investment rate and the population growth rate are averages for the period 1960-85. MRW assume that the rate of technology growth plus the depreciation rate is equal to 5% for all countries over the sample period. ln(•) refers to the natural logarithm.

In equation (4.6) the growth rate of income per capita is a function of the determinants of the steady state, and the initial level of income.

MRW estimate equation (4.6) 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 mean secondary school enrolment rates, as proxies for human capital accumulation, further improves the fit of the regression for all samples.

Table 4.3 below reports the MRW convergence regression results but only for their final estimation of equation (4.6), i.e. that conditional on the investment, population growth and human capital accumulation rates, for the three samples of countries. The coefficient on the initial level of income is of the expected sign and highly significant across the three samples. The coefficients for the physical capital investment and population growth rates are of the expected sign and are statistically significant at either the 5% level or the 10% level. The coefficients on the proxy for human capital accumulation are also of the expected sign and significant for the two larger samples at the 5% level. These four variables together explain up to 65% of the variation in per capita incomes.

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).

**Table 4.3**
**Regression Results for Equation (4.6)**
**Dependent Variable: log difference GDP per worker (1960-85)**

| *Sample* | *Non-Oil* | *Intermediate* | *OECD* |
|---|---|---|---|
| Observations | 98 | 75 | 22 |
| ln(y60) | -0.29<br>(-4.83) | -0.37<br>(-5.29) | -0.40<br>(-5.71) |
| ln(I/GDP) | 0.52<br>(5.78) | 0.54<br>(5.40) | 0.34<br>(2.00) |
| ln(n+g+δ) | -0.51<br>(-1.76) | -0.55<br>(-1.90) | -0.84<br>(-2.55) |
| ln(SCHOOL) | 0.23<br>(3.83) | 0.27<br>(3.38) | 0.22<br>(1.57) |
| Adjusted $R^2$ | 0.46 | 0.43 | 0.65 |
| s.e.e. | 0.33 | 0.30 | 0.15 |

**Notes**: t-statistics are in parentheses. The regression constants have been omitted to save space. y60 is the initial level of income per worker. I/GDP is investment as a proportion of GDP. n+g+δ is the sum of the population and technology growth rates plus the depreciation rate. SCHOOL measures the secondary school enrolment rates. The investment rate and the population growth rate are averages for the period 1960-85. MRW assume that the rate of technology growth plus the depreciation rate is equal to 5% for all countries over the sample period. ln(•) refers to the natural logarithm.

Tax policies influence savings rates, tastes for children influence population growth rates and political stability influences, among other things, the rate of technological advance. Of particular interest here is the impact which education policies may have on the accumulation of human capital. With respect to the augmented Solow model of MRW, education policy, such as the compulsory minimum school leaving age, may influence the secondary schooling enrolment rate and hence the quantity of schooling.

However, education policy may also influence the productivity of schools by, for instance, impacting on the curriculum taught at school, the training and experience of teachers, and the incentives they face. Furthermore, cross-country differences in schooling quality may also be important determinant of cross-country differences in economic growth rates. To date, this possibility appears to have been largely ignored in the empirical literature on economic growth.

In the next section we present data on schooling quality across a sample of countries and then introduce a term for schooling quality into the augmented Solow model of MRW. We then derive the corresponding equations for the steady-state level of per capita income and for the economic growth rate, and re-estimate the convergence equation with the data of MRW plus our data on schooling quality, to determine whether schooling quality matters in the relationship between human capital accumulation and economic growth.

## 4.3 The Impact of Schooling Quality on the Empirical Results from the Augmented Solow Model of MRW

This section investigates whether the addition of cross-country test scores, as proxies for schooling quality, affects the empirical results obtained from the augmented Solow model of MRW. We begin by presenting data on mean test scores across a sample of countries.

Table 4.4 below presents national standardised test scores published as part of the Third International Mathematics and Science Study (T.I.M.S.S.) by the International Association for the Evaluation of Educational Achievement (I.E.A.). 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.[44] Table 4.4 also includes the rank of each country by school year and test.

As discussed in Chapter 2, test scores are likely to indicate only the extent to which students have retained knowledge and are able to solve problems specific to the relevant subject, and so are not ideal indicators of other desirable outcomes of schooling such as the ability to successfully adapt to change, tolerate diversity and think creatively. Nevertheless if the retention of knowledge and the ability to solve problems are necessary outcomes of a productive education system then schooling quality may be reasonably well proxied by national mean scores on standardised tests. The data of Table 4.4 thus indicates that there exists great disparities in mean schooling quality across countries. If schooling quality is an important determinant of the rate of human capital accumulation, then these disparities may help to explain the large differences in cross-country standards of living. Our objective in this section is to determine if this is in fact the case.

To do so, we now introduce a term for schooling quality into the augmented Solow model of MRW. Suppose that, in the manner of Lucas (discussed in detail in Chapter 2), effective human capital accumulation is a function of both the quantity of schooling and the productivity of time spent at school. Then the accumulation of human capital may be modelled as equation (4.7) where the term $Q_H$ is a measure of national mean schooling quality and all other variables are as previously defined.

$$dH(t)/dt = [s_H Y(t)]\,Q_H - \delta H(t) \qquad (4.7)$$

[44] See Appendix 4.2 for a discussion of the testing procedure used in the T.I.M.S.S.

## Table 4.4 Cross-Country Test Scores by Year and Subject

| *Country* | *4Math:Rk* | *4Sci:Rk* | *8Math:Rk* | *8Sci:R* | *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 |
| **CzechRep** | 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 | | |
| **HongKong** | 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** | 400:26 | 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 | 25:21 | 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** | | | 547:7 | 544:13 | | |
| **Slovenia** | 552:8 | 546:11 | 541:9 | 560:7 | 512:12 | 517:10 |
| **SouthAfrica** | | | 354:41 | 326:41 | 356:21 | 349:21 |
| **Spain** | | | 487:32 | 517:27 | | |
| **Sweden** | | | 519:22 | 535:16 | 552:2 | 559:1 |
| **Switzerland** | | | 545:8 | 522:25 | 540:4 | 523:8 |
| **Thailand** | 490:22 | 473:24 | 522:21 | 525:22 | | |
| **U.S.A.** | 545:12 | 565:4 | 500:28 | 534:17 | 461:19 | 480:16 |
| **MeanScore** | 529 | 524 | 513 | 516 | 500 | 500 |
| **Range** | 400-625 | 401-597 | 354-643 | 326-607 | 356-560 | 349-559 |
| **n** | 26 | 26 | 41 | 41 | 21 | 21 |

**Notes:** *'4Math:Rk'* in column two refers to 4th grade mathematics test scores and the rank of each country. Likewise for columns three to seven. Blank cells indicate that the relevant country did not participate in that test. 'MeanScore' 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. 'n' reports the number of countries who participated in that test and whose mean test scores are reported in Table 4.4. 'Korea' refers to the Republic of Korea, 'Iran' to the Islamic Republic of Iran, 'Russia' to the Russian Federation, 'Slovak' to the Slovak Republic, and NZ to New Zealand. The Flemish and French educational systems in Belgium participated separately.

The term $s_H Y(t)$ in equation (4.7) captures mean annual expenditures on schooling. In the spirit of Hanushek, amongst others, we interpret this as an indicator of the quantity of schooling only. Other things being equal, more educational expenditures typically result in more schools and/or more teachers. These additional resources may be provided to accommodate an increasing school age population and/or to reduce average class sizes. In the former case, increased educational expenditures are clearly producing an increased quantity of schooling. On the other hand increased educational expenditures which, for instance, reduce class sizes, whilst probably aiming to increase schooling quality, in many cases have no systematic positive impact on learning outcomes.[45] Hence we believe that, as a first approximation, educational expenditures across countries are a good measure of the quantity of schooling. The term $[s_H Y(t)]Q_H$ in equation (4.7) thus captures the interaction between schooling quantity and schooling quality and is our measure of the gross accumulation of effective human capital.

The objective now is to derive expressions for the levels of physical capital and human capital, and the equation for per capita income, in the steady state. As the remainder of the augmented Solow model of MRW is unchanged, equation (4.8) re-states the equation for physical capital accumulation per effective worker, which was derived in Chapter 2 as equation (3.32).

$$dk(t)/dt = s_K\, k(t)^{\alpha}\, h(t)^{\beta} - (n+g+\delta)k(t) \qquad (4.8)$$

[45] The relationship between expenditures on schooling and schooling quality is controversial. See Chapter 2 for a review of the literature on this issue. Across our sample of countries, there is no statistically significant relationship between educational expenditures and test scores (see Chapter 5).

We derive a similar expression for human capital accumulation, but now including our term for schooling quality, as equation (4.9).

$$dh(t)/dt = s_H k(t)^\alpha h(t)^\beta Q_H - (n+g+\delta)h(t) \qquad (4.9)$$

In the steady state, by definition, the accumulation of physical capital and effective human capital per (technology augmented) worker is zero. Hence equations (4.10) and (4.11) must hold, where the asterisk refers to the steady state.

$$s_K k^{*\alpha} h^{*\beta} = (n+g+\delta)k^* \qquad (4.10)$$

$$s_H k^{*\alpha} h^{*\beta} Q_H = (n+g+\delta)h^* \qquad (4.11)$$

By taking natural logarithms of equations (4.10) and (4.11) and solving, we derive two linear equations (4.12) and (4.13) for, respectively, $lnk^*$ and $lnh^*$ .

$$lnk^* = (1-\beta)/(1-\alpha-\beta)\, lns_K + \beta/(1-\alpha-\beta)\, lns_H + \beta/(1-\alpha-\beta)\, lnQ_H$$
$$- 1/(1-\alpha-\beta)\, ln(n+g+\delta) \qquad (4.12)$$

$$lnh^* = (1-\alpha)/(1-\alpha-\beta)\, lns_H + \alpha/(1-\alpha-\beta)\, lns_K + (1-\alpha)/(1-\alpha-\beta)\, lnQ_H$$
$$- 1/(1-\alpha-\beta)\, ln(n+g+\delta) \qquad (4.13)$$

The production function, which was derived in intensive form in Chapter 3 (see equation 3.31), is reproduced below as equation (4.14).

$$y^* = k^{*\alpha} h^{*\beta} \qquad (4.14)$$

By substituting equations (4.12) and (4.13) into (4.14) we derive equation (4.15) for the steady-state level of income per effective worker.

$$lny^* = \alpha/(1-\alpha-\beta)\, ln\, s_K + \beta/(1-\alpha-\beta)\, ln s_H + \beta/(1-\alpha-\beta)\, ln Q_H$$
$$- (\alpha+\beta)/(1-\alpha-\beta)\, ln(n+g+\delta) \qquad (4.15)$$

Equation (4.15) may be expressed in terms of steady-state income per capita, as follows.

$$ln[Y/L]^* = lnA(0) + gt + \alpha/(1-\alpha-\beta)\, ln\, s_K + \beta/(1-\alpha-\beta)\, ln s_H + \beta/(1-\alpha-\beta)\, ln Q_H$$
$$- (\alpha+\beta)/(1-\alpha-\beta)\, ln(n+g+\delta) \qquad (4.16)$$

Equation (4.16) states that income per capita in the steady state 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 ($\delta$) and the rates of technological advance and population growth ($g$ and $n$).

Conditional convergence to the steady state is again modelled as equation (4.17) where $y(0)$ is initial income per effective worker.

$$lny(t) - lny(0) = (1-e^{-\lambda t})lny^* + e^{-\lambda t}\, lny(0) \qquad (4.17)$$

Finally, substituting $lny^*$ in equation (4.17) with equation (4.15) yields equation (4.18).

$$lny(t) - lny(0) = (1-e^{-\lambda t})(\alpha/1-\alpha-\beta)\, ln(s_K) + (1-e^{-\lambda t})(\beta/1-\alpha-\beta)\, ln(s_H)$$
$$+ (1-e^{-\lambda t})(\beta/1-\alpha-\beta)\, ln(Q_H) - (1-e^{-\lambda t})(\alpha+\beta/1-\alpha-\beta)\, ln(n+g+\delta)$$
$$- (1-e^{-\lambda t})\, ln(y(0)) \qquad (4.18)$$

Hence in this model the average growth rate of GDP per worker is a function of the determinants of the steady-state level of income per worker, which now include schooling quality, and the initial level of income per worker.

In the remainder of this section, we investigate whether the inclusion of schooling quality affects the empirical results from this model. In Table 4.4 we have scores on mathematics and science tests in up to 40 countries for years 4, 8 and 12 which we have argued are reasonable proxies for schooling quality. *A priori*, if schooling quality matters at all, then the year 12 test scores should be the proxies most relevant to the estimation of per capita incomes and growth rates because the mathematics and science abilities of year 12 students are probably close to their lifetime maximums, and because many students of this age are, or are close to, participating in the labour market.[46] However, we have year 12 test scores for only 21 countries and, of these, the Czech Republic, Hungary, Lithuania, Russia and Slovenia were not independent market based countries during the sample period. This leaves us with a sample of just 16 countries and so even though we would prefer to use year 12 test scores, we concentrate on the larger sample of year 8 test scores instead.[47]

A potential problem here is the use of mean cross country scores on tests conducted in the early 1990's as proxies for mean schooling quality in those countries as much as 30 years earlier, and so the test scores, rather than predicting earlier growth, may themselves be a result of the earlier economic development[48]. If this is so then OLS estimates of the impact of test scores on economic growth rates will be biased upwards. One possibility is that, whilst the absolute levels of schooling quality in the 1990's were probably different to

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[46] Ideally, we would like to have data on the quality of both year 12 and tertiary schooling. Such data would capture the abilities of the great majority of school graduates. Unfortunately, comparable cross-country data on tertiary schooling quality does not appear to exist.

[47] We nevertheless conducted OLS regressions with this sample of 16 countries using year 12 test scores as proxies for schooling quality to determine whether these results are at least consistent with those reported for year 8 test scores, in Table 4.5 in the text. The data used, and the regression results, are included in Appendix 4.5.

[48] In Chapter 5 we show in a simultaneous equation system that real incomes per capita are not statistically significantly related to test scores across our sample of countries. However, this may be because parental education levels are included as an explanatory variable.

those up to 30 years earlier, schooling quality relativities may have remained constant over the sample period. If this is so then the use of 1990's test scores will affect the regression constant only. In any case, to the best of our knowledge, there simply is no earlier data for a comparable sample of countries.

We have year 8 test scores for 40 countries (41 school systems, as the Flemish and French systems in Belgium participated separately). For a variety of reasons, we omitted 12 of these countries, leaving us with data on 28 countries, most of which are members of the OECD.[49] This is still a small sample for empirical purposes, but is the best available to us at this time. Hence we proceeded as follows. We focused on the mean growth rate equation using the data of MRW, plus our data on test scores as proxies for schooling quality.[50] The estimation results are presented in Table 4.5 whilst the data used for the regressions are included in Appendix 4.3[51].

The results of Table 4.5 indicate that schooling quality has a significant positive impact on the growth regression. The results in column one indicate that, as was the case for the OECD subset in MRW, there is a strong tendency towards unconditional convergence, with initial incomes alone accounting for over 40% of the variation in mean growth rates for these countries over the sample period. When savings and population growth rates are added (column two), convergence remains with the coefficient on the initial income level being even more statistically significant. The coefficient on the 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

49 The Solow model assumes market based production. Of the 40 countries for which we have year 8 test scores, Bulgaria, the Czech Republic, Hungary, Latvia, Lithuania, Romania, Russia, the Slovak Republic and Slovenia were not independent market based countries during the sample period and so were excluded. Kuwait, which generates much of its income by extracting and exporting crude oil, received a windfall gain as a result of the OPEC oil embargoes of the 1970's. Its' mean GDP growth rate would thus be artificially high over the sample period, and hence Kuwait was also excluded. Iran was excluded because, in the late 1970's, its' income level approximately halved as a result of the Islamic revolution. Finally, Scotland was excluded from the analysis because it was not an independent country during the sample period. The number of countries excluded from the initial sample of 40 is thus 12. For empirical purposes, we used the mean of the two test scores for Belgium.

50 Regression results not reported here, for the steady-state income equation which included schooling quality, for this small sample of countries, produced $R^2$ values of zero. Hence we focused on estimating the mean growth rate equation only.

51 It is well known that the MRW specification is over-identified, as there are 5 estimated coefficients but only 2 independent parameters. Whilst identification issues are discussed briefly in Chapter 5, we note once again that we are primarily interested in the sensitivity of the MRW results to the inclusion of a proxy for schooling quality.

fit of the regression is substantially improved by the addition of these two variables, with the adjusted $R^2$ of the regression increasing from .43 to .53.

**Table 4.5**
**Estimation Results for Equation (4.18)**
**Dependent Variable: log difference GDP per worker (1960-85)**
**Sample Size: 28**

| *Variable* | *(1)* | *(2)* | *(3)* | *(4)* | *(5)* |
|---|---|---|---|---|---|
| ln(y60) | -.37<br>(-4.63) | -.42<br>(-5.17) | -.46<br>(-5.71) | -.41<br>(-5.89) | -.43<br>(-5.56) |
| ln(I/GDP) | | .62<br>(2.56) | .50<br>(2.08) | .31<br>(1.48) | .46<br>(2.03) |
| ln(n+g+δ) | | -.14<br>(-.38) | -.14<br>(-.39) | -.23<br>(-.80) | -.10<br>(-.29) |
| ln(SCHOOL) | | | .28<br>(1.82) | .005<br>(.03) | .04<br>(.24) |
| ln(mscore8) | | | | 3.04<br>(3.47) | |
| ln(sscore8) | | | | | 2.46<br>(2.11) |
| Adj $R^2$ | .43 | .53 | .57 | .71 | .62 |

**Notes**: t-statistics are in parentheses. The regression constants have been omitted to save space. y60 is the initial level of income per worker. I/GDP is investment as a proportion of GDP. n+g+δ measures the sum of the growth rates of workers and technology plus the depreciation rate. SCHOOL measures the secondary school enrolment rate. mscore8 (sscore8) refers to the mathematics (science) test scores for year 8 students. The investment rate and the population growth rate are averages for the period 1960-85. The rate of technology growth plus the depreciation rate is assumed to equal 5% for all countries over the sample period. ln(•) refers to the natural logarithm.

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 (the 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 (mscore8). With this additional explanatory variable 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 the schooling quantity variable (SCHOOL) is now essentially zero whilst that on the schooling quality variable (mscore8) is of the expected sign and highly statistically significant. Hence the addition of year 8 mathematics test scores has a substantial positive impact on the growth rate regression results from an augmented Solow model which includes schooling quality.

The regression whose results are presented in column five uses year 8 science test scores (sscore8) as proxies for schooling quality instead of year 8 maths test 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 5% level, whilst that on the schooling quantity variable (SCHOOL) is again essentially equal to 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 appears to lose much of its explanatory power only with the addition of mathematics test scores.

Clearly, the addition of test scores as proxies for schooling quality across countries has a substantial positive impact on the fit of the convergence regressions based on the augmented Solow model of MRW. Mathematics test 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.

Are our results robust to a more comprehensive measure of schooling quantity? SCHOOL in MRW measures only mean secondary school enrolment rates between 1960 and 1985 for each country.[52] The value of 0.045 for Algeria, for instance, means that a yearly average of 4.5% of the Algerian population aged between 15 and 64 years were enrolled in secondary school between 1960 and 1985.[53] However. whilst secondary schooling is likely to be an important determinant of economic growth, tertiary schooling may also be important.

In the past, tertiary institutions were regarded as a source of highly specialised skills. Today, tertiary schooling is regarded in many of the countries in our sample as an important source of general labour market training. Accordingly, in many countries, the proportion of the population with a university degree has grown rapidly, and hence any measure of schooling enrolment rates which fails to capture tertiary school enrolments may substantially underestimate the quantity of schooling, and hence the rate of human capital accumulation.[54]

To determine if this is the case, we constructed a variable, UPSCHOOL, which measures the sum of the mean secondary and tertiary school enrolment rates across countries and over the sample period. Due to further data limitations concerning tertiary school enrolment rates, our sample size for this exercise was reduced to 25. Table 4.6 below reports the regression results when we use UPSCHOOL as our proxy for schooling quantity, whilst the data used for this regression is included in Appendix 4.4.

[52] *SCHOOL* in MRW is calculated by multiplying the proportion of the population aged 12-17 years enrolled in secondary school by the proportion of the working age population that is aged 15-19 years, in each country, averaged over the period 1960-1985.

[53] See data line 1 in Appendix 4.1.

[54] This will be a statistically relevant factor only if tertiary schooling enrolment rates across our sample of countries are not proportional to secondary school enrolment rates.

**Table 4.6**
**Estimation Results for Equation (4.18)**
**Dependent Variable: log difference GDP per worker (1960-85)**
**Sample Size: 25**

| *Variable* | *(1)* | *(2)* | *(3)* | *(4)* | *(5)* |
|---|---|---|---|---|---|
| ln(y60) | -.37<br>(-4.49) | -.42<br>(-4.86) | -.46<br>(-4.55) | -.42<br>(-5.20) | -.44<br>(-4.75) |
| ln(I/GDP) | | .64<br>(2.48) | .60<br>(2.22) | .21<br>(.86) | .41<br>(1.57) |
| ln(n+g+δ) | | -.08<br>(-.19) | -.08<br>(-.20) | -.32<br>(-.99) | -.14<br>(-.37) |
| ln(UPSCHOOL) | | | .19<br>(.77) | .09<br>(.47) | .09<br>(.38) |
| ln(mscore8) | | | | 3.76<br>(3.52) | |
| ln(sscore8) | | | | | 3.35<br>(2.12) |
| Adj $R^2$ | .44 | .53 | .52 | .70 | .59 |

**Notes**: t-statistics are in parentheses. The regression constants have been omitted to save space. y60 is the initial level of income per worker. I/GDP is investment as a proportion of GDP. n+g+δ measures the sum of the growth rates of workers and technology plus the depreciation rate. UPSCHOOL measures the sum of the secondary and tertiary school enrolment rates. mscore8 (sscore8) refers to the mathematics (science) test scores for year 8 students. The investment rate and the population growth rate are averages for the period 1960-85. The rate of technology growth plus the depreciation rate is assumed to equal 5% for all countries over the sample period. ln(•) refers to the natural logarithm.

The results in Table 4.6 are very similar to those of Table 4.5. However, it is clear from the results in column (3) of Table 4.6 that the variable UPSCHOOL has less explanatory power than the variable SCHOOL used in Table 4.5. The improved fit of the regression with the addition of year 8 test scores is still evident, as is the impact which the inclusion of the mathematics scores in particular has on the explanatory power of the savings rate. Hence we conclude that, whilst our new variable seems to be a less satisfactory proxy for schooling quantity, the results for year 8 test scores presented in

Table 4.5 are robust to an alternate measure of schooling quantity which includes tertiary schooling enrolment rates across countries.

In this section we have shown that, with an augmented Solow model of economic growth which includes schooling quality as an additional explanatory variable in the human capital accumulation equation, the quantity of schooling is essentially unrelated to mean cross-country growth rates when the quality of schooling is controlled for. On the other hand test scores, as proxies for schooling quality, are significantly and positively associated with mean cross-country growth rates, and when included on the right hand side of the equation, substantially improve the fit of the convergence regressions.

Is it plausible that the quantity of schooling, for example the number of children educated, is a statistically insignificant factor for economic growth across this sample of mostly developed countries? Perhaps not. However, our results may be pointing to the idea that, in such countries, increased rates of economic growth may depend heavily on the existence of sufficient numbers of innovative and creative thinkers who are thereby able to expand the technological frontier. If this is so then, to a large extent, what may matter most for economic growth is not simply the raw number of people educated but rather the production of sufficient numbers of high achieving students as reflected, for example, in their mathematics and science abilities.

In any case our results indicate that differences in schooling quality are an important source of differences in human capital accumulation, and thus economic growth rates, across countries. Therefore, schooling quality should not be ignored by researchers investigating the determinants of cross-country differences in incomes or economic growth rates, at least with an augmented Solow model such as that of MRW. However, including schooling quality in regressions of mean growth rates appears to be the exception rather than the rule.[55]

Our results may help to explain some recent findings which suggest that schooling is unrelated to economic growth.[56] By using a measure of human capital accumulation which captures only the quantity of schooling, these studies may have ignored the impact of schooling quality differentials across countries. Our results also indicate that, at least when mathematics test scores are added as proxies for schooling quality, the physical capital savings rates lose much of their explanatory power in the convergence regressions. This is not unexpected, however, as the relationship between economic growth and the savings rate was derived in a closed economy framework.

## 4.4 Concluding Comments

This Chapter has investigated the impact of schooling quality rates of economic growth using the augmented Solow model of MRW as the basis of analysis. Our results indicate that the addition of schooling quality, as proxied by standardised scores on tests of mathematics and science knowledge, improves the goodness of fit of the convergence regressions from this model. Hence studies which include only measures of schooling quantity, such as school enrolment rates or years of schooling completed, may be ignoring an important determinant of the rate at which human capital accumulates, and thus of the economic growth rate. These results are robust to a measure of schooling quantity which includes mean enrolments in tertiary schooling. If schooling quality matters, then what factors help to determine schooling quality? We investigate this issue in the next Chapter.

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

[56] 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.

# APPENDIX 4.1
## The Data Used in MRW

| Country | Non Oil | Inter | OECD | y60 | y85 | dydt | n | s | SCHOOL | ngd |
|---|---|---|---|---|---|---|---|---|---|---|
| Algeria | 1 | 1 | 0 | 2485 | 4371 | .048 | .026 | .241 | .045 | .076 |
| Angola | 1 | 0 | 0 | 1588 | 1171 | .008 | .021 | .058 | .018 | .071 |
| Argentina | 1 | 1 | 0 | 4852 | 5533 | .021 | .015 | .253 | .05 | .065 |
| Australia | 1 | 1 | 1 | 8440 | 13409 | .038 | .02 | .315 | .098 | .07 |
| Austria | 1 | 1 | 1 | 5939 | 13327 | .036 | .004 | .234 | .08 | .054 |
| Bangladesh | 1 | 1 | 0 | 846 | 1221 | .04 | .026 | .068 | .032 | .076 |
| Belgium | 1 | 1 | 1 | 6789 | 14290 | .035 | .005 | .234 | .093 | .055 |
| Benin | 1 | 0 | 0 | 1116 | 1071 | .022 | .024 | .108 | .018 | .074 |
| Bolivia | 1 | 1 | 0 | 1618 | 2055 | .033 | .024 | .133 | .049 | .074 |
| Botswana | 1 | 1 | 0 | 959 | 3671 | .086 | .032 | .283 | .029 | .082 |
| Brazil | 1 | 1 | 0 | 1842 | 5563 | .073 | .029 | .232 | .047 | .079 |
| BurkinaFaso | 1 | 0 | 0 | 529 | 857 | .029 | .009 | .127 | .004 | .059 |
| Burma | 1 | 1 | 0 | 517 | 1031 | .045 | .017 | .114 | .035 | .067 |
| Burundi | 1 | 0 | 0 | 755 | 663 | .012 | .017 | .051 | .004 | .067 |
| Cameroon | 1 | 1 | 0 | 889 | 2190 | .057 | .021 | .128 | .034 | .071 |
| Canada | 1 | 1 | 1 | 10286 | 17935 | .042 | .02 | .233 | .106 | .07 |
| CAR | 1 | 0 | 0 | 838 | 789 | .015 | .017 | .105 | .014 | .067 |
| Chad | 1 | 0 | 0 | 908 | 462 | -.009 | .019 | .069 | .004 | .069 |
| Chile | 1 | 1 | 0 | 5189 | 5533 | .026 | .023 | .297 | .077 | .073 |
| Colombia | 1 | 1 | 0 | 2672 | 4405 | .05 | .03 | .18 | .061 | .08 |
| CongoPR | 1 | 0 | 0 | 1009 | 2624 | .062 | .024 | .288 | .038 | .074 |
| CostaRica | 1 | 1 | 0 | 3360 | 4492 | .047 | .035 | .147 | .07 | .085 |
| Denmark | 1 | 1 | 1 | 8551 | 16491 | .032 | .006 | .266 | .107 | .056 |
| DiminicanRep | 1 | 1 | 0 | 1939 | 3308 | .051 | .029 | .171 | .058 | .079 |
| Ecuador | 1 | 1 | 0 | 2198 | 4504 | .057 | .028 | .244 | .072 | .078 |
| Egypt | 1 | 0 | 0 | 907 | 2160 | .06 | .025 | .163 | .07 | .075 |
| ElSalvador | 1 | 1 | 0 | 2042 | 1997 | .033 | .033 | .08 | .039 | .083 |
| Ethiopia | 1 | 1 | 0 | 533 | 608 | .028 | .023 | .054 | .011 | .073 |
| Finland | 1 | 1 | 1 | 6527 | 13779 | .037 | .007 | .369 | .115 | .057 |
| France | 1 | 1 | 1 | 7215 | 15027 | .039 | .01 | .262 | .089 | .06 |
| GermanyFR | 1 | 1 | 1 | 7695 | 15297 | .033 | .005 | .285 | .084 | .055 |
| Ghana | 1 | 0 | 0 | 1009 | 727 | .01 | .023 | .091 | .047 | .073 |
| Greece | 1 | 1 | 1 | 2257 | 6868 | .051 | .007 | .293 | .079 | .057 |
| Guatamala | 1 | 1 | 0 | 2481 | 3034 | .039 | .031 | .088 | .024 | .081 |
| Haiti | 1 | 1 | 0 | 1096 | 1237 | .018 | .013 | .071 | .019 | .063 |
| Honduras | 1 | 1 | 0 | 1430 | 1822 | .04 | .031 | .138 | .037 | .081 |
| HongKong | 1 | 1 | 0 | 3085 | 13372 | .089 | .03 | .199 | .072 | .08 |
| India | 1 | 1 | 0 | 978 | 1339 | .036 | .024 | .168 | .051 | .074 |
| Indonesia | 1 | 1 | 0 | 879 | 2159 | .055 | .019 | .139 | .041 | .069 |
| Ireland | 1 | 1 | 1 | 4411 | 8675 | .038 | .011 | .259 | .114 | .061 |
| Israel | 1 | 1 | 0 | 4802 | 10450 | .059 | .028 | .285 | .095 | .078 |
| Italy | 1 | 1 | 1 | 4913 | 11082 | .038 | .006 | .249 | .071 | .056 |
| IvoryCoast | 1 | 1 | 0 | 1386 | 1704 | .051 | .043 | .124 | .023 | .093 |
| Jamaica | 1 | 1 | 0 | 2726 | 3080 | .021 | .016 | .206 | .112 | .066 |
| Japan | 1 | 1 | 1 | 3493 | 13893 | .068 | .012 | .36 | .109 | .062 |
| Jordan | 1 | 1 | 0 | 2183 | 4312 | .054 | .027 | .176 | .108 | .077 |
| Kenya | 1 | 1 | 0 | 944 | 1329 | .048 | .034 | .174 | .024 | .084 |
| KoreaR | 1 | 1 | 0 | 1285 | 4775 | .079 | .027 | .223 | .102 | .077 |
| Liberia | 1 | 0 | 0 | 863 | 944 | .033 | .03 | .215 | .025 | .08 |

| *Country* | *Non Oil* | *Inter* | *OECD* | *y60* | *y85* | *dydt* | *n* | *s* | *SCHOOL* | *ngd* |
|---|---|---|---|---|---|---|---|---|---|---|
| Madagascar | 1 | 1 | 0 | 1194 | 975 | .014 | .022 | .071 | .026 | .072 |
| Malawi | 1 | 1 | 0 | 455 | 823 | .048 | .024 | .132 | .006 | .074 |
| Malaysia | 1 | 1 | 0 | 2154 | 5788 | .071 | .032 | .232 | .073 | .082 |
| Mali | 1 | 1 | 0 | 737 | 710 | .021 | .022 | .073 | .01 | .072 |
| Mauritania | 1 | 0 | 0 | 777 | 1038 | .033 | .022 | .256 | .01 | .072 |
| Mauritius | 1 | 0 | 0 | 1973 | 2967 | .042 | .026 | .171 | .073 | .076 |
| Mexico | 1 | 1 | 0 | 4229 | 7380 | .055 | .033 | .195 | .066 | .083 |
| Morocco | 1 | 1 | 0 | 1030 | 2348 | .058 | .025 | .083 | .036 | .075 |
| Mozambique | 1 | 0 | 0 | 1420 | 1035 | .014 | .027 | .061 | .007 | .077 |
| Nepal | 1 | 0 | 0 | 833 | 974 | .026 | .02 | .059 | .023 | .07 |
| Netherlands | 1 | 1 | 1 | 7689 | 13177 | .036 | .014 | .258 | .107 | .064 |
| Nicaragua | 1 | 1 | 0 | 3195 | 3978 | .041 | .033 | .145 | .058 | .083 |
| Niger | 1 | 0 | 0 | 539 | 841 | .044 | .026 | .103 | .005 | .076 |
| Nigeria | 1 | 1 | 0 | 1055 | 1186 | .028 | .024 | .12 | .023 | .074 |
| Norway | 1 | 1 | 1 | 7938 | 19723 | .043 | .007 | .291 | .10 | .057 |
| NZ | 1 | 1 | 1 | 9523 | 12308 | .027 | .017 | .225 | .119 | .067 |
| Pakistan | 1 | 1 | 0 | 1077 | 2175 | .058 | .03 | .122 | .03 | .08 |
| Panama | 1 | 1 | 0 | 2423 | 5021 | .059 | .03 | .261 | .116 | .08 |
| Paraguay | 1 | 1 | 0 | 1951 | 3914 | .055 | .027 | .117 | .044 | .077 |
| Peru | 1 | 1 | 0 | 3310 | 3775 | .035 | .029 | .12 | .08 | .079 |
| Phillipines | 1 | 1 | 0 | 1668 | 2430 | .045 | .03 | .149 | .106 | .08 |
| PNG | 1 | 0 | 0 | 1781 | 2544 | .035 | .021 | .162 | .015 | .071 |
| Portugal | 1 | 1 | 1 | 2272 | 5827 | .044 | .006 | .225 | .058 | .056 |
| Rwanda | 1 | 0 | 0 | 460 | 696 | .045 | .028 | .079 | .004 | .078 |
| S.Africa | 1 | 1 | 0 | 4768 | 7064 | .039 | .023 | .216 | .03 | .073 |
| Senegal | 1 | 1 | 0 | 1392 | 1450 | .025 | .023 | .096 | .017 | .073 |
| SierraLeone | 1 | 0 | 0 | 511 | 805 | .034 | .016 | .109 | .017 | .066 |
| Singapore | 1 | 1 | 0 | 2793 | 14678 | .092 | .026 | .322 | .09 | .076 |
| Somalia | 1 | 0 | 0 | 901 | 657 | .018 | .031 | .138 | .011 | .081 |
| Spain | 1 | 1 | 1 | 3766 | 9903 | .049 | .01 | .177 | .08 | .06 |
| SriLanka | 1 | 1 | 0 | 1794 | 2482 | .037 | .024 | .148 | .083 | .074 |
| Sudan | 1 | 0 | 0 | 1254 | 1038 | .018 | .026 | .132 | .02 | .076 |
| Sweden | 1 | 1 | 1 | 7802 | 15237 | .031 | .004 | .245 | .079 | .054 |
| Switzerland | 1 | 1 | 1 | 10308 | 15881 | .025 | .008 | .297 | .048 | .058 |
| SyrianArabR | 1 | 1 | 0 | 2382 | 6042 | .067 | .03 | .159 | .088 | .08 |
| Tanzania | 1 | 1 | 0 | 383 | 710 | .053 | .029 | .18 | .005 | .079 |
| Thailand | 1 | 1 | 0 | 1308 | 3220 | .067 | .031 | .18 | .044 | .081 |
| Togo | 1 | 0 | 0 | 777 | 978 | .034 | .025 | .155 | .029 | .075 |
| Trin&Tobago | 1 | 1 | 0 | 9253 | 11285 | .027 | .019 | .204 | .088 | .069 |
| Tunisia | 1 | 1 | 0 | 1623 | 3661 | .056 | .024 | .138 | .043 | .074 |
| Turkey | 1 | 1 | 1 | 2274 | 4444 | .052 | .025 | .202 | .055 | .075 |
| U.S.A. | 1 | 1 | 1 | 12362 | 18988 | .032 | .015 | .211 | .119 | .065 |
| Uganda | 1 | 0 | 0 | 601 | 667 | .035 | .031 | .041 | .011 | .081 |
| UK | 1 | 1 | 1 | 7634 | 13331 | .025 | .003 | .184 | .089 | .053 |
| Uruguay | 1 | 1 | 0 | 5119 | 5495 | .009 | .006 | .118 | .07 | .056 |
| Venezuela | 1 | 1 | 0 | 10367 | 6336 | .019 | .038 | .114 | .07 | .088 |
| Zaire | 1 | 0 | 0 | 594 | 412 | .009 | .024 | .065 | .036 | .074 |
| Zambia | 1 | 1 | 0 | 1410 | 1217 | .021 | .027 | .317 | .024 | .077 |
| Zimbabwe | 1 | 1 | 0 | 1187 | 2107 | .051 | .028 | .211 | .044 | .078 |

**Notes**: *Non-oil* and *OECD* are self explanatory. *Inter* refers to an intermediate subset of 75 countries for which the data is more reliable. *y60* is real per capita GDP in 1960, *y85* is real per capita GDP in 1985, *dydt* is the mean annual growth rate of per capita GDP, *n* is the mean annual population growth rate, *s* is the mean annual savings rate as a proportion of GDP, *SCHOOL* is the mean annual secondary school enrolment rate, and *ngd* is the sum of the population, technological growth and depreciation rates. The latter five variables are expressed as decimals. All means are for the period 1960-1985.

## APPENDIX 4.2
## The Testing Procedure for the T.I.M.S.S.

The most appropriate way to describe the testing procedure is to quote from the T.I.M.S.S. report.

"What was the nature of the science/mathematics test? Together with the quality of the samples, the quality of the test also receives considerable scrutiny in any comparative study. All participants wish to ensure that the achievement items are appropriate for their students and reflect their current curriculum. Developing the T.I.M.S.S. test was a cooperative venture involving all of the National Research Coordinator's during the entire process. Through a series of efforts, countries submitted items that were reviewed by science/mathematics subject-matter specialists, and additional items were written to ensure that the desired science/mathematics topics were covered adequately. Items were piloted, the results reviewed, and new items were written and piloted. The resulting T.I.M.S.S. science/mathematics test contained 135/151 items representing a range of science/mathematics topics and skills.

The T.I.M.S.S. curriculum frameworks described the content dimensions for the T.I.M.S.S. tests as well as performance expectations (behaviours that might be expected of students in school science/mathematics. Five/six content areas are covered in the science/mathematics test taken by .....students. About one-fourth of the questions were in free-response format, requiring students to generate and write their answers. These questions, some of which required extended responses, were allotted approximately one third of the testing time. Responses to the free-response questions were evaluated to capture diagnostic information, and some were scored using procedures that permitted partial credit.....The T.I.M.S.S. tests were prepared in English and translated into 30 additional languages using explicit guidelines and procedures. A series of verification checks were conducted to ensure the comparability of the translations.

The tests were given so that no one student took all of the items, which would have required more than three hours. Instead, the test was assembled in eight booklets, each requiring 90 minutes to complete. Each student took only one booklet, and the items were rotated through the booklets so that each one was answered by a representative sample of students....T.I.M.S.S. conducted a Test-Curriculum Matching Analysis whereby countries examined the T.I.M.S.S. test to identify items measuring topics not addressed in their curricula. The analysis showed that omitting such items for each country had little effect on the overall pattern of achievement results across all countries" (see T.I.M.S.S. reports, section titled: What Was the Nature of the .....Test?).

## APPENDIX 4.3
## Data for the Sample of 28 Countries

| *Country* | *y60* | *y85* | *dy/dt* | *n* | *s* | *SCHOOL* | *ngd* | *mscore* | *sscore* |
|---|---|---|---|---|---|---|---|---|---|
| Australia | 8440 | 13409 | 3.8 | 2 | 31.5 | 9.8 | 7 | 530 | 545 |
| Austria | 5939 | 13327 | 3.6 | 0.4 | 23.4 | 8 | 5.4 | 539 | 558 |
| Belgium | 6789 | 14290 | 3.5 | 0.5 | 23.4 | 9.3 | 5.5 | 546 | 511 |
| Canada | 10286 | 17935 | 4.2 | 2 | 23.3 | 10.6 | 7 | 527 | 531 |
| Colombia | 2672 | 4405 | 5 | 3 | 18 | 6.1 | 8 | 385 | 411 |
| Cyprus | 2948 | 8261 | 5.2 | 0.9 | 31.2 | 8.2 | 5.9 | 474 | 463 |
| Denmark | 8551 | 16491 | 3.2 | 0.6 | 26.6 | 10.7 | 5.6 | 502 | 478 |
| France | 7215 | 15027 | 3.9 | 1 | 26.2 | 8.9 | 6 | 538 | 498 |
| Germany | 7695 | 15297 | 3.3 | 0.5 | 28.5 | 8.4 | 5.5 | 509 | 531 |
| Greece | 2257 | 6868 | 5.1 | 0.7 | 29.3 | 7.9 | 5.7 | 484 | 497 |
| HongKong | 3085 | 13372 | 8.9 | 3 | 19.9 | 7.2 | 8 | 588 | 522 |
| Iceland | 8091 | 14951 | 3.9 | 1.2 | 29 | 10.2 | 6.2 | 487 | 494 |
| Ireland | 4411 | 8675 | 3.8 | 1.1 | 25.9 | 11.4 | 6.1 | 527 | 538 |
| Israel | 4802 | 10450 | 5.9 | 2.8 | 28.5 | 9.5 | 7.8 | 522 | 524 |
| Japan | 3493 | 13893 | 6.8 | 1.2 | 36 | 10.9 | 6.2 | 605 | 571 |
| Korea | 1285 | 4775 | 7.9 | 2.7 | 22.3 | 10.2 | 7.7 | 607 | 565 |
| Netherlands | 7689 | 13177 | 3.6 | 1.4 | 25.8 | 10.7 | 6.4 | 541 | 560 |
| Norway | 7938 | 19723 | 4.3 | 0.7 | 29.1 | 10 | 5.7 | 503 | 527 |
| NewZealand | 9523 | 12308 | 2.7 | 1.7 | 22.5 | 11.9 | 6.7 | 508 | 525 |
| Portugal | 2272 | 5827 | 4.4 | 0.6 | 22.5 | 5.8 | 5.6 | 454 | 480 |
| SouthAfrica | 4768 | 7064 | 3.9 | 2.3 | 21.6 | 3 | 7.3 | 356 | 349 |
| Singapore | 2793 | 14678 | 9.2 | 2.6 | 32.2 | 9 | 7.6 | 643 | 607 |
| Spain | 3766 | 9903 | 4.9 | 1 | 17.7 | 8 | 6 | 487 | 517 |
| Sweden | 7802 | 15237 | 3.1 | 0.4 | 24.5 | 7.9 | 5.4 | 519 | 535 |
| Switzerland | 10308 | 15881 | 2.5 | 0.8 | 29.7 | 4.8 | 5.8 | 545 | 522 |
| Thailand | 1308 | 3220 | 6.7 | 3.1 | 18 | 4.4 | 8.1 | 522 | 525 |
| UK | 7634 | 13331 | 2.5 | 0.3 | 18.4 | 8.9 | 5.3 | 506 | 552 |
| U.S.A. | 12362 | 18988 | 3.2 | 1.5 | 21.1 | 11.9 | 6.5 | 500 | 534 |

**Notes**: *y60* and *y85* refer to GDP per adult, i.e. (15-65) yr old, for the relevant year, in 1985 international prices. *dy/dt* refers to the mean real GDP growth rate for the sample period. *n* refers to adult population growth rate for the sample period. *s* is the mean investment to GDP ratio for the sample period. *SCHOOL* is defined as the average percentage of the total population that was enrolled in secondary schooling over the sample period. *ngd* refers to the sum of the mean population growth rate, the rate of technological advance and the depreciation rate. *mscore* refers to year 8 maths test scores, whilst *sscore* refers to year 8 science test scores. All mean s are for the period 1960-1985. The test scores reported for Belgium are the means for the Flemish and French schooling systems. All means are for the period 1960-1985.

# APPENDIX 4.4
# Data for the Sample of 25 Countries

| *Country* | *y60* | *y85* | *dy/dt* | *n* | *s* | *UPSCHOOL* | *ngd* | *mscore* | *sscore* |
|---|---|---|---|---|---|---|---|---|---|
| Australia | 8440 | 13409 | 3.8 | 2 | 31.5 | 12.5 | 7 | 530 | 545 |
| Austria | 5939 | 13327 | 3.6 | 0.4 | 23.4 | 12.6 | 5.4 | 539 | 558 |
| Belgium | 6789 | 14290 | 3.5 | 0.5 | 23.4 | 14.3 | 5.5 | 546 | 511 |
| Canada | 10286 | 17935 | 4.2 | 2 | 23.3 | 17.1 | 7 | 527 | 531 |
| Colombia | 2672 | 4405 | 5 | 3 | 18 | 9.7 | 8 | 385 | 411 |
| Denmark | 8551 | 16491 | 3.2 | 0.6 | 26.6 | 15.4 | 5.6 | 502 | 478 |
| France | 7215 | 15027 | 3.9 | 1 | 26.2 | 13.9 | 6 | 538 | 498 |
| Germany | 7695 | 15297 | 3.3 | 0.5 | 28.5 | 15.5 | 5.5 | 509 | 531 |
| Greece | 2257 | 6868 | 5.1 | 0.7 | 29.3 | 11.7 | 5.7 | 484 | 497 |
| HongKong | 3085 | 13372 | 8.9 | 3 | 19.9 | 9.9 | 8 | 588 | 522 |
| Ireland | 4411 | 8675 | 3.8 | 1.1 | 25.9 | 15.5 | 6.1 | 527 | 538 |
| Israel | 4802 | 10450 | 5.9 | 2.8 | 28.5 | 14.8 | 7.8 | 522 | 524 |
| Japan | 3493 | 13893 | 6.8 | 1.2 | 36 | 16.7 | 6.2 | 605 | 571 |
| Korea R | 1285 | 4775 | 7.9 | 2.7 | 22.3 | 14.5 | 7.7 | 607 | 565 |
| Netherlands | 7689 | 13177 | 3.6 | 1.4 | 25.8 | 16.2 | 6.4 | 541 | 560 |
| Norway | 7938 | 19723 | 4.3 | 0.7 | 29.1 | 14.6 | 5.7 | 503 | 527 |
| NewZealand | 9523 | 12308 | 2.7 | 1.7 | 22.5 | 16.7 | 6.7 | 508 | 525 |
| Portugal | 2272 | 5827 | 4.4 | 0.6 | 22.5 | 9.6 | 5.6 | 454 | 480 |
| Singapore | 2793 | 14678 | 9.2 | 2.6 | 32.2 | 11 | 7.6 | 643 | 607 |
| Spain | 3766 | 9903 | 4.9 | 1 | 17.7 | 13.1 | 6 | 487 | 517 |
| Sweden | 7802 | 15237 | 3.1 | 0.4 | 24.5 | 12.9 | 5.4 | 519 | 535 |
| Switzerland | 10308 | 15881 | 2.5 | 0.8 | 29.7 | 9.1 | 5.8 | 545 | 522 |
| Thailand | 1308 | 3220 | 6.7 | 3.1 | 18 | 6.4 | 8.1 | 522 | 525 |
| UK | 7634 | 13331 | 2.5 | 0.3 | 18.4 | 12.5 | 5.3 | 506 | 552 |
| U.S.A. | 12362 | 18988 | 3.2 | 1.5 | 21.1 | 19.3 | 6.5 | 500 | 534 |

**Notes**: *y60* and *y85* refer to GDP per adult, i.e. (15-65) yr old, for the relevant year, in 1985 international prices. dy/dt refers to the mean real GDP growth rate for the sample period. *n* refers to adult population growth rate for the sample period. *s* is the mean investment to GDP ratio for the sample period. *UPSCHOOL* is defined as the average percentage of the total population that was enrolled in secondary and tertiary schooling over the sample period. *ngd* refers to the sum of the mean population growth rate, the rate of technological advance and the depreciation rate. *mscore* refers to year 8 maths test scores, whilst *sscore* refers to year 8 science test scores. All mean s are for the period 1960-1985. The test scores reported for Belgium are the means for the Flemish and French schooling systems. All means are for the period 1960-1985.

## APPENDIX 4.5
## Data and Estimation Results for the Sample of 16 Countries Using Year 12 Test Scores

### Part 1: Data

| *Country* | *y60* | *y85* | *dy/dt* | *n* | *s* | *SCHOOL* | *ngd* | *mscore* | *sscore* |
|---|---|---|---|---|---|---|---|---|---|
| Australia | 8440 | 13409 | 3.8 | 2 | 31.5 | 9.8 | 7 | 522 | 527 |
| Austria | 5939 | 13327 | 3.6 | 0.4 | 23.4 | 8 | 5.4 | 518 | 520 |
| Canada | 10286 | 17935 | 4.2 | 2 | 23.3 | 10.6 | 7 | 519 | 532 |
| Cyprus | 2948 | 8261 | 5.2 | 0.9 | 31.2 | 8.2 | 5.9 | 446 | 448 |
| Denmark | 8551 | 16491 | 3.2 | 0.6 | 26.6 | 10.7 | 5.6 | 547 | 509 |
| France | 7215 | 15027 | 3.9 | 1 | 26.2 | 8.9 | 6 | 523 | 487 |
| Germany | 7695 | 15297 | 3.3 | 0.5 | 28.5 | 8.4 | 5.5 | 495 | 497 |
| Iceland | 8091 | 14951 | 3.9 | 1.2 | 29 | 10.2 | 6.2 | 534 | 549 |
| Italy | 4913 | 11082 | 3.8 | 0.6 | 24.9 | 7.1 | 5.6 | 476 | 475 |
| Netherlands | 7689 | 13177 | 3.6 | 1.4 | 25.8 | 10.7 | 6.4 | 560 | 558 |
| Nzealand | 9523 | 12308 | 2.7 | 1.7 | 22.5 | 11.9 | 6.7 | 522 | 529 |
| Norway | 7938 | 19723 | 4.3 | 0.7 | 29.1 | 10 | 5.7 | 528 | 544 |
| Sth.Africa | 4768 | 7064 | 3.9 | 2.3 | 21.6 | 3 | 7.3 | 356 | 349 |
| Sweden | 7802 | 15237 | 3.1 | 0.4 | 24.5 | 7.9 | 5.4 | 552 | 559 |
| Switzerland | 10308 | 15881 | 2.5 | 0.8 | 29.7 | 4.8 | 5.8 | 540 | 523 |
| U.S.A. | 12362 | 18988 | 3.2 | 1.5 | 21.1 | 11.9 | 6.5 | 461 | 480 |

**Notes**: *y60* and *y85* refer to GDP per adult, i.e. (15-65) yr old, for the relevant year, in 1985 international prices. *dy/dt* refers to the mean real GDP growth rate for the sample period. *n* refers to adult population growth rate for the sample period. *s* is the mean investment to GDP ratio for the sample period. *SCHOOL* is defined as the average percentage of the total population that was enrolled in secondary schooling over the sample period. *ngd* refers to the sum of the mean population growth rate, the rate of technological advance and the depreciation rate. *mscore* refers to year 12 maths test scores, whilst *sscore* refers to year 12 science test scores. All means are for the period 1960-1985.

**Part 2: Estimation Results**

**Equation (4.18)**
**Dependent Variable: log difference GDP per worker (1960-85)**
**Sample Size: 16**

| *Variable* | *(1)* | *(2)* | *(3)* | *(4)* | *(5)* |
|---|---|---|---|---|---|
| ln(y60) | -.36 | -.28 | -.37 | -.32 | -.34 |
| | (-2.91) | (-3.08) | (-3.98) | (-2.53) | (-2.75) |
| ln(I/GDP) | | .29 | .22 | .31 | .27 |
| | (1.12) | (.95) | (1.13) | (.98) | |
| ln(n+g+δ) | | -1.07 | -1.00 | -1.15 | -1.07 |
| | | (-3.22) | (-3.33) | (-3.03) | (-2.93) |
| ln(SCHOOL) | | | .18 | .22 | .21 |
| | | | (2.00) | (1.99) | (1.70) |
| ln(mscore) | | | | -.35 | |
| | | | | (-.67) | |
| ln(sscore) | | | | | -.19 |
| | | | | | (-.37) |
| Adj $R^2$ | .33 | .65 | .72 | .70 | .69 |

**Notes**: t-statistics are in parentheses. The regression constants have been omitted to save space. y60 is the initial level of income per worker. I/GDP is investment as a proportion of GDP. n+g+δ measures the sum of the population and technology growth rates plus the depreciation rate. SCHOOL measures the secondary school enrolment rates. mscore refers to year 12 maths test scores whilst sscore refers to year 12 science test scores. The investment rate and the population growth rates are averages for the period 1960-85. The rate of technology growth plus the depreciation rate is assumed to equal 5% for all countries over the sample period. ln(•) refers to the natural logarithm.

**Part 3: Discussion**

The results in column one indicate that this sample of 16 largely OECD countries displays a tendency towards unconditional convergence. Initial incomes alone account for 33% of the variation in average growth rates over the sample period. When we add the savings and population growth rates (column two) the fit of the regression improves substantially. The signs of the coefficients on these two additional variables are as expected and that on the population growth rate is statistically significant although the savings rate has poor explanatory power.

In column three we add secondary school enrolment rates (SCHOOL) as proxies for schooling quantity. The fit of the regression improves further and the coefficient on SCHOOL is close to statistically significant. The results for the initial level of income, the savings rate and the population growth rate are essentially unchanged with the addition of SCHOOL.

However, when we add year 12 test scores, firstly for mathematics (mscore in column 4) and then for science (sscore in column 5) the fit of the regression deteriorates marginally. In both cases, the coefficients on the test score variables are not of the expected sign although the t-statistics indicate that they are essentially zero in any case. These results indicate that year 12 test scores, as proxies for schooling quality across countries, are not significantly associated with mean rates of economic growth, and their inclusion actually reduces the goodness of fit of the regression. However, given the small number of observations, these results should be treated with caution.

# CHAPTER 5

# THE DETERMINANTS OF SCHOOLING QUALITY ACROSS COUNTRIES

## 5.1 Introduction

In the previous Chapter we concluded that schooling quality, proxied by year 8 mathematics and science test scores across countries, is important in the relationship between human capital accumulation and economic growth within the augmented Solow model of MRW. In this Chapter we investigate whether, across countries, variations in schooling quality can be explained by variations in the background characteristics of students and schools.

In section 5.2 we present and discuss data on the characteristics of students and schools which participated in the Third International Mathematics and Science Study (T.I.M.S.S.). In section 5.3 we develop and estimate a model of student educational achievement as a function of these background characteristics, and report the results. In section 5.4 we briefly relate our findings to a recent debate concerning the importance of innate ability, as opposed to environmental factors, for student success in school and in the labour market, and for national productivity more generally. Finally, section 5.5 concludes.

## 5.2 Background Characteristics of Students and Schools Across Countries

Mean cross-country scores on tests of the mathematics and science abilities of year 4, 8 and 12 students were presented in Table 4.4. As we explained in that Chapter, these were published as part of the Third International Mathematics and Science Study (T.I.M.S.S.). As well as test scores, the T.I.M.S.S. also collected data on a number of background characteristics of students, mostly concerning home and school environment. These include the prevalence of computers and books in student homes, parental education levels and the education and experience of mathematics and science teachers. Data on national mean per capita real incomes and national mean per capita expenditures on education were also reported. In the next section, we use these background data as explanatory variables in an analysis of the determinants of cross-country schooling quality. However, before doing so, we discuss the variables in greater detail.

### 5.2.1 Mean Test Scores Across Countries

It is reasonable to expect considerable variation in the mathematics and science test scores of students within a country. In fact, the most able students in each country produced test scores which were, in some cases, over twice those of the least able students.[57] Variations of this magnitude may reflect, among other things, the naturally occurring distribution of innate talent or ability, and differences in home education, across the large sample of students tested in each country. However, it is clear from the data of Table 4.4 that considerable variation also exists in the mean test scores of students across countries.

In many cases, the differences among the three or four highest scoring countries are small and probably not significant.[58] This is also the case among the three or four lowest scoring countries. So it should not be concluded on the basis of the data of Table 4.4 that, for instance, schooling quality in Singapore is significantly greater than that in Japan, or that schooling quality in Colombia is significantly lower than that in Kuwait.

However, it is reasonable to conclude that schooling quality in the highest scoring countries is significantly greater than that in the lowest scoring countries. The differences in mean national test scores between, for instance, South Korea and Kuwait are not easily explained solely by reference to variations in innate ability or home education across the two countries.

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[57] See the individual year and subject reports of the T.I.M.S.S. for details of within country variations in test scores.

[58] See Figure 1.1 in each of the T.I.M.S.S reports for multiple comparisons of achievement.

To explain such variations, we investigate which family, school and national characteristics impact on the productivity of schools across countries, as proxied by mean national test scores. Background characteristics for which we have data, and which are used in the next section as explanatory variables in an analysis of the determinants of schooling quality across countries are discussed in greater detail below.

### 5.2.2 Background Characteristics of Students Across Countries

The T.I.M.S.S. reports contain data on a number of student background characteristics. Data on those we considered to be potentially important determinants of cross-country test scores have been included in Appendices 5.1 (mathematics students) and 5.2 (science students).[59] As, in the growth regressions of Chapter Four, the year 8 test scores proved to be the most useful proxies for schooling quality across countries, we restrict our attention to the analysis of the determinants of year 8 test scores only.[60] We now define each background variable and discuss conditional expectations regarding their likely relationship with mean test scores. We collated the data for some of these variables directly from the T.I.M.S.S. report, whereas data for others were constructed. Details of methods used, and the assumptions made, in the construction of these data are included in Appendix 5.3.

The first two explanatory variables, *comp* and *book*, are defined as the percentage of students in each country who reported having a computer at home and the mean number of books per student home, respectively. Whilst it is possible that students use computers and read books mostly as a source of leisure, we expect computers and books to be positively associated with test scores because they allow students to access information on a range of topics, especially computers which are capable of accessing the internet.

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[59] Some data in the T.I.M.S.S. reports relate to student background characteristics which showed very little variation across countries and so were ignored.

[60] Unfortunately, data on some background characteristics for Bulgaria and South Africa is not available, and hence these two countries are not included in the analysis which follows.

This assumes that computers and books are complements. However, if computers and books are substitutes then more of one will imply less of the other. For instance, it is possible that as a greater proportion of students acquire a computer in the home, a correspondingly smaller proportion simultaneously acquire or consult fewer books, which may come to be regarded as obsolete. Computers may also be largely used by students to facilitate leisure activities rather than study. In this case the total impact of computers on mean test scores will be composed of a positive direct impact via easier access to a greater range of information, plus a negative indirect impact via increased leisure and less books. The net impact in this case will depend on the absolute magnitudes of these two effects.

The variable *parent* is defined as the mean number of years of formal schooling of one or other parent.[61] If more highly educated parents are a role model for their children, or are better able to assist them with school work, or possess higher than average innate ability which has been genetically transmitted to their children then, other things being equal, parental education levels should be positively associated with test scores.

The variable *hwork* is defined as the mean number of hours per day spent by students in each country completing mathematics or science homework. One possibility is that students who spend more hours per day completing homework learn more and thus achieve higher test scores. However, another possibility is that these students are inherently less able and so end up achieving lower test scores despite spending more time completing homework. Thus, *a priori*, the relationship between hours of homework and test scores is ambiguous.

The variable *other* is defined as the mean number of hours per day spent completing non mathematics or non-science homework. If students allocate a specified number of

[61] Unfortunately, separate education levels of mothers and fathers is not reported. This would have been useful for the discussion of section 4 of this Chapter.

hours per day for the completion of all homework, then subject specific homework are substitutes. If this is the case then more hours spent on other homework results in less hours spent on mathematics or science homework. Holding constant the ability of the student, if more other homework results in less mathematics or science homework than would otherwise have been undertaken, then *other* is likely to be negatively associated with test scores.

The variable *leisure* is defined as the mean number of leisure hours per day. Students benefit from some leisure time. However, it is possible that, beyond some point, leisure activities and performance at school are substitutes. Once again, if more leisure results in less attendance at school or less homework being completed than would otherwise have been undertaken then *leisure* is likely to be negatively associated with test scores.

The variable *labor* is defined as the mean number of daily hours spent by students working at home, presumably in activities such as cleaning, meal preparation, gardening, etc. We expect that such activities will be negatively associated with achievement at school if they increase student fatigue or reduce school attendance.

Other variables describe characteristics of the mathematics and science teachers and the schools sampled within each country. These variables are the mean teacher age (*age*), the minimum number of years of post secondary education which must be completed by teachers in each country (*educ*) and their mean years of teaching experience (*years*), and the mean number of weekly hours spent by teachers on work related but non-teaching duties (*duties*). The variables *ratio* and *meet* are defined, respectively, as the national mean student-teacher ratio and the national mean number of collaborative teacher meetings attended per teacher per year.

The likely impact of some of these variables on test scores is difficult to determine *a priori*. If younger teachers are more energetic then *age* may be negatively associated with test scores . On the other hand if younger teachers are less experienced, and as a result more likely to experiment with a range of teaching strategies, many of which prove to be successful, then *age* may be positively associated with test scores. If *age* and *years* are highly collinear, as we expect, then these expectations also hold for *years*. Also, if more highly trained and more committed teachers are also the most productive then *educ* and *duties* will both be positively associated with test scores.

Much effort has recently been devoted, especially in richer nations, to reducing class sizes. The implicit assumption has been that smaller classes result in greater learning, perhaps because teachers are able to offer more personalised and more frequent attention to both weaker and stronger students. If this is the case then *ratio* will be negatively associated with test scores. On the other hand, if students learn as much or more from their fellow students as they do from their teachers then *ratio* will be positively associated with test scores.

If collaboration via regular formal meetings between teachers results in more productive classrooms activities then *meet* will be positively associated with higher test scores. On the other hand if such activities detract from the time and energy which teachers have for their students then the relationship will be reversed.

The final two variables describe national macroeconomic aggregates. The first, *gnp*, measures gross national product per capita, taking account of purchasing power parity across countries. If students in wealthier nations are healthier and have access to more advanced classroom and home technologies which complement learning then *gnp* will be positively associated with test scores.[62] The variable *dollar* measures the yearly per capita expenditure on primary and secondary education in each country as a ratio of per capita GNP, again taking account of purchasing power parity. For similar reasons, *dollar* may

[62] See Pritchett and Summers (1996) on the relationship between per capita incomes and health outcomes across countries.

be positively associated with test scores, although we note the controversy surrounding this issue as discussed in chapter 2.

In the next section, we present a model of student educational achievement so as to determine which of the above defined variables helps to explain cross-country test scores.

## 5.3 A Model of Student Educational Achievement

Each of the background variables defined in the previous section is a potentially significant determinant of test scores across countries. Hence we could begin by estimating equation (5.1) below, a variation of the earnings function discussed in chapter 1, where all variables are expressed as natural logarithms.

$$scor = \alpha_0 + \alpha_1 comp + \alpha_2 book + \alpha_3 parent + \alpha_4 hwork + \alpha_5 other + \alpha_6 leisure$$
$$+ \alpha_7 labor + \alpha_8 age + \alpha_9 educ + \alpha_{10} years + \alpha_{11} duties + \alpha_{12} ratio$$
$$+ \alpha_{13} meet + \alpha_{14} gnp + \alpha_{15} dollar + \varepsilon \qquad (5.1)$$

We investigated whether a log-linear form is more appropriate than a linear one by using the MacKinnon, White, Davidson (1983) PE test for functional form. This involves including the natural logarithm of the predicted scores from the linear 2sls regression as an additional regressor in the log-linear 2sls regression, and then including the exponent of the predicted scores from the log-linear 2sls regression as an additional regressor in the linear 2sls regression (see below for details of the 2sls regressions, and Begg (1988, pp.94-5) for details of the MacKinnon, White, Davidson (1983) PE test). On the basis of our results, which are set out in Table 5.1 below, we conclude that there is no clear evidence that linear is superior than log-linear, or vice versa, possibly because there is insufficient power in the test to distinguish between the alternate specifications. Hence we maintain the log-linear specification which is commonly used and which allows us to derive elasticities directly from the coefficient estimates.

**Table 5.1**
**MacKinnon, White, Davidson (1983) PE Test of Functional Form**
**Educational Achievement Function**

| **Alternate Model ($H_1$)** | **Maintained Model ($H_0$)** | |
|---|---|---|
| | *Linear* | *Log-Linear* |
| *Linear* | -------- | $t$=.48 Accept $H_0$ |
| *Log-Linear* | $t$=.29 Accept $H_0$ | -------- |

Equation (5.1) assumes that all of the right hand side background variables are exogenous. However, this may not be the case. For instance, if weaker students need to complete more homework in order to pass exams, then teachers in countries with weaker students may set more homework. If this is so then there will be some feedback between *scor* and *hwork*. Similarly if parents of more able children invest more heavily in the education of their children than do parents with less able children then *comp*, for example, and *scor* may be determined simultaneously.

These two possibilities suggest that there may be some simultaneity between *scor* and some of the right hand side variables in equation (5.1). To account for this possibility, a systems approach is required where one regression equation is specified for each potentially endogenous variable. Hence we now consider which background variables may reasonably be regarded as exogenous.

Gross national product per capita (*gnp*) is a broad macroeconomic variable which is unlikely to be a function of current period test scores. National expenditures on primary and secondary education relative to GNP (*dollar*) and student-teacher ratios (*ratio*) are also unlikely to be functions of current period test scores. Years of post secondary teacher education (*educ*), the mean age of teachers (*age*), years of teaching experience (*years*), hours spent on other teaching related duties (*duties*) and the number of annual teacher meetings (*meet*) are also likely to be functions of past policies and practices rather than current period national mean test scores. Finally, mean years of parental education (*parent*) and mean hours spent by students completing other homework (*other*) are also unlikely to be functions of current period test scores. This, suggests that the potentially endogenous variables are *scor*, *comp*, *book*, *hwork*, *leisure* and *labor*. If all of these variables are interdependent, then we will have a system of six simultaneous equations, each as a function of up to thirteen right hand side variables. Potentially, then, we have a very large system to be estimated.

To maximise degrees of freedom, we combined the data on mathematics and science test scores and background variables giving us 78 observations in total. As each of the observations is an average of all the individual within country student scores, heteroscedasticity may be a problem. One approach would be to weight each country observation by, for instance, the country population and then use weighted least squares. Instead, we tested for heteroscedasticity by regressing the country residuals from the 2sls regression (see below) on the country populations. The coefficient on population in this regression was almost zero and statistically insignificant, suggesting that heteroscedasticity is not a severe problem with this data set. Also, to control for possible different effects across the mathematics and science data, we included a dummy variable (*dum*) which took the value of 1 for the mathematics scores and zero otherwise.

We conducted ordinary least squares (ols) regressions for each potentially endogenous variable on all exogenous system variables, and then used a t-test on the dummy coefficients in each equation. The results from this procedure suggest that $8^{th}$ grade maths students do more homework than $8^{th}$ grade science students, and hence we include the dummy variable in the equation for homework. We thus constructed a system of log-linear equations, (5.2) to (5.7) below, where all (non-dummy) variables are expressed in terms of natural logarithms. Each equation satisfies the order condition and is identified.

$$scor = \beta_0 + \beta_1 comp + \beta_2 book + \beta_3 hwork + \beta_4 leisure + \beta_5 labor + \beta_6 parent$$
$$+ \beta_7 gnp + \beta_8 dollar + \beta_9 ratio + \beta_{10} years + \beta_{11} educ + \beta_{12} meet$$
$$+ \beta_{13} duties + \varepsilon \qquad (5.2)$$

$$comp = \omega_0 + \omega_1 gnp + \omega_2 scor + \omega_3 parent + \varepsilon \qquad (5.3)$$

$$book = \gamma_0 + \gamma_1 gnp + \gamma_2 scor + \gamma_3 parent + \varepsilon \qquad (5.4)$$

$$hwork = \tau_0 + \tau_1 scor + \tau_2 gnp + \tau_3 leisure + \tau_4 labor + \tau_5 age + \tau_6 duties$$
$$+ \tau_7 years + \tau_8 other + \tau_9 dum + \varepsilon \qquad (5.5)$$

$$leisure = \zeta_0 + \zeta_1 hwork + \zeta_2 labor + \zeta_3 gnp + \zeta_4 scor + \zeta_5 comp$$
$$+ \zeta_6 parent + \varepsilon \qquad (5.6)$$

$$labor = \theta_0 + \theta_1 scor + \theta_2 leisure + \theta_3 gnp + \theta_4 parent + \varepsilon \qquad (5.7)$$

We are primarily interested in the determinants of mean test scores, ie in estimating equation (5.2). Our system assumes that feedback may exist from test scores to the first five right hand side variables in equation (5.2). However, before estimating this equation, we test for the existence of simultaneity with a version of the Hausman specification test.[63]

The procedure involves two steps. In the first, an ordinary least squares regression is performed for each potentially endogenous right hand side variable in equation (5.2) on all

[63] See Pindyck and Rubinfeld (1991, p.303) and Kmenta (1986, p.718).

exogenous variables in the system. The residuals are then calculated for each of the reduced form regressions. In the second step, the residuals obtained from the first step are added to the right hand side of equation (5.2) to 'correct' for simultaneity. Under the null hypothesis of no simultaneity, the coefficients on the residuals will be insignificantly different from zero. The results for step two of this test are presented in Table 5.2 below. The residual calculated from the first step for *comp* is labelled *rcomp*, that for *book* is labelled *rbook*, and so on.

**Table 5.2**
**Hausman Specification Test for Equation (5.2)**
**Dependent Variable: (log) Test Scores**

| Variable | Coefficient Estimate | t-statistic |
|---|---|---|
| comp | 151.68 | (.98) |
| book | -86.44 | (-.95) |
| hwork | -23.88 | (-.63) |
| leisure | -201.09 | (-.1.00) |
| labor | 122.04 | (.73) |
| parent | 10.37 | (.30) |
| gnp | -93.05 | (-.85) |
| dollar | 9.72 | (.24) |
| ratio | 11.35 | (.96) |
| years | -55.03 | (-1.00) |
| educ | 16.86 | (.99) |
| meet | -9.22 | (-.99) |
| duties | 30.04 | (.54) |
| rcomp | -144.02 | (-.94) |
| rbook | -.32 | (-.48) |
| rhwork | .15 | (3.23) |
| rleisure | .12 | (.86) |
| rlabor | -51.53 | (-.34) |
| adj$R^2$ | .56 | |
| F-Statistic | 3.03 | |

**Notes**: t-statistics are in parenthesis. The regression constant has been omitted to save space. The F statistic tests the null hypothesis that the coefficients for the 5 residuals are jointly statistically insignificant from zero.

From the results in Table 5.2, we conclude that the only statistically significant residual is that for *hwork*. This suggests that *scor* and *hwork* are the only interdependent variables in equation (5.2). The F statistic tests the null hypothesis that the coefficients for the five residuals are jointly insignificantly different from zero. This is rejected at the 10%

level.[64] Hence we modify our system to just two equations, equation (5.2) for test scores and equation (5.5) for homework.

An appropriate procedure for estimating this system of two equations is the method of two-stage least squares (2sls) where, in the first stage, all exogenous system variables are used as instruments in an ordinary least squares regression of the right hand side endogenous variables in each equation. The corresponding estimates are then used, along with the relevant exogenous variables in that equation, to estimate the dependent variable in that equation. In our case, there is now only one endogenous right hand side variable in equation (5.2), that being *hwork*. The results from the 2sls estimation procedure for equation (5.2) are presented in Table 5.3 below.

The results in column (1) indicate that *hwork* may be negatively associated with test scores, whilst *parent*, *ratio*, and *years* may be positively associated with test scores. On the other hand, a number of the other right hand side variables are not significantly associated with test scores. Hence by omitting these, one by one, we arrived at the most parsimonious specification which maximises the goodness of fit of this model. This is reported in column two of Table 5.3. These results are consistent with those in column one and indicate that, across our sample of countries, test scores are significantly and positively associated with parental education levels (*parent*), student-teacher ratios (*ratio*) and hours of teaching related duties (*duties*). On the other hand test scores are significantly and negatively associated with hours of subject specific homework (*hwork*).

The coefficients on the other variables in column two are not statistically significant at usual confidence limits. Nevertheless in most cases the size of the t-statistic is such that the suggested relationship can not be ruled out. The F statistic tests the null hypothesis that the coefficients on the five variables omitted from the regression of column two but included in column one are jointly zero. This hypothesis is not rejected at the

64 $F_{0.10}(1,59) = 2.79$.

**Table 5.3**
**2SLS Estimates of Equation (5.2)**
**Dependent Variable: (log) Test Scores**

| *Variables* | *(1)* | *(2)* |
|---|---|---|
| comp | -.009 | |
| | (-.31) | |
| book | -.028 | |
| | (-.51) | |
| hwork | -.096 | -.094 |
| | (-1.85) | (-2.24) |
| leisure | -.089 | -.096 |
| | (-1.09) | (-1.35) |
| labor | -.067 | -.058 |
| | (-1.19) | (-1.58) |
| parent | .196 | .174 |
| | (2.01) | (2.29) |
| gnp | .008 | |
| | (.26) | |
| dollar | .019 | |
| | (.39) | |
| ratio | .082 | .093 |
| | (1.52) | (2.13) |
| years | .007 | .07 |
| | (1.49) | (1.46) |
| educ | .013 | |
| | (.20) | |
| meet | -.028 | -.03 |
| | (-1.19) | (-1.51) |
| duties | .16 | .15 |
| | (1.98) | (2.09) |
| Adj $R^2$ | .31 | .35 |
| $R^2$ (obs & predict) | .43 | .43 |
| F statistic | | .08 |

**Notes**: t-statistics are reported in parentheses. The regression constants have been omitted to save space. Adj $R^2$ reports the multiple coefficient of determination adjusted for degrees of freedom. $R^2$ (obs & predict) reports the squared correlation coefficient between the observed and predicted variable which in the case of 2sls may preferred by some over the $R^2$ statistic. The F statistic in column 2 tests the null hypothesis that the coefficients of the 5 variables omitted from that regression but included in column 1 are jointly zero.

usual confidence limit. The adjusted $R^2$ statistic indicates that this specification explains 35% of the cross-country variation in test scores.

The negative and significant coefficient estimate for *hwork* is a surprising result. Intuition suggests that, other things being equal, students who complete more hours of homework should achieve higher test scores. However, as already mentioned, it is equally plausible that these students have less natural ability or less home education and hence spend more time completing homework. Our regression partially controls for natural ability or home education by including years of parental education (*parent*) on the right hand side. If *parent* is a good proxy for the innate ability or home education of students then our result for *hwork* implies that, other things being equal, *hwork* and test scores are inversely related.

One possible explanation is that there exists rapidly diminishing, and eventually negative, returns to time spent completing homework. Another possibility is that the quality of homework is more important than the quantity, and that in recent years the latter has been increased at the expense of the former. In the United States, for instance, there has been much recent debate concerning the most appropriate practices for increasing the productivity of public schools (see Chapter Two for a brief review of some of this literature). One response has been to advocate an increase in the time spent by students 'on task', by requiring them to complete more homework. Whilst this may be an appropriate response in individual cases, or even within one country, our results suggest that, across countries, homework and test scores are inversely related.

Another possible explanation is that homework may have been used as a substitute for effective in-class teaching, and it has turned out to be a poor substitute. For instance, the relative salaries of teachers in Australia have fallen over the last two or three decades. This deterioration has been reflected in greatly reduced entrance scores into teacher training courses. If these trainees, upon becoming teachers, end up possessing poorer class management and teaching skills, then perhaps they use homework to compensate for lower in-class productivity. This hypothesis is consistent with the positive coefficient for teacher experience (*years*). Other things being equal, teachers who consistently have a more difficult time in class may end up leaving the profession earlier and so, in aggregate, *years* may be a good proxy for teaching ability.

Another surprising result is the positive sign of the coefficient on *ratio*, which indicates that, other things being equal, countries with higher student-teacher ratios achieved higher test scores. As discussed earlier, much of the increased education spending in developed countries over the last 20 years has been directed at decreasing class sizes, the implicit assumption being that students in smaller classes learn more. Our result for *ratio* suggests that, at least across our sample of countries, the reverse is true. This might be so if many students learn more from their fellow students in class than they do from their teachers. If there are significant peer group externalities to learning then, over the range of class sizes of our sample of countries, larger classes are better than smaller classes.[65] Another possible explanation is that teachers faced with large classes are forced to use instructional techniques which turn out to be more effective than those used with smaller class sizes.

One possible explanation for the results regarding the variables *hwork* and *ratio* is that teachers in countries where the student-teacher ratio is high, or perhaps where the home environment makes it difficult for students to complete homework, compensate by devoting more effort to their in-class activities. Perhaps students in these countries also compensate for these more difficult learning conditions by being more motivated and attentive in class. These teacher and student responses may sum to an *over*compensation such that these students end up outperforming their cross-country peers. Large class sizes may also result in teachers necessarily resorting to more 'traditional' styles of teaching, such as teacher centred instruction, which may turn out to be more effective.

The coefficient for *labor* is negative and whilst not statistically significant at usual confidence limits, this result is consistent with the notion of a self sustaining cycle of low educational achievement leading to low earnings. If school age children from poorer

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65 The relationship between student-teacher ratios and test scores is probably non-linear, in which case there may be an optimal class size.

families are required by necessity to work long hours at home, or in the paid workforce, then our results suggest that their education attainment in the current period, and hence their future earnings potential, will be compromised.

The coefficient on *parent* is also statistically significant and indicates that students with more highly educated parents achieved higher test scores. This result suggests that higher educational achievements by a past generation of students determines a higher level of achievement for the subsequent generation. One possible explanation is that highly educated parents are endowed with much innate ability which has been genetically transmitted to their children. Another possibility is that highly educated parents undertake more creative and productive child caring activities during their children's early years, and present a role model to their children which values schooling. These children subsequently develop more advanced learning skills and go on to be more successful at school. These alternate channels whereby parental schooling levels may affect the schooling outcomes of their children are discussed further in section 4 of this Chapter, in light of the other results of this section.

Perhaps equally surprising as some of the results discussed so far is the fact that neither per capita real incomes (*gnp*) nor per capita spending on education (*dollar*) are significantly associated with test scores. These are surprising results for a number of reasons. For example, students in richer countries are generally healthier and have access to the latest in-class technologies. Hence students in richer countries should, other things being equal, achieve higher test scores than their peers in poorer countries. This is clearly not the case, at least across our sample of countries.

These two result may be due to an income threshold effect. If national health and educational outcomes improve rapidly once a threshold level of real per capita income is achieved, then there may be relatively little additional educational return from mean per capita incomes and educational expenditures which are greatly in excess of the threshold.

Perhaps very quickly diminishing marginal returns to increased educational spending set in beyond the threshold. If this is the case then, for many countries, learning outcomes will be determined by national characteristics other than per capita incomes and education spending.

The last three results in column 2 of Table 5.3 are consistent with expectations. Firstly, years of teaching experience (*years*) are positively associated with test scores (though not statistically significant at usual confidence limits). More experienced teachers may be more familiar with the curricula, may be better able to manage their classes and may have built up a greater stock of effective teaching capital. Secondly, school systems which require their teachers to organise and attend more meetings with fellow teachers achieve lower test scores. If *meet* is a proxy for school bureaucracy then this result is consistent with the macro literature which finds that excessive or inefficient bureaucracies reduce productivities.[66] Finally, hours spent performing teaching related tasks (*duties*) are positively and significantly associated with test scores. This result is as expected if *duties* is a proxy for teacher commitment to the job and more committed teachers are more effective in the classroom.

An examination of the residuals from the estimation process allows one to determine which countries achieved test scores which were either above or below expectations, given their exogenous national characteristics. The residuals from the two stage least squares estimates of column 2 in Table 5.3 are presented in Table 5.4 below. The countries which performed above expectations include Austria, (Flemish) Belgium, the Czech Republic, Hungary, Singapore, the Slovak Republic and Slovenia whilst those which performed below expectations include (French) Belgium, Colombia, Denmark, Iceland, Lithuania, New Zealand and Romania.

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[66] On this point see, for example, Ayal and Karras (1996).

**Table 5.4**
**Residuals from the 2SLS Estimates of Equation (5.2)**

| *Country* | *maths* | *science* |
|---|---|---|
| Australia | -.016 | -.005 |
| Austria | .007 | .028 |
| Belgium(Fl) | .096 | .057 |
| Belgium(Fr) | -.009 | -.125 |
| Canada | -.052 | -.039 |
| Colombia | -.231 | -.204 |
| Cyprus | -.027 | -.076 |
| Czech Rep | .054 | .075 |
| Denmark | -.032 | -.081 |
| England | -.033 | .039 |
| France | .012 | -.083 |
| Germany | -.034 | .013 |
| Greece | -.033 | -.013 |
| HongKong | .138 | -.022 |
| Hungary | .078 | .111 |
| Iceland | -.073 | -.055 |
| Iran | -.027 | .085 |
| Ireland | -.022 | .002 |
| Israel | -.028 | -.044 |
| Japan | .067 | -.012 |
| Korea | .035 | -.043 |
| Kuwait | -.057 | .038 |
| Latvia | -.035 | -.085 |
| Lithuania | -.097 | -.102 |
| Netherlands | .018 | .029 |
| New Zealand | -.041 | -.039 |
| Norway | -.038 | .018 |
| Portugal | .013 | .056 |
| Romania | -.027 | -.021 |
| Russia | -.011 | .007 |
| Scotland | -.02 | .101 |
| Singapore | .146 | .092 |
| Slovak Rep | .051 | .072 |
| Slovenia | .07 | .094 |
| Spain | -.043 | .012 |
| Sweden | -.003 | .03 |
| Switzerland | .036 | -.018 |
| Thailand | .119 | .114 |
| U.S.A. | -.073 | -.002 |

**Notes:** Residuals are the differences between the natural logarithm of the actual scores and the natural logarithm of the predicted scores based on the 2sls regression of column 2, Table 5.2.

There do not appear to be any common characteristics within these two groups of countries which might indicate why the former group performed above expectations whilst the latter group performed below expectations. Cultural characteristics such as language and religion do not seem to provide an explanation, nor does the geographic location of these countries. Interestingly, four of the seven countries who performed above expectation were members of the former USSR. *A priori*, we expect that the teaching methods and the curriculum in these countries may have been substantively different to those commonly found in Western democratic nations. For instance, in the formerly communist countries, the curriculum may have been more centrally determined and the instruction may have been relatively more teacher dominated, than in most Western countries. Also, the curricula may have placed relatively more emphasis on the development of generic skills in core subjects such as mathematics and science. If this is the case then perhaps part of the explanation as to why some countries over-achieved whilst some under-achieved may lie with the curricula and the teaching methods used in schools. However, we note that two of the countries who performed below expectations were also members of the former USSR.

This discussion has attempted to make sense of the results of columns one and two of Table 5.3, some of which are counter-intuitive, and all of which only indicate a strength of association. Necessarily, then, much of this discussion has been speculative. Clearly, more research is needed to better understand the precise causes of the great disparities which exist in schooling quality across countries, as highlighted by the data of Table 4.4.

An interesting issue, which we have already touched on, concerns whether the achievement of students are, in the main, a function of their innate abilities, or whether background variables such as educational practices and policies are also important. We briefly discuss this issue in the next section.

## 5.4 Are Test Scores A Function of Schooling, the Home Education, or the Innate Ability of Students?

The data of Table 4.4 indicates that there exists great variations across our sample of countries in the mathematics and science abilities of similarly aged students. One possible interpretation of the results in Table 5.3 is that home education, as proxied by parental education levels, are important. Another interpretation is that mathematics and science abilities are, in the main, genetically inherited from one's ancestors, that this is the channel being proxied by parental education levels, and that schooling is thus largely irrelevant in the process of human capital accumulation.

A recent contribution in this latter vein is Heernstein and Murray (1994) who investigate possible sources of human differences, and the consequences of such differences, for social and economic policy.[67] Their main arguments may be summarised as follows:

- economic and social inequality is increasing around the world, including the USA,
- this trend is in large part due to an increasing wage premium for skilled labour,
- skills are in large part determined by innate ability (IQ) which is, in the main, genetically transmitted from one, to subsequent, generations and is thus not a product of environmental conditioning, and hence,
- egalitarian economic and social policies, such as more educational spending for low achievers, will not overcome the genetic forces and are thus doomed to failure. To the extent that they result in less spending on the talented, or higher taxes, they are counter-productive. Finally,
- given relatively higher reproductive rates for low skill people and the immigration into the USA of people with generally lower levels of skills, the mean skill level in the USA, and hence national productivity, is diminishing.

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[67] See Heckman (1995) for an excellent survey and discussion of Heernstein and Murray (1994).

Our findings suggest that mean cross-country scores on test of mathematics and science abilities are (or are close to) significantly positively and negatively associated with a number of student and school characteristics. If parental education levels are proxies for innate ability which may be genetically transmitted from parents to children then our results indicate that, other things being equal, genetic factors are certainly an important determinant of student achievement. However if, other things being equal, better educated parents contribute more to the human capital accumulation of their children by providing more and better assistance with homework, higher level communication and personal interactions, and so on, then home education is an important determinant of student achievement. Also, other environmental factors were shown to be significantly associated with test scores, such as student-teacher ratios, hours of subject specific homework and teacher commitment.

Therefore, our findings suggest that student achievement is, in part, a function of family and school background characteristics and not simply a function of genetically inherited ability, and thus our findings thus do not support the argument of Heernstein and Murray (1994). Whilst the genetic transmission of ability, as proxied by parental levels of education, may be an important factor in the determination of test scores, it is at least equally likely that environmental factors such as home education and the characteristics of teachers are also important.

## 5.5 Concluding Comments

What are the implications of this analysis for the factors affecting cross-country schooling quality? Equation (5.8) summarises the standard production function approach to the determination of national productivity, where $y$ is real GDP, $k$ is units of physical capital, $l$ is units of labor, $h$ is units of human capital, all expressed in per capita terms, and $A$ represents the level of technology.

$$y = Af(k, l, h) \tag{5.8}$$

In Chapter 4, we showed that, across a sample of countries, standardised test scores, as proxies for schooling quality, are positively and significantly associated with rates of economic growth. Schooling quality is thus important in the relationship between the accumulation of human capital and economic growth.

Much of the analysis of this Chapter has concentrated on determining which economic, school and student characteristics have a significant impact on schooling quality. Our tentative conclusions are that schooling quality is positively and significantly associated with parental education levels, the student-teacher ratio and teachers' commitment to teaching, whilst negatively and significantly associated with hours of subject specific homework. Furthermore, a number of other characteristics of schools were close to statistically significant which, given our relatively small sample size, suggests that the impact of school factors may be stronger than our preliminary results indicate.

An interesting and related issue is whether male schooling is more or less important for economic growth than female schooling. Some recent work suggests that the education of females may be more important in the long run because mothers undertake the majority of child care duties and because much of the learning potential of children is developed during those early years. If this is so then a natural question is to ask whether schooling quality across countries differs significantly by gender and, if so, whether these gender differences are significantly associated with differences in cross-country rates of economic growth. We investigate this issue in the next Chapter.

**Appendix 5.1**
**Cross-Country Data on Background Characteristics of 8th Grade Mathematics Students**

| *Country* | *scor* | *comp* | *book* | *parent* | *hwork* | *other* | *leisure* | *labor* | *age* | *educ* | *years* | *duties* | *ratio* | *meet* | *gnp* | *dollar* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Australia** | 530 | 73 | 180 | 11.5 | 0.7 | 1.4 | 6.6 | 0.9 | 38.9 | 4 | 15.8 | 12.3 | 25.1 | 42 | 19000 | 701 |
| **Austria** | 539 | 59 | 121 | 11.74 | 0.8 | 1.5 | 8.1 | 0.8 | 40 | 4 | 17.5 | 12.9 | 22.3 | 46 | 20230 | 858 |
| **Belg(Fl)** | 565 | 67 | 115 | 10.68 | 1.1 | 2.3 | 6.6 | 1.1 | 42.5 | 3 | 20.6 | 12.7 | 17.7 | 21 | 20450 | 757 |
| **Belg(Fr)** | 526 | 60 | 153 | 11.51 | 1 | 2 | 6 | 0.8 | 43.7 | 3 | 21.8 | 11.8 | 18.6 | 53 | 20450 | 757 |
| **Canada** | 527 | 61 | 157 | 12.52 | 0.7 | 1.5 | 7.7 | 1 | 43 | 5.5 | 18.8 | 12.8 | 25.6 | 40 | 21230 | 981 |
| **Colombia** | 385 | 11 | 58 | 9.44 | 1.3 | 3.2 | 7.3 | 2.3 | 39.1 | 4 | 16.3 | 13.5 | 34.9 | 47 | 5970 | 169 |
| **Cyprus** | 474 | 39 | 119 | 9.36 | 1.2 | 2.4 | 7 | 1 | 42.7 | 4 | 13.9 | 11.7 | 31.1 | 89 | 15348 | 553 |
| **Czech** | 564 | 36 | 170 | 11.24 | 0.6 | 1.2 | 9 | 1.3 | 44.5 | 4.5 | 22.3 | 13.7 | 24.4 | 66 | 7910 | 297 |
| **Denmark** | 502 | 76 | 163 | 10.75 | 0.5 | 0.8 | 8.1 | 1.1 | 44.8 | 4 | 21.2 | 13.8 | 17.7 | 79 | 20800 | 998 |
| **England** | 506 | 89 | 149 | 9.79 | 0.6 | 1.2 | 8.3 | 0.8 | 41 | 4 | 16.7 | 14.2 | 24.3 | 59 | 18170 | 649 |
| **France** | 538 | 50 | 117 | 9.88 | 0.9 | 1.8 | 6 | 0.9 | 43.5 | 4.5 | 20.8 | 12.7 | 23.7 | 32 | 19820 | 716 |
| **Germany** | 509 | 71 | 148 | 9.38 | 0.6 | 1.4 | 8.6 | 0.9 | 48.8 | 6 | 19.5 | 15.7 | 21.6 | 31 | 19890 | 483 |
| **Greece** | 484 | 29 | 94 | 10.26 | 1.2 | 3.2 | 7.1 | 0.9 | 42.5 | 4 | 14.4 | 10.5 | 26.4 | 35 | 11400 | 259 |
| **HK** | 588 | 39 | 70 | 8.58 | 0.9 | 1.7 | 6.4 | 0.7 | 33.7 | 4 | 9.7 | 12.7 | 37.6 | 19 | 23080 | 309 |
| **Hungary** | 537 | 37 | 175 | 12.42 | 1.1 | 2.3 | 8.9 | 2 | 42.2 | 4 | 18.4 | 17.1 | 20.1 | 107 | 6310 | 272 |
| **Iceland** | 487 | 77 | 172 | 11.71 | 0.9 | 1.5 | 8.7 | 0.8 | 40.7 | 3 | 17.2 | 13.4 | 19.6 | 42 | 18900 | 902 |
| **Iran** | 428 | 4 | 48 | 7.58 | 2 | 4.4 | 5.5 | 1.8 | 32.4 | 2 | 10.8 | 12 | 34.1 | 41 | 4650 | 183 |
| **Ireland** | 527 | 78 | 122 | 10.78 | 0.7 | 2 | 6.1 | 0.9 | 39.6 | 4.5 | 16.7 | 9.8 | 25.2 | 15 | 14550 | 613 |
| **Israel** | 522 | 76 | 136 | 12.87 | 1 | 1.8 | 9.5 | 1.2 | 41.9 | 4 | 16.4 | 16.4 | 28.5 | 78 | 15690 | 584 |
| **Japan** | 605 | 59 | 121 | 11.26 | 0.8 | 1.6 | 7.3 | 0.6 | 37.3 | 4 | 13.8 | 14.7 | 35.4 | 44 | 21350 | 602 |
| **Korea** | 607 | 39 | 121 | 11.26 | 0.8 | 1.7 | 4.5 | 0.5 | 37.4 | 4 | 12.6 | 11.4 | 43.7 | 37 | 10540 | 362 |
| **Kuwait** | 392 | 53 | 78 | 6.42 | 1.6 | 3.8 | 6.6 | 1.2 | 32.9 | 4 | 10 | 11 | 30.3 | 86 | 24500 | 848 |
| **Latvia** | 493 | 13 | 214 | 12.19 | 0.9 | 1.8 | 7.7 | 1.5 | 40.3 | 4 | 17.7 | 14.1 | 20.1 | 60 | 5170 | 147 |
| **Lithuania** | 477 | 42 | 129 | 13.01 | 0.8 | 1.9 | 8.6 | 1.2 | 43.2 | 5 | 20.5 | 13 | 18.9 | 73 | 3240 | 71 |
| **Netherls** | 541 | 85 | 119 | 11.22 | 0.6 | 1.6 | 8.4 | 0.9 | 41.6 | 4 | 15.7 | 11.1 | 23.3 | 23 | 18080 | 597 |
| **NZ** | 508 | 60 | 177 | 11.45 | 0.7 | 1.5 | 7 | 0.9 | 40.3 | 4 | 13.9 | 12.3 | 25.5 | 43 | 16780 | 529 |
| **Norway** | 503 | 64 | 185 | 11.56 | 0.7 | 1.6 | 9.1 | 1.1 | 44.4 | 3.5 | 19.4 | 12.4 | 22.6 | 68 | 21120 | 1111 |
| **Portugal** | 454 | 39 | 99 | 7.75 | 1 | 2 | 6.8 | 1 | 33.1 | 4 | 8.5 | 12.5 | 23.7 | 25 | 12400 | 370 |
| **Romania** | 482 | 19 | 106 | 10.14 | 1.8 | 3.2 | 6.6 | 1.9 | 44 | 4.5 | 21.9 | 16.9 | 24.4 | 61 | 2920 | 55 |
| **Russia** | 535 | 35 | 139 | 12.95 | 0.9 | 2 | 9.1 | 1.5 | 41.1 | 4.5 | 18.3 | 18.5 | 23.4 | 43 | 5260 | 150 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scotland** | 498 | 90 | 125 | 9.79 | 0.6 | 1.2 | 9.1 | 0.7 | 41.2 | 4 | 16.6 | 10.1 | 24 | 66 | 18170 | 649 |
| **Singapore** | 643 | 49 | 87 | 10.94 | 1.4 | 3.2 | 6.6 | 1 | 40.3 | 4.5 | 17.7 | 16.4 | 35.9 | 28 | 21430 | 724 |
| **SlovakRep** | 547 | 31 | 119 | 11.22 | 0.7 | 1.7 | 9 | 1.5 | 44.1 | 4.5 | 22 | 13.5 | 24.9 | 96 | 6660 | 179 |
| **Slovenia** | 541 | 47 | 126 | 11.65 | 0.9 | 1.9 | 6.8 | 1.6 | 38.3 | 4.5 | 16.7 | 13.8 | 23.3 | 96 | 14280 | 600 |
| **Spain** | 487 | 42 | 132 | 8.98 | 1.2 | 2.4 | 6.2 | 1.1 | 45.4 | 3 | 21.8 | 11.4 | 27.7 | 38 | 14040 | 445 |
| **Sweden** | 519 | 60 | 176 | 10.99 | 0.7 | 1.6 | 7.5 | 0.9 | 44.9 | 4.25 | 18.8 | 13.8 | 19.6 | 79 | 17850 | 878 |
| **Switz** | 545 | 66 | 130 | 11.34 | 0.9 | 1.7 | 6.7 | 1 | 42.4 | 3 | 19.2 | 15.3 | 16.6 | 28 | 24390 | 907 |
| **Thailand** | 522 | 4 | 68 | 7.73 | 1.2 | 2.3 | 5.7 | 1.6 | 36 | 4 | 9.1 | 12.2 | 38.2 | 19 | 6870 | 206 |
| **U.S.A.** | 500 | 59 | 145 | 12.79 | 0.8 | 1.5 | 8.7 | 1.2 | 41.2 | 4 | 16.4 | 15 | 23.2 | 37 | 25860 | 1040 |

## Appendix 5.2
## Cross-Country Data on Background Characteristics of 8th Grade Science Students

| *Country* | *scor* | *comp* | *book* | *parent* | *hwork* | *other* | *leisure* | *labor* | *age* | *educ* | *years* | *duties* | *ratio* | *meet* | *gnp* | *dollar* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Australia** | 545 | 73 | 180 | 11.5 | 0.5 | 1.6 | 6.6 | 0.9 | 40.55 | 4 | 14.9 | 13.2 | 25.1 | 42 | 19000 | 701 |
| **Austria** | 558 | 59 | 121 | 11.74 | 0.7 | 1.6 | 8.1 | 0.8 | 40.7 | 4 | 18.1 | 12.9 | 22.3 | 41 | 20230 | 858 |
| **Belg(Fl)** | 550 | 67 | 115 | 10.68 | 0.8 | 2.6 | 6.6 | 1.1 | 41.9 | 3 | 19.1 | 13 | 18.5 | 24 | 20450 | 757 |
| **Belg(Fr)** | 471 | 60 | 153 | 11.51 | 0.8 | 2.2 | 6 | 0.8 | 40.8 | 3 | 18.3 | 12.9 | 18.8 | 44 | 20450 | 757 |
| **Canada** | 531 | 61 | 157 | 12.52 | 0.6 | 1.6 | 7.7 | 1 | 40 | 5.5 | 15.6 | 12.8 | 26.6 | 37 | 21230 | 981 |
| **Colombia** | 411 | 11 | 58 | 9.44 | 1.2 | 3.3 | 7.3 | 2.3 | 39.3 | 4 | 17.7 | 15.5 | 38.7 | 43 | 5970 | 169 |
| **Cyprus** | 463 | 39 | 119 | 9.36 | 0.9 | 2.7 | 7 | 1 | 44.1 | 4 | 15 | 12.6 | 30 | 89 | 15348 | 553 |
| **Czech** | 574 | 36 | 170 | 11.24 | 0.6 | 1.2 | 9 | 1.3 | 45.8 | 4.5 | 22.5 | 12.5 | 24.5 | 61 | 7910 | 297 |
| **Denmark** | 478 | 76 | 163 | 10.75 | 0.3 | 1 | 8.1 | 1.1 | 44.1 | 4 | 18.5 | 14 | 15.7 | 80 | 20800 | 998 |
| **England** | 552 | 89 | 149 | 9.79 | 0.5 | 1.3 | 8.3 | 0.8 | 41.4 | 4 | 16.4 | 14.2 | 24.3 | 44 | 18170 | 649 |
| **France** | 498 | 50 | 117 | 9.88 | 0.6 | 2.1 | 6 | 0.9 | 43.2 | 4.5 | 20.6 | 13.1 | 22.7 | 32 | 19820 | 716 |
| **Germany** | 531 | 71 | 148 | 9.38 | 0.6 | 1.4 | 8.6 | 0.9 | 47.8 | 6 | 20.1 | 15.1 | 22.4 | 44 | 19890 | 483 |
| **Greece** | 497 | 29 | 94 | 10.26 | 1.2 | 3.2 | 7.1 | 0.9 | 41.5 | 4 | 13.3 | 12.2 | 26.5 | 33 | 11400 | 259 |
| **HK** | 522 | 39 | 70 | 8.58 | 0.6 | 2 | 6.4 | 0.7 | 35.2 | 4 | 10.9 | 13.1 | 39.1 | 19 | 23080 | 309 |
| **Hungary** | 554 | 37 | 175 | 12.42 | 1.1 | 2 | 8.9 | 2 | 41.5 | 4 | 18.6 | 16.3 | 19.4 | 86 | 6310 | 272 |
| **Iceland** | 494 | 77 | 172 | 11.71 | 0.6 | 1.8 | 8.7 | 0.8 | 36.8 | 3 | 11.5 | 14.3 | 19.9 | 26 | 18900 | 902 |
| **Iran** | 470 | 4 | 48 | 7.58 | 1.9 | 4.5 | 5.5 | 1.8 | 32.2 | 2 | 10.5 | 10.1 | 34.2 | 48 | 4650 | 183 |
| **Ireland** | 538 | 78 | 122 | 10.78 | 0.6 | 2.1 | 6.1 | 0.9 | 38.7 | 4.5 | 15.8 | 9.9 | 24.4 | 17 | 14550 | 613 |
| **Israel** | 524 | 76 | 136 | 12.87 | 0.6 | 2.2 | 9.5 | 1.2 | 36.3 | 4 | 11.9 | 16.9 | 30.5 | 39 | 15690 | 584 |
| **Japan** | 571 | 59 | 121 | 11.26 | 0.6 | 1.8 | 7.3 | 0.6 | 37.7 | 4 | 14.6 | 14.4 | 35.4 | 41 | 21350 | 602 |
| **Korea** | 565 | 39 | 121 | 11.26 | 0.6 | 1.9 | 4.5 | 0.5 | 37.1 | 4 | 11.9 | 13 | 42.7 | 56 | 10540 | 362 |
| **Kuwait** | 430 | 53 | 78 | 6.42 | 1.5 | 3.9 | 6.6 | 1.2 | 34.2 | 4 | 9.5 | 10.9 | 30.4 | 88 | 24500 | 848 |
| **Latvia** | 485 | 13 | 214 | 12.19 | 0.6 | 2.1 | 7.7 | 1.5 | 41.8 | 4 | 18 | 12.1 | 21.7 | 33 | 5170 | 147 |
| **Lithuania** | 476 | 42 | 129 | 13.01 | 0.7 | 2 | 8.6 | 1.2 | 40.4 | 5 | 17.6 | 12.3 | 19.8 | 45 | 3240 | 71 |
| **Netherls** | 560 | 85 | 119 | 11.22 | 0.6 | 1.6 | 8.4 | 0.9 | 42.8 | 4 | 17.4 | 12.9 | 23.8 | 25 | 18080 | 597 |
| **NZ** | 525 | 60 | 177 | 11.45 | 0.6 | 1.6 | 7 | 0.9 | 42.2 | 4 | 15.5 | 13.9 | 26.2 | 47 | 16780 | 529 |
| **Norway** | 527 | 64 | 185 | 11.56 | 0.6 | 1.7 | 9.1 | 1.1 | 43.5 | 3.5 | 18.6 | 11.4 | 21.4 | 66 | 21120 | 1111 |
| **Portugal** | 480 | 39 | 99 | 7.75 | 0.9 | 2.1 | 6.8 | 1 | 33.8 | 4 | 8.5 | 14.1 | 23.6 | 28 | 12400 | 370 |
| **Romania** | 486 | 19 | 106 | 10.14 | 1.6 | 3.4 | 6.6 | 1.9 | 43.7 | 4.5 | 21.1 | 14.7 | 24.7 | 41 | 2920 | 55 |
| **Russia** | 538 | 35 | 139 | 12.95 | 1 | 1.9 | 9.1 | 1.5 | 41.3 | 4.5 | 18.7 | 15.7 | 23.7 | 38 | 5260 | 150 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scotland** | 517 | 90 | 125 | 9.79 | 0.5 | 1.3 | 9.1 | 0.7 | 41.2 | 4 | 16.6 | 10.5 | 10.6 | 73 | 18170 | 649 |
| **Singapore** | 607 | 49 | 87 | 10.94 | 1.3 | 3.3 | 6.6 | 1 | 38.6 | 4.5 | 15.9 | 16.9 | 36 | 26 | 21430 | 724 |
| **SlovakRep** | 544 | 31 | 119 | 11.22 | 0.8 | 1.6 | 9 | 1.5 | 41.6 | 4.5 | 19.3 | 12.3 | 25.1 | 92 | 6660 | 179 |
| **Slovenia** | 560 | 47 | 126 | 11.65 | 1 | 1.8 | 6.8 | 1.6 | 39.7 | 4.5 | 17.4 | 13.5 | 23.4 | 57 | 14280 | 600 |
| **Spain** | 517 | 42 | 132 | 8.98 | 1 | 2.6 | 6.2 | 1.1 | 42.9 | 3 | 19.2 | 11.6 | 28.6 | 33 | 14040 | 445 |
| **Sweden** | 535 | 60 | 176 | 10.99 | 0.7 | 1.6 | 7.5 | 0.9 | 44.9 | 4.25 | 18.2 | 14 | 19.6 | 80 | 17850 | 878 |
| **Switz** | 522 | 66 | 130 | 11.34 | 0.7 | 1.9 | 6.7 | 1 | 40.9 | 3 | 17.5 | 15.4 | 17.8 | 30 | 24390 | 907 |
| **Thailand** | 525 | 4 | 68 | 7.73 | 1 | 2.5 | 5.7 | 1.6 | 36.5 | 4 | 9.1 | 14.1 | 38.3 | 30 | 6870 | 206 |
| **U.S.A.** | 534 | 59 | 145 | 12.79 | 0.6 | 1.7 | 8.7 | 1.2 | 41.7 | 4 | 14.7 | 13.1 | 23.2 | 33 | 25860 | 1040 |

# APPENDIX 5.3
## Explanatory Notes on the Construction of Some of the Variables in Appendices 5.1 and 5.2

Some of the data in Appendices 5.1 and 5.2 were taken directly from the TIMSS reports. Other data had to be constructed. The methods by which these variables were constructed are explained below.

The variable *book* is defined as the mean number of books per student home. In the TIMSS report, student responses were grouped into the following categories: 'none or very few' (0-10 books), 'about one shelf' (11-25 books), 'about one bookcase' (26-100 books), 'about two bookcases' (101-200 books), and 'three or more bookcases' (more than 200 books). For estimation purposes, these categories were assigned the following mean values, respectively: 5 books, 18 books, 63 books, 150 books and 300 books. The variable *book* was then calculated as follows:

$$book = 5.(\%0\text{-}10) + 18.(\%11\text{-}25) + 63.(\%26\text{-}100) + 150.(\%101\text{-}200) + 300.(\%>200)$$

where (%x-y) is the proportion of students who reported having between (x-y) number of books at home.

The variable *parent* is defined as the mean years of formal schooling of one or other parent. Students reported their parental education level as either 'finished university' (u), 'finished upper secondary school only' (s), 'finished primary school only' (p) or 'not known' (n). We assume that (u) implies 16 years of schooling, (s) implies 12 years of schooling, and (p) implies 6 years of schooling. The variable *parent* was thus calculated as follows:

$$parent = 16.(\%u) + 12.(\%s) + 6.(\%p) + M.(\%n)$$

where (%x) is the proportion of students who reported that one or other of their parents had achieved x level of education and M is the mean level of education achieved by the parents of students who did know their parents' education level. This method assumes that the distribution of parental education levels for the students who responded 'do not know' is identical to that for the students who did know.

The variable *leisure* is defined as the mean hours of daily leisure per student, calculated as the sum of hours spent watching television and videos and playing video games, playing and talking with friends, playing sport and reading for pleasure.

The variable *age* is defined as the mean age, in years, of either 8th grade mathematics or science teachers. In the TIMSS report teachers were categorised as being either less than 29 years, 30-39 years, 40-49 years or 50 and over years. We assumed the following mean ages, respectively: 25 years, 35 years, 45 years, and 55 years. Using a methodology similar to that used for the variable *book*, *age* was calculated as follows:

$$age = 25.(\%{<}29) + 35.(\%30\text{-}39) + 45.(\%40\text{-}49) + 55.(\%50+)$$

where (%x) is the proportion of teachers who reported being in the x age category.

The variable *years* is defined as the mean years of teaching experience of 8th grade mathematics and science teachers. In the TIMSS report teachers were categorised as having either 0-5 years, 6-10 years, 11-20 years or more than 20 years of teaching experience. We assumed the following mean years of experience, respectively: 2.5 years, 8 years, 15.5 years and 30 years. Using a methodology similar to that used for the variable *book*, *exp* was calculated as follows:

$$exp = 2.5.(\%0\text{-}5) + 8.(\%6\text{-}10) + 15.5.(\%11\text{-}20) + 30.(\%20+)$$

where %x is the proportion of teachers who reported having x years of experience

The variable *meet* is defined as the mean annual number of collaborative teacher meetings per teacher. In the TIMSS report teachers were categorised as meeting never or 1-2 times per year (n), meeting monthly or every other month (m), meeting once, twice or three times per week (w), or meeting almost every day (d). By assuming a 10 month or 40 week teaching year in all countries, we determined the following values: n=1, m=7.5, w=80, d=160. Hence *meet* was calculated as follows:

$$meet = 1.(\%n) + 7.5.(\%m) + 80.(\%w) + 160.(\%d)$$

where (%x) is the proportion of teachers who reported collaborating with a yearly frequency of x.

# CHAPTER 6

# ECONOMIC GROWTH AND GENDER DIFFERENCES IN SCHOOLING QUANTITY AND QUALITY

## 6.1 Introduction

Much of this thesis has been concerned with the measurement and determinants of schooling quality, and with the impact of schooling quality on rates of economic growth across countries. In Chapter 4 we concluded that schooling quality across countries, as proxied by national mean scores on standardised tests of mathematics and science, is significantly and positively associated with mean economic growth rates over the period 1960 to 1985. In that Chapter, we were only interested in the aggregate quality of schooling across countries, without reference to the performance of particular sub-groups of students within and across countries. In Chapter 5, we concluded that test scores, as proxies for schooling quality, are a function of the innate ability or home education and other quantifiable background characteristics of students.

Now suppose that the schooling of girls is more important than that of boys for the purpose of maximising economic growth, but the quality of schooling is biased in favour of boys. Then for any given input of resources into schooling, economic growth will not be maximised. On this issue, a number of recent studies have concluded that the private rate of return to female schooling is positive and marginally greater than that to male schooling (see, for example, Psacharopoulos, 1994). The same conclusion appears to hold for the social rate of return to female schooling. The basic idea is that, other things being equal, an increase in the education of females relative to that of males results in correspondingly greater reductions in fertility, infant and child mortality and family morbidity, and greater increases in life expectancy and child educational attainment (see, for instance, Subbarao and Raney, 1995). If this is so then one could conclude that developing countries in particular should increase the share of their education budget which is devoted to the schooling of females. However, in many countries, males acquire a greater quantity of schooling than females. Other things being equal, this educational gender gap in favour of males may be contributing to a lower rate of economic growth in these countries.

A recent contribution to this literature is Knowles, Lorgelly and Owen (1998)[68] who develop an augmented Solow model very similar to that used by MRW, but in which male and female education enter as separate terms in the production function, which includes the stock of health capital as well as the levels of physical capital, labour and technology. They then derive expressions for the steady-state levels of physical capital, female education, male education, health capital, and for the steady-state level of income per worker, and estimate their steady-state income equation for the 73 countries for which they have data[69].

KLO conclude that female education levels are positively and significantly associated with mean per capita incomes from 1960 to 1990, whereas male education levels are statistically insignificant. However, the education data in KLO are estimates of the average years of male and female schooling and thus measure only the mean quantity of schooling across countries. As was the case with MRW, this approach ignores the possibility that differentials in the levels of male and female human capital across countries may also be due to differences in the productivity of time spent by males and females at school.

The objective of this Chapter is thus to determine whether the inclusion of proxies for male and female schooling quality across a sample of countries affects the estimation results from an augmented Solow model which includes separate terms for the schooling quality of males and females.

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68 Knowles, Lorgelly and Owen (1998) shall, from here on, referred to as KLO.

69 The years of schooling data used by KLO are from Barro and Lee (1997). Their life expectancy data are from the World Bank. Their other data are from the Penn World Tables (version 5.6).

The remainder of this Chapter is organised as follows. In section 6.2 we propose an augmented Solow model of economic growth which includes separate terms for male and female schooling quantity and quality, and then simply state the corresponding equations for the steady-state level of per capita incomes and for the mean rate of economic growth, leaving relevant mathematical details to an Appendix. In section 6.3 we present and discuss our cross-country data, particularly that on male and female schooling quality, estimate the income and growth rate equations, and discuss the results. Finally, section 6.4 concludes.

## 6.2 Male and Female Schooling Quantity and Quality in an Augmented Solow Model of Economic Growth

The augmented Solow model of MRW contains aggregate human capital as an explanatory variable in the production function. We modify this approach by including separate variables for the human capital of males and females and for the aggregate stock of health capital. The production function becomes equation (6.1), where

$\eta = 1-\alpha-\beta_f-\beta_m-\psi$.

$$Y_{i,t} = K_{i,t}^{\alpha}\, Ef_{i,t}^{\beta f}\, Em_{i,t}^{\beta m}\, X_{i,t}^{\psi}\, (A_{i,t}L_{i,t})^{\eta} \tag{6.1}$$

The variables *Y*, *K*, *A* and *L* are defined as the level of real output, the stock of physical capital, the level of technology and the labour force, respectively. *Ef* is the stock of female human capital, *Em* is the stock of male human capital and *X* is the stock of health capital. Equation (6.1) is Cobb-Douglas and exhibits constant returns to scale. By denoting quantities per unit of effective labour (*AL*) with lower case letters, equation (6.1) can be re-written in intensive form as equation (6.2).

$$y_{i,t} = k_{i,t}^{\alpha}\, ef_{i,t}^{\beta f}\, em_{i,t}^{\beta m}\, x_{i,t}^{\psi} \tag{6.2}$$

The labour force and the level of technology evolve, and physical capital accumulates, over time according to, respectively, equations (6.3) to (6.5) below. Also, the accumulation equations for the stocks of female and male human capital and for aggregate level of health capital are given as, respectively, equations (6.6) to (6.8).

$$L_{i,t} = L_{i,0}\, e^{nt} \tag{6.3}$$

$$A_{i,t} = A_{i,0}\, e^{gt} \tag{6.4}$$

$$dk_{i,t} / dt = s_{k,i}\, y_{i,t} - (n_i + g + \delta) k_{i,t} \tag{6.5}$$

$$def_{i,t} / dt = s_{ef,i}\, y_{i,t} - (n_i + g + \delta) ef_{i,t} \tag{6.6}$$

$$dem_{i,t} / dt = s_{em,i}\, y_{i,t} - (n_i + g + \delta) em_{i,t} \tag{6.7}$$

$$dx_{i,t} / dt = s_{x,i}\, y_{i,t} - (n_i + g + \delta) x_{i,t} \tag{6.8}$$

The parameters $s_{k,i}$, $s_{ef,i}$, $s_{em,i}$, and $s_{x,i}$, are the fractions of real output invested in physical capital, female human capital, male human capital and health capital, respectively, per time period, whilst $n_i$ is the population growth rate, $g$ is the rate of technological advance and $\delta$ is the depreciation rate. The subscript $i$ denotes countries.

The multiplicative terms in equations (6.6) and (6.7), ($s_{ef,i}\, y_{i,t}$) and ($s_{em,i}\, y_{i,t}$), represent the proportions of income devoted in each country to female and male schooling, respectively. As we have argued elsewhere (see Chapter 4), these terms are reasonable proxies for the quantity of female and male schooling, but do not adequately capture the quality of female and male schooling. If the accumulation of human capital by females and males is, *a priori*, a function of both the amount of time spent studying and the mean productivity per unit of time spent studying, then equations (6.6) and (6.7) must be augmented so as to include a term for schooling quality by gender. The modified equations are presented as (6.9) and (6.10) below, where $Q_{f,i}$ refers to female schooling quality and $Q_{m,i}$ refers to male schooling quality, by country.

$$def_{i,t} / dt = [s_{ef,i}\, y_{i,t}]\, Q_{f,i} - (n_i+g+\delta)\, ef_{i,t} \qquad (6.9)$$

$$dem_{i,t} / dt = [s_{em,i}\, y_{i,t}]\, Q_{m,i} - (n_i+g+\delta)\, em_{i,t} \qquad (6.10)$$

From equations (6.5) and (6.8) to (6.10) we derive the following expressions for the steady-state levels (denoted by an asterisk) of physical capital, female schooling, male schooling and health capital, respectively. Details concerning relevant mathematical derivations are included in Appendix 6.1.

$$k_i^* = \{[s_{k,i}^{(1-\beta f-\beta m-\psi)}\, s_{f,i}^{\beta f}\, s_{m,i}^{\beta m}\, s_{x,i}^{\psi}\, Q_{f,i}^{\beta f}\, Q_{m,i}^{\beta m}\,] / (n_i+g+\delta)\}^{1/\eta} \qquad (6.11)$$

$$ef_i^* = \{[s_{k,i}^{\alpha}\, s_{f,i}^{(1-\alpha-\beta m-\psi)}\, s_{m,i}^{\beta m}\, s_{x,i}^{\psi}\, Q_{f,i}^{\beta f}\, Q_{m,i}^{\beta m}\,] / (n_i+g+\delta)\}^{1/\eta} \qquad (6.12)$$

$$em_i^* = \{[s_{k,i}^{\alpha}\, s_{f,i}^{\beta f}\, s_{m,i}^{(1-\alpha-\beta m-\psi)}\, s_{x,i}^{\psi}\, Q_{f,i}^{\beta f}\, Q_{m,i}^{\beta m}\,] / (n_i+g+\delta)\}^{1/\eta} \qquad (6.13)$$

$$x_i^* = \{[s_{k,i}^{\alpha}\, s_{f,i}^{\beta f}\, s_{m,i}^{\beta m}\, s_{x,i}^{(1-\alpha-\beta m-\psi)}\, Q_{f,i}^{\beta f}\, Q_{m,i}^{\beta m}\,] / (n_i+g+\delta)\}^{1/\eta} \qquad (6.14)$$

By substituting equations (6.11) to (6.14) into equation (6.2), taking natural logarithms and re-arranging, we get the following expression for the steady-state level of output per worker, $ln[Yi/Li]^*$, where $\eta$ is as previously defined.

$$ln[Y_i/L_i]^* = lnA_{i,0} + gt + \alpha/\eta \; lns_{k,i} + \beta_f/\eta \; lns_{f,i} + \beta_m/\eta \; lns_{m,i} + \psi/\eta \; lns_{x,i}$$

$$+ \beta_f(1-\eta)\eta \; lnQ_{f,i} + \beta_m(1-\eta)\eta \; lnQ_{m,i} - (1-\eta)\eta \; ln(n_i+g+\delta) \qquad (6.15)$$

For estimation purposes, it may be preferable to have a per capita income equation where the human capital variables enter as steady-state stocks rather than an equation in terms of their respective savings rates, as is the case with equation (6.15) (see footnote 43, page 68 on this point). By solving our equations (6.12) to (6.14) for the respective human capital savings rates and substituting these expressions into equation (6.15), we derive equation (6.16) below which is in terms of the steady-state stock of human capital and where $C \equiv (lnA_{i,0} + gt)$.

$$ln[Y_i/L_i]^* = C + \alpha/(1-\alpha) \; lns_{k,i} + \beta_f/(1-\alpha) \; lnef_i^* + \alpha\beta_f/(1-\alpha) \; lnQ_{f,i} + \beta_m/(1-\alpha) \; lnem_i^*$$

$$+ \alpha\beta_m/(1-\alpha) \; lnQ_{m,i} + \psi/(1-\alpha) \; lnx_i^* - \alpha/(1-\alpha) \; ln(n_i+g+\delta) \qquad (6.16)$$

In equation (6.16) the steady-state level of output per worker is a function of the share of output devoted to physical capital accumulation ($s_{k,i}$), the steady-state levels of female schooling ($ef_i^*$), male schooling ($em_i^*$) and health capital ($x_i^*$), the quality of female and male schooling ($Q_{f,i}$ and $Q_{m,i}$ respectively) and the population growth rate ($n_i$).

Consistent with our approach in Chapter 4, we substitute $lny^*$ in the equation for the average growth rate (equation 4.17) with equation (6.16) above to yield equation (6.17) below for the average growth rate of real output per worker.

$$lny(t) - lny(0) = (1\text{-}e^{-\lambda t})\alpha/(1-\alpha)lns_{k,i} + (1\text{-}e^{-\lambda t})\beta_f/(1-\alpha)lnef_i^* + (1\text{-}e^{-\lambda t})\alpha\beta_f/(1-\alpha)lnQ_{f,i}$$

$$+ (1\text{-}e^{-\lambda t})\beta_m/(1-\alpha)lnem_i^* + (1\text{-}e^{-\lambda t})\alpha\beta_m/(1-\alpha)lnQ_{m,i} + (1\text{-}e^{-\lambda t})\psi/(1-\alpha)lnx_i^*$$

$$-(1\text{-}e^{-\lambda t})\alpha/(1-\alpha)ln(n_i+g+\delta) - (1\text{-}e^{-\lambda t})lny(0) \qquad (6.17)$$

In the next section, we estimate equations (6.16) and (6.17) for the steady-state level of per capita income and for the mean economic growth rate, respectively. The coefficients on the (natural logarithm of the) physical capital savings rate ($s_{k,i}$) and on the growth rate of the population aged 15-64 years ($n_i$) in equation (6.16) and (6.17) sum to zero and so we apply and test this restriction. The model also predicts that the impact of male and female schooling quality will be quantitatively less that that of schooling quantity, for $0<\alpha<1$.

We begin the next section with a brief discussion of our data, which can be found in Appendix 6.2. We then present and discuss our estimation results for equations (6.16) and (6.17).

## 6.3 Steady-State Per Capita Incomes and Mean Growth Rates: Estimation Results

The objective of this section is to determine whether the addition of data on male and female schooling quality affects the estimation results from an augmented Solow model where male and female years of schooling enter the production function separately and where the explanatory variables are mean per capita incomes and mean economic growth rates. The data used for estimation, with some brief explanatory notes, are presented in Appendix 6.2 and are distinguished from that used in earlier Chapters by the addition of separate year 8 mathematics and science tests scores for males (8mathM and 8sciM, respectively) and females (8mathF and 8sciF, respectively) across countries, and by the addition of data on cross-country health capital ($X_i$). For this section, our earlier sample of 28 countries has been reduced to 25 due to data limitations on schooling quantity by gender for Cyprus, Iceland and Germany[70].

Test scores by gender were simply taken from the appropriate TIMSS report. We constructed the proxies for health capital across countries ($X_i$) by calculating the difference between the mean life expectancy in 1980, and 85 years. Data on the quantity of schooling by gender is from Barro and Lee (1996) whilst data for physical capital investment rates and for mean population growth rates are as per Chapter 4. Table 6.1 below presents the estimation results for the income equation (6.16) for the period 1960-1990.

In column one we find that the coefficients for the physical capital investment rate ($s_{k,i}$) and for the population growth rate ($n_i$) are of the expected signs but statistically insignificant. The coefficient for female years of schooling (schoolF) is positive and highly statistically significant whilst that for male years of schooling (schoolM) is negative and almost statistically significant at the 5% level (critical t-value with 19 df is 2.09). These two results indicate that countries with more mean years of female (male) schooling were, on average, also those with higher (lower) mean per capita incomes from 1960 to 1990. The sign on the coefficient for health capital ($X_i$) is also as expected and significant at the 5% level. Hence richer countries in the period 1960 to 1990 were, on average, also those with the greatest mean life expectancy in 1980.

The regression whose results are reported in column two is as per that of column one, but with the addition of female and male mathematics test scores (8mathF and 8mathM) whilst the regression whose results are reported in column three adds female and male science test scores instead (8sciF and 8sciM). Neither of these proxies for male and female schooling quality is significantly associated with mean per capita incomes, whilst their addition leaves the previous results for the physical capital investment rates and for the population growth rates essentially unchanged. However, the coefficient on female

[70] In an earlier chapter we tested for heteroscedasticity and concluded that this was not a problem.

**Table 6.1**
**OLS Estimation Results for Equation (6.16)**
**Dependent Variable: Mean Log GDP per Worker (1960-90)**

| *Variable* | *(1)* | *(2)* | *(3)* | *(4)* | *(5)* | *(6)* |
|---|---|---|---|---|---|---|
| $\ln(s_{k,i})$ | .29 | .53 | .33 | | | |
| | (.71) | (1.23) | (.79) | | | |
| $\ln(n_i+g+\delta)$ | -.47 | -.33 | -.37 | | | |
| | (-.86) | (-.61) | (-.67) | | | |
| $\ln(s_{k,i})-\ln(n_i+g+\delta)$ | | | | .35 | .45 | .34 |
| | | | (1.09) | (1.39) | (1.05) | |
| ln(schoolF) | 1.80 | 1.07 | 1.44 | 1.84 | 1.07 | 1.45 |
| | (3.27) | (1.51) | (2.15) | (3.56) | (1.55) | (2.25) |
| ln(schoolM) | -1.31 | -.36 | -.87 | -1.37 | -.36 | -.88 |
| | (-2.02) | (-.42) | (-1.05) | (-2.32) | (-.42) | (1.12) |
| ln(Xi) | .73 | .88 | .96 | .74 | .86 | .96 |
| | (2.10) | (2.46) | (2.40) | (2.19) | (2.52) | (2.52) |
| ln(8mathF) | | 1.37 | | | 1.35 | |
| | | (.36) | | | (.37) | |
| ln(8mathM) | | -2.72 | | | -2.62 | |
| | | (-.67) | | | (-.67) | |
| ln(8sciF) | | | -.86 | | | -.85 |
| | | (-.19) | | | (-.19) | |
| ln(8sciM) | | | -.07 | | | -.09 |
| | | (-.01) | | | (-.02) | |
| F statistic | | | | .07 | .10 | .00 |
| Adj $R^2$ | .71 | .72 | .71 | .72 | .73 | .72 |

**Notes:** t-statistics are in parentheses. The regression constants have been omitted to save space. $S_{k,i}$ measures the savings rate. $(n_i+g+\delta)$ is the population growth rate plus 5%. schoolF (schoolM) is the mean level of schooling for females (males). $X_i$ is the difference between mean life expectancy and 85 years. 8mathF (8mathM) is the mean test score of females (males) on the year 8 mathematics test. Likewise for 8sciF (8sciM). The F statistic tests the null hypothesis that the coefficients on $s_{k,i}$ and $(n_i+g+\delta)$ are equal. ln(•) refers to the natural logarithm.

years of schooling becomes statistically insignificant with the addition of mathematics test scores whilst that on male years of schooling becomes statistically insignificant with the addition of both mathematics and science test scores. Also, the addition of these two explanatory variables has little effect on the fit of the regression. Finally, columns four to six of Table 6.1 test the restriction that the coefficients on the physical capital investment rate and the growth rate of the population sum to zero. With $F_{0.05}$ (1,20) = 4.35, we do not reject the restriction in all three specifications. The previous conclusions regarding columns one to three are also applicable in the case of columns four to six. Hence we conclude that the addition of proxies for female and male schooling quality has little impact on the estimation results for mean incomes across countries.

Table 6.2 below presents the estimation results for the mean growth rate equation (6.17). The results in column one of Table 6.2 indicates that there is a strong tendency towards unconditional convergence. Variations in initial incomes alone account for 65% of the variation in mean growth rates between 1960 and 1990. When savings rates ($s_{k,i}$), the population growth rate ($n_i$), years of female and male schooling (schoolF and schoolM, respectively), and health capital ($X_i$) are added to the regression (column 2), the fit of the regression improves substantially (the adjusted $R^2$ increases from .65 to .87). Conditional convergence is strong, as is the positive association between health and mean growth rates, whilst the coefficients on the savings and population growth rates are not statistically significant. So far, the regression results for these variables in column two of Table 6.2 are consistent with those in column one of Table 6.1.

However, in contrast to the result for the mean level of income, years of female schooling (schoolF) are negative and close to significant, whilst years of male schooling (schoolM) are positive and almost significant. These two results in column two indicate that, across our sample of countries, those with a higher quantity of male (female) schooling were also those which grew most quickly (slowly) between 1960 and 1990. These results are controversial because they suggest that developing countries seeking to maximise economic growth rates should, other things being equal, devote relatively more resources to the schooling of males.

**Table 6.2**
**OLS Estimation Results for Equation (6.17)**
**Dependent Variable: Mean Growth Rate of GDP per Worker (1960-90)**

| *Variable* | *(1)* | *(2)* | *(3)* | *(4)* | *(5)* | *(6)* |
|---|---|---|---|---|---|---|
| ln(y60) | -.52<br>(-6.76) | -.64<br>(-7.04) | -.50<br>(-6.36) | -.59<br>(-6.62) | -.50<br>(-6.57) | -.60<br>(-6.81) |
| $\ln(s_{k,i})$ | | .26<br>(1.13) | -.03<br>(-.17) | .21<br>(.94) | | |
| $\ln(n_i+g+\delta)$ | | .019<br>(.06) | -.04<br>(-.17) | -.02<br>(-.06) | | |
| $\ln(s_{k,i})-\ln(n_i+g+\delta)$ | | | | | -.005<br>(-.03) | .14<br>(.79) |
| ln(schoolF) | (-1.79) | -.75<br>(-.95) | -.32<br>(-1.16) | -.49<br>(-.98) | -.32<br>(-1.23) | -.51 |
| ln(schoolM) | | .87<br>(2.05) | .09<br>(.24) | .45<br>(.97) | .09<br>(.23) | .49<br>(1.09) |
| $\ln(X_i)$ | | .60<br>(2.99) | .37<br>(2.19) | .39<br>(1.74) | .37<br>(2.35) | .37<br>(1.72) |
| ln(8mathF) | | | -2.85<br>(-1.69) | | -2.85<br>(-1.73) | |
| ln(8mathM) | | | 4.39<br>(2.36) | | 4.35<br>(2.41) | |
| ln(8sciF) | | | | -2.48<br>(-1.03) | | -2.51<br>(-1.07) |
| ln(8sciM) | | | | 3.51<br>(1.28) | | 3.57<br>(1.34) |
| F statistic | | | | | .06 | .28 |
| Adj $R^2$ | .65 | .87 | .92 | .88 | .93 | .88 |

**Notes**: t-statistics are in parentheses. The regression constants have been omitted to save space. y60 is real per capita income in 1960. $S_{k,i}$ measures the savings rate. $(n_i+g+\delta)$ is the population growth rate plus 5%. schoolF (schoolM) is the mean level of schooling for females (males). $X_i$ is the difference between mean life expectancy and 85 years. 8mathF (8mathM) is the mean test score of females (males) on the year 8 mathematics test. Likewise for 8sciF (8sciM). The F statistic tests the null hypothesis that the coefficients on $s_{k,i}$ and $(n_i+g+\delta)$ are equal. ln(•) refers to the natural logarithm.

How can the results for years of female and male schooling in the growth rate regressions of column 2, Table 6.2 be reconciled with the corresponding results for the steady-state income regression of column 1 in Table 6.1? Part of the answer may lie with the strong tendency for convergence. Our results imply that the initially poorest countries are also those with the highest mean levels of male schooling and the highest mean growth rates. As mean per capita incomes increase in these countries, and mean economic growth rates consequently fall, a greater relative proportion of resources is devoted to the schooling of females. This may explain our results of a positive relationship between income levels and female schooling, but of a negative relationship between economic growth rates and female schooling.

So what may explain the fact that higher economic growth rates are positively associated with a schooling quantity gender gap favouring males, whilst higher per capita income levels are positively associated with a schooling quantity gender gap favouring females? One possible explanation for female years of schooling initially lagging behind those of males, but catching up as mean incomes increase (and economic growth rates decrease) may be that social customs change relatively slowly. If educated women in less developed countries are subject to great social pressures to have children and to be the primary child care providers then, at the margin, female years of schooling in less developed countries may be relatively less productive than male years of schooling.

If this is so then (some) developing countries, simultaneously, initially invest relatively more heavily in male schooling and grow more rapidly than richer countries. However, as these countries become more prosperous (and their economic growth rates decline), their social customs eventually become more like those in the initially rich countries and so women receive increasing levels of schooling relative to those received by men.

A process such as this may explain why (some) initially poorer countries tend to invest more heavily in male schooling, whilst they simultaneously grow at a more rapid rate, than initially richer countries. If this is so then, at least in less developed countries with social customs which change only slowly, a policy of encouraging relatively higher levels of female schooling may not be the most appropriate. Reducing an educational gender gap in favour of males may be an appropriate policy response only when educated women are capable of contributing to national productivity at a level commensurate with their accumulation of human capital. This finding, whilst preliminary, is controversial because many bodies such as the World Bank advocate more female schooling relative to that of males as a policy to accelerate economic development. Our results suggest that, other things being equal, such a policy would be growth retarding for the currently poorer nations[71].

In column three of Table 6.2 we add male and female schooling quality, in the form of mathematics test scores, to the regression of column two and note that the fit of the regression again improves substantially (the adjusted $R^2$ increases from .87 to .92). Convergence is still strong, and the results for savings rates, population growth rates and health capital are consistent with those of column two. Again, of these three regressors, the coefficient on health capital is the only one which is statistically significant. However, the coefficients on female and male years of schooling are now of the same sign but statistically insignificant, whilst that on male schooling quality is statistically significant at the 5% level. The signs on these two variables are consistent with those on the schooling quantity variables in column two and indicate that countries with higher male (female) mathematics test scores had a higher (lower) mean economic growth rate, other things being equal.

71 We note, however, that our analysis generally ignores the social benefits from increased female education relative to that of males.

The regression reported in column four is identical to that of column three, but with schooling quality now proxied by female and male science test scores. The fit of this regression is only slightly better than that without schooling quality (column two). The results are similar to those of column three, although on this occasion the coefficients on health capital, female and male test scores are no longer statistically significant at usual confidence limits. As was the case in Chapter 4, we obtain better results when mathematics, rather than science, test scores are used as proxies for schooling quality across countries. This result suggests that mathematics skills may be better proxies for human capital than science skills. This may be so if mathematics skills are more generic and hence useful in a wide range of productive applications.

Columns five and six report the results of restricted regressions which test the hypothesis that the coefficients on the savings and population growth rates sum to zero. As was the case with Table 6.1, we do not reject the null hypotheses irrespective of whether we use maths (column five) or science (column six) test scores to proxy for schooling quality.

We also investigated the existence of outliers by comparing actual and predicted values for the dependent variables. In the case of the growth rate equation, where we used mathematics scores as proxies for schooling quality, all predicted growth rates were less than two standard deviations from their actual values (see Table 6.3 below), and so we conclude that there are no observations sufficiently outside their predicted value to warrant the introduction of, for instance, a relevant dummy variable. This is further justifiable on the grounds that our sample is small and so any additional variable would further reduce our degrees of freedom.

**Table 6.3**
**Residuals from the OLS Estimation of Equation (6.17)**
**Standard Error of the Estimate: .12522**

| *Observation* | *Residual* |
|---|---|
| 1 | .051 |
| 2 | -.045 |
| 3 | .131 |
| 4 | .141 |
| 5 | -.006 |
| 6 | -.091 |
| 7 | -.016 |
| 8 | .006 |
| 9 | .068 |
| 10 | .062 |
| 11 | -.084 |
| 12 | .017 |
| 13 | .082 |
| 14 | -.136 |
| 15 | .012 |
| 16 | -.159 |
| 17 | .011 |
| 18 | .079 |
| 19 | .125 |
| 20 | .073 |
| 21 | -.097 |
| 22 | -.145 |
| 23 | -.232 |
| 24 | .005 |
| 25 | .148 |

## 6.4 Concluding Comments

In this Chapter, we have investigated whether gender gaps in the quality of schooling across countries, as proxied by female and male scores on tests of mathematics and science understanding, affect the empirical results from an augmented Solow model of economic growth which includes separate terms for male and female schooling. Our estimation results for the steady-state income equation are consistent with those of other studies (see, for instance, Barro 1996) in that the quantity of female schooling is positively and significantly associated with per capita incomes whilst the quantity of male schooling is negatively and significantly associated with per capita incomes. These conclusions are little changed by the addition of our proxies for male and female schooling quality.

However, these conclusions are completely reversed when estimating the mean growth rate equation. In this case, the quantity of female schooling is negatively and significantly associated, whilst the quantity of male schooling is positively and significantly associated, with mean growth rates across our sample of countries. Furthermore, when data on female and male schooling quality are added to this regression, the coefficients on the schooling quantity variables become statistically insignificant but maintain their signs. On the other hand, male scores on mathematics tests are significantly and positively associated with mean growth rates, whilst the addition of male and female test scores results in a substantial improvement to the goodness of fit of the model. However, we note that our results are based on a small sample of countries and are sensitive to the sample used, and so we stress that these conclusions are tentative.

Nevertheless, on the basis of these results, we cautiously conclude that schooling quality by gender does matter for economic growth. In particular, recent claims that developing countries should devote more resources to the schooling of females may be erroneous. Some of these claims are based on regression results for the steady-state income equation from an augmented Solow model, such as those of Table 6.1. However, developing countries will improve their average standard of living only by achieving a higher and sustained rate of economic growth. The results from this Chapter are preliminary and controversial, but suggest that economic growth rates may be maximised, other things being equal, if developing countries concentrate on improving the skills of those most closely and associated with the paid workforce.

## APPENDIX 6.1
## Mathematical Derivation of Equation (6.11)

We can rewrite equations (6.5) and (6.8) to (6.10) by noting that, in the steady state, d(•)/dt =0. Hence new get equation (6A.1) to (6A.4) below, where the asterisk (*) proceeding each variable *k*, *f*, *m* and *x* refers to the steady state.

$$s_k[k*^{\alpha} f*^{\beta f} m*^{\beta m} x*^{\psi}] = (n+g+\delta)k* \qquad (6A.1)$$

$$s_f[k*^{\alpha} f*^{\beta f} m*^{\beta m} x*^{\psi}]Q_f = (n+g+\delta)f* \qquad (6A.2)$$

$$s_m[k*^{\alpha} f*^{\beta f} m*^{\beta m} x*^{\psi}]Q_m = (n+g+\delta)m* \qquad (6A.3)$$

$$s_x[k*^{\alpha} f*^{\beta f} m*^{\beta m} x*^{\psi}] = (n+g+\delta)x* \qquad (6A.4)$$

From (6A.1) to (6A.4) we derive expressions for the steady-state levels of physical capital, female schooling, male schooling and health capital, respectively, as follows:

$$k^* = [(s_k f*^{\beta f} m*^{\beta m} x*^{\psi})/(n+g+\delta)]^{1/(1-\alpha)} \qquad (6A.5)$$

$$f* = [(s_f k*^{\alpha} m*^{\beta} x*^{\psi} Q_f)/(n+g+\delta)]^{1/(1-\beta f)} \qquad (6A.6)$$

$$m* = [(s_m k*^{\alpha} f*^{\beta f} x*^{\psi} Q_m)/(n+g+\delta)]^{1/(1-\beta m)} \qquad (6A.7)$$

$$x* = [(s_x k*^{\alpha} f*^{\beta f} m*^{\beta m})/(n+g+\delta)]^{1/(1-\psi)} \qquad (6A.8)$$

We now substitute equation (6A.6) into equation (6A.5) to get:

$$k^* = [(s_k^{(1-\beta f)}\, s_f^{\beta f}\, m^{\beta m}\, x^{\psi}\, Q_f^{\beta f})/(n+g+\delta)]^{1/(1-\beta f-\alpha)} \qquad (6A.9)$$

Similarly, we substitute equation (6A.6) into equations (6A.7) and (6A.8) to get, respectively, equations (6A.10) and (6A.11) below.

$$m^* = [(s_m^{(1-\beta f)}\, k^{\alpha}\, s_f^{\beta f}\, x^{\psi}\, Q_f^{\beta f}\, Q_m^{(1-\beta f)})/(n+g+\delta)]^{1/(1-\beta f-\beta m)} \qquad (6A.10)$$

$$x^* = [(s_x^{(1-\beta f)}\, k^{\alpha}\, s_f^{\beta f}\, m^{\beta m}\, Q_f^{\beta f})/(n+g+\delta)]^{1/(1-\beta f-\psi)} \qquad (6A.11)$$

We next substituted equation (6A.10) into equations (6A.9) and (6A.11) to get, respectively, equations (6A.12) and (6A.13) below.

$$k^* = [(s_k^{1-\beta f-\beta m}\, s_f^{\beta f}\, s_m^{\beta m}\, x^{\psi}\, Q_f^{\beta f}\, Q_m^{\beta m})/(n+g+\delta)]^{1/(1-\beta f-\beta m-\alpha)} \qquad (6A.12)$$

$$x^* = [(s_x^{1-\beta f-\beta m}\, s_m^{\beta m}\, k^{\alpha}\, s_f^{\beta f}\, Q_f^{\beta f}\, Q_m^{\beta m})/(n+g+\delta)]^{1/(1-\beta f-\beta m-\psi)} \qquad (6A.13)$$

Finally, we substitute equation (6A.13) into (6A.12) to get equation (6A.14) below.

$$k^* = [(s_k^{1-\beta f-\beta m-\psi}\, s_f^{\beta f}\, s_m^{\beta m}\, s_x^{\psi}\, Q_f^{\beta f}\, Q_m^{\beta m})/(n+g+\delta)]^{1/(1-\beta f-\beta m-\alpha-\psi)} \qquad (6A.14)$$

Equation (6A.14) is identical to equation (6.11) in Chapter 6. A similar process is applicable to the derivation of equations (6.12) to (6.14).

## APPENDIX 6.2 Data Used for the Estimation of Equations (6.16) and (6.17)

| *Country* | *gdpw60* | *gdpw90* | *Ski* | *schoolF* | *schoolM* | *8mathF* | *8mathM* | *8sciF* | *8sciM* | *Xi* | *n+g+d* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **SthAfrica** | 6306 | 9595 | 0.184 | 4.38 | 4.59 | 349 | 360 | 315 | 337 | 28 | 0.0739 |
| **Canada** | 19484 | 34380 | 0.239 | 9.97 | 9.99 | 530 | 526 | 525 | 537 | 10 | 0.073 |
| **U.S.A.** | 24433 | 36771 | 0.199 | 10.27 | 10.3 | 497 | 502 | 530 | 539 | 11 | 0.0673 |
| **Colombia** | 5485 | 10108 | 0.158 | 3.91 | 3.88 | 384 | 386 | 405 | 418 | 19 | 0.076 |
| **HK** | 4172 | 22827 | 0.199 | 5.9 | 8.24 | 577 | 597 | 507 | 535 | 11 | 0.0774 |
| **Israel** | 9685 | 23780 | 0.261 | 8.11 | 8.87 | 509 | 539 | 512 | 545 | 12 | 0.0795 |
| **Japan** | 4998 | 22624 | 0.342 | 7.81 | 8.44 | 600 | 609 | 562 | 579 | 9 | 0.0615 |
| **Korea** | 2703 | 16022 | 0.232 | 5.74 | 7.91 | 598 | 615 | 551 | 576 | 18 | 0.0758 |
| **Singapore** | 5008 | 24369 | 0.309 | 4.43 | 6.13 | 645 | 642 | 603 | 612 | 14 | 0.0796 |
| **Thailand** | 1884 | 6754 | 0.174 | 4.01 | 4.99 | 526 | 517 | 526 | 524 | 21 | 0.0772 |
| **Austria** | 10713 | 26700 | 0.257 | 5.2 | 6.6 | 536 | 544 | 549 | 566 | 12 | 0.0527 |
| **Belgium** | 14310 | 31730 | 0.238 | 8.12 | 8.64 | 546 | 547 | 503 | 519 | 12 | 0.0558 |
| **Denmark** | 14807 | 24971 | 0.258 | 9.93 | 10.48 | 494 | 511 | 463 | 494 | 11 | 0.0606 |
| **France** | 13478 | 30357 | 0.273 | 5.4 | 5.73 | 536 | 542 | 490 | 506 | 11 | 0.0592 |
| **Greece** | 5151 | 17717 | 0.247 | 5.27 | 7.26 | 478 | 490 | 489 | 505 | 11 | 0.0546 |
| **Ireland** | 8391 | 24058 | 0.247 | 7.25 | 7.06 | 520 | 535 | 532 | 544 | 12 | 0.0564 |
| **Netherls** | 17117 | 31242 | 0.247 | 7.23 | 7.65 | 536 | 545 | 550 | 570 | 9 | 0.0641 |
| **Norway** | 14291 | 29248 | 0.31 | 6.52 | 7.03 | 501 | 505 | 520 | 534 | 9 | 0.0645 |
| **Portugal** | 4853 | 16637 | 0.227 | 2.71 | 3.5 | 449 | 460 | 468 | 490 | 14 | 0.0587 |
| **Spain** | 8186 | 26364 | 0.253 | 5.07 | 5.52 | 483 | 492 | 508 | 526 | 9 | 0.0565 |
| **Sweden** | 17352 | 28289 | 0.235 | 8.59 | 9.03 | 518 | 520 | 528 | 543 | 9 | 0.0603 |
| **Switz** | 20149 | 32812 | 0.302 | 7.56 | 8.32 | 543 | 548 | 514 | 529 | 9 | 0.06 |
| **UK** | 14754 | 26755 | 0.181 | 8.09 | 8.03 | 504 | 508 | 542 | 562 | 11 | 0.0552 |
| **Australia** | 19261 | 30312 | 0.286 | 9.67 | 10.28 | 532 | 527 | 540 | 550 | 11 | 0.0725 |
| **NZ** | 21285 | 25413 | 0.246 | 10.62 | 10.96 | 503 | 512 | 512 | 538 | 12 | 0.0679 |

**Explanatory Notes**

The data for the physical capital investment rate ($s_{k,i}$) and for the growth rate of the population aged 15-64 years ($n+g+\delta$) were constructed in a manner similar to that described in previous Chapters. The data on schooling quantity by gender measure the mean number of years of schooling attained by the female and male populations aged 15 years and over (*schoolF* and *schoolM*, respectively).

Health capital ($X_i$) is proxied by the difference between the average life expectancy in each country and 85 years. Due to data limitations, we used simply the life expectancy in each country in 1980, rather than a mean of the life expectancy over the sample period. Finally, the schooling quality data are simply the separate male and female test scores, by country, for the year 8 mathematics and science tests (*8mathF*, *8mathM* and *8sciF*, *8sciM* respectively). These data were obtained from the T.I.M.S.S. report.

# CHAPTER 7

## Conclusion

The differences in the material standard of living between the richest and poorest countries in the world are large and increasing. One of the most important challenges facing economists is to better understand the causes of these disparities. Over the last few decades, a number of different economic models of income determination and growth have been constructed. Most emphasise the importance of human capital as an engine of growth. One of the objectives of this thesis has been to further promote our understanding of the factors which influence the accumulation of human capital and hence the economic growth rate.

We defined human capital as the skills, abilities and knowledge of workers which result in the creation of value added. Whilst human capital is also acquired via on-the-job training and learning-by-doing, we concentrated on the importance of human capital acquired via formal schooling. Most theoretical models and empirical studies of economic growth assume that human capital is an increasing function of the quantity of schooling, such as the proportion of non-leisure time spent studying or the share of total output devoted to schooling. However, these studies have ignored the substantial variations which exist in the quality of schooling across countries as a potential source of differences in measured economic growth rates. We have shown that, within the augmented Solow model of MRW, differences in schooling quality are positively and significantly associated with differences in economic growth rates across a sample of countries.

We also investigated which factors are important determinants of schooling quality. Our results indicated that hours of subject specific homework are negatively and significantly associated with schooling quality across countries, whilst the education level of parents, the student-teacher ratio and hours spent by teachers performing non-teaching duties are positively and significantly associated with mean test scores across countries. Our results also indicated that neither of the two macroeconomic variables included in the analysis, real per capita incomes and real per capita expenditures on schooling, were significantly associated with mean schooling quality in our sample of countries.

The final issue examined concerned whether cross-country differences in schooling quality by gender are significant determinants of cross-country differences in per capita incomes and mean growth rates. Our preliminary investigation suggests that both the quantity and quality of schooling of males (females) is negatively (positively) associated with per capita incomes but that both the quantity and the quality of schooling of males are positively and significantly associated with economic growth rates across countries.

These findings suggest that schooling quality is important for the accumulation of human capital, and thus for economic growth, and that countries should also aim to increase the quality of schooling rather than simply encouraging more schooling.

This thesis has left a number of issues unresolved. For instance, we have assumed that test scores are reasonable proxies for schooling quality, although we noted at the outset that an ideal measure would capture only value added by schooling. Hence one obvious question is whether there exists a better method of measuring value-added by schools across countries. We also noted that mathematics test scores had a particularly strong positive impact in the growth rate regressions. It would be useful to know what is driving this outcome. Another issue concerns whether social and institutional biases against the participation of women in the paid workforce exist in poorer countries, and if so whether such biases diminish over time simply as a result of natural economic development which brings with it increases in per capita incomes, or whether more interventionist government policy is needed. Finally, we note from the data of Table 4.4 that schooling quality in the French and Flemish education systems in Belgium varies greatly. If students in Belgium are essentially homogeneous with respect to their background characteristics then a closer examination of the educational practices and policies pursued by these two systems may shed further light on which factors are important determinants of schooling quality.

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