Growth and Multiple Forms of Human Capital in an Augmented Solow Model: A Panel Data Investigation

Scott McDonald, and Jennifer Roberts[1]

PRELIMINARY DRAFT. PLEASE DO NOT QUOTE

1. Introduction

Since the late 1980s there has been a resurgence of interest in economic growth, especially in the empirical research that has sought to examine the extent to which competing economic theories describe the growth process. A substantial part of the literature has been dedicated to quantifiying the contribution of human capital to the growth process (Mankiw *et al.*, 1992; Barro and Lee, 1993; Benhabib and Spiegel, 1994). Mankiw *et al*., (1992), hereafter MRW, justify the inclusion of a human capital variable by noting that if multiple forms of capital exist then "omitting human-capital accumulation biases the estimated coefficients" (1992, p 408). To overcome the misspecification bias due to an omitted variable MRW 'augmented' the Solow model by adding a term for human-capital accumulation in terms of education. This has become a standard approach in the empirical growth literature. However there is a long tradition that human capital is a complex input consisting of far more than knowledge capital, and, in particular, that attention should be given to health capital (e.g., Schultz, 1961; Mushkin, 1962.). This implies that a failure to include other dimensions of human capital than education will only partially address the misspecification bias. Only three papers are known that report estimates of the effects of health on growth, Hicks (1979), Wheeler (1980) and Knowles and Owen (1995). Although the methods vary, all three studies adopt estimating equations that use the cross-country cross-section method dominant in the literature.

The cross-country cross-section method has been extensively criticised in recent years. First, the method requires the imposition of restrictions assuming common initial technologies, common rates of technical progress and common preferences across countries. Second, cross section regressions collapse dynamics and therefore discard potentially important information. Panel data methods on the other hand permit explicit testing of the assumptions required by the cross-section method and they make use of information arising from variation across

1 Jennifer Roberts is a Lecturer in Health Economics, ScHARR, and Scott McDonald a Lecturer in Economics at the University of Sheffield. The research reported in this paper was supported by a research grant from ScHARR. The authors gratefully acknowledge research assistance by Jon Harper but retain sole responsible for all errors in the arguments and conclusions reported in this paper.

countries and over time. In the context of economic growth, panel data studies have indicated that the results of cross-section studies may be suspect (Islam, 1995; Lee et al., 1996, 1997, 1998; Miller, 1996; Cellini, 1997; McDonald and Roberts, 1999).

In this paper an augmented Solow model is developed that incorporates both health and education capital in a dynamic panel data model. The model is an extension to previous research by Islam (1995) and Knowles and Owen (1995). The next section reports the derivation of the estimating equation and discusses panel data methods. The results from the econometric estimates, using a panel data set of 77 countries for the period 1960 to 1989, are reported in Section 3, which also records details of the data used. Section 4 contains concluding comments.

2. Health, Growth and Convergence in an Augmented Solow Model

The Augmented Solow Model

Augmenting the Solow model with terms for both education capital (*E*) and health capital (*H*) is a straightforward extension. Defining the aggregate production function as a Cobb-Douglas function with constant returns to scale and labour augmenting technical progress, the process of augmentation simply involves the addition of an argument for health capital, i.e.,

$$Y(t) = \left[A(t)\,L(t) \right]^{1-a} K_p{}^{a_p} K_h{}^{a_h} \tag{1}$$

where *Y* is output, *A* is technology, *L* is the stock of labour, *K*, *E* and *H* are respectively the stocks of physical, education and health capital, a, b and y are the elasticities of output with respect to the various capital terms, and the subscripts denote country (*i*) and time (*t*). Knowles and Owen (1995) start from the same production function. Equation (1) can be re-written in intensive form as

$$\hat{y}(t) = \hat{k}(t)^{a_p}\,\hat{h}(t)^{a_h} = \frac{y(t)}{A(t)} \tag{2}$$

where $y(t)$ is output per capita and $\hat{y}(t)$ is output per 'effective' labour unit $\left(A_{it}L_{it}\right)$, and $h(t)$ and $\hat{h}(t)$, $h(t)$ and $\hat{h}(t)$ and $h(t)$ and $\hat{h}(t)$ are respectively physical, education and health capital per capita and per 'effective' labour unit.

Assuming that the labour forces grow at the constant rates n_i, and technologies advance at period specific constant rates g_t i.e., the growth rates of labour and technology are country- and time-period specific, and that the physical, education and human capital stocks depreciate at the same constant rate, δ, then

$$K_p(t) = I_p(t-1) + (1-d)K_p(t-1) \cdot \qquad (3)$$
$$K_h(t) = I_h(t-1) + (1-d)K_h(t-1)$$

If savings are divided between physical, education and human capital accumulation, i.e., education and health capital accumulation is treated as an investment activity, such that

$$s = s_p + s_h = \frac{S}{Y} = \frac{I}{Y} = \frac{I_p + I_h}{Y} \cdot \qquad (4)$$

then the rates of physical, education and health capital growth per unit of labour are defined as

$$\dot{\hat{k}}(t) = s_p \hat{y}(t) - (n+g+d)\hat{k}(t) \qquad (5)$$
$$\dot{\hat{h}}(t) = s_h \hat{y}(t) - (n+g+d)\hat{h}(t)$$

and the steady state values of $\hat{k}^*$, $\hat{k}^*$ and $\hat{h}^*$ are

$$\hat{k}^* = \left[\frac{s_h^{a_h} s_p^{1-a_h}}{n+g+d}\right]^{1/(1-a)} \qquad (6)$$
$$\hat{h}^* = \left[\frac{s_p^{a_p} s_h^{1-a_p}}{n+g+d}\right]^{1/(1-a)}$$

and therefore

$$\ln \hat{k}^* = \frac{1}{1-a}\left[\ln\left(s_h^{a_h} s_p^{1-a_h}\right) - \ln\left(n+g+d\right)\right] \cdot \qquad (7)$$
$$\ln \hat{h}^* = \frac{1}{1-a}\left[\ln\left(s_p^{a_p} s_h^{1-a_p}\right) - \ln\left(n+g+d\right)\right]$$

Incorporating physical, education and health capital the augmented steady state output per capita is

$$\ln y^*(t) = \ln A(0) + gt - \frac{a}{1-a}\ln(n+g+d) + \frac{a_p}{1-a}\ln s_p + \frac{a_h}{1-a}\ln s_h \qquad (8)$$

which is equivalent, although marginally different, to MRW's equation 11 (p 417) and Knowles and Owen's equation 11 (1995, p101).

MRW, and subsequently Knowles and Owen (1995) propose alternative formulations of the estimating equation according to whether the augmenting capital terms are recorded as rates of accumulation, as in equation 8, or as levels, i.e.,

(9)

$$\ln y^*(t) = \ln A(0) + gt - \frac{a_p}{1-a_p}\ln(n+g+d) + \frac{a_p}{1-a_p}\ln s_p + \frac{a_h}{1-a_p}\ln h^*$$

The choice of estimating equation is likely to be determined by the available data. But, since in general the savings/investment data for a country are likely to refer to physical capital, those variants dependent upon data for savings/investment in education and health capital are unlikely to be empirically viable. The mixing of stock and accumulation terms in (9) may be considered anomalous. Extending the logic behind equation (9) gives[2]

$$\ln y^*(t) = \ln A(0) + gt - \frac{a_p}{1-a_p}\ln(n+g+d) + \frac{a_p}{1-a_p}\ln s_p + \frac{a_h}{1-a_p}\ln h^* \quad . \qquad (10)$$

A major advantage of (10) is that it avoids the necessity of imposing (arbitrary) assumptions (see below).

Linearising the growth equations around the steady-state level of income per effective unit of labour, $\hat{y}^*_{it}$, by following the method used by MRW produces

(11)

$$\ln y^*(t) = \ln A(0) + gt - \frac{a_p}{1-a_p}\ln(n+g+d) + \frac{a_p}{1-a_p}\ln s_p + \frac{a_h}{1-a_p}\ln h^*$$

Equations (11) are the basis for the econometric estimates reported in this paper. The distinctive differences between these expressions and those used by MRW and Knowles and Owen (1995) are the allowances for cross-time variations in the rates of growth of technology, g_t, and the country specific initial states of technology, lnA_{i0}.

To estimate (11) as a cross-section by Ordinary Least Squares (OLS) MRW imposed two assumptions.[3] First, it was assumed that (g_i + d) equals 0.05 for all countries since no data on the exogenous rates of technical change (g_i) and the rates of depreciation (d) were available. And second, the term lnA_{i0}, which includes technology, resource endowments, climate, institutions and other non-observable country specific factors, needs specifying. MRW (p 411, 1992) made the identifying assumption that

2 The exposition follows MRW for ‘consistency’ but in fact (9) is based on an implicit (10).

3 Knowles and Owen (1995) imposed the same assumptions (see Notes to Table 1, p 104).

$$\ln A(0) = a + e \,. \tag{12}$$

It is presumed that a is a constant, invariant across countries, that all country differences are accounted for by the random term, e, and that the stochastic term is independent of all other explanatory variables. MRW (pp 411-2) provide three qualitative arguments to justify their (identifying) assumptions.

Consequently, embedded within the vast majority of the empirical growth literature there are two strong assumptions, i.e., $A_{i0} = A_0, g_i = g \forall i$, that have in general gone untested. If these assumptions are not valid then doubts must be cast upon the results from empirical research dependent on these assumptions.

Equations 11 are a dynamic panel data model with two-way fixed effects, i.e., time-invariant country effects and time-specific technology effects. Hence the equations can be expressed in notation common in the panel data literature as

$$g_{it}^{*} = -f z_{i0}^{*} + \sum_{j=1}^{4} q_j x_{it}^{j} + h_t + m_i + n_{it} \tag{13}$$

where

$$g_{it}^{*} = \ln \hat{y}_{it}^{*} - \ln \hat{y}_{i0}^{*}$$
$$f = \left(1 - e^{lt}\right)$$
$$z_{i0}^{*} = \ln \hat{y}_{i0}^{*}$$
$$q_1 = -q_2 = \frac{fa}{(1-a)}$$
$$x_{it}^{1} = \ln(n_i + g_t + d)$$
$$x_{it}^{2} = \ln s_i^{k}$$
$$q_3 = \frac{fb}{(1-a)}$$
$$x_{it}^{3} = \ln \hat{e}_{it}^{*}$$
$$q_4 = \frac{fy}{(1-a)}$$
$$x_{it}^{4} = \ln h_{it}^{*}$$
$$h_t = g_t t$$
$$m_i = f \ln A_{i0}$$

Estimates using (13) can be used to test the restriction required by OLS.

The early empirical research (e.g., Barro and Sala-i-Martin, 1992; MRW, 1992; Knowles and Owen, 1995) reported cross-section estimates of variants of (11). These studies allowed for country specific differences in steady-state level of income, through the concept of conditional convergence, but assumed that the parameters of the underlying production function were homogeneous. Solow (1994), among others, cast doubt upon the validity of the assumption that the parameters of the production function were common across countries with only the variables subject to differences. Using panel data Islam (1995) re-estimated the augmented Solow model with fixed-effects to allow for parameter heterogeneity. The fixed-effects estimates address the potential problem of bias in the cross-section estimates due to correlation between the intercepts and regressors. While the fixed-effects estimation procedure allows the levels of income to vary across countries, it retained the presumption of a common rate of technology growth. By so doing Islam maintained the standard interpretation of convergence (Islam, 1998). On the otherhand, Lee *et al*., (1997 and 1998) argue that estimation of (11) with a common technology growth rate (*g*) produces inconsistent fixed-effects panel estimators.

The analyses that are reported in this paper proceed by progressively relaxing the imposed restrictions on the estimating equations and testing the validity of these commonly used restrictions. While Islam (1998) is undoubtedly correct when stating that cross-country variations in the rate of technical progress undermine the concept of convergence, this does not affect the importance of testing whether the restriction is consistent with the evidence.

3. Analysis

Data

The main source of data is the Penn World Tables version 5.6 (PWT) (see Summers and Heston, 1988 and 1991). The data used are real GDP per worker (RGDPW in the PWT), share of real GDP invested (I), and working population (POPW) which is calculated from real GDP per capita, total population and RGDPW. It is assumed that s_p is measured by the rate of investment in real GDP (per worker), I, and is solely used for physical capital accumulation. The rates of growth of GDP and working population are estimated by log linear regression from RGDPW and POPW.

The education and physical capital stock data come from Nehru and Dhareshwar (1993) and Nehru et al. (1995). These sources provide physical and education capital stock data for 92 countries between 1960 and 1987. The physical capital stock series, PKS87, is converted to capital stock per worker (PKSW) using POPW. The education capital stock data are recorded as four series; mean years of primary education, mean years of secondary education, mean years of tertiary education, mean years of total education. The results presented below use the latter which is denoted HKT.

Two alternative measures of health capital are used, and both data series come from World Data (World Bank, 1997). Infant mortality (INF) is defined as the number of infant deaths under one year of age per 1000 live births. Life expectancy at birth is defined as the mean age at death of a fictitious generation subject to the mortality conditions of the period considered. The life expectancy data were transformed into terms of the shortfall of life expectancy relative to a nominal benchmark, i.e., LE = - ln(80 – life expectancy).[4] While these proxies have been criticised as crude because they make "no allowance for the quality of health beyond survival" (Knowles and Owen, 1995, p 102), they have been strongly defended in the macroeconomic context of developing countries (see Sen, 1998).

All the variables are in logarithms. There are three samples, a 22-country OECD sample a 77-country sample, and a 55 country sample of LDCs. The 77 country sample is defined as the intersection of the MRW's 98 non-oil producing country sample with the human capital data series by Nehru *et al*., (1995).[5] Details of the sample are reported in the Appendix.

Results[6]

Cross section regressions largely confirm the results of Knowles and Owen (1995)[7]. When health capital is not included as an explanatory variable, education capital is a significant variable in the full sample and the OECD sample. When LE is included to account for health capital, the coefficient on HKT is insignificant in all three samples (although p = 0.11 for the OECD). The coefficient on LE is positive and significant for the full and OECD samples, but only significant at $t_{0.20}$ for the LDC group. Including INF as an alternative measure of health capital produces very similar results. The coefficient on INF has the expected negative sign and substantially reduces the marginal significance level of the coefficient on HKT.

The cross section results are derived having collapsed the time series information present in the data, and also implicitly impose the restrictions discussed above. The results reported in Table 1 address this weakness by following Islam (1995) and estimating the equations using a 5 yearly panel. The dependent variable in each case is the average annual growth rate of income for each five year period derived from a regression of the logarithm of RGDPW on a time trend. The models reported allow for country specific fixed effects; this specification was confirmed by Breush-Pagan and Hausman tests. Our approach differs slightly from that of Islam (1995) who estimated two-way error components models. Here we include only those time effects that have coefficients significant at t0.10. In all cases Wald tests confirm our preferred specification. Estimation allows for White's heteroscedasticity consistent standard errors.

The various results are reported for both restricted and unrestricted regressions, where the restriction is that ln(I) and ln($n + g + d$) are equal and opposite. The lower panel in each table

---

4 This transformation is typical of the Human Development Report (e.g., UN, 1998) and has been used by Anand and Ravallion (1993) and Knowles and Owen (1995).

5 There 84 countries in the sample used by Knowles and Owen (1995).

6 All estimation was carried out using STATA v6.0 and Eviews v3.0.

7 The cross section results are available from the authors.

reports the restricted regressions, where INGD =ln(I) – ln(ngd) and the WALD(F) statistic is a test of the restriction. While we find positive coefficients on ln(I) and negative on ln(ngd) (except for the OECD sample, where the estimates are not statistically significant) we do not find that the coefficient estimates are equal and opposite[8].

8 This restriction is not rejected in the cross section results of Knowles and Owen (1995), but in general the relevant estimated coefficients are not individually significant. Islam (1995) does not report the restriction test for his panel model with education capital.

Table 1 Five Yearly Panel - Fixed Effects Models

	Full Sample n = 77			**LDC Sample n = 55**			**OECD Sample n = 22**		
Unrestricted									
I	0.025	0.026	0.027	0.027	0.027	0.028	-0.009	-0.009	-0.017
	(4.34)	(4.68)	(4.74)	(4.45)	(4.51)	(4.64)	(-0.62)	(-0.71)	(-1.09)
NGD	-0.084	-0.081	-0.079	-0.093	-0.091	-0.090	-0.028	-0.018	-0.019
	(-9.80)	(-9.03)	(-8.67)	(-9.37)	(-9.09)	(-8.82)	(-1.98)	(-1.49)	(-1.21)
HKT	0.008	0.005	0.005	0.014	0.011	0.010	0.026	0.011	0.020
	(1.97)	(1.05)	(1.06)	(2.95)	(2.11)	(1.73)	(1.44)	(0.77)	(1.08)
INF		-0.018			-0.010			-0.032	
		(-2.51)			(-1.01)			(-4.65)	
LE			0.023			0.021			0.021
			(2.72)			(1.39)			(3.39)
YW(-1)	-0.049	-0.068	-0.066	-0.060	-0.067	-0.071	-0.046	-0.087	-0.068
	(-8.61)	(-6.53)	(-6.98)	(-7.52)	(-5.90)	(-6.09)	(-5.65)	(-7.18)	(-5.90)
Y3								0.006	0.006
								(2.10)	(1.98)
Y4	0.005	0.006	0.006	0.008	0.009	0.009			
	(1.74)	(2.12)	(2.26)	(2.35)	(2.50)	(2.57)			
Y5	-0.019	-0.019	-0.018	-0.021	-0.021	-0.021	-0.016	-0.017	-0.016
	(-6.09)	(-6.07)	(-5.81)	(-5.26)	(-5.14)	(-5.07)	(-5.80)	(-6.17)	(-5.69)
$\bar{R}^2$	0.51	0.52	0.52	0.51	0.51	0.51	0.62	0.67	0.64
λ	0.010	0.014	0.014	0.012	0.014	0.015	0.009	0.018	0.014
Restricted									
INGD	0.038	0.039	0.039	0.041	0.041	0.041	0.010	0.005	0.001
	(7.10)	(7.38)	(7.37)	(7.12)	(7.12)	(7.26)	(0.77)	(0.55)	(0.06)
HKT	0.004	-0.0004	-0.0002	0.010	0.006	0.004	0.027	0.010	0.018
	(0.77)	(-0.08)	(-0.04)	(1.59)	(0.813)	(0.507)	(1.38)	(0.65)	(0.95)
INF		-0.023			-0.014			-0.036	
		(-3.19)			(-1.38)			(-5.33)	
LE			0.032			0.031			0.025
			(3.67)			(1.93)			(4.25)
YW(-1)	-0.053	-0.075	-0.076	-0.067	-0.076	-0.081	-0.043	-0.091	-0.069
	(-7.99)	(-6.80)	(-7.31)	(-7.19)	(-6.11)	(-6.41)	(-5.15)	(-7.58)	(-6.02)
$\bar{R}^2$	0.47	0.49	0.49	0.46	0.46	0.47	0.60	0.67	0.63
Wald (F)	29.20	23.85	21.80	29.06	27.79	25.89	4.62	2.55	3.17
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.04]	[0.11]	[0.08]
λ	0.011	0.016	0.016	0.014	0.016	0.017	0.009	0.019	0.014
α	0.418	0.342	0.339	0.380	0.350	0.336	0.189	0.052	0.014
β	0.044	-0.004	-0.002	0.093	0.051	0.033	0.509	0.104	0.257
ψ (INF)		-0.202			-0.120			-0.375	
ψ (LE)			0.278			0.254			0.357

Dependent variable is AYW. t statistics in parentheses (White's heteroscedasticity consistent standard errors)
Panel estimation based on 5 yearly averages 1960-1989 (i.e. t = 1,2,…,6)
In all cases Breusch-Pagan tests confirm the presence of individual effects and Hausman tests suggest fixed effects are the appropriate specification. In all cases $\chi 2$ tests confirm the presence of both country and time effects.
Time effects in the restricted models are very similar to the unrestricted models, and are not reported here.
Wald (F) is a test of the linear restriction implied by the restricted regression., i.e. that the coefficients on LI and LNGD are equal and opposite.

For the full sample the results are very similar to those of the cross section. Education capital is significant when health capital is omitted but loses significance when either LE or INF are included in the growth model. Both LE and INF have the expected signs and are significant at $t_{0.01}$. In the LDC sample HKT retains significance when health capital is introduced, and while both LE and INF have the expected signs their estimated coefficients are not significant at $t_{0.10}$. For the OECD group I, NGD and HKT are not significant and the model is driven by the lagged income variable and by the health variables when they are included .

For the two larger samples explanatory power is around 0.50. Significant time effects are found for 1975 to 79 (positive) and 1980 to 84 (negative). Explanatory power rises to over 0.60 in the OECD group and significant time effects are found in 1970 to 74 (positive) and 1980 to 84 (negative). The importance of country specific fixed effects challenges the assumption of common initial states of technology implicitly assumed in the cross section approach. Similarly the significance of time effects casts doubt on the assumption of a constant rate of growth of technology over time.

In terms of the structural parameters reported at the bottom of Table 1, traditionally l has been interpreted as the speed of convergence. However, there are problems with this interpretation in the cross section framework (Quah, 1993; Islam, 1995) and more recently a debate has emerged concerning the concept of convergence in a more fundamental sense, in the context of dynamic models (Lee *et al*., 1997, 1998; Islam, 1995, 1998). Our estimates of l are similar to Islam (1995), and if we accept his argument that l is an acceptable estimate of the convergence parameter in a fixed effects model, then it appears that the inclusion of health capital speeds up the rate of convergence slightly. This result is robust across both the restricted and unrestricted models. The elasticity of output (α) is reduced substantially by the inclusion of heath capital. The exponents of health capital themselves (ψ) are similar whichever measure of health is used. The inclusion of health capital does substantially alter the coefficient on the education variable, and this is the expected finding if omission of health capital causes a misspecification problem, with health and education stock correlated.

5 Concluding Comments

The significance of health capital in the Solow model provides empirical support for the commonly held suspicion that education capital is an inadequate proxy for human capital. At the same time appreciable evidence has been obtained as to the relative importance of health capital in the growth process. The results from using infant mortality rates and life expectancy in this way are consistent with the arguments of Sen (1998), that these measures are meaningful in a macroeconomic context.

The importance of country specific fixed effects challenges the assumption of common initial states of technology implicitly assumed in the cross section approach. Similarly the significance of time effects casts doubt on the assumption of a constant rate of growth of technology. The analyses reported in this paper substantially complements the earlier work of Islam (1995) and Knowles and Owen (1995). Our panel framework is consistent with criticisms of the cross section approach, and our results confirm those of Islam (1995) in this sense. The inclusion and significance of health capital are consistent with Knowles and Owen (1995).

The invalidity of the restrictions imposed in the lower half of Table 1, casts some doubt on the structural parameters derived from the estimates of equation (13). Our aim is to further investigate the role of both health and education capital in the growth process by endogenising these variables in a macroeconomic growth model. In addition the current five yearly panel framework does not permit variation of growth rates of technology across countries. Lee *et al.*, (1998) argue that if there is heterogeneity in both growth rates and the speed of convergence across countries then fixed effects estimates will be inconsistent. A further aim is to extend our work using annual panel data with a mean group estimator. Initial results are promising with significant coefficient estimates on both education and health capital variables, and strong evidence for cross-country variation in growth rates of technology. This questions the simple vision of technology as a universal good, and suggests that efforts to improve the diffusion of technology may reap substantial returns. However, the introduction of annual data raises a number of time series issues concerning non-stationarity and cointegration, which is further complicated by the fact that the neo-classical model assumes a cointegrating relationship. These issues warrant further consideration.

References

Anand, S. and Ravallion, M., (1993). 'Human Development in Poor Countries: On the Role of Private Incomes and Public Services', Journal of Economic Perspectives, Vol 7, pp 133-150.

Barro, R.J. and Sala-i-Martin, X., (1992). 'Convergence', *Journal of Political Economy*, Vol 100, pp 223-251.

Barro, R.J. and Lee, J., (1993). 'International Comparisons of Educational Attainment', *Journal of Monetary Economics*, Vol 32, pp 363-394.

Cellini, R., (1997). 'Growth Empirics: Evidence from a Panel of Annual Data', *Applied Economics Letters*, Vol 4, pp 347-351.

Hicks, N.L., (1979). 'Growth vs. Basic Needs: Is There a Trade-Off', *World Development*, Vol 7, pp 985-994.

Islam, N., (1995). 'Growth Empirics: A Panel Data Approach', *Quarterly Journal of Economics*, Vol 110, pp 1127-1170.

Islam, N., (1998). 'Growth Empirics: A Panel Data Approach – A Comment', *Quarterly Journal of Economics*,

Knowles, S. and Owen, P.D., (1995). 'Health Capital and Cross-Country Variation in Income per Capita in the Mankiw-Romer-Weil Model', Economics Letters, Vol 48, pp 99-106.

Lee, K., Pesaran, M.H. and Smith, R., (1996). 'Growth and Convergence: A Multi-Country Empirical Stochastic Solow Model', University of Leicester, *Department of Economics*, *Discussion Paper* 96/14.

Lee, K., Pesaran, M.H. and Smith, R., (1997). 'Growth and Convergence in a Multi-Country Empirical Stochastic Solow Model', *Journal of Applied Econometrics*, Vol 12, pp 357-392.

Lee, K., Pesaran, M.H. and Smith, R., (1998). 'Growth Empirics: A Panel Data Approach - A Comment', *Quarterly Journal of Economics*, Forthcoming.

Mankiw, N.G., Romer, D. and Weil, D.N., (1992). 'A Contribution to the Empirics of Economic Growth', *Quarterly Journal of Economics*, Vol 107, pp 407-437.

McDonald, S. and Roberts, J., (1999). 'Testing Growth Models: Should Cross-Section Growth Studies be Used to Inform Policy?', *South African Journal of Economics*, Vol ??, pp ?? -??.

Miller, S.M., (1996). 'A Note on Cross-country Growth Regressions', *Applied Economics*, Vol 28, pp 1019-1026.

Mushkin, S.J. (1962) 'Health as an investment' *Journal of Political Economy*, 70, 129-157

Nehru, V. and Dhareshwar, A., (1993). 'A New Database on Physical Capital Stock: Sources, Methodology and Results', *Revista de Analisis Economico*, Vol 8, pp 37-59.

Nehru, V., Swanson, E. and Dubey, A., (1995). 'A New Database on Human Capital Stock in Developing and Industrial Countries: Sources, Methodology and Results', *Journal of Development Economics*, Vol 46, pp 379-401.

OECD (1996). *OECD Health Data CD-ROM*. Paris: OECD.

Quah, D., (1993). 'Galton's Fallacy and Tests of the Convergence Hypothesis', *Scandinavian Journal of Economics*, Vol 95, pp 427-443.

Schultz, T.W. (1961) ' Investment in human capital', *American Economic Review*, 51, 1-17

Sen, A., (1998). 'Mortality as an Indicator of Economic Success and Failure', *Economic Journal*, Vol 108, pp 1-25.

Solow, R.M., (1994). 'Perspectives on Growth Theory', Journal of Economic Perspectives, Vol 8, pp 45-54.

Summers, R. and Heston, A., (1991). 'The Penn World Table (Mark 5): An Expanded Set of International Comparisons, 1950-1988', *Quarterly Journal of Economics*, Vol 106, pp 327-368.

UN, (Annual), *Human Development Report*, Oxford University Press: Oxford.

World Bank (1997). *World Development Indicators 1997*. Washington: World Bank.

Appendix

Samples

The full sample contains all 77 listed above. The OECD sample includes those countries denoted O and the LDC sample contains the remaining countries.

Angola		Egypt		Korea		Portugal	O
Argentina		Spain	O	Sri Lanka		Paraguay	
Australia	O	Ethiopia		Morocco		Rwanda	
Austria	O	Finland	O	Madagascar		Sudan	
Belgium	O	France	O	Mexico		Senegal	
Bangladesh		Great Britain	O	Mali		Singapore	
Bolivia		Ghana		Myanmar		Sierra Leone	
Brazil		Greece	O	Mozambique		El Salvador	
Canada	O	Guatemala		Mauritius		Sweden	O
Switzerland	O	Honduras		Malawi		Thailand	
Chile		Haiti		Malaysia		Tunisia	
Ivory Coast		India		Nigeria		Turkey	O
Cameroon		Ireland	O	Netherlands	O	Tanzania	
Colombia		Iceland		Norway	O	Uganda	
Costa Rica		Israel		New Zealand	O	Uruguay	
Germany	O	Italy	O	Pakistan		United States	O
Denmark	O	Jamaica		Panama		Venezuela	
Algeria		Japan	O	Peru		Zaire	
Ecuador		Kenya		Philippines		Zambia	
						Zimbabwe	

Definitions

Variable	Definition	Source
YW	real GDP per worker	PWT
AYW	Average annual growth rate of YW	Derived from a regression of the logarithm of YW on a time trend
YW60	real GDP per worker in 1960 (initial income)	PWT
I	share of real GP invested	PWT
NGD	(n + g + d) n = rate of growth of labour force g = rate of growth of technology d = depreciation rate of all capital stocks	PWT
HKT	mean years of total education	Nehru et al (1995)
INF	infant mortality	World Data, (World Bank 1997)
LE	shortfall in life expectancy	World Data, (World Bank 1997)