In Sickness and in Health

The story of health as told by an augmented Solow model and cross-country dynamic panel data

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Abstract

This paper tests whether the Solow model augmented with multiple forms of human capital can explain cross-country difference in growth and investigates the effect of health on the growth of per capita income. Following Knowles and Owen (1995), we introduce both education human capital and health human capital into the textbook Solow model and extend their cross-section analysis to a dynamic panel data analysis to control for omitted variable and endogeneity bias, using a robust and consistent system GMM estimator. By adopting the latest available data for a sample of 111 developed and developing countries over 1960-2004 and various health indicators, as well as splitting our data into sub-samples, We find firstly, the GMM estimators provide relatively more consistent results. The augmented MRW model provides a fairly good account of international variation in economic growth. Conditional convergence, with a speed of around 2 percent per annum, has been found in either the full sample or sub-samples. Secondly, the role of education capital measured as average years of schooling has been partially identified in the extended Solow model, rather than the original MRW model. Finally, both the stock of health, and the investment or accumulation of health capital appears strongly associated with the output growth, particularly for low income countries. The effects of health on economic growth largely vary with different samples of countries.

Keywords: Augmented Solow model, Cross-country growth regression, Dynamic panel data, Health

JEL codes: C23, I10, O47

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1 Introduction

Economic growth is indisputably important. A small difference in growth rate when compounded over a long period of time will have large consequences. There is a long history of economists who have tried to find why some countries have grown rich while others have remained poor, why some have grown quickly while others have grown slowly, and what eventually determines the long-run economic growth rates. Solow and Swan (1956) predicted *conditional convergence*[1]*;* however, they have been challenged by the so-called *endogenous growth*[2] theory. From the early 1990s, a series of empirical studies that questioned the new endogenous growth model have been largely facilitated by the development of larger and richer databases and more advanced statistical and econometric techniques, which enabled the identification of determinants of economic growth with higher precision and confidence. They were called 'the Neoclassical Revival'[3] since they utilized the Solow model to suggest that economic growth was fueled more by capital (physical and human capital)

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[1] Conditional convergence means the lower the starting level of per capita GDP, relative to the long-run or steady-state position, the faster the growth rate. It is different from the concept, absolute convergence, which states poor economies tend to grow faster than rich ones. Solow and Swan also predicted that per capita growth must eventually cease based on the assumption of diminishing returns to capital as well as the absence of continuing improvements in technology.

[2] Endogenous growth model are characterized by the assumption of non-decreasing returns to the set of reproducible factors of production, therefore countries that save more grow faster indefinitely and countries need not converge in income per capita.

[3] We are indebted to Young (1994, 1995) and Klenow and Rodriguez-Clare (1997a) for this phrase. From 1990's, the endogenous growth models endogenizing a country's technology have been shaken by a series of empirical studies. Mankiw, Romer, and Weil (1992) for the first time estimated that Solow model augmented with human capital could explain 78% of the cross-country variance of output per capital in 1985. Young looked at the East Asian growth miracles and found that their growth was fueled by growth in labor and capital than by rising productivity. Barro and Sala-i-Martin (1995) also shown that augmented Solow model was consistent with the speed of convergence they got from across countries and across regions. All these studies suggest that the level and growth rate of productivity is roughly the same across countries, so that differences in output levels and growth rates are largely due to differences in physical and human capital.

accumulation than productivity.

Mankiw, Romer, and Weil, henceforth MRW (1992) for the first time estimated that the Solow model augmented with human capital could powerfully explain the cross-country difference in the level and growth rate of income. Inspired by their work, a number of studies have empirically tested the (augmented) Solow model and the literature has witnessed the evolution of various econometric methods adopted according to different types of data structures. Criticizing one of the MRW's assumptions, that is, a constant initial technology across countries, Islam (1995); Knight, Loayza and Villanueva, henceforth KLV (1993); Caselli, Esquivel and Lefort, henceforth CEL (1996) as the first wave used panel data approach allowing differences in the aggregate production functions for different countries. Some recent studies (Bond et al., 2001; Hoeffler, 2002; Ding and Knight, 2009) use dynamic panel data and more complicated econometric techniques, e.g. GMM estimators to deal with potential problems such as omitted variables and endogeneity biasis. It was common to find in the growth literature that, the speed of convergence is stable, at around 2 percent a year[4]. However the magnitude of convergence rate is found to be sensitive to empirical methodologies, the sample of member observations and the periods in which the analysis is conducted.

The MRW model has also been criticized for ignoring the role of health capital in

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[4] See Barro and Sala-i-Martin (2004, ch.11 and 12) for application of beta-convergence tests to a variety of data sets. Also see Barro (1991, 1992); Mankiw (1995); Sala-i-Martin (1996); Heoffler (2002); Ding and Knight (2009).

economic growth as the link between economic growth and health became widely accepted. Good health crucially affects economic development and well-being through some mechanisms[5]. Firstly, it has a positive effect on workers' productivity, therefore raising levels of human capital directly, by increasing their physical capacities, such strength and endurance, as well as their mental capacities, such as cognitive functioning and reasoning ability (Strauss and Thomas, 1998). Secondly, good health also raises levels of human capital indirectly, through increasing an individual's education, such as school attendance and student performance by improving cognitive ability and the capacity to reason. Moreover, improved health can increase the effective supply of labour by minimizing the working absence due to illness and enabling existing workers to remain in active employment for more years instead of early retirement due to illness. Good health also enhances labour supply by improving female economic participation, as a decline in fertility allows women to devote more time to work. Furthermore, a population in better health may accumulate physical capital more quickly, through savings, since higher life expectancy increases the expected length of retirement. The rapid growth in some East Asian countries has been found to be attributed to this mechanism (Bloom et al., 2002). The positive effect of good health on inflows of foreign capital may also contribute to the accumulation of physical capital (Bloom and Canning, 2006; Sachs and Malaney, 2002).

Recently some studies have taken account of the neglected effects of health by

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[5] See Lopez-Casasnovas et al. (2005) for references.

incorporating health variables into the MRW model. They differ substantially in terms of functional forms, country samples, time periods, control variables, data definitions and estimation techniques. Knowles and Owen (1995, 1997) and their derivations augmented the MRW model by including health either as a separate input factor of production or a labor augmenting factor and found the significant partial correlation between health and output (also see Heshmati,2001; Webber, 2002; McDonald and Roberts, 2002; Li and Huang, 2009). Aggregate data at the country level for the post 1960 and the panel data approaches have been extensively used to investigate the inter-relationships between health and economic growth since many countries have experienced demographic and health transition in this period.

In the general growth literature, the GMM estimators have been adopted to control for unobserved country-specific effects and potential endogeneity and measurement error problems in the growth regression. But few of the studies that used dynamic panel data (DPD) and GMM estimators has focused on the effect of health on economic growth. In the health-related growth literature, the role of health has been investigated in great depth in studies with various models and datasets. However, few of them have fully dealt with the problems of omitted variable and endogeneity biases in the convergence growth regressions. Moreover, the fact that different health indicators may show different effects on economic growth has not yet been paid enough attention.

Our study is an extension of the previous literature in a number of ways. Firstly, we adopt the dynamic panel data approach to control for unobserved country-specific effects and potential endogeneity and measurement error problems of regressors in the growth regressions. Secondly, by classifying countries at a similar level of development into the same sample, we attempt partially to control for the differences in technology and institutions, as well as alleviate the problem of parameter heterogeneity; By doing this, we can also identify the effect of health on economic growth in different samples of countries. Thirdly, adopting the augmented MRW model with multiple forms of human capitals not only directly investigates the effect of health on economic growth, but also answers the questions whether convergence or divergence exists and whether the model can explain the cross-country difference in output growth. The fourth of my contributions is that we employ a variety of indicators of health and compare the effects of different health variables on economic growth since health may affect economic growth asymmetrically for poor and rich countries. Finally, by including 111 countries over a longer time period (1960-2004), we are able to present a set of more convincing results than those found in the previous studies.

The purpose of this study is to model the proximate determinants of economic growth with emphasis on variables that approximate health of the population. We aim to answer the following questions in this study. Firstly, does the augmented Solow model with multiple forms of human capitals perform well with cross-country data?

Secondly, does health affect economic growth? Thirdly, does the impact of health on output growth vary across different samples of countries? Forthly, does the way in which we measure health matter? We conclude that the answers to the above questions are all ‘yes’.

The remainder of the paper is organized as following. The augemented Solow model used to estimate the effects of health on economic growth is developed in section 2. The literature review is shown in section 3. Section 4 describes the methodology and data used in this study. Section 5 interprets the estimation results. A brief summary of our findings and some of their implications are provided in section 6.

2 Solow model in cross-country growth regressions

The basic neoclassical model of Solow (1956) and Swan (1956) has been the workhorse of economic growth theorists for understanding cross-country growth patterns. The strength of Solow’s version of the neoclassical growth model is that, despite its simplicity, it makes many predictions. To evaluate the usefulness of the model in explaining growth experiences it is worth stating one of these predictions once again: the growth process within an economy will eventually reach the steady-state where the long-run growth rate of output per capita depends only on the rate of technological progress by assuming diminishing returns to capital and exogenous rate of saving, population growth and technological progress. A mass of empirical literature has investigated the convergence prediction of Solow model. One of the most influential and widely cited pieces in the literature is the article by Mankiw, Romer, and Weil (1992). In line with MRW, a lot of empirical studies have been done aiming to explain the difference in long-run growth rates across countries (Islam, 1995; Caselli, Esquivel and Lefort, 1996; Heoffler, 2002; Bond et al., 2001; Ding and Knight, 2009).

However they ignore the human capital in the form of health although the effect of health on human capital accumulation has long been recognized. Some studies such as Knowles and Owen (1995, 1997) for the first time augmented the MRW model by introducing multiple forms of human capital, i.e. in terms of both education and health. They conducted some cross-country estimates using macro level data and suggested a strong positive relationship between growth and health, which is also consistent with the early evidence on the productivity-enhancing effects of improved health status (Schultz, 1961; Mushkin, 1962; Grossman, 1972). The major innovation of Knowles and Owen (1995) is further to augment MRW model[6] by explicitly including both the health capital and education capital components of human capital. The extended MRW aggregate Cobb-Douglas production function is presented as

$$Y(t) = K(t)^{\alpha} E(t)^{\beta} H(t)^{\psi} (A(t)L(t))^{1-\alpha-\beta-\psi} \qquad 0<\alpha,\beta,\psi<1, \qquad 0<\alpha+\beta+\psi<1 \quad (2.1)$$

where Y is real output, K is physical capital, E is human capital of education, H is human capital of health, L is labour and A is the level of technology. α, β and ψ are the share of physical, education and health capital in total output, respectively. We

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[6] For details of the MRW model, refer to their original paper and our Appendix 1.

assume the existence of a steady state with $0 < \alpha + \beta + \psi < 1$.

L and A are assumed to grow exogenously at rates n_{it} and g_{it} according to the following functions,

$$L_{it} = L_{io}e^{n_{it}t} \tag{2.2}$$

$$A_{it} = A_{io}e^{g_{it}t} \tag{2.3}$$

where e is mathematic constant with a approximately numerical value 2.718. Knowles and Owen assumed $n_{it} = n_i$ (the same over time but different for individual country), and $g_{it} = g$ (the same for all countries and over time). This assumption is the same as that of MRW. Let s_{ki} , s_{ei} and s_{hi} be the fraction of income invested in physical capital, education capital and health capital for country i, respectively. Assume also, that the same production function applies to education, health, physical capital and consumption, and additionally education and health depreciate at the same rate as physical capital, δ. The evolution of the economy is determined by

$$\dot{\hat{k}}_{it} = s_{ki}\hat{y}_{it} - (n_i + g + \delta)\hat{k}_{it} = s_{ki}\hat{k}_{it}^{\alpha}\hat{e}_{it}^{\beta}\hat{h}_{it}^{\psi} - (n_i + g + \delta)\hat{k}_{it} \tag{2.4}$$

$$\dot{\hat{e}}_{it} = s_{ei}\hat{y}_{it} - (n_i + g + \delta)\hat{e}_{it} = s_{ei}\hat{k}_{it}^{\alpha}\hat{e}_{it}^{\beta}\hat{h}_{it}^{\psi} - (n_i + g + \delta)\hat{e}_{it} \tag{2.5}$$

$$\dot{\hat{h}}_{it} = s_{hi}\hat{y}_{it} - (n_i + g + \delta)\hat{h}_{it} = s_{hi}\hat{k}_{it}^{\alpha}\hat{e}_{it}^{\beta}\hat{h}_{it}^{\psi} - (n_i + g + \delta)\hat{h}_{it} \tag{2.6}$$

where $\dot{\hat{k}}_{it}$, $\dot{\hat{e}}_{it}$ and $\dot{\hat{h}}_{it}$ are the time derivatives of $\hat{k}_{it}$, $\hat{e}_{it}$ and $\hat{h}_{it}$, respectively; $\hat{y} = Y / AL$, $\hat{k} = K / AL$, $\hat{e} = E / AL$ and $\hat{h} = H / AL$ are quantities per effective unit of labour. The economy converges to a steady state by

$$\hat{k}_i^* = \left(\frac{s_{ki}^{1-\beta-\psi} s_{ei}^{\beta} s_{hi}^{\psi}}{n_i + g + \delta} \right)^{1/\varpi} \tag{2.7}$$

$$\hat{e}_i^* = \left(\frac{s_{ki}^{\alpha} s_{ei}^{1-\alpha-\psi} s_{hi}^{\psi}}{n_i + g + \delta} \right)^{1/\varpi} \tag{2.8}$$

$$\hat{h}_i^* = \left(\frac{s_{ki}^{\alpha} s_{ei}^{\beta} s_{hi}^{1-\alpha-\beta}}{n_i + g + \delta} \right)^{1/\varpi} \tag{2.9}$$

where $\varpi = 1-\alpha-\beta-\psi$ and $\hat{k}_i^*$, $\hat{e}_i^*$ and $\hat{h}_i^*$ are the steady state values of $\hat{k}_{it}$, $\hat{e}_{it}$ and $\hat{h}_{it}$, respectively. Substituting equations (2.7) to (2.9) and (2.3) into equation (2.1) and taking logarithms gives the steady state income per capita:

$$\ln\left[\frac{Y_{it}^*}{L_{it}}\right] = \ln A_{i0} + gt - \frac{1-\varpi}{\varpi}\ln p_{it} + \frac{\alpha}{\varpi}\ln s_{ki} + \frac{\beta}{\varpi}\ln s_{ei} + \frac{\psi}{\varpi}\ln s_{hi} \tag{2.10}$$

where we define $p_i = n_i + g + \delta$. Equation (2.10) shows the level of income per capita at steady state is positively related to saving rates and negatively related to population growth. Alternatively, income per capita can be expressed as a function of the steady state levels of education and health capital. Solving (2.8) and (2.9) for s_{ei} and s_{hi} in terms of $\hat{e}_i^*$ and $\hat{h}_i^*$, and substituting them into (2.10) yields

$$\ln\left[\frac{Y_{it}^*}{L_{it}}\right] = \ln A_{i0} + gt - \frac{\alpha}{1-\alpha}\ln p_{it} + \frac{\alpha}{1-\alpha}\ln s_{ki} + \frac{\beta}{1-\alpha}\ln \hat{e}_i^* + \frac{\psi}{\varpi}\ln \hat{h}_i^* \tag{2.11}$$

Solving equation (2.9) for s_{hi} and substituting it into equation (2.10) yields

$$\ln\left[\frac{Y_{it}^*}{L_{it}}\right] = \ln A_{i0} + gt - \frac{\alpha+\beta}{1-\alpha-\beta}\ln p_{it} + \frac{\alpha}{1-\alpha-\beta}\ln s_{ki}$$

$$+ \frac{\beta}{1-\alpha-\beta}\ln s_{ei} + \frac{\psi}{1-\alpha-\beta}\ln \hat{h}_i^* \tag{2.12}$$

Equations (2.11) shows that the level of income per capita at steady state is positively related to the investment ratio of physical capital, and the stock of education and health; and negatively related to population growth. Equation (2.12) indicates that there are positive coefficients on savings, and the stock of health, but a negative coefficient on population growth. For estimation the choice between (2.10), (2.11) and (2.12) depends on the available data on human capital, corresponding more closely to the rate of accumulation or to the level of human capital (see MRW, 1992; Knowles and Owen, 1995). It is worth noting that each equation implies a different interpretation of and different restrictions on the coefficients.

Equations (2.10), (2.11) and (2.12) also imply that all countries are currently in their steady states or, more generally, the deviations from steady state are random across countries. However it is not convincing to assume the economy is continuously at steady state, especially when we include a large number of developing countries in empirical studies. Following MRW's method, taking the approximation around the steady state, and then reformulating the equations in terms of income per capita, we get out-of-steady-state growth equation ('growth-initial level' equation)[7] as following

$$\ln y_{it} - \ln y_{i0} = -\theta \ln y_{i0} + \theta \frac{\alpha}{\varpi} \ln s_{ki} + \theta \frac{\beta}{\varpi} \ln s_{ei} + \theta \frac{\psi}{\varpi} \ln s_{hi} - \theta \frac{1-\varpi}{\varpi} \ln p_{it} + \theta \ln A_{i0} + gt \qquad (2.13)$$

where $\theta = 1 - e^{-\lambda_i t}$ and $\lambda_i = (n_i + g + \delta)(1 - \alpha - \beta - \psi)$ is defined as the speed of convergence. Equation (2.13) is used to estimate the effects of investment rate of human capital in forms of education and health on economic growth. Solving (2.8) and (2.9) for s_{ei} and s_{hi} in terms of $\hat{e}_i^*$ and $\hat{h}_i^*$, respectively and substituting them into (2.13) yields

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[7] The 'growth-initial level' equations derived from the basic Solow model and the MRW model are presented in Appendix 1. Also see their original paper (MRW, 1992).

$$\ln y_{it} - \ln y_{i0} = -\theta \ln y_{i0} + \frac{\theta\alpha}{1-\alpha-\psi}\ln s_{ki} + \frac{\theta\psi}{1-\alpha-\psi}\ln s_{hi}$$

$$-\frac{\theta(\alpha+\psi)}{1-\alpha-\psi}\ln p_{it} + \frac{\theta\beta}{1-\alpha-\psi}\ln \hat{e}_i^* + \theta \ln A_{i0} + gt \qquad (2.14)$$

$$\ln y_{it} - \ln y_{i0} = -\theta \ln y_{i0} + \frac{\theta\alpha}{1-\alpha-\beta}\ln s_{ki} + \frac{\theta\beta}{1-\alpha-\beta}\ln s_{ei}$$

$$-\frac{\theta(\alpha+\beta)}{1-\alpha-\beta}\ln p_{it} + \frac{\theta\psi}{1-\alpha-\beta}\ln \hat{h}_i^* + \theta \ln A_{i0} + gt \qquad (2.15)$$

$$\ln y_{it} - \ln y_{i0} = -\theta \ln y_{i0} - \frac{\theta\alpha}{1-\alpha}(\ln s_{ki} - \ln p_{it}) + \frac{\theta\beta}{1-\alpha}\ln \hat{e}_i^*$$
$$+\frac{\theta\psi}{1-\alpha}\ln \hat{h}_i^* + \theta \ln A_{i0} + gt \qquad (2.16)$$

Equations (2.13) - (2.16) capture the dynamics of a country's growth rate towards the steady state. For estimation the choice from these four equations depends on the available data on human capital and the research questions. It is also worth noting that each equation implies different interpretation of and different restrictions on the coefficients.

3 Literature review

A number of studies have applied the conditional convergence regression method and empirically investigated the determinants of long-run growth rates across countries. The framework relates the growth rate of income per capita or per worker to the level of initial income and some other explanatory variables such as saving rate, human capital in terms of either investment or stock, and population growth as suggested by the MRW model. A variety of conclusions have been reached. Some cross-section studies have found that countries converge to their steady state level of income per capita at a slow rate of approximately 2-3 percent per annum. Some studies use panel data analysis and observe a much higher convergence rate, i.e. around 10 percent per year. Some studies suggest that human capital does play an important role in determining the long-run growth rate. Some have argued that human capital in the form of education is statistically insignificant in the convergence regression.

However, numerous micro studies show that health affects labour productivity[8]. They have used both experimental and non-experimental methods and documented the existence of a causal impact of health on wages and productivity. Good health status also raises the return to education and training. Therefore ignoring the effect of health on human capital accumulation in growth studies may cause the results to be biased and questionable. Recently some studies have taken account of this neglected effect by incorporating health variables into economic growth models. They differ substantially in terms of functional forms, country samples, time periods, control variables, data definitions and estimation techniques.

Typical examples that use the neoclassical growth model and emphasize health capital include the studies by Knowles and Owen (1995, 1997) and their derivations. They augmented the MRW model by including health, either as a separate input factor of production or a labor augmenting factor, and found the significant partial correlation between health and output. Employing the same theoretical framework, studies such

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[8] See Strauss and Thomas (1998) for some references.

as Heshmati (2001), Webber (2002), McDonald and Roberts (2002), and Li and Huang (2009) have investigated the effects of health human capital on the growth rate of per capita (worker) income adopting different samples of countries and various econometric approaches. Some studies have employed the Barro regression approach[9] which is considered as a crude extension of the MRW model and elucidated the role of health in determining long-run growth, such as Barro and Sala-i-Martin (1995, 2004), CEL (1996), Bhargava et al. (2001), Gyimah-Brempong and Wilson (2004) and Hartwig (2009). Further discussion about the literature in line with the MRW model can be found in section 3.1.

Apart from the studies based on the (augmented) MRW model, strands of research attempt to address the effects of health on growth from different perspectives (see section 3.2). The measurement of health has always been debated and therefore been discussed in section 3.3.

3.1 The role of health in the Solow and its extended models

The theoretical model, i.e. the MRW model augmented by Knowles and Owen (1995), has been discussed in section 2. Health human capital as a separate input factor of production enters the production function and therefore the growth rate is also determined by the stock or investment of health capital besides physical capital, education capital and population growth in equation (2.13) - (2.16). Knowles and

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[9] A type of informal growth regression, named after Barro (1991). For details, refer to Barro and Sala-i-Martin, (2004, ch.12).

Owen derived this model and test it using cross-section data during 1960-1985 of 84 countries. They found the health capital proxy is highly significant for the full sample by using OLS estimator, though the results substantially vary with different samples of countries. Different from their earlier paper, Knowles and Owen (1997) incorporated health capital as labour augmenting in an extension of the Solow-Swan neoclassical framework rather than separate factors of production. They reached the similar conclusions as that of their earlier work, i.e. a strong positive partial correlation between health and output, and an insignificant coefficient of education variable. Their findings consequently have inspired other researchers[10] further to investigate theoretically and empirically the importance of health capital for economic growth. Webber (2002) argued that Knowles and Owen did not offer proof that a policy of deliberate investment in health would boost economic growth because the proxy of health they used i.e. life expectancy did not necessarily reflect investment in health capital. He focused on the statistical impact of undernutrition[11] (proxied by calorific intake per head) on economic growth and asserted that this measure was 'well suited to formulating policies to increase economic growth' (page 1634). Some conclusions which were contrary to Knowles and Owen's findings were given: Firstly, calorific intakes had a positive although insignificant effect on economic growth. Second, education was found to have a positive impact which might result from using three separate levels of education.

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[10] See Appendix 2 for the summary of relevant literature.

[11] Undernutrition is low intakes of dietary energy and results in starvation and such workers need to increase their calorie intake in order to reduce of risk of mortality. Malnutrition is deficiencies of any or all nutrition besides energy and results in various diseases and an increase in the correct vitamin can help to reduce the incidence of morbidity.

Recognizing the limitations of cross-section method, researchers have employed panel data approaches (Heshmati, 2001; McDonald and Roberts, 2002; and Li and Huang, 2009). These works are all based on the augmented MRW framework but with different samples of countries and various health indicators, and therefore obtain relatively different results. Heshmati (2001) examined conditional convergence of OECD countries in GDP and health care expenditure (HCE) per capita during the time period 1970-1992. He concluded that OECD countries converged at 3.7-5.2% per year to their steady state level of income per capita and health care expenditure (HCE) had positive and significant effect on the economic growth as well as the speed of convergence. In addition, including HCE in the growth regression results in an insignificant coefficient of education capital, consistent with the results of Knowles and Owen (1995). McDonald and Roberts (2002) using a 5-yearly panel for 77 countries during 1960-1989, reinforced the key conclusions of Knowles and Owen (1995) and claimed that health seemed more important for low-income countries while education more important for high-income economies. Li and Huang (2009) using provincial data of China from 1978 to 2005 and adopting different health and education proxy variables[12], obtained the results that were consistent with Knowles and Owen (1995) and Islam (1995).

There are many more studies[13] that include health variables among a large set of

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[12] Details about the proxies refer to section 3.3.

[13] See Appendix 2 for the summary of relevant literature.

explanatory variables in a growth regression model, *ad hoc* Barro regressions. Barro and Sala-i-Martin (2004)[14] conducted the regressions for roughly 80 countries during the time period 1965-1995 and indicated that better health predicted higher economic growth (see their ch.12). Barro (1996) also obtained similar results using approximately 100 countries data during 1960-1990. CEL (1996) rejected the Solow model and therefore turned to a more general specification which included health-related variable along with other control variables. They found positive and significant coefficients on health with OLS and 3SLS estimation methods but insignificant coefficient with GMM estimators for around 90 countries during 1960-1985. Hamoudi and Sachs (2000) investigated the simultaneous impacts of heath on income and income on health with considering many factors that play an important role in determining health status, such as a number of geographical, environmental and evolutionary factors. They stated that while life expectancy had a positive impact on overall growth, infant mortality and fertility rates both have a very strong negative effect. Gyimah-Brempong and Wilson (2004) focused on Sub-Saharan African and OECD countries. Using an expanded Solow growth model and a dynamic panel estimator as well as including health capital in the regression in a quadratic way, they suggested that 22% and 30% of the transition growth rate of income per capita could be attributed to health in Sub-Saharan African and OECD countries, respectively.

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[14] In the first edition of this book, they got similar results for health variable though with shorter time periods and different estimation method (see Table A1 in Appendix).

However, some studies in line with Knowles and Owen (1995) present different results for high income countries. Typical example is the work by Bhargava et al. (2001). They showed significant effects of adult survival rate, henceforth ASR on economic growth rates for low income countries, i.e. a 1% change in ASR was associated with an approximate 0.05% increase in growth rate. But they estimated the threshold point beyond which ASR had typically negligible effect on growth rates and suggested that health affected economic growth asymmetrically for poor and rich countries, to be more specific, a negative effect of health found for countries such as USA, France and Switzerland. Therefore they called for analyses based on elaborate datasets. Suhrchke et al. (2006) also found the positive impact of health on growth rates diminished beyond certain levels of nation wealth, and above this level, improved health might either have no impact or even have negative impact.

In general, the positive effect of health on economic growth has been found in large samples of countries and is relatively robust with different estimation methods and various proxies of health capital although a negative effect has also been found in smaller samples of countries with high income. The studies with a large set of explanatory variables have presented relatively smaller coefficient of health.

3.2 The role of health in other growth empirics

The effect of health on economic development has been investigated from different perspectives. Historical studies explored the role of health in determining patterns of economic growth in a specific country over one or two centuries. Fogel (1994) found that about 50% of the economic growth in the United Kingdom over 1780-1980 can be attributed to improved health and nutrition. Arora (2001) focused on ten industrialized countries[15] during the past 100 to 125 years and concluded that improvement in health had raised the rate of economic growth by 30-40% and health related variables were correlated positively with years of schooling.

Growth accounting approach has also been used to find out the relative contribution of health to economic growth. Bloom et al. (2001, 2004)[16] included health in a well-specified aggregate production function[17] and found that good health had a positive and statistically significant effect on economic growth by using a panel of 104 countries during the time period of 1960-1990. Aguayo-Rico et al. (2005) followed Bloom's production function approach and adopted a new definition of health capital which included health services, socioeconomic conditions, lifestyles and environment to capture the impact of health on life cycle savings and capital accumulation. They confirmed the significant effect of health on output and growth with a dataset of 52 countries during time period 1970-2000.

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[15] The countries and time spans selected are Australia (1881–1994), Denmark (1870–1992), Finland (1881–1992), France (1870–1994), Italy (1875–1992), Japan (1891–1994), Netherlands (1880–1992), Norway (1870–1992), Sweden (1870–1994) and the United Kingdom (1871–1992).

[16] Bloom et al. (2004) report the results of 13 studies that all employ cross-country regressions and show large effects of health on growth in their table 1.

[17] $Y = AK^{\alpha}L^{\beta}e^{\phi_1 s+\phi_2 \exp+\phi_3 \exp^2+\phi_4 h}$ where h is health proxied by life expectancy, exp is work experience and s is schooling. They log-liberalized the production function with some other assumptions, and show that growth in output can be decomposed into four components: the growth of world TFP, the growth of inputs which include health, a catch-up term and a shock to the country's TFP (see Bloom et al.,2004 for details).

Micro studies that emphasize the role of health in improving labour productivity, labour supply and education have inspired some researchers to combine microeconomic elements and macroeconomic analysis. It is common to use microeconomic evidence on factor shares and the effect of human capital on wages to calibrate production function models (KRC, 1997; Young, 1994 and 1995). Some studies have used micro estimates of the effect of health on individual outcomes to construct macro estimates of the effect of health on output per capita (Shastry and Weil, 2003; Weil, 2007). Comparing with the results from cross-country regressions, the effect of health on economic growth they found is smaller. Bloom et al. (2002) and Bloom and Canning (2005) found that, similar to Weil, health makes a positive and statistically significant contribution to aggregate output. They also suggested a larger role of health than that of education which is similar as Knowles and Owen's findings. Jamison et al. (2004) used the 'meta-production function' approach[18] with health proxied by ASR, and the Hierarchical Linear Modeling (HLM) technique to estimate an aggregate production function and found that a contribution of 0.23% per year from better health to income growth and no evidence for health improving output through the technological progress.

It is commonly accepted that health affects economic growth and vice versa. Some studies apply Granger-Causality tests to an individual country or a group of countries like OECD to estimate the causality link between them. Mayer (2001) worked on the

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[18] See Lau (1996) and Boskin and Lau (1992, 2000) for the methods and findings.

dataset for 18 Latin American countries during 1975 to 1990 and asserted that there existed long-term conditional Granger causality from health to income. The finding is in line with the conclusions of his earlier work on Mexico and Brazil. Different from these studies on developing countries, Hartwig (2009)[19] applied the panel Granger-causality framework on 22 OECD countries during period 1970-2005 with health proxied as health care expenditure and concluded no support to the view that health improves long-term economic growth in rich countries. His findings are consistent with Bhargava et al. (2001) and Suhrchke et al. (2006).

3.3 Measurement of health

Studies that investigate the determinants of economic growth are likely to be subject to measurement problems from the selection of variables and the validity of those measures to the econometric problems where there are commonly reverse causality and improper assumptions. Research on the links between health and growth also suffers from these problems, particularly limitations of aggregate measures of health. Health is different from other aspects of human capital because firstly, health is multifaceted so that it defies simple definition and no single variable summarizes it. Secondly measurement error in health is likely related to income and labour market outcomes (Strauss and Thomas, 1998). We summarize the use of various health indicators in Table 3.1.

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[19] Hartwig (2009) reports the results of 14 studies that have emphasized the growth-enhancing role of health empirically (see table 1 in his study).

Life expectancy[20] has been widely used as an indicator of general health status in that its calculation is not only based on the annual cross-section of deaths and therefore captures the survival aspects of health but also improvements in life expectancy are assumed to be associated with reductions in morbidity and debility. In the literature that have used life expectancy as the proxy of health, some directly use the natural logarithm of life expectancy at birth or a certain age (Barro, 1996; Arora, 2001; Bloom et al. 2001, 2004), some use the reciprocal of life expectancy at age one (Barro and Sala-i-Martin, 2004[21]), but some adopt the transformation used by Anand and Ravallion (1993), i.e. $-\ln(80-LE)$[22] where LE is life expectancy at birth, and $(80-LE)$ is the shortfall of average life expectancy at birth from 80 years (Knowles and Owen, 1995; McDonald and Roberts, 2002). Based on its definition and calculation, life expectancy is dependent on the criteria used to select the group, and consequently it is sensitive to the rate of death in a certain few years of life so that the use of it has been criticized. But for a cross-country growth study, the choice among these specifications unlikely causes any substantial difference in results, therefore we use the natural logarithm of life expectancy at birth in our study.

The use of life expectancy as a proxy variable of health has been criticized for some reasons. Bloom and Canning (2000) argued that health should have been measured in

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[20] Life expectancy (at birth) indicates the number of years a newborn infant would live if prevailing patterns of mortality at the time of its birth were to stay the same throughout its life (World Bank definition).

[21] They suggest it has slightly more explanatory power than variable based on life expectancy at birth or age 5 (ch. 12, page 524).

[22] Knowles and Owen (1995) suggest that the transformation is 'likely to be a health-status indicator more directly relevant to the production of output' (page 102). However they also criticized it as a crude proxy of health because it does not allow for the quality of health beyond survival or the age distribution of the population.

all its dimensions: mortality, morbidity, disability and discomfort (also see Evans et al., 1993). Moreover, life expectancy is simply a weighted average of mortality rates at all ages and is highly sensitive to infant and child mortality rates (presumably less relevant for current productivity) so that conceptually it is not a good measure to reflect adult health and worker productivity (Bhargava et al., 2001; Jamison et al., 2004; Bloom et al., 2005). Furthermore, as Grossman (1972) suggested, health capital depreciates over time, however life expectancy reveals only the lifetime of the stock of human capital but nothing about population ageing and its resulting problems.

Adult survival rates[23] have been employed by some researchers as a proxy of health because of some potential advantages. First, they are constructed from World Bank demographic files containing mortality data on countries and are supposed to be more closely related to adult health and workforce productivity and less sensitive to child mortality rates. Second, capital formation and technological innovations require skilled worker and experience while investments in education and training critically depend on survival probabilities which are likely to have more interpretation power. Bhargava et al. (2001) and Bloom et al. (2005) used average ASR calculated as the weighted average by share of economically active population of gender-specific ASR. Mayer (2001) measured health as the probability of survival for each age and gender

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[23] ASR is defined as the probability of surviving to age 60 from age 15 given the prevailing age-specific mortality rates (using the current life table), and usually expressed per thousand rather than percent. Adult mortality rate is the probability of dying between the ages of 15 and 60, that is, the probability of a 15-year-old dying before reaching age 60, if subject to current age-specific mortality rates between those ages. Therefore we roughly calculate ASR given ASR=1000- adult mortality rate.

group[24] and maintained 'the full set of survival probabilities contains much more information than life expectancy' (page 1026). However ASR measures mortality rate rather than morbidity, for example it does not reflect the diminishing ability of individuals to perform productive tasks due to poor nutrition at early age. Using ASR as the sole indicator of health likely causes an under-estimation of productivity loss. In addition, health improvements above age 60 are likely to be important due to the trend of late retirement particularly in developed countries. Unfortunately ASR does not necessarily consider health status after age 60. Nonetheless, ASR is probably the best measure of adult health that is available for a large cross section of countries.

Both life expectancy and ASR are a broad measure of population health though they may not accurately reflect the productivity of the labour force because they are only based on mortality information. Webber (2002) argued that life expectancy reflect neither investment in health capital nor all dimensions of health and 'its impact on output might provide more information on educational, rather than health-related policies' (page 1634). He instead used calorific intake per head[25] as a proxy of health and found this measure was well suited to formulating policies to increase economic growth. But the nutrition-related measure of health is likely to have a greater impact in low income countries than in high income countries, in extreme case, where overconsumption of calories may cause obesity and indeed reduce workers' productivity.

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[24] The definition and calculation of the probability of survival refer to Mayer (2001), p.1027.

[25] The stock of health in term of nutrition is calculated as $\text{-ln}\left(\text{4000-calorie intake in 1990}\right)$ (Webber, 2000, endnote).

As we have discussed, the findings in the literature are sensitive to the selection of health indicators and samples of countries. Life expectancy and other mortality-related measures lack of explanatory power in that they vary so little among rich countries. Suhrcke (2006) attempted to overcome this limitation by using cardiovascular mortality among the working-age population for 26 high income countries. Some measures like mental illness and chronic diseases could also been considered. In the cases for developing countries, for example China, Li and Huang (2009) recommended some new proxy variables which focused on the health investment quality. One is the number of hospital beds per 10,000 persons, and another one is the number of doctors per 10,000 persons, which are regarded as well-suited measures for China. Disease-related measures of health e.g. malaria or AIDS have been adopted in studies that focused on some low income countries (Cole and Neumayer, 2006).

Health care expenditure (per capita) has also been used in some studies such as Heshmati (2001), Gyimah-Brempong and Wilson (2004) and Hartwig (2009). Using health care expenditure is more likely to capture the change of investment in health and its time series properties. However, higher health care expenditure does not necessarily result in better health status. The link from health spending to health outcomes might be weak due to both market and government failures, to be specific, the financing and delivery of health care. The lack of sound health institutions may also undermine health investment (Jack and Lewis, 2009).

Thus, we do not expect to find a consensus in the literature on the choice of health indicators because none of them is ideal to accurately capture both mortality and morbidity in a cross-country study with large samples of countries, but each has advantages. Using different measures of health may be one of the reasons why the results presented in health-related growth studies are sometimes contradict one another. Moreover, at a practical level, the accuracy of the data, particularly in many developing countries is poor; interventions that affect morbidity but not mortality may have effects on productivity, but these effects are unlikely to be taken into account if mortality-based indicators are used. In this study, different indicators of health will be employed and a comparison of the results will be presented in section 5.3.

Table 3.1: Measurements of health capital

Measure of health	Papers	Advantages	Disadvantages
Life expectancy (at birth, year 1 or year 5 …)	Barro (1996), CEL (1996), Knowles and Owen (1995, 1997), Arora (2001), McDonald and Roberts (2002), Bloom et al. (2001, 2004), Barrro and Sala-i-Martin (1995, 2004)	1. Widely used measure; 2. Available for most countries in relatively long time period,	1. Sensitive to infant or child mortality rates; 2. Not cover morbidity or disability information,
Mortality rates (Infant, Child, or Adult)	Bhargava et al. (2001), Mayer (2001), Bloom et al. (2002, 2005), Shastry and Weil (2003), Jamison et al. (2004), Gyimah-Brempong and Wilson (2004), Weil (2005)	1. Widely used; 2. more closely related to adult health and productivity; 3. less sensitive to infant or child mortality;	1. Not cover morbidity or disability information; 2. Ignore health status after age 60;
Health care expenditure	Heshmati (2001), Gyimah-Brempong and Wilson (2004), Hartwig (2009)	1. Related to other HCE studies; 2. A direct measure of investment in health;	1. Availability is limited; 2. The link from HCE to health outcomes is ambiguous;
Calorific intake	Webber (2002)	Direct policy implication;	1. Availability; 2. Not a good measure for developed countries;
Cardiovascular mortality	Suhrcke (2005)	For developed countries	Availability
Hospital information	Li and Huang (2008)	Direct measure of investment in health	1. Too narrow; 2. A weak link from health service to health outcomes;

Author’s summary

Generally speaking, the positive effect of health on economic growth has been found in the literature either in neoclassical growth models during the transition to the steady state, or in endogenous growth models within the context of intertemporal optimization. We also observe that a number of studies present unambiguous results but contradict one another, especially when they focus on different samples of countries or employ various health indicators; therefore consensus in the empirical literature is hardly to be expected. Moreover, econometric issues of endogeneity and measurement error are particularly problematic when attempting to untangle the link from health to growth and vice versa even with the use of the most innovative approaches. Caution is required when a researcher concludes estimation results and provides policy implications.

In the general growth literature, the GMM estimators have been adopted to control for unobserved country-specific effects and potential endogeneity and measurement error problems in the growth regression. But none of the studies that used dynamic panel data (DPD) and GMM estimators has focused on the effect of health on economic growth (including no health-related variable in their regressions). In the health-related growth literature reviewed in this chapter, the role of health has been substantially investigated in studies with various models and datasets. However, firstly few of them who followed the MRW model has fully dealt with the typical problems (i.e. omitted variable and endogeneity biases) in the convergence growth regressions; second, most of them have covered a time period up to 1995; thirdly, different indicators of health have been recommended for countries in different development level, but which has not yet been been paid enough attention. Considering these gaps in the literature, we believe our work can have a not insignificant contribution.

4 Empirical methodology and data

4.1 Model specification and econometric issues

Direct estimation of equation (2.10)-(2.12) is valid only if countries are in their steady states or if deviations from steady state are random (MRW, 1992), neither of which seems very plausible. Equations (2.13)-(2.16) have the advantage of explicitly taking into account out-of-steady-state dynamics since they study the correlation between initial levels of income and subsequent growth rates. Following Islam (1995) and Bond et al. (2001), we then put them in the conventional notation that is ready to be empirically estimated:

$$\Delta y_{i,t} = \phi y_{i,t-1} + x'_{i,t}\gamma + \eta_i + \mu_t + \upsilon_{i,t} \tag{4.1}$$

where $\phi = -(1 - e^{-\lambda t})$, $\eta_i = \theta \ln A_{i,0}$, and $\mu_t = gt$, for $i = 1, 2......N$, and $t = 2, 3......T$. To be clarify, the dependent variable lower case of $y_{i,t}$ is defined as $\ln y_{i,t}$ so that Δy_{it} is the growth of real GDP per capita (i.e. log difference) over a five-year period. The explanatory variables fall into three categories:

a) $y_{i,t-1}$: the logarithm of real GDP per capita at the beginning of each period, which is used to capture the income convergence effect;

b) $x'_{i,t}$: a vector of other characteristics measured either at the beginning of each period or as an average over each five-year period. For the basic

Solow model, $x'_{i,t}$ consists of the logarithm of the investment rate, $\ln(s)$, the logarithm of the population growth adjusted by common exogenous rate of technical change and the depreciation rate, $\ln(n+g+\delta)$, the sum of which $(g+\delta)$ is assumed to be 0.05. x_{it}^{j} also includes the logarithm of average years of schooling, $\ln(e^{*})$ and the log difference in the average years of schooling to proxy the stock and accumulation of education human capital, respectively, and the stock of health capital, $\ln(h^{*})$ or the fraction of income invested in health capital, $\ln s_{hi}$;

c) η_i: the country-specific effects that reflect the unobserved heterogeneity in the initial level of efficiency, $\ln A(0)$; and μ_t: the time dummy that is expected to capture global shocks affecting aggregate production functions across countries. They also reflect country-specific and period-specific components of measurement errors. $\upsilon_{i,t}$ is the transitory error term that varies across countries and time periods and has mean equal to zero. In the context of cross-country regressions, the dataset comprises a large number of countries N over a small averaged time-series period T.

We can rearrange equation (4.1) and get

$$y_{i,t} = \phi^{*} y_{i,t-1} + x'_{i,t}\gamma + \eta_i + \mu_t + \upsilon_{i,t} \tag{4.2}$$

where $\phi^{*} = \phi + 1 = e^{-\lambda_i t}$. Equation (4.2) shows properties of dynamic panel data model with a lagged dependent variable on the right-hand side and estimating equation (4.2) is equivalent to estimating equation (4.2). It is also worth noting that in a dynamic panel data model, the saving rates s_{ki} , s_{ei} and s_{hi} are varying over time.

Compared to cross-section regressions, the panel data approach is superior[26]. Firstly, the single cross-section method does not make use of all available information compared with the time series method. Second, single cross-section regressions suffer from an omitted variable bias because it is unable to account for the unobservable country-specific effects representing differences in technology or tastes. It is very likely that OLS estimation (used by most of the early cross-section studies) is inconsistent and biased when wrongly assuming $A(0)$ is uncorrelated with other explanatory variables in the regression. Third, some explanatory variables may be endogenous, therefore ignoring this endogeneity may lead to the bias in estimations of coefficients and convergence rates. Previous studies, such as typically Islam (1995) and CEL (1996), have used a dynamic panel data (DPD) approach to address the omitted variable and/or endogeneity issues and measurement error. DPD naturally invalidates the uses of OLS, within group, and GLS estimator. Hsiao (1986) suggested that omitting unobserved time invariant country effects in a DPD model will cause OLS levels estimates to be biased and inconsistent. To be specific, the estimate of coefficient ϕ in equation (4.1) is likely to be biased upward. As an alternative the within group estimator can take account of the unobserved country specific effects by

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[26] See Baltagi (2001) for the benefits from using panel data (ch. 1).

transforming equation (4.1) and eliminating term η_i by subtracting out the time series means of each variable for each county. However, this estimator may cause the estimates of coefficient ϕ to be biased downward in a DPD model with fixed T (Nickell, 1981). GLS with random effects is not valid where explanatory variables are potentially endogenous and related with the error term in the context of a dynamic model. Alternatively, two generalized method of moments estimators have also been adopted within the DPD framework, i.e. the FD-GMM estimator (Arellano and Bond, 1991) and the system-GMM estimator (Blundell and Bond, 1998). It also worth noting that using the GMM estimator, a consistent estimation of ϕ can be expected to lie in between OLS levels and within group estimates (Bond et al. 2001; Hoeffler, 2002). To summarize, the GMM estimators are designed for a panel analysis and embody the following assumptions:

a) A dynamic panel with the lagged dependent variable on right-hand side;
b) There may be arbitrarily distributed fixed individual effects;
c) Some regressors may be pre-determined instead of strictly exogenous;
d) One or more regressors are potentially endogenous;
e) The idiosyncratic error term may have individual-specific patterns of heteroskedasticity and serial correlation;
f) The idiosyncratic disturbances are uncorrelated across individuals;
g) Small T and large N (if T is large, dynamic panel may be less efficient than fixed effects estimator);
h) Available instruments may be internal, i.e. lags of the instrumented

variables or external, i.e. some variables not included in the regression equation;

We now describe the general form of the GMM estimator. In terms of the FD-GMM estimator, the basic idea[27] is to take all variables as deviations from period means so that there is no need to include time-specific constants (e.g. CEL, 1996), or to include time dummies in each regression which is equivalent to the former transformation (Bond et al., 2001), then to take first-differences[28] to remove unobserved time-invariant country-specific effects η_i, and further instrument the right-hand-side variables in the first-differenced equations using levels of the series lagged two periods or more, under the assumption that the time-varying disturbances in the original levels equations are not serially correlated (Arellano-Bond test is adopted[29]).

$$y_{i,t} - y_{i,t-1} = \phi^*(y_{i,t-1} - y_{i,t-2}) + \gamma(x_{i,t} - x_{i,t-1}) + (\upsilon_{i,t} - \upsilon_{i,t-1}) \tag{4.3}$$

However, the FD-GMM estimator used by CEL and later researchers has been criticized, particularly when the number of time periods available is small[30]. Conceptually, cross-country growth studies aim to find out the relationship between national policies or endowments and output growth rates, which is eliminated in the first-differencing transformation. Statistically, the FD-GMM estimator performs poorly when the time series are persistent and the number of time series observations

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[27] The description of GMM estimator (both FD-GMM and system-GMM) in details can be found in Arellano and Bover (1995); Blundell and Bond (1998); Bond et al. (2001), Hoeffler (2002).

[28] To eliminate the individual effects, there are several transformations, other than first-differencing, for example fixed effects (or within) estimator. However, FE estimator (without using any instrument variable) seems not fit in the context of a DPD model because, by construction, the lagged dependent variable is correlated with the mean of the individual errors, and therefore it would lead to inconsistent estimates (CEL, 1996).

[29] To test whether the condition is satisfied, we actually examine whether the differenced error term is second-order serially correlated because by construction, the differenced error term is probably first-order serially correlated even if the original error term is not.

[30] For example, to avoid the business cycle effects, five-year interval data are normally used in studies with the time period over past 40 years so that typically T =7, 8 or smaller.

is small, which are the typical features presented in empirical growth studies. In this case, lagged levels of the variables are only weakly correlated with the endogenous variables and hence are only weak instruments for subsequent first differences. Therefore, the FD-GMM estimator probably suffers from serious finite sample bias and imprecision. To be specific, the FD-GMM estimator would be biased towards the within group estimator (Blundell and Bond, 1998). The presence of weak instruments and consequent biased estimation possibly explain why CEL (1996) observed a higher convergence rate.

To reduce the potential biases and imprecision associated with the FD-GMM estimator, Arellano and Bover (1995) and Blundell and Bond (1998) introduced a system of regressions in differences and levels, i.e. so called the system-GMM estimator to generate efficient estimators of the DPD model with short T and persistent series. One set of regressions are the differenced equation (4.3) with suitably lagged levels of $y_{i,t}$ and $x_{i,t}$ as instruments as discussed above. The other set of regressions are the level equation (4.1) with suitably lagged first-differences of $y_{i,t}$ and $x_{i,t}$ as instruments. In fact of that consistency of the GMM estimator depends on the validity of these instruments and the no-serial-autocorrelation condition, some tests have been adopted to detect whether the instruments are valid and whether there are first or second-order serial correlation, such as standard Sargan tests and Hansen-J-test of over-identifying restrictions, Difference Sargan tests or Hausman comparisons between the FD-GMM and the system-GMM and

Arellano-Bond test of serial correlation. In terms of performance of these estimators, Blundell and Bond (1998) showed that the system GMM estimator have dramatic efficiency gains over the basic FD-GMM estimator. Using Monte Carlo experiments, Blundell et al. (2000) found that simulations including weakly exogenous covariates exhibited large finite sample bias and very low precision for the standard first-difference estimator while the system-GMM estimator not only improved the precision but also reduced the finite sample bias. Different from FD-GMM, in system-GMM, one can include time-invariant regressors, which would disappear in FD-GMM. This does not affect the coefficient estimates for other regressors because all instruments for levels equation are assumed to be orthogonal to fixed effects, indeed to all time-invariant variables. Considering the potential advantages using the GMM estimator, we would employ a panel data system-GMM estimator as well as a robustness test by comparing the results from using different estimators in this study.

We include time period dummies in each regression to capture common shocks to growth in each 5-year period relative to the base period, 1960-1964. The inclusion of time dummies also allows for common long-run growth in real GDP per capita or worker which is consistent with a standard assumption in this study, i.e. common technological progress.

Both the FD-GMM and system-GMM estimators have one-step and two-step variants. In CEL's study, they reported the results of the two-step GMM estimator since it is supposed to be more efficient, especially for system-GMM. However, the two-step estimators have been shown to have a serious downward bias of their asymptotic standard errors in finite samples. Windmeijer (2005) introduced a finite-sample correction to the two-step covariance matrix. We applied both one-step and two-step GMM estimators and found no significant difference on estimated coeffcients, thus, we just report the results using one-step GMM with heteroskedasticity-robust standard errors.

4.2 Data and samples

Our data are largely traced from several datasets of worldwide aggregate series: Penn World Table (PWT, version 6.2)[31], the Globalization–Health Nexus Database (GHND)[32] and World Bank World Development Indicators (WB WDI, edition 2007). Alternative sources of some variables are specified in the variable definitions (see Table A3 in Appendix). Data are available for roughly 111 countries over the period 1960-2004, but not for all countries for all of the nine periods, thus, making the panel unbalanced. We follow the growth literature considering five-year time intervals (an unoverlapping[33] panel) which show considerate variation but are less likely to be contaminated by business cycles and the problem of parameter heterogeneity than the annual growth rates. The observations in our sample are measured either at the beginning of each period or as an average over each five-year period.

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[31] Data are available at http://pwt.econ.upenn.edu/php_site/pwt62/pwt62_form.php

[32] Data are available at http://www.dse.unifi.it/sviluppo/GHND_eng.html

[33] Some studies set data to an overlapping panel in 5-year intervals, for example Islam (1995) with 1960-65, 1965-1970,… . However, averaging over either overlapping or unoverlapping periods does not alter the estimation results.

Real GDP per capita, namely RGDPCH, are from PWT 6.2 and adjusted for purchasing power parity and based on a chain index. The dependent variable, Δy_{it} is the change in the natural logarithm of real GDP per capita at five year intervals, i.e 1960-1964, 1965-1969, … 2000-2004. The initial level of income, $y_{i,t-1}$ on the right-hand side of equation (4.1) is measured as the natural logarithm of real GDP per capita, starting in 1960, 1965, … and ending in 2000.

The share of saving, s_k is proxied by the share of investment in real GDP (as in MRW, 1992; Islam, 1995; Hoeffler, 2002; and Ding and Knight, 2009). The data, namely KI are from PWT 6.2. The time series are averaged over 1960-1964, 1965-1969, … 2000-2004.

Total population data are obtained from PWT, i.e POP in version 6.2. MRW (1992) and Ding and Knight (2009) took n as the rate of growth of working age population[34]. Islam (1995), CEL (1996) and Hoeffler (2002) calculated n using total population instead. Average population growth rates in this study are computed as the difference between the natural logarithm of total population at the end and beginning of each period and dividing this difference by the number of years. The average growth rates are over period 1960-1964, 1965-1969, … 2000-2004. Moreover, the

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[34] In this study, we have tried both growth rate of total population and working age population (raw data are from WDI) as the proxy of population growth. However the availability of working age population data seems not as good as total population and results in some weird coefficients estimates by using GMM estimator (particularly System-GMM). Therefore, we just report the results based on total population data.

growth rates of total population are adjusted by technological progress and depreciation rate, which are assumed to be constant across countries and summed to 0.05[35]. So it is to take logarithm for the sum of population growth rate and 0.05, i.e. $\ln(n+0.05)$.

We proxy the stock of education capital as the average years of schooling, namely $human$ provided by Barro and Lee (2001), for the population aged over 15 or 25. We use the schooling data at the beginning of each five year period, i.e. 1960, 1965 … and ending in 2000. We also adopt the data from other sources, for example, Lutz et al. (2007) which provides the mean years of schooling for age 15 or 25 plus, namely $schooling$ over 1970-2000 for 120 countries. We just report the estimation results with education data from Barro and Lee for the population aged 15 plus. The reasons are as following: firstly, education data from different resources do not provide a substantial difference in results. Secondly, the estimation results do not seem to be sensitive to the choice of average years of schooling of age 25+ or 15+. Finally, using Barro and Lee dataset allows us to compare directly our results with those of other studies using the same education data.

Data to proxy health are from the Globalization–Health Nexus Database, GHND and

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[35] Following the growth literature, we assume the sum of techonologica progress and depreciation rate is constant for all countries, but this may not be the true case. Therefore the use of $\ln(n+0.05)$ is actually a strong assumption. Panel data allows for unobserved differences in the initial level of technology, but assumes the rate of techonological progress is common to all countries. This standard assumption is maintained in our study in the absence of reliable data on rates of techonological progress. Alternatively, we try differenct values for $g+\delta$ such as 0.06 and 0.07; however, the results remain unchanged.

World Development Indicator, WDI (2007). GHND provides data, including life expectancy at birth, infant mortality rates[36], undernourishment, public health expenditure, and physicians per 1,000 people. WDI provides data for adult mortality rates. We calculate the adult survival rate (ASR) as the difference 1000 minus adult mortality rates[37] for male and female separately. We use the health data at the beginning of each five year period, i.e. 1960, 1965, … and ending in 2000.

We use several samples of countries in this study (see Table A2 in Appendix): the full sample consists of 111 developed or develping countries[38] over 1960-2004 due to the limited availability of both education and health data. In addition, we divide all countries into three income groups, i.e. low, middle and high income groups based on the mean level of real GDP per capita over 1960-2004. Definitions of the variables and summary statistics of the sample data are presented in Table A3 in Appendix.

5 Test the Solow model – the role of health

5.1 The textbook Solow model

In this section we present the results obtained from the textbook Solow model as

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[36] Infant mortality rate is the number of infants dying before reaching one year of age, per 1,000 live births in a given year (World Bank definition).

[37] Adult mortality rate is the probability of dying between the ages of 15 and 60, that is, the probability of a 15-year-old dying before reaching age 60, if subject to current age-specific mortality rates between those ages (World Bank definition).

[38] Barro and Lee’s data include 142 countries of which 107 have complete educational information at five-year intervals from 1960 to 2000. GHND provide health data for 136 countries from 1960 to 2005. The 111 countries in our sample are covered by both datasets.

shown by equation[39] (A.1) in Appendix 1. All reported standard errors are corrected for heteroskedasticity and time dummies are included in each regression. The dependent variable is the growth rate of real GDP per capita over each 5 year period. In the GMM estimation, the initial level of real GDP per capita is treated as a predetermined variable and both investment rates and population growth rates are treated as potentially endogenous variables[40]. In order to conserve space only the heteroskedasticity-robust one-step system GMM results are reported and the coefficients on the time dummies are not reported in the tables.

The results using OLS, within group estimator, first-difference GMM and system GMM estimators are reported in Table (5.1). The first four columns are the results for the full sample including both developed and developing countries. Columns (5)-(8) and (9)-(12) are the results for developed countries (high income sample) and developing countries (middle and low income sample), respectively. In all regressions, the coefficient on initial real GDP per capita have the expected negative sign and are highly significant, which provides strong evidence of conditional convergence. The negative sign coefficient implies that a lower starting value of real income per unit of effective labor tends to generate higher growth, i.e. if we take two countries with the same rate of investment and the same level of efficiency, the poorer one will grow

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[39] The textbook Solow model does not consider human capital. Estimating it allows us to compare the results with the MRW model and the augmented MRW model.

[40] In GMM estimation, the instruments used for first-differenced equations for both FD-GMM and Sys-GMM estimators are $\ln(y_{i,t-2})$, $\ln(s_{i,t-2})$, $\ln(n_{i,t-2}+g+\delta)$ and their suitable lags; additional instruments used for levels equations in Sys-GMM are $\Delta\ln(y_{i,t-1})$, $\Delta\ln(s_{i,t-1})$ and $\Delta\ln(n_{i,t-1}+g+\delta)$; In column (3), $\ln e_{i,t-1}$ and its suitable lags are also used as the instruments for first-difference equation.

more quickly for a transitional period. Estimated value of the coefficients using the system-GMM estimator lies in between the upper bound given by OLS and the lower bound given by the within group estimator as suggested by Bond et al. (2001), Hoeffler (2002) and Ding and Knight (2009). In line with the growth literature, we find the estimated convergence rates for all the samples are around 2 percent per annum, except when using OLS (around 0.3 percent). For example, the implied speed of convergence, λ, is 0.03, 0.02 and 0.013 for OLS, within group and system-GMM estimator for the full sample, respectively. In addition, the Sargan test of over-identifying restrictions detects no problem with instrument validity. The m_1 and m_2 tests suggest the hypothesis of no second order serial correlation in the first-differenced residuals is not rejected for any of the GMM regressions.

The Solow growth model predicts that growth rate is positively related to the saving rate but is negatively related to the population growth rate. The investment rate has been shown to have positive and significant effects on the growth rate for all the samples, even allowing for the likely endogeneity of investment. The coefficients of population growth are negative in the regressions for either the full sample or the developing countries sample. However, population growth is found to be positively related to growth rate for developed countries. A possible reason is the different development levels affect the performance of the textbook Solow model. Population growth rates in high income countries are relatively low (average 0.0086) but economic growth rates have been relatively high (average 0.112) over 1960-2004 while developing countries have higher population growth rates (average 0.025) and grow relatively slowly (average 0.041). Another prediction of the basic Solow model is the identical magnitudes but opposite signs of coefficients on saving rate and population growth rate. This restriction can not be rejected in the full sample using different estimators. However, it is rejected in some of the sub-sample estimations.

The estimated structural parameter, i.e. the output share of physical capital α, is of interest in the Solow model. We re-estimate equation (A.1) imposing the restriction that saving rate and population growth enter as a difference and present the system-GMM results in Table (5.2). The results are reported for the full sample and three sub-samples, i.e. high income, middle income and low income separately. First of all, the estimated coefficients of initial income are not greatly affected by the restricted version for the full sample and high or middle income samples. Hence the characteristics of GMM estimators for correcting the omitted variable biases and potential endogeneity are relatively robust to the modification. The implied value of the convergence rate is in the range of 1.1-2.1 percent per annum. Yet it is reduced to 0.3 percent for low income sample. Secondly, tests detect neither second-order serial correlation nor instrument invalidity in any of the estimations. Moreover, the significantly positive coefficients of the difference between the saving rate and population growth rate support Solow's prediction to some extent. Finally, as for the share of physical capital in income, α is supposed to be approximately one third. However we observe that the value of α for the full sample is unexpectedly as high as 74.5%. The low income sample even suggests a higher value of 84.8%. MRW (1992) rejected the textbook Solow model because they found implausible values of over 60% for the capital share and, therefore, augmented it by adding human capital into the model. CEL (1996) rejected the basic Solow model as well, but for opposite reasons, i.e. they found an implausibly low value of 10%. Therefore, we reject the textbook Solow model for reasons similar to those of MRW, i.e. α is too high.

Table 5.1: The Textbook Solow Model (Unrestricted)

	Total Sample: 111 countries				High Income Sample: 26 countries				Middle and Low Income Sample: 85 countries			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	OLS	WG	FD-GMM	SYS-GMM	OLS	WG	FD-GMM	SYS-GMM	OLS	WG	FD-GMM	SYS-GMM
Constant	-0.175***	0.669***	0.626**	-0.413**	1.330***	1.464***	0.773*	0.999***	-0.267***	0.533**	0.388	-0.502**
	(0.062)	(0.244)	(0.317)	(0.189)	(0.231)	(0.545)	(0.409)	(0.345)	(0.090)	(0.267)	(0.376)	(0.207)
$\ln y_{i,t-1}$	-0.015***	-0.095***	-0.106***	-0.062***	-0.111***	-0.117**	-0.097***	-0.088***	-0.015**	-0.093***	-0.100***	-0.085***
	(0.006)	(0.216)	(0.024)	(0.023)	(0.022)	(0.047)	(0.021)	(0.020)	(0.007)	(0.025)	(0.037)	(0.029)
$\ln s_{kit}$	0.654***	0.054***	0.116***	0.154***	0.039***	0.046	0.112*	0.079***	0.063***	0.052***	0.118***	0.149***
	(0.009)	(0.016)	(0.040)	(0.024)	(0.013)	(0.047)	(0.064)	(0.030)	(0.010)	(0.017)	(0.042)	(0.026)
$\ln(n_{it}+g+\delta)$	-0.095***	-0.028	-0.018	-0.230**	0.100**	0.138*	0.026	0.102	-0.128***	-0.058	-0.075	-0.339***
	(0.030)	(0.058)	(0.141)	(0.109)	(0.044)	(0.082)	(0.109)	(0.128)	(0.038)	(0.074)	(0.174)	(0.122)
R^2	0.209	0.187			0.498	0.437			0.185	0.157		
m_1			-5.626	-5.771			-2.887	-2.929			-5.405	-5.374
			[0.000]	[0.000]			[0.004]	[0.003]			[0.000]	[0.000]
m_2			-1.439	-1.351			1.561	1.496			-1.507	-1.419
			[0.150]	[0.177]			[0.120]	[0.135]			[0.132]	[0.156]
Sargan/Hansen Test (p value)			0.169	0.370			0.587	0.552			0.582	0.692
Adding up restriction (p value)	0.332	0.648	0.459	0.433	0.003	0.020	0.432	0.415	0.095	0.940	0.789	0.086
Implied λ	0.003	0.020	0.019	0.013	0.024	0.025	0.020	0.018	0.003	0.020	0.021	0.018
No. of observations	742	742	742	742	207	207	207	207	535	535	535	535

Notes: Dependent Variable is growth rate of real GDP per capita over each five year period. Sample includes 111 countries and 9 five-year interval time periods over 1960-2004; Heteroskedasticity-consistent standard errors are in parentheses; Time dummies are included in all regressions; In the GMM estimation, $\ln y_{i,t-1}$ is treated as a predetermined variable; $\ln s_{kit}$ and $\ln(n_{it}+g+\delta)$ are treated as endogenous variables. $g+\delta$ is assumed to be equal to 0.05; λ is the convergence rate calculated from $\phi=-(1-e^{-\lambda t})$ where ϕ is the estimated coefficient and t =5; The test statistics for first and second order correlation are given by m_1 and m_2, respectively, and the p-values are reported in brackets; The adding up restriction refers to the hypothesis that the coefficients of investment and population growth rate are equal in magnitude but opposite in sign as predicted by equation (2.14); *, ** and *** indicate that the coefficient is significantly different from zero at 10%, 5% and 1% significance level, respectively.

Table 5.2: System GMM Estimation of the Textbook Solow Model (Restricted)

	Total Sample: 111 countries	High Income Sample: 26 countries	Middle Income Sample: 57 countries	Low Income Sample: 28 countries
Constant	-0.276*** (0.085)	0.571** (0.273)	-0.016 (0.160)	-0.207 (0.364)
$\ln y_{i,t-1}$	-0.052*** (0.015)	-0.098*** (0.020)	-0.072*** (0.024)	-0.014 (0.047)
$\ln s_{kit} - \ln p_{it}$	0.152*** (0.023)	0.082** (0.034)	0.137*** (0.031)	0.078** (0.030)
m_1	-5.779 [0.000]	-2.798 [0.005]	-3.931 [0.000]	-3.404 [0.001]
m_2	-1.385 [0.166]	1.504 [0.133]	-1.394 [0.163]	-0.711 [0.477]
Sargan/Hansen Test p value	0.338	0.456	0.524	0.610
Implied λ	0.011	0.021	0.015	0.003
Implied α	0.745	0.456	0.656	0.848
No. of observations	742	207	370	165

Notes: Definitions are the same as those in the previous tables.

5.2 The Solow model augmented with education human capital – the MRW model

Rejecting the textbook Solow model leads to the test of the augmented Solow model. MRW (1992) suggested that the inclusion of human capital led not only to a better fit of the model, but to an estimated capital share more in line with conventional wisdom, which is around 0.3. Some studies applying the MRW model have found no (or even negative) effect of education[41] on output growth (Islam, 1995; CEL, 1996; Bond et al., 2001; Hoeffler, 2002).

Table (5.3) reports our results for the augmented Solow model as shown in equation (A.2) and (A.3), where the log difference of average years of schooling as a proxy for the accumulation of human capital or the logarithm of average years of schooling as a measure of the stock of human capital are included as an additional explanatory variable, respectively. We also test a specification of the augmented Solow model incorporating both the initial level and the accumulation of human capital in that they are supposed to benefit output growth simultaneously. We present only the system-GMM results after comparing the results obtained using various estimators and finding the GMM estimator produces a somewhat more reasonable coefficient on

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[41] Islam (1995) finds that ‘human capital variable does not prove to be significant … the coefficients on the human capital variable now appears (in the restricted version of the model) with the wrong sign” (page 1153). CEL (1996) finds that the estimate of the share of human capital implied by the restricted resgression is negative, large in absolute value, and strongly significant; therefore take it as clear evidence against the augmented Solow model. They also suggest that the biased OLS estimation leads MRW to accept the augmented Solow model. Bond et al. (2001) suggest that ‘the particular human capital measure [school enrollment rate] used here can be omitted from the specification of the model’ (page 21). Hoeffler (2002) finds that schooling ‘is not statistically significant in any of the results that control for unobserved country-specific effects’ (page 28). Ding and Knight (2009) find that ‘neither the level nor the change of human capital proves to be significant’ (page 26).

initial income.

The initial level of human capital is treated as a predetermined variable and the growth rate of human capital is treated as a potentially endogenous variable[42] as higher educational investment is more likely to appear in a fast-growing economy. Similar to the findings of the textbook Solow model, the coefficients of initial real GDP per capita and investment rates have the right signs and are statistically significant for all samples even though the endogeneity of investment is controlled. They confirm the so-called conditional convergence hypothesis and the prediction of a positive relation between output growth and saving rate, as predicted by the theoretical model. The estimated convergence rates are between 1.4 to 2 percent per annum for the full sample. The rate of convergence is slightly higher than that of the basic Solow model for high income sample. The middle income sample presents a convergence rate of 2.8 percent per annum, while the low income sample suggests a lower rate of convergence, i.e. 1%, around half of the full sample. The coefficient on population growth has a negative sign with acceptable significance level for the full sample, middle income and low income samples, while having a positive sign for high income sample, the same as the basic Solow model's results. Adding education as an additional explanatory variable does not solve the puzzle. Neither second order serial correlation in the first-differenced residuals nor instrument invalidity is detected in any of the regressions.

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[42] Besides the instruments we have used for the Basic Solow model, $\ln e_{i,t-1}$ and $\Delta \ln e_{i,t-2}$ and their suitable lags are used as instruments for first-differenced equation, and $\Delta \ln e_{i,t}$ and $\Delta^2 \ln e_{i,t-1}$ are used as additional instruments for level equation in system-GMM estimations.

The coefficients on the stock or the accumulation of human capital are all positive irrespective of including them separately or simultaneously, except for the low income case with the accumulation of education capital entering by itself. The effect of education is statistically insignificant in the cases when two education variables are included in the model individually for all samples, except for the low income case when stock of human capital enters by itself. Adding both education variables in the Solow model leads to the positive and significant coefficient on the change of human capital for the middle income sample. However, we generally fail to identify the significant role of education in the growth process, which is in line with most of the growth studies that have applied the MRW model.

Compared with the textbook Solow model, inclusion of human capital leads to some improvements. Firstly, the values of estimated convergence rates are slightly closer to the conventionally obtained value of 2% in the literature than those of the basic model for the full sample. Second, none of the unrestricted regressions rejects the adding-up hypothesis as predicted in equation (A.2) and (A.3) except for a case in the high income sample (see column (4)). Moreover, we find some changes shown in Table (5.4) when estimating the restricted version of equation (A.2) and (A.3). It is promising to observe some relatively more plausible values of the estimated elasticity of output with respect to physical capital, lying between 45 to 65 percent, though they are still not as low as 1/3. The sum of the shares of physical capital and human capital, $\alpha + \beta$, is smaller than one in most of the cases, which can be taken as evidence of decreasing returns to the set of reproducible factors of production as assumed in the neoclassical growth theory. However, the estimation based on the specification of equation (A.2) with the accumulation term of human capital shows the difference term has an insignificantly negative coefficient for high income and low income samples, which has also been found in some studies, e.g. CEL (1996). These negative coefficients lead to some implied values of α and β to be implausible. The estimates of other parameters are not greatly affected by the restricted estimation. In general, our results indicate the augmented Solow model performs better than the textbook one, though still with some problems.

There are several possible reasons for the ambiguous role of human capital detected in our estimations. Firstly, the theoretical variable of human capital in the production function might not be properly proxied by the actual variable use in regressions. Average years of schooling are only partial measures of the stock of human capital and, more importantly, do not account for differences in the quality of human capital. Secondly, it is not sensible to expect the stock or the accumulation of education capital to affect growth almost instantaneously. Additionally, the effect of health on human capital accumulation has long been recognized. From this point of view, taking health as one of the measures of human capital and employing a richer specification of the production function with respect to human capital might provide a solution.

Table 5.3: System GMM Estimation of the Augmented Solow Model (Unrestricted)

	Total Sample: 111 countries			High Income Sample: 26 countries			Middle Income Sample: 57 countries			Low Income Sample: 28 countries		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Constant	-0.321	-0.571**	-0.444	1.180***	0.968***	0.807**	-0.002	-0.069	0.062	-0.293	-0.514	0.480
	(0.249)	(0.249)	(0.302)	(0.324)	(0.336)	(0.357)	(0.283)	(0.305)	(0.391)	(0.458)	(0.501)	(0.452)
$\ln y_{i,t-1}$	-0.093***	-0.073**	-0.066**	-0.095***	-0.056**	-0.064**	-0.132***	-0.135***	-0.158***	-0.049	-0.041	-0.046
	(0.026)	(0.029)	(0.026)	(0.025)	(0.024)	(0.030)	(0.032)	(0.034)	(0.035)	(0.033)	(0.050)	(0.042)
$\ln s_{kit}$	0.161***	0.148***	0.132***	0.057***	0.036*	0.048**	0.128***	0.129***	0.123***	0.076***	0.086***	0.067***
	(0.024)	(0.027)	(0.026)	(0.020)	(0.020)	(0.021)	(0.033)	(0.320)	(0.033)	(0.022)	(0.026)	(0.020)
$\ln(n_{it}+g+\delta)$	-0.267**	-0.330**	-0.268*	0.142	0.143	0.089	-0.311***	-0.355**	-0.361**	-0.194	-0.265*	-0.251*
	(0.122)	(0.147)	(0.141)	(0.116)	(0.121)	(0.116)	(0.113)	(0.152)	(0.141)	(0.161)	(0.160)	(0.146)
$\ln e_{it}$	0.033		0.013	0.032		0.023	0.022		0.033	0.056***		0.078***
	(0.027)		(0.038)	(0.055)		(0.069)	(0.039)		(0.046)	(0.020)		(0.020)
$\Delta \ln e_{it}$		0.061	0.036		0.006	0.047		0.126	0.231**		-0.085	0.058
		(0.104)	(0.123)		(0.061)	(0.079)		(0.132)	(0.110)		(0.097)	(0.093)
Joint significance test for $\ln e_{it}$ and $\Delta \ln e_{it}$			0.120			0.370			4.430			17.570
			[0.941]			[0.831]			[0.109]			[0.000]
m_1	-5.395	-5.385	-5.327	-2.740	-2.704	-2.747	-3.886	-3.976	-4.009	-3.069	-2.914	-2.942
	[0.000]	[0.000]	[0.000]	[0.006]	[0.007]	[0.006]	[0.000]	[0.000]	[0.000]	[0.002]	[0.003]	[0.003]
m_2	-1.515	-1.263	-1.326	1.278	1.368	1.433	-1.457	-1.012	-0.912	-1.238	-0.991	-1.220
	[0.130]	[0.207]	[0.185]	[0.201]	[0.171]	[0.152]	[0.145]	[0.311]	[0.362]	[0.216]	[0.322]	[0.223]
Sargan/Hansen Test p value	0.538	0.480	0.317	0.768	0.478	0.457	0.485	0.324	0.491	0.303	0.399	0.148
Adding up restriction p value	0.347	0.477		0.056	0.198		0.144	0.478		0.485	0.116	
Implied λ	0.020	0.015	0.014	0.020	0.012	0.013	0.028	0.029	0.034	0.010	0.008	0.009
No. of observations	687	634	634	197	179	179	360	334	334	130	121	121

Notes: Education data is the average years of schooling of population aged over 15. In the GMM estimation, $\ln e_{it}$ is treated as a predetermined variable and $\Delta \ln e_{it}$ is treated as endogenous variables. The adding up restriction refers to the hypothesis that the three coefficients other than the one on lagged output sum to zero when $\Delta \ln e_{it}$ is included; it refers to the hypothesis that the coefficients on the rates of investment and population growth are opposite in sign and equal in absolute value when $\ln e_{it}$ is included; Other definitions are the same as those in the previous tables.

Table 5.4: System GMM Estimation of the Augmented Solow Model (Restricted)

	Specification with $\ln e_{it}$ (equation 2.21)				Specification with $\ln s_{eit}$ (equation 2.20)			
	(1) Total Sample	(2) High Income	(3) Middle Income	(4) Low Income	(5) Total Sample	(6) High Income	(7) Middle Income	(8) Low Income
Constant	-0.121 (0.124)	0.679*** (0.262)	0.235 (0.208)	-0.035 (0.277)	-0.460** (0.202)	0.768*** (0.281)	-0.030 (0.285)	-0.029 (0.427)
$\ln y_{i,t-1}$	-0.083*** (0.021)	-0.099*** (0.031)	-0.107*** (0.030)	-0.045 (0.032)	-0.065*** (0.023)	-0.059*** (0.022)	-0.126*** (0.031)	-0.038 (0.051)
$\ln s_{kit} - \ln p_{it}$	0.160*** (0.023)	0.061*** (0.021)	0.135*** (0.033)	0.081*** (0.021)	0.148*** (0.027)	0.041** (0.019)	0.130*** (0.032)	0.094*** (0.029)
$\ln e_{it}$	0.040* (0.021)	0.009 (0.063)	0.029 (0.035)	0.031*** (0.011)				
$\ln s_{eit} - \ln p_{it}$					0.113 (0.085)	-0.108 (0.080)	0.180 (0.124)	-0.032 (0.101)
m_1	-5.385 [0.000]	-2.635 [0.008]	-3.770 [0.000]	-3.048 [0.002]	-5.413 [0.000]	-2.595 [0.009]	-3.950 [0.000]	-2.933 [0.003]
m_2	-1.545 [0.122]	1.316 [0.188]	-1.410 [0.159]	-1.221 [0.222]	-1.252 [0.211]	1.200 [0.230]	-0.958 [0.338]	-1.012 [0.312]
Sargan/Hansen test p value	0.735	0.626	0.482	0.374	0.684	0.547	0.391	0.221
Implied λ	0.017	0.021	0.023	0.009	0.013	0.012	0.027	0.008
Implied α	0.658	0.381	0.558	0.643	0.454	1.946	0.298	2.76
Implied β	0.165	0.056	0.120	0.246	0.347	-5.125	0.413	-0.94
No. of observations	687	197	340	130	634	179	334	121

Notes: Education data is the average years of schooling of population aged over 15. In the GMM estimation, $\ln e_{it}$ is treated as a predetermined variable and $\Delta \ln e_{it}$ is treated as a endogenous variable; Other definitions are the same as those in the previous tables.

5.3 The MRW model augmented with health human capital

We now further augment the Solow model with the multiple forms of human capitals and test whether population health status and investment in health contribute to economic growth and whether the model can explain the cross-country variance in economic growth. The estimated results obtained from unrestricted versions of the augmented MRW model as shown in equation (2.14) and (2.16) for the full sample and sub-samples with various proxies of health are presented in Table (5.5) and Table (5.6), respectively. The results obtained from restricted versions of the model for the full sample are presented in Table (5.7). Health capital is proxied by various indicators. The stock of health is measured as life expectancy at birth, infant mortality rate, adult survival rate (female and male separately) and undernourishment following the literature (Knowles and Owen, 1995; McDonald and Roberts, 2002; Webber, 2002; Barro, 1996; Arora, 2001; Bloom et al. 2001, 2004, and 2005; Bhargava et al., 2001; Jamison et al., 2004). The investment of health is measured by public health expenditure per capita and number of physicians per 1,000 persons (Heshmati, 2001; Gyimah-Brempong and Wilson, 2004; Hartwig, 2009). Alternatively, the log difference of health stock is included as a proxy for the accumulation of human capital. The stock of health is treated as a predetermined variable and the investment and the accumulation of health capital are treated as potentially endogenous variables[43], as a fast-growing economy is more likely to invest more in health.

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[43] Besides the instruments we have used for the MRW model, $\ln h_{i,t-1}$ and $\Delta \ln h_{i,t-2}$ and their suitable lags are used as instruments for first-differenced equation, and $\Delta \ln h_{i,t}$ and $\Delta^2 h_{i,t-1}$ are used as additional instruments for level equation in system-GMM estimations.

Besides testing the specifications provided by equation (2.14) - (2.16), we also test some extra specifications of the augmented Solow model as shown in Table (5.5).

For the full sample shown in Table (5.5), we find similar estimation results as those of the baseline and MRW model with respect to the initial income, investment rate and population growth. To be specific, the coefficients of those terms all have the right sign and are highly significant, which confirm the basic predictions of the augmented Solow model, i.e. the prediction of conditional convergence and a positive relation between output growth and the saving rate along with a negative relation between income growth and population growth rate. Most of the estimated convergence rates lie in between 2-3 percent per annum with various measurements of health capital. Moreover, m_2 test suggests that the hypothesis of no second-order serial correlation in the first-differenced residuals is not rejected for any of the GMM regressions except for the cases where health is measured as public health expenditure per capita. The Sargan test of over-identifying restrictions detects no problem with instrument validity in any of the regressions.

Columns (1)-(4) in Table (5.5) report the results obtained from estimating equation (2.16) where both the stock of education capital and health capital are included. Health status, measured by ASR (either female or male) has a statistically significant positive effect on output growth. Life expectancy has a positive but insignificant coefficient while infant mortality rate has an unexpected positive (insignificant) coefficient. A possible explanation for the insignificant effect of life expectancy could be that it is highly sensitive to infant and child mortality rates (presumably less relevant for current productivity) so that conceptually it is not a good measure to reflect adult health and worker productivity. The wrong sign of infant mortality rate is possibly caused by the same reason. Another possible reason is that we estimate the model for a sample of 111 countries that are either developed or developing, rather than estimate sub-samples. Preston (1976) found that impacts of health indicators, like life expectancy or ASR, on the growth rates depend on the level of income. Bhargava et al. (2001) and Suhrchke et al. (2006) also suggested that health affected economic growth asymmetrically for poor and rich countries. Education, measured by average years of schooling, is unsurprisingly found to be statistically insignificant, which is consistent with the findings in the previous research by Knowles and Owen (1995) and Heshmati (2001).

Columns (5)-(10) in Table (5.5) present the results obtained from estimating equation (2.14) where both the stock of education capital and the investment or the accumulation of health capital are included. Coefficients on health terms are correctly signed and statistically significant except for the case of female ASR. In line with some studies focusing on the role of health investment (Heshmati, 2001; Hartwig, 2009), investment in health measured by public health expenditure per capita and numbers of physicians per 1,000 persons is found to have positive effect on output growth. The accumulation of health capital, proxied as the log difference of health stock, such as life expectancy and male ASR in each five-year period, is found to affect the economic growth positively, while the increase of infant mortality rate has a negative impact on growth rate. Surprisingly, the improvement of female ASR is found to have a negative and insignificant effect on output growth. It is possibly caused by data measurement errors or some unknown reasons. Moreover, it is promising to find that the coefficients of education turn out to be statistically significant for the cases where both the stock of education and the accumulation of health are included. Some studies suggest that there is an interaction between health and education (Behrman, 1996; Gertler et al., 2004) and it is not easy to distinguish between the respective roles of health and education as well as to identify their respective impacts on economic growth in cross-country growth studies. Including health in aggregate production function results in a substantially reduced significance level of the coefficient on education in earlier studies is probably due to ignoring the link between education and health. It seems that the inclusion of both the stock of education and the change of health provides a model specification better fitting the data. It is also worth noting that the adding-up hypothesis as predicted in equation (2.14) - (2.16) is not rejected in any of the estimations.

The estimation results from several alternative specifications are given in columns (11)-(13). We include simultaneously life expectancy and health expenditure per capita because output growth may be boosted by both larger initial stock of health and a faster increase in health capital accumulation. As shown in column (11) both of them have positive coefficients and appear jointly significant, providing support for both of them fostering faster output growth. The interaction between average years of schooling and adult survival rate (male) is considered in the specification shown in column (12). The coefficients of education, life expectancy and the interaction term are all statistically significant and positive, as well as being jointly significant. This can all be taken as evidence for positive correlation between education and health, in line with the previous studies (Miguel, 2005; Galor and Mayer, 2002). Gyimah-Brempong and Wilson (2004) suggested that health capital affected the growth rate of per capita income in a quadratic way. We therefore estimate the specification incorporating both health expenditure per capita and its squared variable, without including education, as shown in column (13). Both health and its squared term are found to have significantly positive coefficients and appear jointly significant, which indicates that the impact of health investment on growth decreases at relatively higher level of investment in health.

We next estimate the augmented MRW model in sub-samples for two reasons. Firstly, health may affect economic growth asymmetrically for poor and rich countries and our previous estimation results of life expectancy and infant mortality rate also implicitly support this prediction. Secondly, the GMM estimators control for unobserved heterogeneity in the intercepts (country-specific effects) of the empirical growth model but may not control for the potential heterogeneity in the slope parameters; the presence of which will invalidate the use of lagged values of serially correlated regressors as instruments. Therefore, to investigate the impact of health on growth rates in economies with different development levels and to eliminate the parameter heterogeneity problem, we split our full sample into high, middle and low income sub-samples[44] and report the results for high and low income samples in Table (5.6).

The first six columns in Table (5.6) report the results for the high income sample, comprising 26 countries[45]. Similarly, we find clear evidence of conditional convergence and a positive correlation between investment rate and growth rate. The coefficients of population growth in all regressions are found to be positive, the same as the findings in the baseline and MRW models. Therefore, we conclude that the negative relation between population growth and output per capita growth is not supported by any of the three versions of the Solow model for high income economies. Convergence rates are approximately 2-3 percent per annum. Neither second-order serial correlation in the first-differenced residuals nor instrument invalidity is detected. The adding-up restrictions are found to be rejected at the 5% significant level in five out of six cases, along with the unexpected sign of the coefficients on population growth. Compared with the results in the full sample, the coefficients of health variables are observably changed. Life expectancy (significant at the 10% level) and infant mortality rate show the right signs but health expenditure and physicians per

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[44] The criteria to categorize sub-samples is the mean level of real GDP per capita over 1960-2004. It is preferred in our study rather than the World Bank's category which is based on the level of GNI in 2008 because we believe the mean value provides long-term general information.

[45] These 26 high income countries include both OECD and non-OECD ones (see Appendix Table A1 for list)

1,000 people present the wrong signs (negative) and are insignificant, while results of ASR (female or male) are not much affected. The change with respect to life expectancy and infant mortality rate support the sub-sample hypothesis and prove that, in contrast to Bhargava et al. (2001), the improvement in population health status does play a role in boosting economic growth, even in developed countries. The negative coefficients on health investment terms indicate that the rapidly increasing health expenditure observed in high income countries may slow down, rather than foster economic growth and the increase in number of phisicians per 1,000 persons may not necessarily enhance growth rates of output. Moreover, the insignificant effects of education capital (stock) hold even when the data are split into sub-samples.

The results for the low income sample, comprising 28 countries[46], are presented in columns (7)-(13). Initial incomes have statistically significant coefficients and investment rates have expected positive and significant coefficients for all cases. The speeds of convergence estimated using difference measures of health mainly lie in the range of 1-2 percent per annum except for undernourishment (5.8 percent). Population growth has a significantly negative effect on the growth rate, as in the full sample estimations. m_2 test and Sargan test detect neither second order serial correlation in the first-differenced residuals (except for the case where health is measured by public health expenditure) nor instrument invalidity. The adding-up restrictions cannot be rejected in any of the estimations. Some interesting findings are found with respect to

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[46] See Appendix Table A1 for the list of countries.

the effects of health. Firstly, the fact that the coefficients of life expectancy and infant mortality rate have the right signs that are statistically significant, suggests that population health measured by mortalitybased indicators are associated with economic growth and the positive effect of healthier population appears consistent with findings in some micro-level studies (see Thomas and Frankenberg, 2001 for references) in low income countries. Hence the sub-sample results confirm the positive effect of health status on economic growth for both developed and developing countries, which is in line with the previous studies (Knowles and Owen, 1995, 1997; McDonald and Roberts, 2002; Barro, 1996; Jamison et al., 2004). However, in contrast to the full sample analysis, we fail to identify the positive impact of ASR in the low income sample, though some studies claimed that ASR is a better measurement of health status than life expectancy (Bhargava et al., 2001; Mayer, 2001; Bloom et al., 2005). A possible explanation is that the available data of adult mortality rates in our 28 low income countries may have relatively larger measurement errors. Moreover, the investment of health measured by health expenditure and numbers of physicians is again, as in the full sample, found to be positively associated (statistically significant) with output growth, even with a longer time span than that in the literature, which reinforces the positive relation between them found in the previous studies, (Heshmati, 2001; Gyimah-Brempong and Wilson, 2004; Hartwig, 2009). In addition, the available undernourishment data[47] for low income countries allows us to test its impact on the growth rate in the low income

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[47] Data of undernourishment (notated as $\ln UNtr_{it}$ in our tables) is mainly available for 85 developing countries so that the estimation results using undernourishment as stock of health are reported only for low income sample in Table (5.6). $\ln UNtr_{it}$ is treated as a predetermined variable in the GMM estimation.

sample. Webber (2002) also suggested that a nutrition-based health indicator provided more information on health-related policies and was more likely to be a good measurement of health in developing, rather than developed countries. We unsurprisingly find a statistically significant negative effect of undernourishment on output growth when we include both life expectancy and undernourishment in the model as shown in column (13). Generally speaking, comparing the results obtained from estimating the full sample, or high and low income samples individually, we prefer the sub-sample analysis, and suggest that the augmented MRW model with multiple forms of human capitals performs better in the low income sample.

The estimated results obtained from the restricted version of equation (2.14) - (2.16) for the full sample are presented in Table (5.7). At least a set of estimation results are reported for each model specification. Compared with the textbook Solow and MRW model, the inclusion of health human capital leads to two major changes. Firstly, all estimated coefficients are found to have their expected signs. At least one of the difference terms with health or education variables is found to be of the right sign and statistically significant in estimations based on equation (2.13) - (2.15). Secondly, we observe more plausible values of the output share of physical capital α, which lie in the range between 36 to 54 percent and are relatively closer to the literature recommended 33 percent than those of the previous models. The sum of the shares of physical capital and two human capitals, $\alpha+\beta+\psi$, is smaller than one in all the cases, providing support for the decreasing returns to the set of reproducible factors of production as assumed in the neoclassical growth theory. Thirdly, no implausible values of β and ψ are observed. Particularly all the implied values of β and ψ are positive and almost all of them are between 10-20 percent, which also supports the specification of a production function with both education and health factors. The estimates of other parameters are not greatly affected by the restricted estimation. The values of estimated convergence rates remain close to the conventionally obtained value 2%. Both the m_2 test and Sargan test support the adoption of GMM estimators. Thus, we suggest that the inclusion of health human capital improves the performance of the Solow model, and health is also proved to play an important role in economic growth.

Table 5.5: System-GMM Estimation on the Augmented MRW Model for the Full Sample (Unrestricted)

	$\ln e_{it}$ and $\ln h_{it}$ (equation 3.16)				$\ln e_{it}$ and $\Delta \ln h_{it}$ $or \ln s_{hit}$ (equation 3.14)						Other Specifications		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Constant	-0.247	-0.455*	-3.166**	-2.690***	-0.240	0.576	-0.087	-0.223	-0.106	-0.196	-0.967***	-0.791*	-0.841**
	(0.331)	(0.393)	(1.499)	(0.947)	(0.166)	(0.244)	(0.160)	(0.225)	(0.189)	(0.252)	(0.351)	(0.460)	(0.333)
$\ln y_{i,t-1}$	-0.077***	-0.072**	-0.138***	-0.140***	-0.110***	0.097***	-0.087***	-0.103***	-0.100***	-0.091**8	-0.115***	-0.173***	-0.100***
	(0.017)	(0.028)	(0.023)	(0.024)	(0.022)	(0.024)	(0.016)	(0.022)	(0.019)	(0.026)	(0.022)	(0.015)	(0.037)
$\ln s_{kit}$	0.135***	0.146***	0.120**	0.118**	0.144***	0.142***	0.144***	0.155***	0.177***	0.164***	0.118***	0.151***	0.142***
	(0.171)	(0.019)	(0.061)	(0.047)	(0.018)	(0.019)	(0.017)	(0.021)	(0.020)	(0.026)	(0.019)	(0.024)	(0.027)
$\ln(n_{it} + g + \delta)$	-0.158**	-0.244**	-0.150*	-0.219**	-0.218***	-0.172*	-0.155**	-0.257**	-0.196**	-0.200*	-0.182***	-0.239***	-0.251**
	(0.072)	(0.107)	(0.085)	(0.096)	(0.074)	(0.092)	(0.073)	(0.108)	(0.090)	(0.121)	(0.065)	(0.053)	(0.097)
$\ln e_{it}$	0.025	0.040	0.002	0.013	0.027	0.022	0.064***	0.045*	0.035*	0.052*	0.012	-1.412***	
	(0.021)	(0.026)	(0.035)	(0.037)	(0.022)	(0.020)	(0.021)	(0.026)	(0.021)	(0.028)	(0.021)	(0391)	
$\ln LE_{it}$	0.040										0.249**	0.308**	
	(0.091)										(0.099)	(0.140)	
$\ln IMR_{it}$		0.015											
		(0.023)											
$\ln ASRf_{it}$			0.557**										
			(0.267)										
$\ln ASRm_{it}$				0.465***									
				(0.173)									
$\ln PHE_{it}$					0.024**						0.020*		0.128**
					(0.012)						(0.010)		(0.059)
$\ln Phy_{it}$						0.026*							
						(0.015)							
$\Delta \ln LE_{it}$							0.734***						
							(0.207)						
$\Delta \ln IMR_{it}$								-0.143*					
								(0.078)					
$\Delta \ln ASRf_{it}$									-0.269				
									(0.372)				

To be continued …

	$\ln e_{it}$ and $\ln h_{it}$ (equation 3.16)				$\ln e_{it}$ and $\Delta \ln h_{it}$ $or \ln s_{hit}$ (equation 3.14)						Other Specifications		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
$\Delta \ln ASRm_{it}$										0.565**			
										(0.248)			
$\ln e_{it} \cdot \ln ASRm_{it}$												0.216***	
												(0.060)	
$(\ln PHE_{it})^2$													-0.005*
													(0.003)
Joint significance test											9.97	28.22	6.160
											[0.007]	[0.000]	[0.046]
m_1	-5.433	-5.439	-1.642	-1.677	-4.633	-5.053	-5.360	-5.541	-4.041	-4.008	-4.706	-1.770	-4.913
	[0.000]	[0.000]	[0.101]	[0.093]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.077]	[0.000]
m_2	-1.516	-1.517	0.457	0.522	-2.147	-1.476	-1.606	-1.352	-0.632	-0.851	-2.105	0.517	-2.017
	[0.130]	[0.129]	[0.647]	[0.602]	[0.032]	[0.140]	[0.108]	[0.154]	[0.527]	[0.395]	[0.035]	[0.605]	[0.044]
Sargan/Hansen Test p value	0.462	0.761	0.633	0.659	0.836	0.702	0.628	0.719	0.538	0.614	0.371	0.573	0.494
Adding up restriction p value	0.816	0.633	0.779	0.378	0.606	0.969	0.602	0.757	0.594	0.049			
Implied λ	0.016	0.015	0.030	0.030	0.023	0.012	0.018	0.022	0.021	0.022	0.024	0.038	0.021
No. of observations	687	687	412	413	571	576	687	676	470	471	571	413	599

Notes: In the GMM estimation, $\ln h_{it}$ is treated as a predetermined variable, and $\ln s_{hit}$ or $\Delta \ln h_{it}$ are treated as endogenous variables. $\ln h_{it}$ refers to $\ln LE_{it}$, $\ln IMR_{it}$, $\ln ASRf_{it}$ and $\ln ASRm_{it}$; $\ln s_{hit}$ refers to $\ln PHE_{it}$ and $\ln Doc_{it}$. $\Delta \ln h_{it}$ refers to $\Delta \ln LE_{it}$, $\Delta \ln IMR_{it}$, $\Delta \ln ASRf_{it}$, and $\Delta \ln ASRm_{it}$; $\ln e_{it} \cdot \ln ASRm_{it}$ is the interaction of stock of education and stock of health; $(\ln PHE_{it})^2$ is the square of the health investment term; The adding up restrictions refers to the hypothesis that the coefficients on the rates of investment and population growth are opposite in sign and equal in absolute value when $\ln e_{it}$ and $\ln h_{it}$ are included, and that the sum of the coefficients on the rates of investment, the investment of health (or the growth rate of health) and population growth is zero when $\ln e_{it}$ and $\Delta \ln h_{it}$ $or \ln s_{hit}$ are included; Joint significant test is Wald test; Other definitions are the same as those in the previous tables.

Table 5.6: System-GMM Estimation of the Augmented MRW Model – Comparison of Results from High income and Low Income Samples

	High Income Sample: 26 countries						Low Income Sample: 28 countries						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Constant	-0.431	1.781***	-4.639	-3.789*	1.011***	0.860***	-1.420*	0.821	-0.002	-0.960	-0.616	0.194	-0.235
	(1.082)	(0.391)	(4.057)	(2.101)	(0.222)	(0.305)	(0.725)	(0.631)	(1.318)	(1.187)	(0.382)	(0.444)	(0.975)
$\ln y_{i,t-1}$	-0.146***	-0.128***	-0.152***	-0.176***	-0.097***	-0.076**	-0.080**	-0.082**	-0.076*	-0.035	-0.071**	-0.104***	-0.252**
	(0.035)	(0.040)	(0.042)	(0.042)	(0.034)	(0.032)	(0.039)	(0.034)	(0.044)	(0.043)	(0.031)	(0.038)	(0.117)
$\ln s_{kit}$	0.043***	0.029	0.054***	0.055***	0.083***	0.072***	0.047**	0.042**	0.063**	0.053*	0.098***	0.040*	0.081*
	(0.016)	(0.019)	(0.017)	(0.015)	(0.028)	(0.019)	(0.021)	(0.020)	(0.029)	(0.031)	(0.020)	(0.023)	(0.044)
$\ln(n_{it}+g+\delta)$	0.194***	0.192*	0.175**	0.176**	0.084	0.115	-0.259*	-0.179	-0.360**	-0.407**	-0.244*	-0.217*	-0.486**
	(0.054)	(0.099)	(0.085)	(0.081)	(0.074)	(0.105)	(0.141)	(0.149)	(0.156)	(0.179)	(0.147)	(0.116)	(0.212)
$\ln e_{it}$	0.039	0.033	0.035	0.050	0.036	0.047	0.005	0.011	0.057	0.048	0.021	0.048**	
	(0.041)	(0.052)	(0.061)	(0.061)	(0.059)	(0.063)	(0.036)	(0.027)	(0.036)	(0.037)	(0.024)	(0.021)	
$\ln LE_{it}$	0.529*						0.328**						0.287**
	(0.317)						(0.158)						(0.137)
$\ln IMR_{it}$		-0.026						-0.158**					
		(0.022)						(0.071)					
$\ln ASRf_{it}$			0.948						-0.086				
			(0.656)						(0.205)				
$\ln ASRm_{it}$				0.862**						0.005			
				(0.364)						(0.186)			
$\ln PHE_{it}$					-0.005						0.044**		
					(0.008)						(0.019)		
$\ln Phy_{it}$						-0.035						0.038**	
						(0.025)						(0.018)	
$\ln UNtr_{it}$													-0.154*
													(0.091)
m_1	-2.643	-2.710	-2.564	-2.755	-2.695	-2.475	-2.986	-3.114	-2.086	-2.099	-3.370	-2.895	-2.702
	[0.008]	[0.007]	[0.010]	[0.006]	[0.007]	[0.013]	[0.002]	[0.002]	[0.037]	[0.035]	[0.001]	[0.004]	[0.006]
m_2	1.194	1.271	1.306	1.260	1.212	1.100	-1.208	-1.295	-0.898	-1.059	-1.646	-1.026	1.283
	[0.232]	[0.204]	[0.192]	[0.208]	[0.226]	[0.271]	[0.227]	[0.195]	[0.369]	[0.290]	[0.010]	[0.305]	[0.200]

To be continued …

	High Income Sample: 26 countries						Low Income Sample: 28 countries						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Sargan/Hansen Test p value	0.202	0.471	0.869	0.870	0.242	0.897	0.380	0.442	0.519	0.881	0.588	0.611	0.905
Adding up restriction p value	0.007	0.014	0.010	0.004	0.015	0.112	0.573	0.380	0.770	0.647	0.497	0.414	
Implied λ	0.032	0.027	0.033	0.039	0.020	0.016	0.017	0.017	0.016	0.007	0.015	0.022	0.058
No. of observations	197	197	189	189	177	167	130	130	102	102	105	115	87

Notes: Data of undernourishment ($\ln UNtr_{it}$) is mainly available for 85 developing countries so that the estimation results using undernourishment as stock of health are reported only for low income sample; $\ln UNtr_{it}$ is treated as a predetermined variable; Other definitions are the same as those in the previous tables.

Table 5.7: System GMM Estimation of the Augmented MRW Model (Restricted)

		Model Specifications					
		Equation (3.16)	Equation (3.14)			Equation (3.15)	Equation (3.13)
		$\ln e_{it}$ and $\ln h_{it}$	$\ln e_{it}$ and $\Delta \ln h_{it}$ *or* $\ln s_{hit}$			$\ln s_{eit}$ and $\ln h_{it}$	$\ln s_{eit}$ and $\ln s_{hit}$
		(1)	(2)	(3)	(4)	(5)	(6)
Constant		-0.185 (0.559)	-0.145* (0.087)	-0.110 (0.189)	-0.175 (0.184)	-1.920* (0.968)	-0.367* (0.194)
$\ln y_{i,t-1}$		-0.074*** (0.021)	-0.109*** (0.022)	-0.098*** (0.019)	-0.107*** (0.019)	-0.089*** (0.027)	-0.134*** (0.037)
$\ln s_{kit} - \ln p_{it}$		0.086*** (0.025)	0.144*** (0.018))	0.136*** (0.020)	0.125*** (0.020)	0.083** (0.035)	0.148*** (0.030)
$\ln e_{it}$		0.028 (0.033)	0.029 (0.022)	0.039* (0.021)	0.040** (0.020)		
$\ln s_{eit} - \ln p_{it}$						0.026 (0.085)	0.081 (0.085)
$\ln h_{it}$	$\ln LE_{it}$	0.034 (0.174)					
	$\ln ASRm_{it}$					0.035** (0.018)	
$\ln s_{hit} - \ln p_{it}$	$\ln PHE_{it}$		0.026** (0.012)				0.047*** (0.017)
	$\Delta \ln ASRf_{it}$			0.042 (0.088)			
	$\Delta \ln ASRm_{it}$				0.065 (0.083)		
m_1		-5.395 [0.000]	-4.597 [0.000]	-3.986 [0.000]	-3.939 [0.000]	-4.548 [0.000]	-4.561 [0.000]
m_2		-1.510 [0.131]	-0.989 [0.308]	-0.675 [0.500]	-0.700 [0.484]	-0.251 [0.802]	-1.822 [0.068]
Sargan/Hansen Test p value		0.734	0.691	0.839	0.603	0.482	0.764
Implied λ		0.015	0.023	0.021	0.023	0.019	0.029
Implied α		0.538	0.516	0.493	0.421	0.419	0.361
Implied β		0.175	0.104	0.141	0.135	0.131	0.198
Implied ψ		0.212	0.093	0.152	0.219	0.177	0.115
No. of observations		687	571	470	471	539	519

Notes: Definitions are the same as those in the previous tables.

6 Conclusion

The primary purpose of this paper is to test whether the Solow model augmented with multiple forms of human capitals can explain cross-country difference in growth and to investigate the effect of health on the growth of per capita income. Following Knowles and Owen (1995), we introduce both education human capital and health human capital into the textbook Solow model and extend their cross-section analysis to a dynamic panel data analysis to control for omitted variable and endogeneity biases, using a robust and consistent system GMM estimator. By adopting the latest available data for a sample of 111 developed and developing countries over 1960-2004, we estimate the baseline Solow model and its extended versions and compare the estimated results. Using various health indicators and splitting our data into sub-samples, we investigate the relationship between health capital (both stock and investment) and output growth, particularly the impacts of different health variables on economies at different development levels. Our findings are summarized as following:

Firstly, comparing the results estimated from using various estimators, restricted by different model specifications and for different samples, we find the GMM estimators provide relatively more consistent results. The augmented MRW model incorporating both education and health capitals can better fit the cross-country data and explain more powerfully the growth difference across countries. Conditional convergence predicted by the neoclassical growth theory, with a speed of around 2 percent per annum, has been found in either the full sample or sub-samples. Growth rates are found to be positively related the saving rate in all samples and negatively related to the population growth in all samples except for the high income sample.

Secondly, the role of education capital measured by the average years of schooling has been partially identified in the extended Solow model incorporating both education and health capitals, rather than the MRW model. In contrast to some previous studies, when both the education and the health stock variables are considered simultaneously, their significance levels are not reduced. We also find that the growth effect of health status is positively correlated with the level of education capital.

Finally, both the stock of health, and the investment or accumulation of health capital appears strongly associated with the output growth, particularly for low income countries. The effects of health measured by various data largely vary with different samples of countries. Life expectancy and infant mortality rate are found to have significant effects in sub-samples, rather than the full sample. The impacts of adult survival rates are significantly positive in the full sample, though not significant in sub-samples, which is opposite to some earlier studies that found a positive effect in low income sample but a negative effect in high income economies. The nutrition-based health indicator is found to be preferable in the low income sample.

Moreover, the investment of health measured by public health expenditure per capita or the number of physicians per 1,000 persons is positively associated with economic growth in the full and low income samples, yet negatively in the high income sample. The positive effect of health expenditure is quadratic, implying that the growth effect of health investment diminishes with the level of it increases.

Our findings have some implications for growth policy and growth research. From a policy standpoint, low income countries that desire higher growth rates can possibly achieve that by increasing the investment of health and improving the population health status. The growth-enhancing effect of health may be reinforced by improving the level of education so that policies aiming to increase education capital will also benefit the accumulation of health capital. From the government's point of view, a balance between education and health spending is required due to a trade-off existing between them. For high income countries, rapidly increasing health expenditure may have become a burden for the economy, and therefore has a negative effect on economic growth as shown in above findings. Hence reducing the public health expenditure probably leads to a higher growth rate, though this will be an opposite case in low income countries. From a research standpoint, none of the health indicators we have employed reflects morbidity, disability and mental health, which are closely related to adult health and workforce productivity. It is important that future research compile more elaborate as well as widely available data on health indicators, which proxy health status better and also enable cross-country analysis.

Regarding estimation techniques, we have to admit the fragility of more sophisticated estimators and their proceeding tests, particularly when the sample size is relatively small. Caution is required when we interpret the empirical results. Moreover, the assumption that the growth rate of technological progress is constant across countries is obviously too strong. We leave the relaxation of this assumption for a future research.

Appendix 1: Equations from the textbook Solow model and the MRW model

We redisplay the equations that have been used as the framework for empirical analysis by MRW (1992), Islam (1995), Caselli, Esquivel and Lefort (1996), Heoffler (2002), and Bond et al. (2001). The dynamics of a country's growth towards the steady state can be expressed as[48]

$$\begin{aligned}\ln y(t) - \ln y(0) = &-(1-e^{-\lambda t})\ln y(0) + (1-e^{-\lambda t})\frac{\alpha}{1-\alpha}\ln(s) \\ &-(1-e^{-\lambda t})\frac{\alpha}{1-\alpha}\ln(n+g+\delta) + (1-e^{-\lambda t})\ln A(0) + gt \qquad \text{(A.1)}\end{aligned}$$

where $\lambda = (n+g+\delta)(1-\alpha)$. If considering human capital, it can be expressed as

$$\begin{aligned}\ln y(t) - \ln y(0) = &-\theta\ln y(0) + \theta\frac{\alpha}{1-\alpha-\beta}\ln(s_k) + \theta\frac{\beta}{1-\alpha-\beta}\ln(s_h) \\ &-\theta\frac{\alpha+\beta}{1-\alpha-\beta}\ln(n+g+\delta) + \theta\ln A(0) + gt \qquad \text{(A.2)}\end{aligned}$$

$$\begin{aligned}\ln y(t) - \ln y(0) = &-\theta\ln y(0) + \theta\frac{\alpha}{1-\alpha}\ln(s_k) - \theta\frac{\alpha}{1-\alpha}\ln(n+g+\delta) \\ &+\theta\frac{\beta}{1-\alpha}\ln(h^{*}) + \theta\ln A(0) + gt \qquad \text{(A.3)}\end{aligned}$$

where $\theta = 1-e^{-\lambda t}$, $\lambda = (n+g+\delta)(1-\alpha-\beta)$, and h is the steady state level of education human capital. Eqaution (A.1) is from the textbook Solow model. Equation (A.2) and (A.3) are from the MRW model, including human capital.

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[48] For the details of the derivation, refers to their original papers.

Appendix 2: Table A1: Summary of studies based on the augmented MRW or its extened model

Study	Health measurement	Coefficient	Data	Dependent variable and estimator	Other covariates (see note 1)
			MRW Type		
Knowles and Owen (1995)	Life expectancy	0.381***	84 countries 1960-1985, cross-section	LD, OLS	Average years of schooling
Knowles and Owen (1997)	Life expectancy	0.582*** -0.797**	77 countries 1960-1985, cross-section	L, NLS	Average years of schooling
Heshmati (2001)	Health expenditure per capita	0.175**	22 OECD countries 1970-1992, 5-year interval panel	LD, linear and non-linear regression methods	Average years of schooling
McDonald and Roberts (2002)	Life expectancy and infant mortality	0.120**	77 countries 1960-1989, 5-year interval panel	L, two-way FE	Mean years of total education from Nehru et al. (1995)
Webber (2002)	Calorific intake per capita	0.09-0.13** (OLS), 0.08-0.22** (2SLS)	46 countries 1960-1990, cross-section	LD, OLS and 2SLS	Different measures of education
Li and Huang (2008)	No. of hospital bed or doctors per 10,000 persons	0.00-0.05**	28 provinces in China 1978-2005, annual panel	LD, OLS, FE, RE, IV and 2SLS	Average years of schooling, and other measures of education
			Barro Regression Type		
Barro and Sala-i-Martin (1995)	Life expectancy	0.058***	85 countries 1965-1975, 95 countries 1975-1985	SUR with country random effects	Schooling, public spending on education, government consumption, black market premium, political stability and terms of trade
Barro and Sala-i-Martin (2004)	Life expectancy (the reciprocal)	-4.91***	Roughly 80 countries 1965-1995, 5-year interval panel	3SLS	Schooling, fertility rate, government consumption ratio, law, democracy, openness, and inflation rate
Barro (1996)	Life expectancy	0.042***	Roughly 100 countries 1960-1990, three periods: 1965-75, 1975-85, and 1985-90	3SLS	Similar as above
CEL (1996)	Life expectancy	0.071*** (OLS), 0.080*** (3SLS), -0.001 (GMM)	Around 90 countries 1960-1985, 5-year interval panel	OLS, 3SLS, and GMM	Schooling, government consumption ratio, black market premium, and the number of revolutions
Hamoudi and Sachs (1999)	Life expectancy	0.072 ***	78 countries 1980-1995, cross section	OLS	Institutional quality, openness, net government savings, tropics land area, coastal population density,

					and Africa dummies
Bhargava et al. (2001)	Adult survival rate (ASR)	0.181** -0.358***	92 countries 1965-1990, 5-year interval panel	Dynamic RE	Interaction terms between ASR and lagged GDP, tropics, openness, and fertility rate
Gyimah-Brempong and Wilson (2004)	Health care expenditure, child mortality rate	0.338*** (Africa), 0.059*** (OECD)	21 African countries, and 23 OECD countries 1961-1995, 4-year interval panel	GMM	Schooling, size of dependent population, openness, and political instability

Notes: 'Other covariates' means the explanatory variables besides initial income level, ratio of investment over GDP, health capital, and population growth; Dependent variable of MRW type regressions is either log difference of GDP per capita or per worker (LD) or log of real GDP per capita or per worker (L); ASR: Adult survival rate; OLS: Ordinary least squares; FE: fixed effects; RE: random effects; NLS: Non-linear least squares; GMM: Generalized method of moments; 2SLS: Two stage least squares; 3SLS: Three stage least squares; SUR: Seemingly unrelated regression; *, ** and *** denote significance at the 10%, 5% and 1% levels, respectively (two sided alternatives for the *t* tests); The coefficients reported in the third column are not directly comparable since the models and samples differ;

Appendix 3: Table A2. Countries and Samples in this chapter

Countries	Country Isocode	PWT Order	Region	Low Income Countries (28)	Middle Income Countries (57)	High Income Countries (26)
Algeria	DZA	3	MENA	0	1	0
Argentina	ARG	6	LAC	0	1	0
Australia	AUS	8	HIE	0	0	1
Austria	AUT	9	HIE	0	0	1
Bangladesh	BGD	13	SA	1	0	0
Barbados	BRB	14	LAC	0	0	1
Belgium	BEL	16	HIE	0	0	1
Bolivia	BOL	21	LAC	0	1	0
Botswana	BWA	23	SSA	0	1	0
Brazil	BRA	24	LAC	0	1	0
Bulgaria	BGR	26	EUCA	0	1	0
Burundi	BDI	28	SSA	1	0	0
Cameroon	CMR	30	SSA	0	1	0
Canada	CAN	31	HIE	0	0	1
Central African Republic	CAF	33	SSA	1	0	0
Chile	CHL	35	LAC	0	1	0
China	CHN	36	EAP	1	0	0
Colombia	COL	37	LAC	0	1	0
Congo, Republic of	COG	40	SSA	1	0	0
Costa Rica	CRI	41	LAC	0	1	0
Croatia	HRV	43	EUCA	0	1	0
Cyprus	CYP	45	HIE	0	1	0
Czech Republic	CZE	46	EUCA	0	0	1
Denmark	DNK	47	HIE	0	0	1
Dominican Republic	DOM	50	LAC	0	1	0
Ecuador	ECU	51	LAC	0	1	0
Egypt	EGY	52	MENA	0	1	0
El Salvador	SLV	53	LAC	0	1	0
Estonia	EST	56	EUCA	0	1	0
Ethiopia	ETH	57	SSA	1	0	0
Fiji	FJI	58	EAP	0	1	0
Finland	FIN	59	HIE	0	0	1
France	FRA	60	HIE	0	0	1
Gambia, The	GMB	62	SSA	1	0	0
Germany	GER	64	HIE	0	0	1
Ghana	GHA	65	SSA	1	0	0
Greece	GRC	66	HIE	0	1	0
Guatemala	GTM	68	LAC	0	1	0
Guinea-Bissau	GNB	70	SSA	1	0	0
Guyana	GUY	71	LAC	0	1	0
Honduras	HND	73	LAC	0	1	0
Hong Kong	HKG	74	HIE	0	0	1
Hungary	HUN	75	EUCA	0	1	0

Countries	Country Isocode	PWT Order	Region	Low Income Countries (28)	Middle Income Countries (57)	High Income Countries (26)
India	IND	77	SA	1	0	0
Indonesia	IDN	78	EAP	0	1	0
Iran	IRN	79	MENA	0	1	0
Ireland	IRL	81	HIE	0	0	1
Israel	ISR	82	HIE	0	0	1
Italy	ITA	83	HIE	0	0	1
Jamaica	JAM	84	LAC	0	1	0
Japan	JPN	85	HIE	0	0	1
Jordan	JOR	86	MENA	0	1	0
Kazakhstan	KAZ	87	EUCA	0	1	0
Kenya	KEN	88	SSA	1	0	0
Korea, Republic of	KOR	91	HIE	0	1	0
Latvia	LVA	95	EUCA	0	1	0
Lesotho	LSO	97	SSA	1	0	0
Lithuania	LTU	100	EUCA	0	1	0
Malawi	MWI	105	SSA	1	0	0
Malaysia	MYS	106	EAP	0	1	0
Mali	MLI	108	SSA	1	0	0
Mauritania	MRT	110	SSA	1	0	0
Mauritius	MUS	111	SSA	0	1	0
Mexico	MEX	112	LAC	0	1	0
Moldova	MDA	114	EUCA	0	1	0
Nepal	NPL	119	SA	1	0	0
Netherlands	NLD	120	HIE	0	0	1
New Zealand	NZL	122	HIE	0	0	1
Nicaragua	NIC	123	LAC	0	1	0
Niger	NER	124	SSA	1	0	0
Norway	NOR	126	HIE	0	0	1
Pakistan	PAK	128	SA	1	0	0
Panama	PAN	130	LAC	0	1	0
Papua New Guinea	PNG	131	EAP	0	1	0
Paraguay	PRY	132	LAC	0	1	0
Peru	PER	133	LAC	0	1	0
Philippines	PHL	134	EAP	0	1	0
Poland	POL	135	EUCA	0	1	0
Portugal	PRT	136	HIE	0	1	0
Puerto Rico	PRI	137	HIE	0	0	1
Romania	ROM	139	EUCA	0	1	0
Rwanda	RWA	141	SSA	1	0	0
Senegal	SEN	145	SSA	1	0	0
Serbia and Montenegro	SCG	146	EUCA	0	1	0
Seychelles	SYC	147	SSA	0	1	0
Sierra Leone	SLE	148	SSA	1	0	0
Singapore	SGP	149	HIE	0	0	1

Countries	Country Isocode	PWT Order	Region	Low Income Countries (28)	Middle Income Countries (57)	High Income Countries (26)
Slovak Republic	SVK	150	EUCA	0	1	0
Slovenia	SVN	151	HIE	0	0	1
South Africa	ZAF	154	SSA	0	1	0
Spain	ESP	155	HIE	0	0	1
Sri Lanka	LKA	156	SA	0	1	0
Sudan	SDN	160	SSA	1	0	0
Swaziland	SWZ	162	SSA	0	1	0
Sweden	SWE	163	HIE	0	0	1
Switzerland	CHE	164	HIE	0	0	1
Tajikistan	TJK	167	EUCA	1	0	0
Tanzania	TZA	168	SSA	1	0	0
Thailand	THA	169	EAP	0	1	0
Trinidad &Tobago	TTO	172	LAC	0	1	0
Tunisia	TUN	173	MENA	0	1	0
Turkey	TUR	174	EUCA	0	1	0
Uganda	UGA	176	SSA	1	0	0
United Kingdom	GBR	179	HIE	0	0	1
United States	USA	180	HIE	0	0	1
Uruguay	URY	181	LAC	0	1	0
Venezuela	VEN	184	LAC	0	1	0
Vietnam	VNM	185	EAP	1	0	0
Yemen	YEM	186	MENA	1	0	0
Zambia	ZMB	187	SSA	1	0	0
Zimbabwe	ZWE	188	SSA	0	1	0

Notes: ‘EAP’: East Asia and Pacific; ‘EUCA’: Europe and Central Asia; ‘LAC’: Latin America & the Caribbean; ‘MENA’: Middle East and North Africa; ‘SA’: South Asia; ‘SSA’: Sub-Saharan Africa; and ‘HIE’: High-Income Economies include both high-income OCED members and non-OECD members. Region is defined by WB WDI. Income groups are categorized by the mean level of real GDP per capita over 1960-2004 (author calculation);

Appendix 4: Table A3: Data Resources and Statistics

Variables		Mean	Std. Dev.	Min	Max	Description and Resource
g_y		0.078	0.135	-0.792	0.927	Average growth rate of real GDP per capita over each 5-year period (author calculation)
y		7073.6	6852.9	332.1	34364.5	Real GDP per capita (RGDPCH in PWT6.2)
s_k		0.166	0.094	0.010	0.920	Share of investment in real GDP per capital averaged over each 5-year period calculated from raw data KI in PWT6.2
n	n_1	0.017	0.011	-0.019	0.079	Average annual growth rate of total population over each 5-year period calculated from raw data Pop in PWT6.2
	n_2	0.020	0.012	-0.026	0.089	Average annual growth rate of working-age population over each 5-year period calculated from raw data in WDI (2007)
edu	25+	4.930	2.917	0.040	12.25	Average years of total schooling for the populations aged over 15 or 25 from Barro and Lee (2001)
	15+	5.189	2.829	0.090	12.05	
$life$		62.382	11.754	27.426	81.026	Life expectancy at birth from GHND (originally from WDI)
imr		63.164	52.657	2.9	285	Infant mortality rates from GHND (originally from UNICEF)
asr	$asrf$	808.58	135.49	369.25	952.39	Adult survival rates (female or male) calculated from raw data from WDI (2007)
	$asrm$	728.80	135.40	308.97	912.81	
$untr$		0.224	0.154	0.025	0.650	Percentage of the population whose food intake is insufficient to meet dietary energy requirements continuously from GHND (originally from FAO)
phe		350.86	502.63	1.62	3038.81	Public health expenditure per capita (author calculation) from GHND
Phy		0.962	1.033	0.007	5.789	Physicians per 1,000 people (physicians are defined as graduates of any facility or school of medicine who are working in the country in any medical field) from GHND

Notes: Statistics are calculated for the full sample (111 countries over 1960-2004); Undernourishment data is mainly available for 85 developing countries (defined as middle or low income groups in my sample) in year 1970, 1980, 1990, 1995 and 2005.

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