



**A Reevaluation of the Effect of Human
Capital Accumulation on Economic Growth:
Using Natural Disasters as an Instrument**

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Abstract

Theoretic growth models and microeconomic evidence suggest that human capital accumulation is an important determinant of per capita income growth. However, outliers, measurement errors, and incorrect specifications may have affected early macroeconomic studies that found a weak relationship between growth and human capital accumulation. While recent studies addressing these problems are beginning to show larger positive effects, the potential endogeneity of human capital accumulation has received relatively little attention. In this paper, we demonstrate that endogeneity is significant and find that natural disasters are a good instrument for changes in schooling. Our resulting instrumental variable estimates are larger than our OLS estimates and are generally larger than those in previous studies. Our analysis also provides some limited evidence of human capital externalities.

1. Introduction

Theoretic models of economic growth suggest that human capital accumulation is a significant determinant of rising per capita income. Microeconomic evidence of the positive relationship between schooling and wages supports this prediction. Estimates using macroeconomic data demonstrate that the initial stock of human capital is an important determinant of economic growth,¹ but empirical estimates of the effects of changes in human capital (human capital accumulation) poorly match theoretic predictions (Barro and Sala-i-Martin (1995) and Benhabib and Spiegel (1994)).

Most studies approach this poor match as a measurement error problem (Temple (1999a), Mankiw, Romer, and Weil (1992), Krueger and Lindahl (2001)), including correcting for imperfect measures of quality (Hanushek and Kimko (2000), Wossmann (2003)). Other studies have focused on the effects of outliers (Temple 1999b) or the use of incorrect specifications (Englander and Gurney (1994) Gemmel (1996), Bassanini and Scarpetta (2002), Engelbrecht (2003)). These studies suggest that restricting the sample to OECD countries can generate a generally positive effect of changes in schooling or school enrollments on growth that is similar in magnitude to those found in microeconomic estimates based on survey data, but tell us little about the experience of countries outside the OECD, which are often considered to be the developing countries.

Our contribution to the literature is based on the possibility that the poor match between theory and empirical work results not from how we measure human capital, but from the potentially endogenous relationship between changes in human capital and economic growth. Using data from developed and developing countries, we present

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evidence suggesting that human capital is, in fact, endogenously determined and therefore empirical analysis requires an instrumental variable approach.

Of course, we are not the first to introduce instrumental variables to this literature. Pritchett (2001) and Krueger and Lindahl (2001) apply an instrumental variables technique to estimate the effect of changes in average years of schooling on growth, using Nehru, Swanson, and Dubey (1995) and Kyriacou's (1991) schooling data as instruments, respectively.² Their purpose in using the instrumental variables method is to overcome the measurement error issue, and not necessarily to address endogeneity per se. Indeed, the Nehru, Swanson, and Dubey and Kyriacou schooling variables are not appropriate instruments if one is trying to address endogeneity. A valid instrument in this context is one that determines changes in schooling but is not a direct determinant of economic growth; alternative measures of schooling are arguably just as important a determinant to growth as is the Barro and Lee measure of schooling. Furthermore, researchers like Glewwe and Hanan (2004) have shown that demand for education is positively correlated with increases in household income and wealth, thus emphasizing the two-way relationship between economic growth and human capital accumulation.

It appears that a key reason that researchers have not yet addressed the endogeneity issue is because of the lack of valid instruments. To our knowledge, no studies exist in which the endogeneity of human capital accumulation is tested, and if found to be present, the instrumental variables method is used to estimate the effects of changes in human capital on growth. Skidmore and Toya (2002) demonstrate that

² Curiously, Pritchett (2001) finds that instrumental variables does not lead to a positive estimated effect of changes in schooling on growth, but Krueger and Lindahl (2001) find that instrumental variables yields a positive effect of changes in schooling on per capita GDP growth. Depending on specification and whether the coefficient on capital is constrained, these coefficient estimates range from 0 to a range similar to estimates generated from micro data.

climatic natural disasters affect growth through human capital accumulation, indicating that a climatic disaster variable may be an appropriate instrument. In the aftermath of the 2004 Southeast Asian Tsunami that killed more than 280,000 and affected millions, it is not unreasonable for economists to consider how the threat of natural disasters might affect human and physical capital decisions. Skidmore and Toya (2002) suggest that due to relatively recent advances in forecasting, climatic disasters (as opposed to geologic disasters) are primarily a threat to immobile physical capital but not mobile forms of capital such as human capital. The relative increase in exposure to risk of physical capital provides an incentive for economic agents to invest relatively more heavily in human capital. The correlation between exogenous natural disasters and endogenous investment decisions over time suggest that disasters are a valid instrument for factors that affect growth.

In this paper, we use measures of the propensity for natural disasters to test for the endogeneity of schooling enrollment and changes in average years of schooling over the 1960-1990 period.³ We find evidence of endogeneity. We therefore employ instrumental variables techniques to estimate the effects of changes in human capital on economic growth. The instrumental variables estimation procedure yields a coefficient on human capital accumulation that is larger in magnitude than found in our OLS estimates and in most previous studies that use data from a wide range of countries and is closer to theoretic predictions.

Bils and Klenow (2000) attempt to determine the causal relationship between schooling and economic growth. They point out that a common belief is that “reverse causality” or simultaneity is likely to lead to an over-estimate of the effect of human

³ Schooling enrollment data run through 1985.

capital accumulation on growth because anticipated increases in future economic growth could cause schooling to increase. In fact, however, the direction of bias introduced by simultaneity is indeterminate. To illustrate, consider Figure 1. We characterize two-way causality with two equations: One in which changes in human capital is a function of changes in output, $\Delta h = g(\Delta y)$, and vice versa, $\Delta y = f(\Delta h)$, for two countries A, and B. These two countries can also be thought of as representative of, say, OECD verses developing countries. The intersections between the two equations for each country depict what we might observe in the data. In this example, the line connecting the two intersections indicates a negative relationship between changes in output and changes in human capital. Of course, this is just an example; the direction of bias could be in another direction. Therefore, to observe the causal relationship of changes in human capital on changes in output, we control for other factors that determine economic growth and identify the $\Delta y = f(\Delta h)$ function with an appropriate instrument.

Our paper mirrors instrumental variables approaches to estimating the contribution of physical capital. Barro and Sala-i-Martin (1995) use the instrumental variables technique to show that the rate of physical capital investment is not a significant determinant of long-run growth. A smaller role for capital may be consistent with the idea that current coefficient estimates of changes human capital are too small, and an instrumental variables approach for human capital accumulation may be valuable.

The remainder of the paper is organized as follows. The next section provides a review of the relevant theoretical considerations and outlines our empirical strategy. In section 3, we present an overview of natural disasters and describe the intuition behind their effectiveness as instruments. In section 4, we carefully evaluate the validity of

natural disasters as an instrument and present the empirical analysis. Section 5 concludes.

2. Theoretical and Empirical Underpinnings

Two general theoretic approaches have been used as a basis for determining the appropriate functional form for empirical growth research. First, Barro (1991) and others build on endogenous growth models (such as in Romer (1990)) in which human capital is a primary input to research and development. In this approach, the rate of technological progress depends on initial stocks of human capital. Nelson and Phelps (1966) suggested that countries with larger stocks of human capital absorb new ideas and products that have been developed abroad more easily, which could generate a feedback effect between growth and human capital.

A second approach follows the work of Lucas (1988) who stressed the importance of externalities associated with connections to others who are well educated. In this context, increases in human capital per person lead to higher rates of human and physical capital investment and per capita economic growth. In addition, rising human capital per person increases productivity in the market place, reducing fertility rates and thus increasing output per capita (Becker, Murphy, and Tamura, 1990). These two approaches suggest that human capital could enter into the growth equation in initial levels or in changes.

A growth accounting approach is often used to empirically evaluate the determinants of growth: an aggregate production function in which per capita income y_i for country i is dependent upon three input factors, per capita physical capital, k_i , per

capita human capital, h_i , and technology, A . Transforming a Cobb-Douglas production function, such as $y_i = A_i k_i^\alpha h_i^{1-\alpha}$, into a growth equation yields

$$\Delta y_i / y_i = \Delta A_i / A_i + \alpha(\Delta k_i / k_i) + (1 - \alpha)(\Delta h_i / h_i), \quad (1)$$

which suggests that changes in human capital should be an important determinant of growth.

Pritchett's (2001) microeconomic estimates of the return to schooling support these theories and imply that even in the absence of any human capital externalities the contribution of changes in human capital to growth should be somewhere on the order of 0.20-0.40.⁴ More recent studies also generate estimates in this range. Evidence of human capital externalities would require estimates that exceed this upper bound, but disentangling the feedback effects of income, technological advances, human capital accumulation, and physical capital investment is difficult. The appropriate approach would be an instrumental variables technique such as one used by Barro and Sala-i-Martin (1995). The problem has been finding appropriate instruments. To our knowledge, researchers have not yet identified valid instruments to appropriately test for, and (if endogeneity is found), use appropriate econometric procedures to estimate the effects of human capital accumulation on growth. Thus, researchers have been cautious in their interpretation of the coefficient estimates on changes in average years of schooling. In the next section, we examine whether the propensity for natural disasters is an appropriate instrument, and subsequently use measures of disasters to estimate a growth equation using the instrumental variables technique.

⁴ Krueger and Lindahl (2001) summarize the microeconomic research on returns to schooling. Their conclusion regarding the how much education should matter in a growth regression is similar to that of Pritchett (2001).

3. Natural Disasters as an Instrument

Exposure to catastrophes varies significantly from country to country.⁵ Although death tolls vary from year to year, major disasters kill about 140,000 annually worldwide. While about 95% of the deaths occur in developing countries, natural catastrophes also have severe impacts on developed countries.⁶ Asia is affected most severely by natural disasters both in terms of the number of events and deaths.

In pre-modern times disasters affected both physical and human capital decisions. Historically, recovery from extreme disasters such as region-wide famine caused by severe drought may have taken as long as 25 years. Physical capital and skills disappeared with death and out-migration of craftsmen. Before the industrial revolution, natural disasters affected the wealthy, who ignorant of engineering principles, spent enormous sums of money to over-design their structures to withstand forces well in excess of the likely forces (Alexander, 1993), which may have reduced investment in other forms of productive capital.

It is important to note that different types of disasters may affect physical and human capital differently. Climatic disasters, which are generally more predictable than geologic disasters, may increase investment in human capital relative to physical capital because people are easier to evacuate than physical capital. The higher relative risk associated with disasters provides an incentive for economic agents to invest relatively more heavily in mobile capital like education. As an illustration of the exposure of

⁵ For example, Jones (1981) compiles data on disasters and finds that a person living in Asia is about 30 times more likely to die in a seismic disaster than one living in Europe. This calculation is, of course, based on very imprecise data as tallies on deaths and damages was not always compiled. Alexander (1993) shows that most hurricanes occur within the tropics between latitudes 30° N and S, but not within $\pm 5^\circ$ of the equator where atmospheric disturbances tend to be insufficient to cause them.

⁶ For example, according to Alexander (1993), in the United States 30 disasters are declared in an average year, of which floods account for about 40% of property damage, while hurricanes and other tropical storms yield 20% of all disaster related fatalities. See Shah (1983).

physical capital relative to human capital to climatic disasters, in 1992 Hurricane Andrew caused damages in southern Florida and Louisiana exceeding \$20 billion but due to effective forecasting and evacuation procedures, only 13 deaths occurred.

The effects on physical relative to human capital of geologic disasters are less clear. Shaw (1994) estimates the cost of an earthquake equivalent in magnitude to the Great Kanto earthquake of 1923 in the Tokyo area, home to about one-fifth of Japan's population, to be as much as \$1.2 trillion⁷ and holds potentially horrific consequences for human life. The recent tsunami event in Southeast Asia is a dire illustration of the catastrophic human loss that can accompany a disaster event. In the case of climatic disasters or more generally natural events that can be forecasted, disaster risk could lower the expected return to physical capital, reducing physical capital investment. This in turn increases the relative return to human capital. We therefore expect a positive relationship between climatic disasters and human capital, but the net long-run effect of disaster risk on physical capital is theoretically ambiguous. Alternatively, Dacy and Kunreuther (1969) and Tol and Leek (1999) suggest that the short-run economic effects of natural disasters are positive. Since disaster-prone areas are likely to use some of the limited resources for disaster management (stronger and better engineered structures for example), we might expect a higher level of investment to meet these needs.

This discussion suggests that disaster risk may indeed have an effect on steady state levels of human and physical capital. We assert, however, that during the 20th

⁷ \$1.2 trillion is roughly one-fifth of the Japanese GDP. To provide a frame of reference, the estimated losses from the Kobe earthquake were \$114 billion or about one-tenth of the estimated effect of a quake of similar magnitude in Tokyo. Kobe's population is roughly one-fifth of Tokyo's more than 8 million people. If economic losses are proportional to population size, then a quake in Tokyo of similar magnitude would yield losses of about \$570 billion or about half of Shaw's estimate. But Yokohama (with a population of 3.3 million) and the highly populated area surrounding Tokyo would also be affected.

century disaster risk has also played a role in human and physical capital accumulation, and this assertion is supported by our empirical analysis. Improvements in forecasting as well as information dissemination that occurred over the past 100 years have enabled economic agents to assess risk, particularly from climatic disasters, and make appropriate responses to such events. Technology-enhanced forecasting has effectively enabled agents to protect human life (and thus human capital) from the onslaught of hurricanes, typhoons, and the like. This change may have altered the relative expected returns to human and physical capital accumulation during the period of analysis, and as a result we might observe changes in the accumulation of human and perhaps physical capital.

The above discussion suggests that disasters can affect growth by affecting human and physical capital investment. In Lucas (1988) and Azariadis and Drazen (1990), individuals invest in physical and human capital, and the aggregate stock of human capital accumulated by previous generations has a positive intergenerational externality on the aggregate level of human capital of succeeding generations. This intergenerational externality is the driving force of growth and is implicitly assumed in a number of growth models in which human capital is the key determinant of growth.⁸ Consider the case where an economic agent may invest in human and physical capital. Increased risk of capital destruction lowers the expected return to physical capital, making human capital relatively more attractive.⁹ Agents respond by increasing human capital investment, $\Delta h_i / h_i$. In addition, since human capital is an important component in the

⁸ For example, if, in the Lucas (1988) model, the infinitely-lived representative agent is interpreted as a family consisting of finitely-lived agents, no growth would arise without assuming some kind of intergenerational externality.

⁹ Of course, natural disasters are also a risk to life and thus also lower the expected return to human capital investment. However, human capital destruction (death) is a far less likely result than loss of physical capital. Therefore we expect the risks to physical capital to dominate the risks to life.

adoption of new technologies (Benhabib and Spiegel, 1994), the rate of technological advancement might be enhanced, particularly for developing countries in the process of “catch-up.”

We can formalize this reasoning with a simple four equation- model similar to the approach used by Frankel and Romer (1999) to evaluate the effects of trade on economic development. First, the growth rate in a country is a function of the rate of technological advancement, the rate of human capital accumulation, and the rate of physical capital investment and other factors:

$$\Delta y_i / y_i = \Delta A_i / A_i + \beta(\Delta k_i / k_i) + \lambda(\Delta h_i / h_i) + \varepsilon_i \quad (2)$$

where y_i is per capita income for country i , A_i represents the level of technology, k_i is per capita physical capital stock, h_i represents human capital stock per capita, and Δ indicates a change over time. Finally, ε represents other factors that determine growth in per capita income. In the spirit of Nelson and Phelps (1966), the rate of change in technological advancement depends on the initial stock of human capital, the growth in human capital as well as other factors:

$$\Delta A_i / A = \alpha(h_i) + \chi(\Delta h_i / h_i) + \pi_i \quad (3)$$

The idea here is that in order for a country to adopt and make use of new technology, its workers must first have the ability to learn and put the new technology to use.

Substituting equation (3) into equation (2) yields:

$$\Delta y_i / y_i = \alpha(h_i) + \beta(\Delta k_i / k_i) + (\chi + \lambda)(\Delta h_i / h_i) + \pi_i + \varepsilon_i \quad (4)$$

where π represents factors that indirectly affect growth via technological advancement (e.g., government subsidized research and development) and ε represents factors that affect growth directly.

The two other equations concern the determinants of physical capital investment and human capital accumulation. The rate of physical capital investment is a function of two variables that reflect climatic and geologic disaster propensities and other factors:

$$\Delta k_i / k_i = \varphi + \phi C_i + \gamma G_i + \delta_i \quad (5)$$

in which C_i represents the propensity for climatic disasters and G_i represent the propensity for geologic disasters. The two disaster types enter into the equation separately because each may have their own effects on investment decisions. Lastly, δ_i represents other factors that determine investment in physical capital.

Human capital accumulation is also modeled as a function of climatic and geologic disasters and other factors:

$$\Delta h_i / h_i = \pi + \lambda C_i + \mu G_i + \nu_i \quad (6)$$

Again, climatic and geologic disasters enter into the equation separately.

The residual in equation (4), $\pi_i + \varepsilon_i$, are likely to be correlated with the residuals in equations (5) and (6), δ_i , and ν_i . That is, factors that determine growth are also likely to determine physical and human capital accumulation. The key identifying assumption is that countries' disaster characteristics are uncorrelated with the residual in equation (2). In other words, the propensities for climatic and geologic disasters are not affected by economic growth or by other factors that affect growth. It is difficult to think of important ways that natural disasters could affect long-run growth other than through their effects on investment decisions.

If C_i and G_i are uncorrelated with $\pi_i + \varepsilon_i$, data on $\Delta y_i / y_i$, initial period h_i , $\Delta h_i / h_i$, $\Delta k_i / k_i$, C_i and G_i would allow us to estimate equation (2) by instrumental

variables: C_i and G_i are correlated with $\Delta h_i / h_i$ and $\Delta k_i / k_i$ by (5) and (6) and are uncorrelated with $\pi_i + \varepsilon_i$ by our identifying assumption. Skidmore and Toya (2002) show that the prevalence of climatic and geologic disasters are significant determinants of human capital accumulation, suggesting that disasters may work well as instruments.

To empirically evaluate the validity of disasters as instruments, we use data from the Center for Research on the Epidemiology of Disasters (CRED) at the Universite Catholique de Louvain in Brussels, Belgium (EMDAT, 2000). CRED has compiled data on the occurrences and effects of mass disasters in the world from 1900 to the present. CRED uses specific criteria for determining whether an event is classified as a natural disaster.¹⁰ The database includes information on number of events, damages, numbers affected, and deaths.

We are reluctant to use data on damages, number affected, and deaths in this study for three reasons. First, data on these factors are not always available. More importantly, since total damages increase with income, the damages caused by disasters may be endogenously determined. Similarly, numbers of people affected fall with income so that low-income countries experience more human casualties and losses. Wealthy countries clearly spend more money on safety in terms of building codes, engineering, and other safety precautions, reducing deaths. On the other hand, wealthy countries also have far more physical capital at risk should a natural event occur, increasing the possible damages. Finally, as noted by Albala-Bertrand (1993), the impacts of disasters are sometimes exaggerated in developing countries in order to secure

¹⁰ The reasons for taking into account a disaster are: 1) 10 or more people were killed; 2) 100 or more people were affected/injured/homeless, 3) significant damages were incurred; or 4) a declaration of a state of emergency and/or an appeal for international assistance was made.

international assistance. Therefore, data on damages and loss of life are to some degree unreliable. Instead of damages, number affected, and deaths, we use the total number of significant events occurring in a country over the 1960-1990 period because we believe the occurrence of a natural event is the best exogenous measure of disaster risk available. Whether or not a country experiences a natural event does not depend on its level of development.

In the remainder of this paper, we use the total number of natural events normalized by land area since larger countries generally experience more natural disasters. We note, however, that using the unadjusted total number of natural events yields qualitatively similar results.¹¹

4. Empirical Analysis

4.1 Quality of the Instruments

We begin our empirical analysis by estimating several regressions of different measures of human capital to assess whether climatic and geologic disasters are robust determinants of both human and physical capital accumulation. The estimates presented in Table 1 come from a 1960 through 1990 cross-section of 89 countries (or 87 countries in some specifications). We examine the relationship between three measures of human capital (secondary schooling enrollment, changes in average years of secondary schooling, and changes in average years of total schooling)¹² and the disaster variables while controlling for the log of the initial level of human capital and several continent

¹¹ See Skidmore and Toya (2002) for a summary of results using the total number of natural events.

¹² See Appendix Tables A, B, and C for detailed information on specific definitions, a list of countries, and summary statistics for all variables included in the analysis.

specific indicator variables.¹³ These and all regressions presented in the paper use White's (1980) heteroskedasticity-consistent covariance matrix. The climatic disaster variables are significant and positively correlated with each measure of human capital accumulation, whereas there is a negative but generally statistically insignificant coefficient on the geologic disaster variable. In column 4 of Table 1 we also present estimates of the determinants of physical capital accumulation. Neither geologic nor climatic disasters are significant determinants of growth in physical capital per worker.¹⁴

While these estimates demonstrate that climatic disasters are significantly correlated with several different measures of human capital accumulation, they must also be uncorrelated with the residual from the growth equation to be valid instruments. Table 2 contains the results from tests of the correlation between the instruments and the residuals from the growth equations shown in Table 3 (which are discussed below). These results show that the instruments are uncorrelated with the residuals from the growth equations.

4.2 Growth Estimates

Given that the natural disaster variables appear to be appropriate instruments, we conduct a Hausman test to determine whether an endogenous relationship exists between growth and our measures of human capital. To conduct the Hausman test, we first calculated the predicted values of our measures of human capital accumulation (the first-stage regression). Since physical capital investment is also endogenously determined we

¹³ In regressions not presented but are available upon request, we also examine measures of schooling quality or quality-adjusted human capital stock as in Wossman (2003). However, the primary objective in this paper is to examine changes in schooling over time and not stock measures such as schooling quality or quality-adjusted human capital stock. Skidmore and Toya (2002) find a positive correlation between measures of schooling quality (Hanushek and Kim, 1995) and climatic disasters.

¹⁴ In our three-stage least squares estimates, we also use the initial level of physical capital stock as an instrument. Barro and Sali-i-Martin (1995) also use the initial level of physical capital stock as instrument for growth in physical capital.

also generate a predicted value from a physical capital investment equation, which is presented in column 4 of Table 1. We then include the predicted values of human and physical capital accumulation variables in the second-stage growth regression. The coefficients on the predicted values of human and physical capital investment are tested against zero using an F test.¹⁵ All three measures of changes in schooling (as well as growth in physical capital) are shown to be endogenously determined. Results of the Hausman test are presented in Appendix Table D.

We now proceed to estimate the relationship between the three measures of human capital accumulation and growth, using the climatic and geologic natural disasters and the initial level of physical capital per worker as instrumental variables, while controlling for the natural logarithm of the respective measure of the initial level of human capital, the growth in physical capital per worker, and several continent-specific indicator variables.

Before we present the results, a brief discussion of the how changes in schooling should enter into the growth regression is in order. A common approach to estimating a growth equation is the log-log specification. As described in Krueger and Lindahl (2001), a log-log specification is appropriate if one assumes that schooling enters an aggregate Cobb-Douglas production function linearly. Topel (1999), however, argues that the Mincer-type specification is more appropriate, and that human capital should be specified as an exponential function of schooling in the production function. This means

¹⁵ See Kennedy (1994) for detailed discussion of this version of the Hausman test.

that the change in linear years of schooling would enter the growth function.¹⁶ We follow Krueger and Lindahl (2001) and others who estimate linear education specifications.

The first column in Table 3 contains estimates of growth in GDP per capita regressed on a constant, growth in physical capital per worker, and secondary schooling enrollment. This regression yields a positive and significant coefficient on secondary schooling enrollment. We find a similar coefficient on secondary schooling enrollment when we include initial secondary schooling years and a series of regional dummy variables as additional covariates. When these variables are included (column 2), the OLS estimates of the contribution of human capital accumulation is nearly identical to column 1. Column 3 presents the instrumental variables estimation. Here the coefficient on secondary schooling enrollment nearly triples. While these estimates suggest that the effect of human capital accumulation is biased downward in the OLS estimates, the nature of this specification prevents us from making direct comparisons with the micro-estimates of the effect of human capital accumulation. We now turn to an examination of measures of changes in schooling, which provide estimates that are directly comparable to the micro-estimates.

The fourth column in Table 3 contains estimates of growth in GDP per capita regressed on a constant, growth in physical capital per worker, and the change in average years of secondary schooling. This regression yields a positive and significant coefficient on the change in average years of secondary schooling: a coefficient estimate of 0.21 is

¹⁶ Consider the following Cobb-Douglas production function: $y = Ak^{\alpha}h^{1-\alpha}$, where y is per capita GDP, A is the level of technology, k is per capita capital stock, and h is per capita human capital. Transforming this function into log form yields: $\ln y = \ln A + \alpha \ln k + (1-\alpha) \ln h$. With a Mincer-type model, h equals ψe^s with s = average years of schooling. Taking the log difference over time yields: $\ln y_t - \ln y_{t-1} = (\ln A_t - \ln A_{t-1}) + \alpha(\ln k_t - \ln k_{t-1}) + (1-\alpha)(\ln h_t - \ln h_{t-1})$. Substituting in for h yields: $\ln y_t - \ln y_{t-1} = \ln A_t - \ln A_{t-1} + \alpha(\ln k_t - \ln k_{t-1}) + (1-\alpha)(\ln \psi + s_t - \ln \psi - s_{t-1})$ or $\ln y_t - \ln y_{t-1} = \ln A_t - \ln A_{t-1} + \alpha(\ln k_t - \ln k_{t-1}) + (1-\alpha)(s_t - s_{t-1})$.

in the lower range suggested by Pritchett (2001). We find a smaller coefficient on changes in secondary schooling when we include initial years of schooling and a series of regional dummy variables as additional covariates.¹⁷ When these variables are included (column 5), the OLS estimates of the contribution of human capital accumulation is about 0.14, a number that falls below Pritchett's (2001) suggested range. This result reflects our motivation for exploring endogeneity: OLS estimates are generally smaller than values suggested by theoretic or microeconomic studies.

In column 6, we present the three-stage least squares estimates of changes in average years of secondary schooling. Using instrumental variables leads to a coefficient estimate on changes in secondary schooling of 0.46, which is two to three times higher than the OLS estimates. Evidence of human capital externalities would require estimates to exceed Pritchett's upper range of 0.40. These findings suggest that human capital accumulation plays a more important role in economic growth than many of the existing empirical studies that include a wide range of countries in the analyses suggest.¹⁸ The estimates presented here also provide some empirical evidence in support of Lucas' human capital externality theory: an estimate of 0.46 exceeds the upper range value of 0.4 suggested by micro evidence. We also notice that once we use the instrumental variable approach, the coefficient on physical capital investment is reduced and becomes statistically insignificant, consistent with Barro and Sala-i-Martin (1995).

¹⁷ The error terms are normally distributed when both changes in schooling and initial schooling are included in the specifications.

¹⁸ Krueger and Lindahl (2001) present on page 1125 coefficients on changes in schooling that range between 0.013 and 0.069. On page 1112, they obtain coefficient estimates on changes in human capital that are as high as 0.61, but only if they exclude growth in physical capital from the regression. After removing outliers Temple (1999b) present coefficients on changes in schooling ranging between 0.063 and 0.165 after removing influential outliers. Using data on OECD countries and constraining the coefficient on growth in physical capital to 0.35, Englebrecht (2003) generates coefficients on changes in schooling that are as high as 0.37 and 0.71. However, he must constrain the coefficient on capital to obtain coefficient estimates on changes in schooling that are this high.

In columns 7-9, we modify the regressions presented in columns 4-6 by replacing changes in average years of secondary schooling with average years of total schooling. These estimates mirror those found in columns 4-6 except that the coefficient estimates on change in average years of total schooling are slightly smaller. The instrumental variables coefficient estimate on the change in average years of schooling is 0.32, which is still in the upper range suggested by micro evidence. Again consistent with Barro and Sala-i-Martin (1995), the coefficient on growth in physical capital becomes insignificant in the instrumental variables analysis.

4.3 Robustness

The estimated coefficients on human capital accumulation are robust to the inclusion of other variables that influence economic growth. We explored the robustness of human capital effects to the inclusion of a country's distance from the equator (Latitude), the approximate proportion of land area subject to a tropical climate (Tropics), the average ratio of exports plus imports to GDP for the period 1960-1990 (Trade), and whether a country is landlocked (Landlocked). The estimated findings on the variables that characterize human capital accumulation in these estimates, which are presented in Appendix Table E-1, are qualitatively similar to those presented in Table 3.

Countries in Asia have experienced a remarkable rate of economic development over the period of analysis. Thus, rates of both physical and human capital accumulation have been exceptionally high. It is also the case the Asian countries experience frequent natural disasters. It is possible that our findings may be driven by a spurious correlation between disasters and economic development in these Asian countries. Although we include regional dummies in Table 3 to control for these factors, we also examine

whether our findings are robust to the exclusion of these countries. In a series of additional regressions presented in Appendix Table E-2, we find that our results are robust to the exclusion of these countries. In a series of regressions that exclude different sets of Asian and “ring of fire” countries, we show that the coefficients on the measures of human capital accumulation are similar to those presented in this paper.¹⁹

Temple (1999b) shows that in a broader dataset, such as the one used in the present study, the correlation between economic growth and increases in educational attainment can be masked by unrepresentative data. Using the same data but omitting a number of outliers, Temple shows that the results of Benhabib and Spiegel (1994) are sensitive to the exclusion of outliers. We therefore use a procedure outlined by Krasker, Kuh, and Welsch (1983) to identify outliers. The test results identify just five countries (Botswana, Korea, Lesotho, Singapore, and Thailand) as potential outliers. We then omitted these countries and then re-estimated each regression. The results are very similar to those reported here (see Appendix Table E-2). Thus, the presence of influential outliers does not appear to be affecting our results.

4.4 Why Are the Three-Stage Least Squares Estimates Greater Than the OLS Estimates?

The finding that the instrumental variables estimates generate coefficients on human capital accumulation that are larger than the ordinary least squares estimates is consistent with theory, but, to be thorough, we explore in a mechanical sense why this is

¹⁹ We estimate three sets of regressions. First, we exclude five high-growth East Asian countries (Hong Kong, Japan, Korea, Singapore, and Taiwan). We then exclude a larger set of eight high-growth Asian countries (Hong Kong, Indonesia, Japan, Korea, Malaysia, Singapore, Thailand, and Taiwan). Finally, we exclude all 18 countries considered by the U.S. Geological Survey to be in the “ring of fire” (Canada, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Honduras, Indonesia, Japan, Malaysia, Mexico, New Zealand, Nicaragua, Panama, Papua New Guinea, Philippines, and the United States). All of these results are qualitatively similar to those presented in this paper.

so. The ordinary least squares estimate is determined by the partial association between economic growth and human capital accumulation, while the instrumental variables estimate is determined by the partial association between economic growth and the component of human capital accumulation correlated with the instruments. Given that the ordinary least squares estimates are smaller than the instrumental variables estimate, the partial association between economic growth and component of human capital accumulation not associated with the instruments is weaker than its partial association the component that is associated with the instruments.

In Figures 2, 3, and 4 we present these two partial associations for the same two measures of human capital accumulation used in Table 3. In each of the figures, Panel A shows the positive partial association between economic growth and the component of human capital accumulation that is correlated with the instruments. This is the positive association that underlies the positive coefficient on human capital accumulation in the instrumental variables regressions found in Table 3. Panel B shows the partial association between economic growth and the component of human capital accumulation that is not correlated with the instruments. This association is considerably smaller than the association shown in Panel A. It is this smaller relationship that causes the ordinary least squares estimate to be less than the instrumental variables estimates. The figures again confirm that the difference between the ordinary least squares estimate and the instrumental variables estimates is not due to just a few outliers.

IV. Conclusions

The gap between the theoretically-predicted contribution of human capital to growth and the contribution estimated in most studies is increasingly receiving attention.

Nearly all studies that address this problem, however, address the problem as one of measurement or specification error. Very few studies address the possibility that human capital is an endogenous function of growth. The most likely reason that most studies do not address this possibility is that appropriate instruments are difficult to find.

In this paper, we first show that human capital is, in fact, endogenously determined. We then show that climatic natural disasters are a significant determinant of secondary schooling enrollment, and changes in secondary and total schooling, but not of economic growth directly. Thus, we appear to have identified a valid instrument with which we can examine the potential endogeneity of human capital accumulation in estimates of economic growth. We then use an instrumental variables procedure to estimate the effects of changes in schooling on long-run economic growth.

We demonstrate that our findings are robust; they appear not to be driven by outliers and are robust to the inclusion of a wide range of variables considered important determinants of economic growth and factor accumulation in the previous literature. These estimates also provide limited empirical evidence in support of the Lucas human capital externality theory. Our results suggest that previous estimates may be biased downward due to the simultaneity between human capital accumulation and economic growth, and that endogeneity should be seriously considered in studies of economic growth.

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Table 1
Disasters and Capital Accumulation

Dependent variables	Secondary School Enrollment	Change in Secondary Schooling Years	Change in Total Schooling Years	Growth in Physical Capital Per Worker
Constant	0.413 (8.304)	0.025 (4.352)	0.844 (9.658)	0.122 (5.550)
Per Land Climatic Disasters	0.037 (3.223)	0.005 (3.143)	0.004 (1.671)	0.001 (0.878)
Per Land Geologic Disasters	-0.055 (-2.758)	-0.004 (-1.214)	-0.001 (-0.146)	-0.002 (-1.020)
Log (Initial Secondary Schooling Years)	0.060 (2.708)	-0.002 (-1.356)		
Log (Initial Total Schooling Years)			-0.005 (-0.951)	
Log (Initial Physical Capital Per Worker)				-0.011 (-4.434)
Sub-Saharan Africa	-0.164 (-4.377)	-0.018 (-3.112)	-0.038 (-3.718)	-0.031 (-3.409)
Latin America	-0.036 (-0.821)	-0.005 (-0.849)	-0.020 (-0.021)	-0.007 (-1.224)
NIES and ASEAN	0.031 (0.416)	0.016 (1.292)	0.021 (1.121)	0.031 (4.105)
OECD	0.271 (4.569)	0.019 (2.548)	0.017 (1.707)	0.019 (3.169)
Number of Observations	89	89	89	87
Adjusted R ²	0.752	0.259	0.217	0.441

Numbers in parentheses are t-values based on the White (1980) heteroscedasticity-consistent covariance matrix.

Table 2
Residuals and Natural Disasters Variables

Dependent Variables	Residuals from OLS Estimate Using Secondary School Enrollment	Residuals from OLS Estimate Using Change in Secondary Schooling Years	Residuals from OLS Estimate Using Change in Total Schooling Years
Per Land Climatic Disasters	0.0006 (1.056)	0.0005 (0.971)	0.0005 (0.955)
Number of Observations	86	86	86
Adjusted R ²	0.028	0.022	0.024

Dependent Variables	Residuals from OLS Estimate Using Secondary School Enrollment	Residuals from OLS Estimate Using Change in Secondary Schooling Years	Residuals from OLS Estimate Using Change in Total Schooling Years
Per Land Geologic Disasters	0.0005 (0.493)	0.0002 (0.211)	0.0001 (0.135)
Number of Observations	86	86	86
Adjusted R ²	0.005	0.001	0.000

Residuals, which are used as dependent variables here, come from equations 2, 5, and 8 of Table 3, respectively. Numbers in parentheses are t-values based on the White (1980) heteroscedasticity-consistent covariance matrix.

Table 3
Human Capital Accumulation and Growth
Dependent Variable: Per Capita GDP Growth (1960–1990 Average)

	1	2	3	4	5	6	7	8	9
Estimation	OLS	OLS	IV	OLS	OLS	IV	OLS	OLS	IV
Constant	-0.002 (-0.985)	0.003 (0.680)	-0.007 (-0.696)	0.001 (0.237)	0.008 (1.987)	0.004 (0.491)	0.001 (0.319)	0.002 (0.333)	0.016 (0.807)
Growth in Physical Capital Per Worker	0.504 (9.336)	0.380 (6.805)	0.128 (0.960)	0.493 (9.213)	0.379 (6.918)	0.116 (0.723)	0.508 (9.397)	0.355 (6.665)	0.161 (0.965)
Secondary School Enrollment	0.023 (5.914)	0.022 (2.664)	0.060 (3.710)						
Change in Secondary Schooling Years				0.210 (4.193)	0.140 (3.029)	0.462 (3.362)			
Change in Total Schooling Years							0.083 (2.278)	0.068 (2.308)	0.324 (1.866)
Log (Initial Secondary Schooling Years)		0.001 (0.708)	-0.003 (-1.900)		0.002 (2.171)	0.002 (1.760)			
Log (Initial Total Schooling Years)								0.005 (2.821)	0.007 (3.626)
Sub-Saharan Africa		-0.001 (-0.224)	-0.000 (-0.025)		-0.001 (-0.304)	0.001 (0.078)		-0.002 (-0.475)	0.006 (0.628)
Latin America		-0.007 (-1.653)	-0.007 (-1.819)		-0.006 (-1.607)	-0.006 (-1.621)		-0.008 (-1.968)	-0.005 (-0.831)
NIES and ASEAN		0.017 (3.029)	0.025 (3.769)		0.015 (2.760)	0.020 (2.083)		0.015 (2.675)	0.015 (1.201)
OECD		-0.002 (-0.371)	-0.010 (-1.760)		0.002 (0.390)	-0.020 (-0.327)		0.002 (0.432)	-0.007 (-1.177)
Number of Observations	87	86	86	86	86	86	86	86	86
Adjusted R ²	0.641	0.717	0.594	0.631	0.721	0.550	0.570	0.726	0.585

Numbers in parentheses are t-values based on the White (1980) heteroscedasticity-consistent covariance matrix.

Figure 1
Simultaneity between Changes in Human Capital and Economic Growth

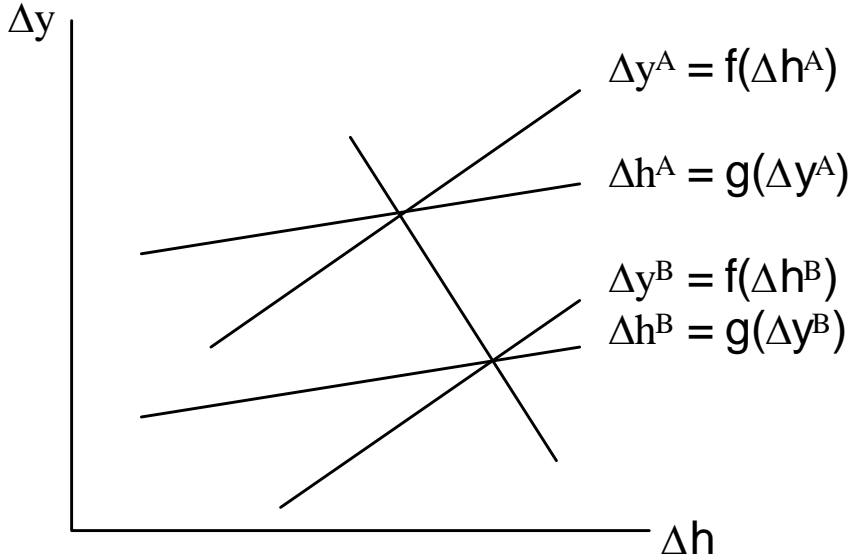
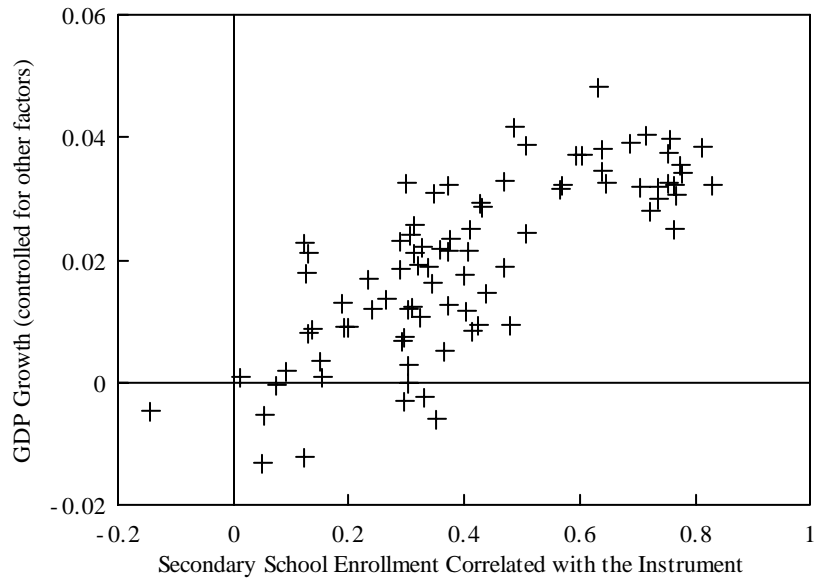


Figure 2
Partial Association Between Growth in Per Capita GDP
and the Component of Secondary School Enrollment

A: Correlated with the Instrument



B: Uncorrelated with the Instrument

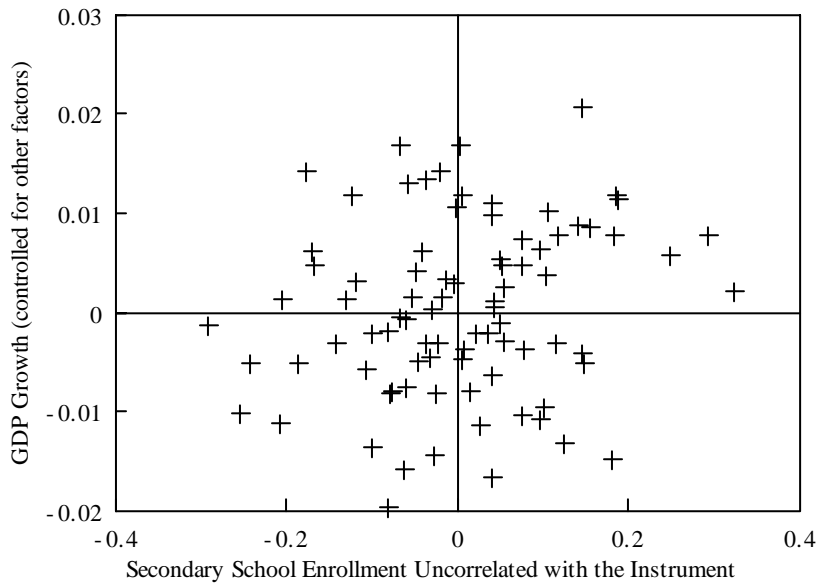
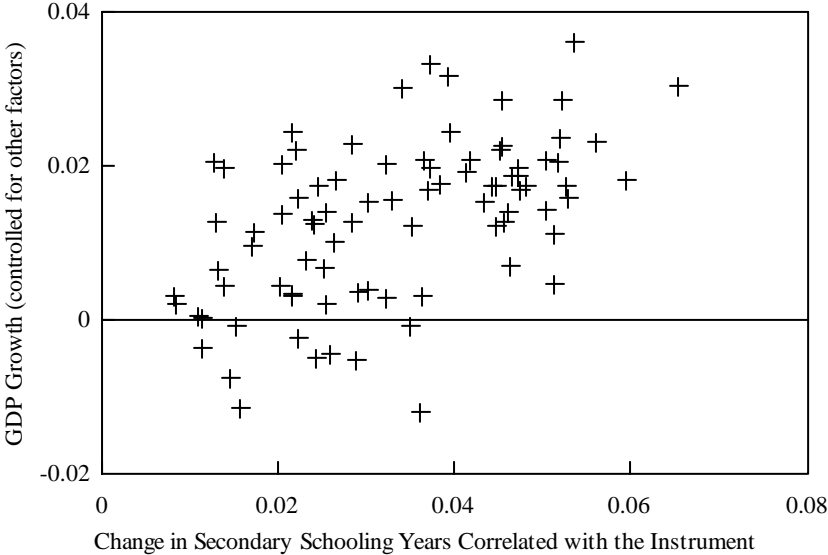


Figure 3
Partial Association Between Growth in Per Capita GDP
and the Component of Change in Secondary Schooling Years

A: Correlated with the Instrument



B: Uncorrelated with the Instrument

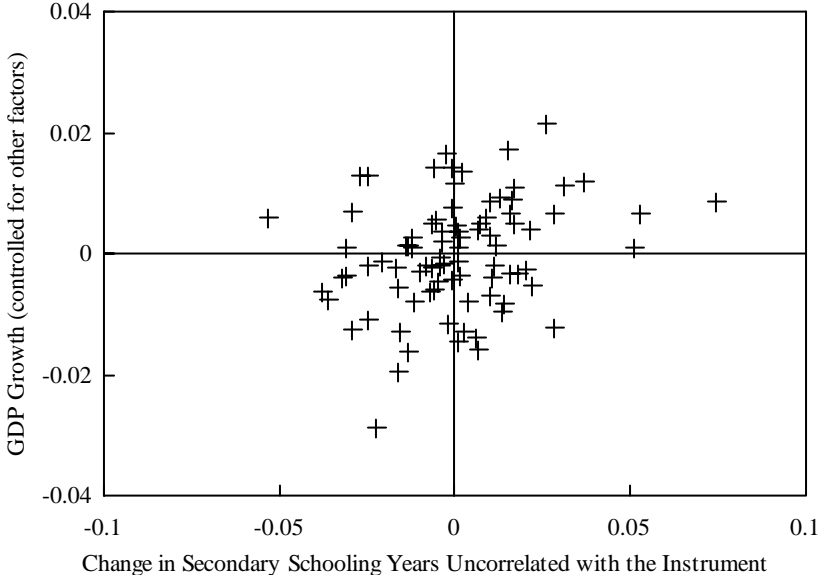
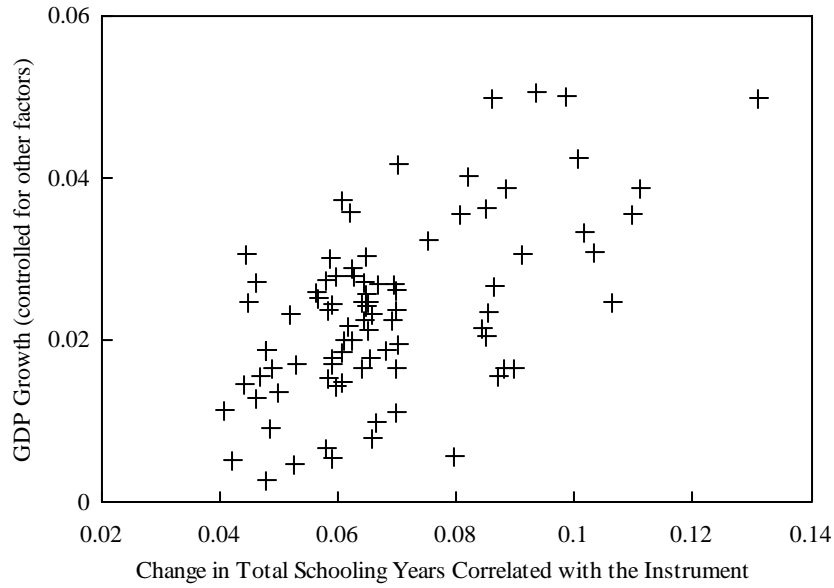
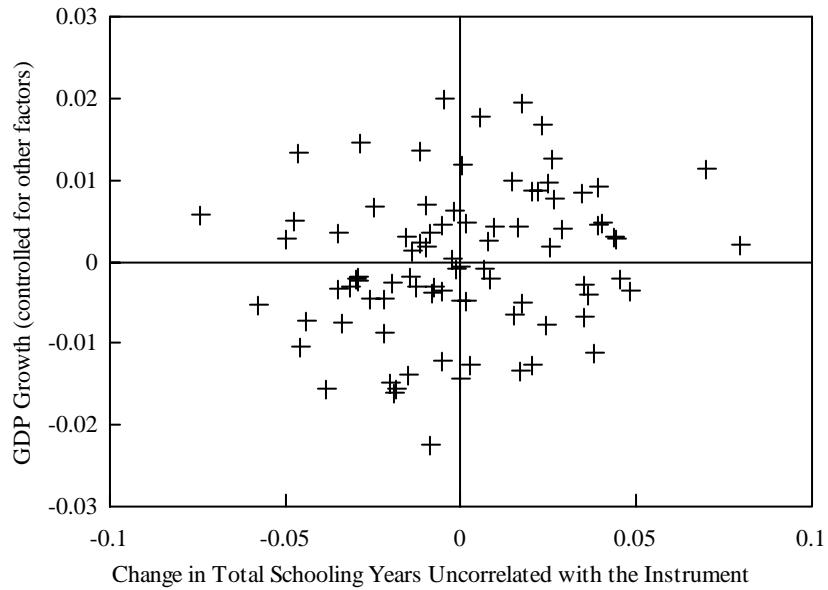


Figure 4
Partial Association Between Growth in Per Capita GDP
and the Component of Change in Total Schooling Years

A: Correlated with the Instrument



B: Uncorrelated with the Instrument



Appendix Table A: Definitions and Sources of Variables

Variables	Definition	Source
Per Capita GDP Growth	Average annual growth rate of real per-capita GDP for the period 1960-1990	SH
Growth in Physical Capital Per Worker	Average annual growth rate of physical capital per worker for the period 1961-1990	GDN
Secondary School Enrollment	Average gross enrollment ratio for secondary education for the period 1960-1985	BL
Change in Secondary Schooling Years	Difference between years of secondary schooling in 1990 and years of secondary schooling year in 1960	BL
Change in Total Schooling Years	Difference between average years of schooling in 1990 and average years of schooling in 1960	BL
Log (Initial Total Schooling Years)	Natural logarithm of years of secondary schooling in the total population aged 15 and over in 1960	BL
Log (Initial Secondary Schooling Years)	Natural logarithm of years of secondary schooling in the total population aged 15 and over in 1960	BL
Log (Initial Physical Capital Per Worker)	Logarithm of physical capital per worker in 1961	GDN
Per Land Climatic Disasters	Logarithm of 1 + number of climatic disaster events per million square Km	CRED
Per Land Geologic Disasters	Logarithm of 1 + number of geological disaster events per million square Km	CRED
Sub-Saharan Africa	Dummy for Sub-Saharan African countries	
Latin America	Dummy for Latin-American Countries	
NIES and ASEAN	Dummy for NIES and ASEAN members	
OECD	Dummy for OECD members	
Latitude	Country's absolute distance from the equator	HJ
Tropics	Proportion of land area subject to a tropical climate	SW
Trade	Average ratio of exports plus imports to GDP for the period 1960-1990	SH
Landlocked	Dummy for a country is landlocked	SW

Sources:

BL: Barro and Lee (1996) "International Measures of Schooling Years and Schooling Quality," American Economic Review, 86(2), 218-23, taken from the World Bank Research Department's Web page, <http://www.worldbank.org/research/growth/ddbarle2.htm>.

CRED: EMDAT, The OFDA/CRED International Disaster Database (2000). Universite Catholique de Louvain, Brussels, Belgium, www.md.ucl.ac.be/cred.

GDN: Global Development Network Growth Database (2000) by William Easterly and Hairong Yu, taken from the World Bank Research Department's Web page, <http://www.worldbank.org/research/growth/GDNdata.htm>.

SH: Summers and Heston (1994) "The Penn World Table (Mark 5.6)," taken from the NBER Web page, <http://www.nber.org/data/>

SW: Sachs and Warner (1997) "Fundamental Source of Long-Run Growth", American Economic Review, Papers and Proceedings, May 1997, taken from Economic Growth Resources Web page, <http://www.bris.ac.uk/Depts/Economics/Growth/sachs.htm>

HJ: Hall and Jones (1999) "Why Do Some Countries Produce So Much More Output per Worker than Others?", Quarterly Journal of Economics, 114, 83-116, taken from Charles I. Jones's web page, <http://elsa.berkeley.edu/~chad/datasets.html>

Appendix Table B: List Of Countries

Algeria	Haiti	Norway
Argentina	Honduras	Pakistan
Australia	Hong Kong, China	Panama
Austria	Iceland	Papua New Guinea
Bangladesh	India	Paraguay
Barbados	Indonesia	Peru
Belgium	Iran, Islamic Rep.	Philippines
Bolivia	Iraq	(2,3) Portugal
Botswana	Ireland	Senegal
Brazil	Israel	Singapore
Cameroon	Italy	South Africa
Canada	Jamaica	Spain
Central African Republic	Japan	Sri Lanka
Chile	Jordan	Swaziland
Colombia	Kenya	Sweden
Congo, Dem. Rep.	Korea, Rep.	Switzerland
Costa Rica	Lesotho	Syrian Arab Republic
Cyprus	Liberia	(2,3) Taiwan
Denmark	Malawi	Thailand
Dominican Republic	Malaysia	Togo
Ecuador	Mali	Trinidad and Tobago
El Salvador	Malta	(1,3) Tunisia
Fiji	Mauritius	Turkey
Finland	Mexico	Uganda
France	Mozambique	United Kingdom
Germany	Nepal	(2,3) United States
Ghana	Netherlands	Uruguay
Greece	New Zealand	Venezuela
Guatemala	Nicaragua	Zambia
Guyana	Niger	Zimbabwe

The number in parentheses represents the data availability: (1) not available in the sample of 89 countries, (2) not available in the sample of 87 countries, and (3) not available in the sample of 86 countries, respectively. See Appendix A for a listing of data sources and Appendix C for the number of countries for which data are available.

Appendix Table C: Summary of Statistics of all Variables Used in the Analysis

	Mean	Standard Deviation	Number of Observations
Per Capita GDP Growth	0.021	0.018	89
Growth in Physical Capital Per Worker	0.029	0.024	87
Secondary School Enrollment	0.399	0.254	89
Change in Secondary Schooling Years	0.033	0.248	89
Change in Total Schooling Years	0.069	0.035	89
Log (Initial Total Schooling Years)	0.948	0.960	89
Log (Initial Secondary Schooling Years)	-0.954	1.367	89
Log (Initial Physical Capital Per Worker)	8.667	1.385	87
Per Land Climatic Disasters	1.306	1.418	89
Per Land Geologic Disasters	0.584	0.814	89
Sub-Saharan Africa	0.225	0.417	89
Latin America	0.258	0.438	89
NIES and ASEAN	0.079	0.269	89
OECD	0.258	0.438	89
Latitude	25.51	16.77	86
Tropics	0.512	0.503	86
Trade	0.618	0.406	86
Landlocked	0.186	0.391	86

Appendix Table D: Hausman Test of Endogeneity*

	F-value
Secondary School Enrollment	7.054 (0.0016)
Change in Secondary Schooling Years	7.917 (0.0008)
Change in Total Schooling Years	7.357 (0.0012)

Numbers in parentheses are upper tail areas.

* See Kennedy (1994, p. 169) for a discussion of the Hausman Test as a test of endogeneity. For each measure of human capital accumulation, we reject the null hypothesis of exogeneity with a 99 percent level of confidence.

Appendix Table E-1: Checking Robustness: Inclusion of Other Explanatory Variables

Dependent Variable: Per Capita GDP Growth (1960–1990 Average)

	1	2	3	4	5	6
Estimation	OLS	IV	OLS	IV	OLS	IV
Secondary School Enrollment	0.013 (1.532)	0.047 (2.076)				
Change in Secondary Schooling Years			0.113 (2.201)	0.360 (2.120)		
Change in Total Schooling Years					0.061 (1.995)	0.212 (1.842)
Latitude	0.000 (0.655)	0.000 (0.340)	0.000 (0.065)	-0.000 (-0.254)	0.000 (0.572)	0.000 (0.320)
Tropics	-0.001 (-0.303)	-0.003 (-0.542)	-0.003 (-0.654)	-0.005 (-1.090)	-0.001 (-0.321)	-0.002 (-0.485)
Trade	0.007 (2.759)	0.005 (1.534)	0.008 (3.153)	0.006 (1.956)	0.007 (2.897)	0.006 (2.594)
Landlocked	-0.003 (-1.095)	-0.002 (-0.525)	-0.004 (-1.147)	-0.002 (-0.608)	-0.004 (-1.195)	-0.002 (-0.811)
Number of Observations	86	86	86	86	86	86
Adjusted R ²	0.728	0.667	0.738	0.658	0.742	0.711

* Numbers in parentheses are t-values based on the White (1980) heteroscedasticity-consistent covariance matrix. Other explanatory variables not reported here are constant term, growth in physical capital per worker, logarithm of initial years of schooling, and the regional dummies.

Appendix Table E-2: Checking Robustness: Different Sample Size
Dependent Variable: Per Capita GDP Growth (1960–1990 Average)

	Exclusion of five Asian countries		Exclusion of eight Asian countries		Exclusion of 18 “ring of fire” countries		Exclusion of five outliers	
	OLS	IV	OLS	IV	OLS	IV	OLS	IV
Estimation								
Secondary School Enrollment	0.021	0.062	0.021	0.060	0.021	0.074	0.022	0.058
	(2.283)	(3.979)	(2.282)	(3.899)	(2.140)	(3.922)	(2.586)	(3.023)
Number of Observations	81	81	78	78	68	68	81	81
Adjusted R ²	0.601	0.424	0.563	0.375	0.735	0.588	0.660	0.548

	Exclusion of five Asian countries		Exclusion of eight Asian countries		Exclusion of 18 “ring of fire” countries		Exclusion of five outliers	
	OLS	IV	OLS	IV	OLS	IV	OLS	IV
Estimation								
Change in Secondary Schooling Years	0.154	0.651	0.157	0.639	0.117	0.505	0.160	0.547
	(2.916)	(3.658)	(2.914)	(3.735)	(2.227)	(2.564)	(3.046)	(3.518)
Number of Observations	81	81	78	78	68	68	81	81
Adjusted R ²	0.614	0.372	0.577	0.336	0.733	0.532	0.671	0.487

	Exclusion of five Asian countries		Exclusion of eight Asian countries		Exclusion of 18 “ring of fire” countries		Exclusion of five outliers	
	OLS	IV	OLS	IV	OLS	IV	OLS	IV
Estimation								
Change in Total Schooling Years	0.074	0.408	0.078	0.447	0.061	0.253	0.084	0.512
	(2.287)	(1.282)	(2.337)	(1.291)	(1.697)	(1.475)	(2.440)	(1.906)
Number of Observations	81	81	78	78	68	68	81	81
Adjusted R ²	0.622	0.438	0.585	0.382	0.746	0.671	0.673	0.443

* Numbers in parentheses are t-values based on the White (1980) heteroscedasticity-consistent covariance matrix. Five Asian countries are Hong Kong, Japan, Korea, Singapore, and Taiwan. Eight Asian countries are Hong Kong, Indonesia, Japan, Korea, Malaysia, Singapore, Thailand, and Taiwan. 18 “ring of fire” countries are Canada, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Honduras, Indonesia, Japan, Malaysia, Mexico, New Zealand, Nicaragua, Panama, Papua New Guinea, Philippines, and the United States. Other explanatory variables not reported here are constant term, growth in physical capital per worker, logarithm of initial years of schooling, and the regional dummies.