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

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JEL: 047

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, 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 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.[1] 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 Jacoby (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

[1] 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 changes in average years of schooling over the 1960-1990 period.[2] We find evidence of endogeneity, and 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, 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 capital accumulation on growth because anticipated increases in future economic growth

[2] Schooling enrollment data run through 1985.

could cause schooling to increase. In fact, however, the direction of bias introduced by simultaneity is indeterminate. (deleted and revised as per last comment by referee #3) The fact that empirical macroeconomic estimates of the contributions of human capital accumulation to growth are considerably smaller than that which is suggested by the microeconomic evidence of the returns to schooling suggests that perhaps the macroeconomic estimates suffer from downward rather than upward bias. This bias could be result of a combination of factors: mismeasurement, simultaneity, and omitted variable bias.

(deleted as per comment #2, referee #2)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, especially in the context of estimating transitional dynamics as opposed to steady state relationships: 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

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

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.[3] More recent studies also generate estimates in this range. Evidence of human

[3] 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).

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.

3. Natural Disasters as an Instrument

Exposure to catastrophes varies significantly from country to country.[4] 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.[5] Asia is affected most severely by natural disasters both in terms of the number of events and deaths.

It is important to note that different types of disasters may affect physical and human capital differently, especially taking into consideration the improvements in

[4] 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 ±5° of the equator where atmospheric disturbances tend to be insufficient to cause them.

[5] 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).

forecasting that occurred during the 20th century. Over the period of analysis, improvements in forecasting and communications have enabled countries to prepare in advance for coming climatic events. We suggest that changes in forecasting technology has significantly reduced the probability of human loss and thus raised the expected return to human capital relative to physical capital. Reduced climatic disaster risk associated with improved forecasting, may increase investment in human capital relative to physical capital because people are easier to evacuate than physical capital. As an illustration of the exposure of 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.[6] The change in relative risk associated with climatic disasters generated from improved forecasting provides a incentive for economic agents to invest relatively more heavily in mobile capital like education. We suggest that changes in forecasting ability enables us to observe the relationship between human capital accumulation and economic growth in a transitional context.

In a endogenous growth model, it can be shown that reductions in climatic disaster impacts on human capital would lead to a relatively lower depreciation rate of human capital relative to physical capital, there is no effect on the steady state growth rates of human or physical capital. This is so because in equilibrium the net returns to human and physical capital must equalize. We argue, however, that changes in forecasting capabilities allow us to observe transitional dynamics. During the period of

[6] We note that hurricane Katrina had a much larger death toll, taking approximately 1,319 lives. The losses are primarily attributable to the flooding that occurred in Louisiana when levies failed. The economic losses are estimated to be roughly $125 billion, See Tierney (2008) for an overview of the impacts of hurricane Katrina.

analysis, improvements in forecasting have significantly reduced the negative effects of climatic natural disasters, especially for human capital. This has led to an increase in the relative return to human capital in disaster-prone countries. We therefore expect to observe a positive correlation between climatic disasters and human capital accumulation over the period of analysis, although we also acknowledge that once a steady state is achieved we would not expect the positive correlation to continue. The effect of climatic disasters on physical capital in transition, however, is ambiguous: On the one hand, increases in human capital raises the return to physical capital thus may increase physical capital accumulation. On the other hand, the return to physical capital relative to human capital is falling, which may lead to reductions in physical capital investment.

This discussion suggests that disaster risk is not likely to have an effect on the growth rates of human and physical capital accumulation in the steady state, but we assert that during the 20th century improvements in forecasting have increased the return to human capital relative to physical capital. This provides an opportunity to observe a transitional relationship between human capital accumulation and economic growth.

More formally, 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.[7] Consider the case where an economic agent may invest in human and physical capital. Reduced risk of

[7] 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.

human capital destruction increases the expected return to human capital, making human capital relatively more attractive.[8] Agents respond by increasing human capital investment, $\Delta h_i / h_i$. In addition, since human capital is an important component in the 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 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:

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

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. The rate of change in technological advancement depends on factors that affect ability to develop and absorb new technologies. These factors may include the quality of government, government subsidized research and development, initial levels of human capital, interactions with other societies through trade, etc…:

$$\Delta A_i / A = \pi_i \qquad (3)$$

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

[8] 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.

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

where π represents factors that indirectly affect growth via technological advancement 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 three variables that reflect climatic and geologic disaster propensities as well as the initial investment per capita, and other factors:

$$\Delta k_i / k_i = \varphi + \phi C_i + \gamma G_i + \eta I6069_i + \delta_i \qquad (5)$$

in which C_i represents the propensity for climatic disasters, G_i represent the propensity for geologic disasters, and $I6069_i$ represents the natural logarithm of investment per capita over the 1960-1969 period. Consistent with Barro and Sala-i-Martin (1995), we use I6069 as an instrument for $\Delta k_i / k_i$ for two reasons. First, theoretically it is unclear whether either of our disaster variables will serve as strong instruments for physical capital accumulation. Second, the work of Barro and Sala-i-Martin (1995) work as well as our own analysis suggests that past investment is an appropriate instrument for current investment. The two disaster types enter into the equation separately because each may have their own effects on investment decisions. Last, 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:

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

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 (and past investment levels ($I6069_i$) in the case of physical capital investment) 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, G_i and $I6069_i$ are uncorrelated with $\pi_i + \varepsilon_i$, data on $\Delta y_i / y_i$, $\Delta h_i / h_i$, $\Delta k_i / k_i$, C_i, G_i and $I6069_i$ allow us to estimate equation (2) by instrumental variables: C_i, G_i are correlated with $\Delta h_i / h_i$ and C_i, G_i and $I6069_i$ are correlated with $\Delta k_i / k_i$ 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 disasters are significant determinants of human capital accumulation but not of economic growth directly, 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 Catholicque 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.[9] 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 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. It is still possible, however, that the likelihood of a disaster event being recorded depends, in part, on the level of development. In a careful analysis, Kahn (2005) demonstrates that the probability of a disaster event occurring and being recorded is not dependent on the level of development: With the exception of floods, high and low income countries are equally likely to experience a naturally occurring disaster event.

[9] 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.

Relying on Kahn's (2005) result, we move directly to an analysis of the determinants of disaster-related fatalities.

In the remainder of this paper, we use the total number of climatic and geologic natural events normalized by land area as our key independent variables because larger countries generally experience more natural disasters. We note, however, that using the unadjusted total number of natural events yields qualitatively similar results.[10]

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 two measures of human capital (changes in average years of secondary schooling and changes in average years of total schooling)[11] and the disaster variables while controlling for several continent specific indicator variables.[12] These and all regressions presented in the paper use White's (1980) heteroskedasticity-consistent covariance matrix. The climatic disaster variable is 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

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

[11] 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.

[12] 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.

estimates of the determinants of physical capital accumulation. Neither geologic nor climatic disasters are significant determinants of growth in physical capital per worker, but past investment (I6069) is highly significant.[13] We also use Sargan's Test of Overidentifying Restrictions to further examine the appropriateness of our instruments. In each case, we fail to reject the null hypothesis that our instruments correlated with the error terms. Thus, it appears that we have identified valid instruments for human capital accumulation (our primary interest) as well as for physical capital accumulation

4.2 Growth Estimates

Given that the natural disaster variables appear to be valid instruments for human capital accumulation, 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 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.[14] Both 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.

[13] 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.

[14] See Kennedy (1994) for detailed discussion of this version of the Hausman test.

We now proceed to estimate the relationship between the two 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 initial GDP per capita, an index of government quality, 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 that the change in linear years of schooling would enter the growth function.[15] We follow Krueger and Lindahl (2001) and others who estimate linear education specifications, but we note that our main findings are unaltered if we use the Mincer-type specification.

The first column in Table 2 contains OLS estimates of growth in GDP per capita regressed on a constant, growth in physical capital per worker, and change secondary schooling years. This regression yields a positive and significant coefficient on the change in secondary schooling years variable. Column 2 presents the instrumental variables estimation. Here the coefficient on secondary schooling enrollment quadruples.

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[15] 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 column 3 we add the natural logarithm of GDP per capita and a measure of government quality as an additional control and our results mirror those in columns 1 and 2. Here the instrumental variable regression yields a coefficient on change in secondary schooling years that is very similar to those presented in column 2.

In columns 4-6 of Table 2, we repeat the specifications presented in columns 1-3 except we replace the change secondary schooling years variable with the change in total schooling years as our measure of human capital accumulation. Again, the two-stage least squares estimates are three to four times as large as the OLS estimates. Generally, the two-stage least squares approach yields a larger coefficient on both measures o human capital accumulation than does the OLS estimation procedure.

The OLS estimates presented in column 1 of Table 2 yield a positive and significant coefficient on the change in average years of secondary schooling: a coefficient estimate of 0.13 is below the lower range suggested by Pritchett (2001).[16] This result reflects our motivation for exploring endogeneity: OLS estimates are generally smaller than values suggested by theoretic or microeconomic studies.

In column 3 of Table 2, we present the three-stage least squares estimates of changes in average years of secondary schooling. Using instrumental variables (column 2) leads to a coefficient estimate on changes in secondary schooling of 0.54, which is more than four times higher than the OLS estimates. Further, 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

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

countries in the analyses suggest.[17] The estimates presented here also provide some empirical evidence in support of Lucas' human capital externality theory: an estimate of 0.54 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).

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 several additional variables that receive much attention in the debate over the role of institutions and geography in growth.[18] We first add a country's distance from the equator (Latitude), which if often considered a proxy for history and distance from developed countries. To control for climate, we also include the approximate proportion of land area subject to a tropical climate (Tropics). Frankel and Romer (1999) also suggest that trade affects growth, so we also consider the average ratio of exports plus imports to GDP for the period 1960-1990 (Trade). Finally we also incorporate other geographical factors by adding whether or not a country is landlocked (Landlocked). These additional explanatory variables are included because latitude, tropical climates, availability of ports may determine economic growth, but may

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[17] 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.

[18] A good example of this debate is the sequence of Frankel and Romer (1999), Rodriguez and Rodrik (2001), and Noguer and Siscart.(2005)

also determine the degree to which a country is exposed to natural disasters. To further test the robustness of our core results, it is important to consider these factors. 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 2.

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 2 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

[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.

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.

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, do so in the context 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 present evidence that human capital is, in fact, endogenously determined. We then show that a measure of climatic natural disaster propensity is a significant determinant of 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	Change in Secondary Schooling Years	Change in Total Schooling Years	Growth in Physical Capital Per Worker
Constant	0.029	0.084	0.040
	(5.903)	(10.01)	(6.291)
Per Land Climatic Disasters	0.005	0.004	0.001
	(2.960)	(1.505)	(0.915)
Per Land Geologic Disasters	-0.004	0.000	-0.002
	(-1.128)	(0.003)	(-0.686)
Log (Initial Investment per capita)			-0.011
			(-3.433)
Sub-Saharan Africa	-0.016	-0.037	-0.029
	(-2.979)	(-3.769)	(-2.939)
Latin America	-0.006	-0.024	-0.009
	(-1.141)	(-2.459)	(-1.547)
NIES and ASEAN	0.013	0.017	0.033
	(1.133)	(0.852)	(4.426)
OECD	0.015	-0.024	0.021
	(2.135)	(-2.464)	(3.100)
Number of Observations	89	89	87
RMSE	0.021	0.031	0.019
Adjusted R^2	0.258	0.216	0.392

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

Table 2: Human Capital Accumulation and Growth
Dependent Variable: Per Capita GDP Growth (1960–1990 Average)

	1	2	3	4	5	6
Estimation Method	OLS	3SLS	3SLS	OLS	3SLS	3SLS
Constant	0.006	0.002	0.091	0.006	-0.023	0.063
	(1.473)	(0.132)	(3.069)	(1.199)	(-0.771)	(1.368)
Growth in Physical Capital Per Worker	0.364	0.048	-0.069	0.358	0.013	-0.068
	(6.220)	(0.312)	(-0.442)	(5.819)	(0.081)	(-0.358)
Change in Secondary Schooling Years	0.132	0.538	0.500			
	(2.473)	(2.541)	(2.330)			
Change in Total Schooling Years				0.056	0.498	0.446
				(1.710)	(1.715)	(2.221)
Log (Initial GDP per capita)			-0.017			-0.018
			(-4.210)			(-3.783)
Government Quality Index			0.073			0.092
			(3.544)			(4.982)
Sub-Saharan Africa	-0.004	-0.002	-0.013	-0.005	0.008	-0.005
	(-1.030)	(-0.206)	(-1.559)	(-1.023)	(0.537)	(-0.360)
Latin America	-0.006	-0.006	0.000	-0.005	0.002	0.008
	(-1.352)	(-1.075)	(0.073)	(-1.228)	(0.184)	(1.159)
NIES and ASEAN	0.018	0.023	0.011	0.019	0.022	0.006
	(2.824)	(2.370)	(1.612)	(2.901)	(1.750)	(0.650)
OECD	0.005	0.001	-0.004	0.008	0.020	0.007
	(1.331)	(0.110)	(-0.800)	(2.099)	(2.270)	(0.926)
Number of Observations	86	86	86	86	86	86
RMSE	0.010	0.014	0.012	0.010	0.017	0.013
R-squared	0.729	0.373	0.533	0.711	0.088	0.438
P-value for overidentification		0.147	0.275		0.361	0.266

Numbers in parentheses are t-values.

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
Change in Secondary Schooling Years	Difference between years of secondary schooling in 1990 and years of secondary schooling year in 1960	BL1
Change in Total Schooling Years	Difference between average years of schooling in 1990 and average years of schooling in 1960	BL1
Growth in Physical Capital Per Worker	Average annual growth rate of physical capital per worker for the period 1961-1990	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
Log (Initial Investment per capita)	Logarithm of average investment per capita for 1960-1969	BL2
Log (Initial GDP per capita)	Logarithm of real per-capita GDP in 1960	SH
Government Quality Index	An index of government antidiversion policies	HJ
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
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	

Sources:

BL1: 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.

BL2: Barro and Lee (1994)" Data Set for a Panel of 138 Countries," taken from the NBER Web page, http://www.nber.org/pub/barro.lee/ZIP/

CRED: EMDAT, The OFDA/CRED International Disaster Database (2000). Universite Catholicque 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	86
Change in Secondary Schooling Years	0.033	0.025	89
Change in Total Schooling Years	0.069	0.035	89
Growth in Physical Capital Per Worker	0.029	0.024	87
Per Land Climatic Disasters	1.306	1.426	89
Per Land Geologic Disasters	0.584	0.818	89
Log (Initial Investment per capita)	1.122	1.323	87
Log (Initial GDP per capita)	7.530	0.858	86
Government Quality Index	0.645	0.209	86
Latitude	25.51	16.77	86
Tropics	0.512	0.503	86
Trade	0.618	0.406	86
Landlocked	0.174	0.382	86
Sub-Saharan Africa	0.225	0.420	89
Latin America	0.258	0.440	89
NIES and ASEAN	0.079	0.270	89
OECD	0.258	0.440	89

Appendix Table D: Hausman Test of Endogeneity*

	F-value
Change in Secondary Schooling Years	8.139
	(0.0006)
Change in Total Schooling Years	8.676
	(0.0004)

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	3SLS	3SLS	OLS	3SLS	3SLS
Change in Secondary Schooling Years	0.103	0.445	0.571			
	(1.788)	(1.759)	(2.650)			
Change in Total Schooling Years				0.051	0.255	0.347
				(1.481)	(1.589)	(2.926)
Log (initial GDP per capita)			-0.017			-0.017
			(-3.750)			(-4.199)
Government Quality Index			0.071			0.084
			(4.114)			(6.099)
Latitude	0.000	-0.000	-0.000	0.000	0.000	-0.000
	(0.154)	(-0.978)	(-1.627)	(0.651)	(0.298)	(-0.328)
Tropics	-0.003	-0.008	-0.010	-0.002	-0.003	-0.003
	(-0.700)	(-1.623)	(-2.010)	(-0.502)	(-0.564)	(-0.482)
Trade	0.008	0.008	0.004	0.009	0.010	0.007
	(3.179)	(2.118)	(1.154)	(3.157)	(3.302)	(2.060)
Landlocked	-0.003	0.001	0.002	-0.003	0.001	0.003
	(-0.692)	(0.213)	(0.446)	(-0.765)	(0.249)	(0.804)
Number of Observations	86	86	86	86	86	86
RMSE	0.009	0.012	0.013	0.009	0.011	0.011
R-squared	0.762	0.571	0.495	0.755	0.619	0.626
P-value for overidentification		0.327	0.171		0.461	0.168

* Numbers in parentheses are t-values. Other explanatory variables not reported here are constant term, growth in physical capital per worker, and the regional dummies.

Appendix Table E-2: Checking Robustness: Different Sample Sizes

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	
Estimation	OLS	3SLS	OLS	3SLS	OLS	3SLS	OLS	3SLS
Change in Secondary Schooling Years	0.144	0.772	0.146	0.743	0.108	0.539	0.149	0.653
	(2.464)	(2.157)	(2.474)	(2.183)	(1.809)	(2.135)	(2.473)	(2.248)
Number of Observations	81	81	78	78	68	68	81	81
RMSE	0.009	0.016	0.009	0.016	0.010	0.014	0.009	0.015
R-squared	0.634	-0.151	0.602	-0.181	0.750	0.410	0.683	0.134
P-value for overidentification		0.131		0.129		0.176		0.069

	Exclusion of five Asian countries		Exclusion of eight Asian countries		Exclusion of 18 "ring of fire" countries		Exclusion of five outliers	
Estimation	OLS	3SLS	OLS	3SLS	OLS	3SLS	OLS	3SLS
Change in Total Schooling Years	0.058	0.724	0.064	0.873	0.044	0.246	0.075	0.883
	(1.618)	(1.078)	(1.737)	(1.116)	(1.131)	(1.182)	(1.960)	(1.269)
Number of Observations	81	81	78	78	68	68	81	81
RMSE	0.010	0.021	0.010	0.024	0.010	0.012	0.010	0.024
R-squared	0.609	-0.973	0.575	-1.887	0.738	0.589	0.662	-1.242
P-value for overidentification		0.217		0.278		0.006		0.457

* Numbers in parentheses are t-values. 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. Five outliers are Botswana, Korea, Lesotho, Singapore, and Thailand. Other explanatory variables not reported here are constant term, growth in physical capital per worker, and the regional dummies.