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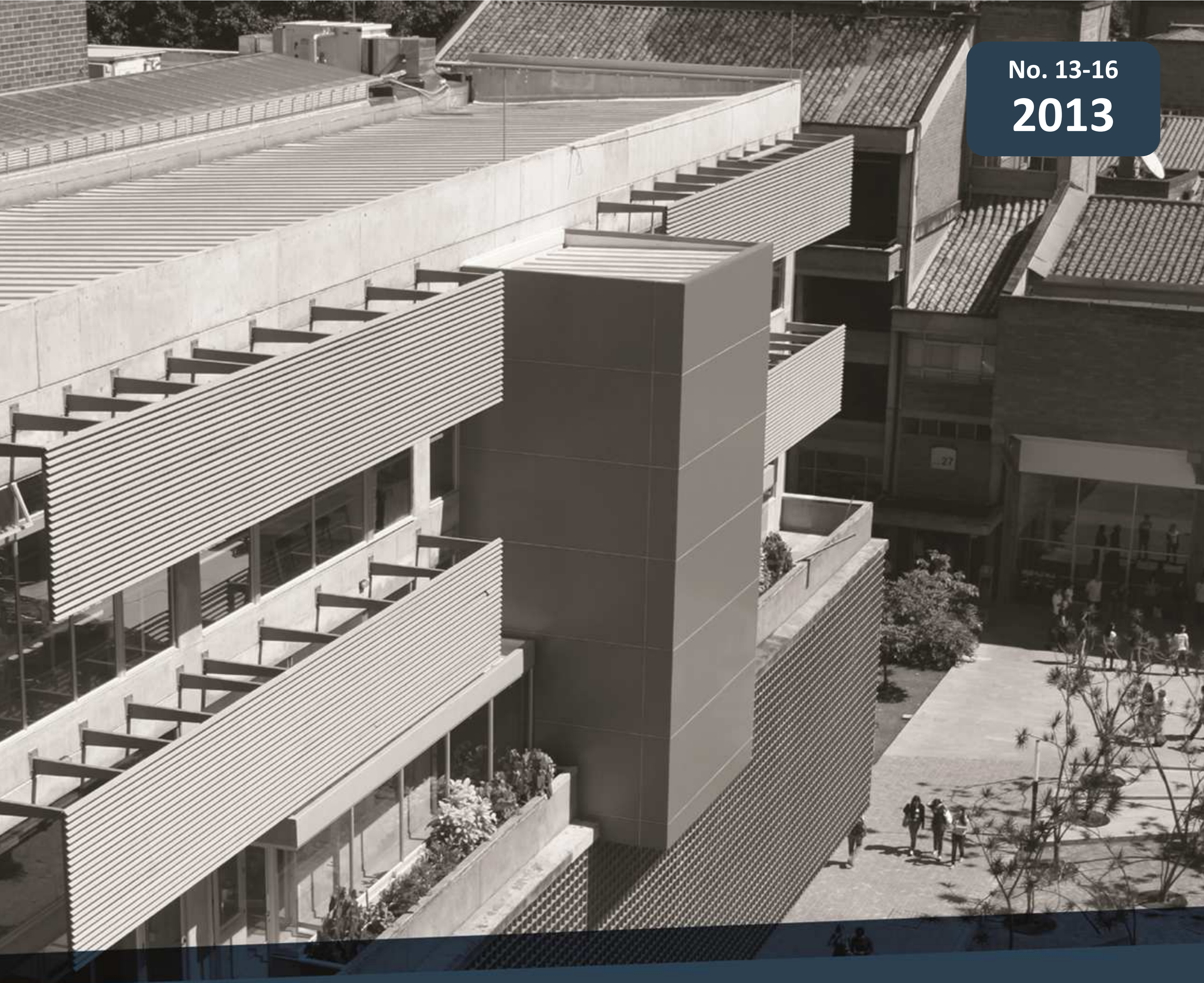

SCHOOLING ATTAINMENT, SCHOOLING EXPENDITURES, AND TEST SCORES WHAT CAUSES ECONOMIC GROWTH?

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What Causes Economic Growth?

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Abstract

Using a dynamic augmented Solow model, I estimate the effect of students' schooling attainment, schooling expenditures, and students' test scores on growth rates over the period 1985-2005. I also estimate the effect of related measures for human capital stocks on national income in a static model in 2005. Individually all of the measures cause growth, and when included in the same model, more than one is statistically significant. Relative measurement error appears to determine which measure provides the best results. The results support the importance of increases in human capital for growth and the validity of the augmented Solow model.

Key Words: Schooling Attainment; Schooling Expenditures, Test Scores, Economic Growth

JEL Codes: O41; I25

Hanushek and Woessmann [2008, 2012a, and 2012b] (hereafter HW) averaged available student scores on international tests of science and mathematics between 1964 and 2006 to create a measure of students' cognitive skills for a large set of countries. They show that this measure explains three times as much of the variation in national growth rates during 1960-2000 as adults' average schooling attainment in 1960 and that when both measures are included in their growth model, average schooling attainment in 1960 has no effect on growth.

HW [2008 and 2012a] interpret their empirical results to mean that students' cognitive skills at ages 9 to 15 determine economic growth and that schooling only affects growth to the degree that it raises students' cognitive skills. They document the low level of students' cognitive skills in developing countries and argue that increases in schooling attainment have a limited effect on growth because schools in developing countries do not reliably raise students' skills.

Breton [2011] disputes HW's [2008] finding that students' average test scores explain income differences much better than adults' average schooling attainment. He argues that their analysis is flawed because their average test scores are a proxy for workers' human capital in 2010, ten years after their growth period and fifty years after their measure of adult schooling attainment. He shows that when their average scores and adults' average schooling attainment in 2000 are compared, either measure can explain differences in national income in 2000, but adults' schooling attainment explains more of the variation than average test scores.[1]

HW [2012a and 2012b] present additional estimates of essentially the same growth model used in HW [2008]. They use a slightly larger data set with test scores obtained during 1964-2006 and several instruments for test scores, and again they show that average test scores explain economic growth much better than adults' schooling attainment in 1960. In HW [2012a] they claim that adults' average schooling in Latin America in 1960 did not produce the expected economic growth during 1960-2000 because students (mostly tested in 1997 and in 2006) did not acquire adequate cognitive skills while in school.

HW [2008 and 2012b] argue that their findings provide direction for a nation's educational strategy, because they show that better schools, as measured by students' test scores,

[1] A number of other recent studies show that increases in average schooling attainment cause growth, including Cohen and Soto [2007], Breton [2013a], and Gennaioli, La Porta, Lopez-de-Silanes, and Shleifer [2013].

can raise a nation's future level of income. Using their estimated coefficients on average test scores, they estimate how much growth rates could increase if students' test scores were raised.

Breton's [2011] results suggest that HW have misinterpreted their findings. If their comparison of adults' average schooling attainment and students' average test scores is invalid and either can explain growth, then implicitly both measures are a proxy for a nation's human capital, and HW's estimated coefficient on average test scores measures the effect of increasing a nation's human capital on growth, not solely the effect of raising students' skills at ages 9 to 15.

If children's test scores are an incomplete measure of a nation's human capital, then other aspects of their human capital are omitted variables in HW's growth model, and their results do not provide clear guidance for educational policy. Increasing other components of a nation's human capital, such as the share of the population completing secondary school, might be more feasible or more cost-effective than increasing children's test scores as a means to increase economic growth.[2]

In this paper I investigate whether students' average test scores are the key determinant of a nation's future growth rate, or just a proxy for a nation's level of human capital. I begin this investigation by specifying a theoretically-consistent growth model and selecting estimation periods that are appropriate for the vintage of the test scores. I then compare the estimated effect of average test scores and two other measures of human capital, being careful to use measures that are appropriate for the specified models and that represent the correct time period. I estimate the growth models with each measure separately and with combinations of these measures to determine whether the effect of average test scores is robust to the inclusion of the other measures in the model.

For reasons explained in detail below, I use a dynamic version of the augmented Solow model as the primary model for this analysis. This model includes the statistically-significant variables in HW's model, but in a different mathematical form, and it also has other differences that are important for proper model specification. This model estimates the effect of *flows* of human capital on growth rates, so I compare three measures of these flows during the estimation period: students' average test scores, average schooling expenditures, and *students*' (not adults') average schooling attainment.

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[2] HW [2008, P. 658] observe that "student achievement has been relatively impervious to a number of interventions that have been tried by countries around the world."

I also examine the effect of three measures of human capital in a static version of the augmented Solow model. The static model examines the effect of changes in capital *stocks* rather than capital *flows*. My stock measures are students' (earlier) average test scores, the cumulative earlier investment in workers' schooling, and *adults*' average schooling attainment. Since the measurement error differs in the stock and flow data, the empirical results from the dynamic and static models provide information on whether differences in the estimated coefficients for the different measures are due to the aspect of human capital measured or to differences in the accuracy of the data.

For the dynamic model the estimation period is 1985-2005 and for the static model it is 2005. I estimate all of the models using both OLS and 2SLS, with instruments for the human capital measures.

Overall my empirical results differ substantially from HW's results. I first examine the data and show that across countries adults' average schooling attainment (in years) is highly correlated with (the log of) the financial stock of human capital. These results contradict HW's [2008, 2012a, and 2012b] repeated claim that average schooling attainment is not a good measure of human capital across countries.

I then show that in the dynamic models average test scores, average schooling expenditures, and students' average schooling attainment all provide similar, statistically-significant estimates of the effect of human capital on growth. All of the models have estimated coefficients on physical capital and initial income that correspond to the expected results for a dynamic augmented Solow model. Subsequently, I show that in the static models average test scores, the financial stock of human capital, and adults' average schooling attainment provide similar, statistically-significant estimates of the effect of human capital on national income.

Since each measure of schooling quantifies a different aspect of a nation's human capital, the effects of the measures are not mutually exclusive. When two or more measures are included in the same model, generally at least two are statistically significant. These results indicate that children's cognitive skills are not the only component of human capital that contributes to economic growth.

The average test score measure provides good estimates of the effect of human capital in the growth model, and it explains more of the variation in growth rates than the other two measures. But the opposite is the case in the static model where the average test score measure explains less of the variation in national income than the other two measures. In each set of models, the human capital measure with the data that appear to be most accurate, provides the best statistical estimates of the effect of human capital on growth or income.

HW [2012a] show that students' scores on international tests in Latin America are low compared to other regions with similar adult levels of schooling attainment. In my results either average schooling expenditures or average test scores explain growth. One possible interpretation is that average schooling expenditures/year of schooling are relatively low in Latin America. This interpretation is consistent with the relatively high pupil-teacher ratios in primary school in Latin America.

Overall the results presented in this paper support the validity of the augmented Solow growth model and provide considerable evidence that increases in human capital cause economic growth. The results support HW's contention that increases in students' cognitive skills, as measured by average test scores, raise the rate of economic growth, but they reject their contention that cognitive skills measured at ages 9 to 15 are the only aspect of human capital that causes growth.

The rest of the paper is organized as follows: Section II presents the conceptual framework and specifies the econometric models. Section III describes the data. Section IV presents the empirical results. Section V presents additional analysis of the effect of schooling expenditures on student achievement. Section VI concludes.

II. Methodological Considerations

HW [2008, 2012a, and 2012b] use the following model to estimate the effect of average test scores on growth rates:

1) $d(Y/cap)/dt = \alpha_0 + \alpha_1\ \text{Sch-1960}_i + \alpha_2\ \text{AvgTS}_i + \alpha_3\ \text{Y/cap-1960}_i + \alpha_4\ X_i + \varepsilon_i$

In this model d(Y/cap)/dt is the annual average growth rate in real GDP/capita during 1960-2000, Sch-1960 is adults' average schooling attainment in 1960, AvgTS is average student test scores during 1964-2006, Y/cap-1960 is GDP/capita in 1960, and X are other conditioning variables that differ in each of their articles. This model does not correspond to any particular growth theory, and HW do not explain why these particular variables are included in their model.

HW include the initial level of GDP/capita in all of their models, which is included in neoclassical models to control for the state of convergence on the steady-state growth rate. But HW's growth model is not a neoclassical model. Neoclassical models do not include a variable for the initial human capital stock, since in this model the *change* in this stock, and not its initial level, determines the rate of growth [Acemoglu, 2009]. In a dynamic neoclassical model, the effect of the initial capital stocks is captured in the initial level of GDP/capita, which unlike their model, is included in log form. Since the initial level of GDP/capita and the initial level of schooling/capita are measuring the same thing, it is not surprising that in all of HW's empirical results, the estimated coefficient on the initial level of schooling is insignificant.[3]

The most unusual aspect of their model is that it includes the average schooling attainment of the *adult* population in 1960 and the average test scores of *students* obtained during 1964-2006 (or for most developing countries during 1990-2006). These two variables do not measure the characteristics of the same population at the same time, so it is impossible to conclude anything about whether students' level of schooling or their test scores is more important for growth.

Conceptual Framework for the Analysis

I begin my analysis by selecting a conceptual framework for specifying all of the econometric models. Given the choices of either an endogenous or a neoclassical growth model, I adopt the neoclassical, augmented Solow model for six reasons.

First, the structure of the neoclassical model is consistent with the widely-accepted Mincerian relationship between workers' salaries and their level of schooling, while the structure of the endogenous model is not [Krueger and Lindahl, 2001]. The Mincerian model and the neoclassical model assume that increases in human capital rather than the level of human capital raise income, and both models exhibit diminishing returns [Breton, 2013b].

Second, the empirical evidence rejects the endogenous growth model [Jones, 1995 and Lau, 2008]. The endogenous growth model predicts that increases in physical capital and/or R&D will lead to permanent increases in the rate of economic growth, and the empirical evidence indicates that this is not the case.

Third, Mankiw, Romer, and Weil [1992], Breton [2004], Cohen and Soto [2007], Ding and Knight [2009], and Breton [2013a] present evidence that over long periods the augmented Solow model explains economic growth across countries quite well.

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[3] In HW [2012a and 2012b] the initial levels of income, physical capital, and average schooling attainment are all included in the model. Neither coefficient on the two initial stocks of capital is significant.

Fourth, Barro and Sala-i-Martin [2004] show that growth patterns across countries exhibit the conditional convergence predicted by the neoclassical model.

Fifth, Breton [2013b] shows that after accounting for schooling's external effects on physical capital in the augmented Solow model, the model's estimate of the effect of schooling on national income in is consistent with micro estimates of the direct and external effects of schooling on workers' salaries. He also presents evidence that no important variables are omitted in the augmented Solow model.

Sixth, in the particular case of the HW analyses, their regression results consistently reject the importance of initial human capital and support conditional convergence. So if there is a valid existing conceptual model that is consistent with HW's statistical correlations, it is a dynamic version of the neoclassical model.

Mankiw, Romer, and Weil's [1992] Dynamic Neoclassical Model

Mankiw, Romer, and Weil's (hereafter MRW) augmented Solow model is well-known, but it is useful to review its formal specification:

2) $Y_t = K_t^{\alpha} H_t^{\beta} (A_0 e^{gt} L_t)^{1-\alpha-\beta}$

In this model, GDP or national income (Y) changes over time (t) in response to changes in physical capital (K), human capital (H), labor (L), and total factor productivity (A), which is assumed to grow at a constant rate g. In this model $\alpha + \beta < 1$, so increases in physical capital or human capital, or the two together, raise income, but at a diminishing rate. As a consequence, when investment rates are a stable fraction of GDP, a country's rate of economic growth converges on the steady state rate g.

MRW derive the mathematical structure for a dynamic version of this model, in which growth is modeled as convergence to the steady state. As a consequence, the growth rate includes a permanent, steady-state component (gt) and a temporary, transitional component. The transitional component varies in size depending on the difference between the magnitude of the capital stock/worker entering the economy (implicit in y*) and the capital stock/worker already in the economy (implicit in y_0). The variation in this difference across countries creates the difference in growth rates during convergence. Mathematically, the equation is:

3) $\Delta \ln(Y/L)_t = gt + (1-e^{-\lambda t}) \ln(y^*) - (1-e^{-\lambda t}) \ln(y_0)$

Where $y = Y/(e^{gt} L)$, which is constant (y*) in the steady state. MRW show that in equilibrium y* is a function of the shares of GDP invested in human and physical capital (s_h and s_k), the rate of growth in the labor force (n), and the rates of depreciation of the stocks of physical and human capital (δ_k and δ_h):

4) $y^* = \alpha/(1-\alpha-\beta)\ [\log(s_k)/(n + g + \delta_k)] + \beta/(1-\alpha-\beta)\ [\log(s_h)/(n + g + \delta_h)]$

Substitution of equation (4) into equation (3) creates the dynamic version of the model:

5) $\Delta \ln(Y/L)_t = gt + (1-e^{-\lambda t})\ (\alpha/(1-\alpha-\beta)\ [\ln(s_k)/(n+g+\delta_k)] + (1-e^{-\lambda t})\ \beta/(1-\alpha-\beta)\ [\ln(s_h)/(n+g+\delta_h)] - (1-e^{-\lambda t}) \log(Y/L)_0 + (1-e^{-\lambda t}) \log(A_0)$

Importantly, in this model the shares of investment measure the *flow* of physical and human capital resources into the economy. Alternative measures of human capital, such as average test scores, must be used in this model with this conceptual requirement in mind.[4]

The average test score for a cohort of students is a measure of the human capital of a cohort of future workers. Students' average test scores over time can be considered a measure of the changing flow of human capital into the economy. Given the nature of the schooling process, these scores represent this flow with a lag of 5-10 years. So the average score for a cohort of students is a proxy for the amount of human capital flowing into the economy 5-10 years later.

Although s_k and s_h are constant in equation (4), the model remains conceptually valid if s_k and s_h are the average shares of GDP invested during the convergence period. If these shares are not constant, then implicitly y_t is converging on a moving target y^*_t. Although variation in y^*_t introduces measurement error into an estimate of the convergence rate λ, the bias is likely to be small, as long as the variation in ln(average y^*_t) during the period of estimation is small relative to the difference between ln(average y^*_t) and $\ln(y_0)$.

Student's average scores on international tests are an innovative cross-country measure of human capital, but conceptually the measure only represents the human capital of the school-age population that is in school. Its practical limitation is that for most developing countries average test scores are only available since 1990.

HW [2008] use these scores to represent workers' skills at an earlier time by assuming that workers in developing countries during 1960-2000 had the same cognitive skills as the students tested during 1990-2006. Cohen and Soto's [2007] data on the schooling of the work

[4] Since HW do not specify a conceptual growth model for their analyses, it is not clear whether they use average tests scores during 1964-2006 to represent a flow of human capital during 1960-2000 or the stock of human capital in some year. Since they compare these scores to average schooling attainment in 1960, it appears that they are assuming that students' average test scores during 1964-2006 represent the human capital of workers in 1960, which clearly they do not. They obtain good results for average test scores and not for adults' schooling attainment in 1960 because the dynamic neoclassical model requires a measure of the average flow of human capital into the economy, and students average test scores over the 1964-2003 period are a measure of this average flow.

force during 1960-2010 clearly show that HW's assumption is not plausible. A very large share of workers in developing countries during their growth period had little or no schooling.

In developed countries students' average scores on the same international test increase by about 1/3 of a standard deviation (33 points compared to an OECD mean score of 500) for each additional year that they remain in school [Fuchs and Woessmann, 2006, Juerges and Schneider, 2004, and Woessmann, 2003]. Since prior to 1990 a large share of the population of school age in developing countries was not in school, if they had been tested, clearly their scores would have been substantially lower than the scores of the students tested in the 1990s.

The model in equation (4) is estimated in log form, so trends in average scores over the growth period do not bias the estimated coefficients, as long as the trends are similar across countries. Cohen and Soto's [2007] data clearly show, however, that the trends in primary and secondary school attendance were quite different in developed and developing countries over the 1960-2000 period. So the trends in the cognitive skills of the school age population are also likely to have been very different.

One solution to this problem is to estimate the growth model over a later period when a much higher share of the school age population in developing countries attended school until the age that the tests were given. The estimates of the growth model in equation (5) using average test scores are likely to be more accurate if the estimation period begins much later than 1960.

Econometric Model Specification and Period of Estimation

Although a period beginning after 1995 would provide the best match for the test scores obtained in developing countries, estimation of growth models over very short periods increases the measurement error in the other data. National growth rates are unstable over short periods due to economic cycles, and the differencing of data over short periods reduces the signal-to-noise ratio [Krueger and Lindahl, 2001].

Based on these considerations, I estimate the growth model over the 1985-2005 period. This period corresponds relatively well to the period the tests were given, it is long enough to provide good results in the convergence model, and economic data are available to estimate models through 2005.

I estimate the static model in 2005. By this time most of the students tested in developed countries over the 1964-2003 period were in the work force, so the average of their scores is representative of the human capital of the work force in 2005. Since the test scores in the developing countries are mostly from the 1990-2006 period, the average of their scores are not as representative of human capital in 2005, so *a priori* I expect average test scores to be a less accurate measure of human capital in the static model than in the growth model.

As explained below, the relative accuracy of the data for the flows and the stocks of schooling attainment has the opposite pattern. The data for adults' average schooling attainment in 2005 are likely to be more accurate than the data for *students*' average schooling attainment during 1985-2005.

The conceptual specification for human capital in the augmented Solow model is financial, so the form required for these data in the dynamic and static models is clear. In the growth model these data are the share of GDP invested in schooling, while in the static model they are the net financial stock of human capital [OECD, 2001].

Since there is a lag between investment in schooling and the entry of students into the work force, I use the average investment in schooling during 1980-2000 to represent the flow of human capital into the economy during 1985-2005. Although on average, the lag can be longer than five years, higher levels of schooling cost more and the lag between expenditures and students' entry into the work force is shorter for higher levels. Five years is a good average lag from a financial standpoint. For 2005 I use the net stock of human capital calculated from cumulative investment in schooling less depreciation during the prior 40-year period, again lagged five years. This investment includes public and private expenditures, the cost of capital during schooling and students' foregone earnings. The detailed methodology for this calculation is presented in Breton [2013b].

Average schooling attainment of the population 15 to 64 is a measure of the stock of human capital, so I use this measure for 2005 in the static model. The corresponding *flow* of schooling attainment is the average years of schooling for *students* (not adults) of primary, secondary, and tertiary school age. Again I use average attainment during 1980-2000 to represent the flow of resources into the economy during 1985-2005.

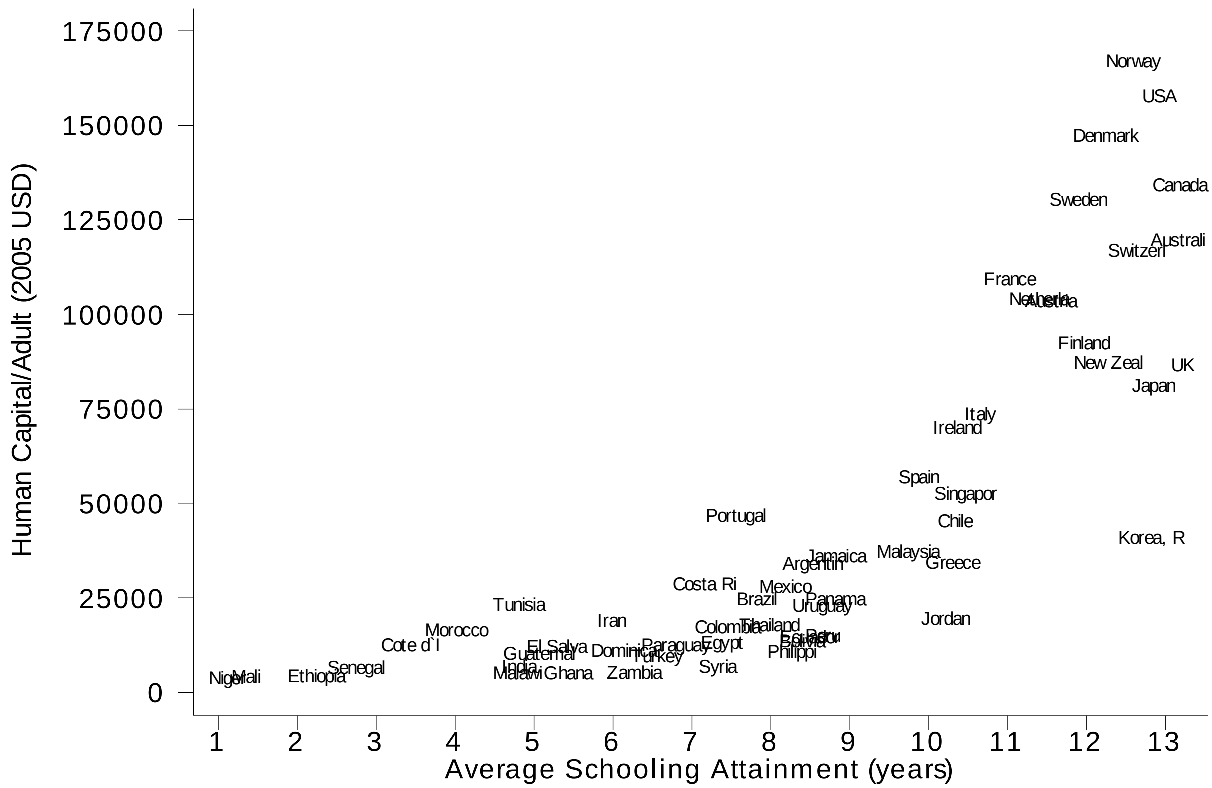
Mathematical Relationships Between the Measures of Human Capital

Utilization of the average test score data and the schooling attainment data as proxies for the financial data requires some care because the data for these measures do not have a linear relationship to the financial data. If an inappropriate form of these data is used to estimate the models, the resulting model is mis-specified and the estimated coefficients will be biased.

In the case of the schooling attainment data, this issue is not just theoretical. As shown in Figure 1, the relationship between adults' average schooling attainment and human capital/adult is exponential. As countries raise their average level of schooling attainment, they invest an increasing amount per average year of attainment.

Figure 1

Human Capital/Adult vs. Average Schooling Attainment in 2005

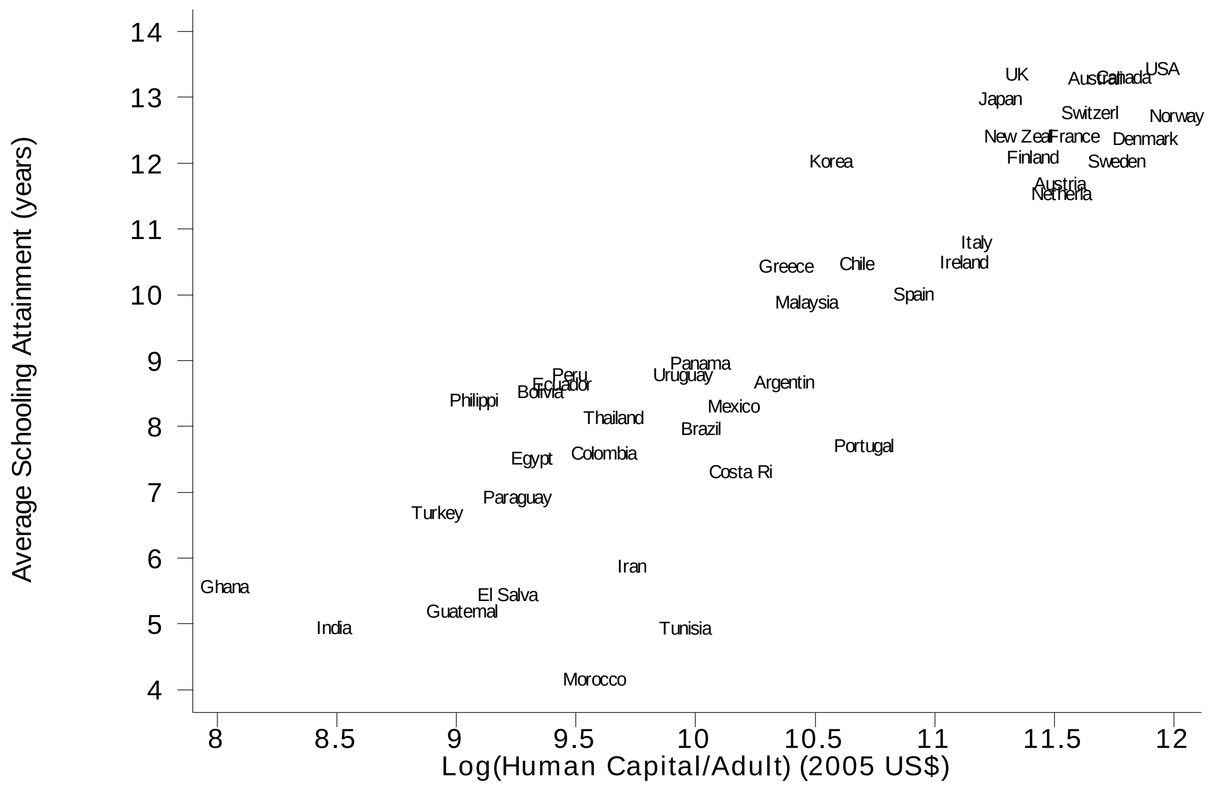


In 2005 developing countries with two years of schooling had invested about $2,000/adult. Developed countries with 13 years of schooling on average had invested about $130,000/adult, *or ten times as much per year of schooling*. In the figure South Korea appears to have invested much less than other highly-educated countries, but its investment in schooling does not include its expenditures on private tutoring, which are almost as large as its expenditures on schooling [Dang and Rogers, 2008].

As a consequence, a static augmented neoclassical model should be estimated using adults' average schooling attainment to represent log(H/adult), not H/adult. Figure 2 shows the linear relationship in 2005 between the log of the (net) human capital stock estimated from investment rates from 1960 to 2000 and Cohen and Soto's [2007] estimates of average schooling attainment for the countries used later in this analysis. The correlation coefficient is very high between these two data sets (ρ = 0.88).

Figure 2

Average Schooling Attainment vs. Log(Human Capital/Adult) in 2005



Augmented Solow models that do not use this log-linear relationship to represent human capital/adult are mis-specified. Benhabib and Spiegel [1994] made this error and found that the relationship between changes in schooling attainment and economic growth is negative. They then added the initial level of schooling to their growth model because the estimated coefficient on this variable is positive, but this correlation is spurious. As shown in HW's [2008, 2012a, and

2012b] results, the positive estimated coefficient on the initial level of schooling is not robust to the inclusion of correctly-specified human capital variables in a growth model.

As part of their comprehensive review of the growth literature, Krueger and Lindahl [2001] discuss the inconsistency between Benhabib and Spiegel's linear income-schooling specification and the standard assumption in the Mincerian model. They show that the log-linear relationship provides better empirical results. Cohen and Soto [2007] and Breton [2011, 2013a, and 2013b] also discuss the necessity of using the log-linear relationship in the augmented Solow model.

HW [2008, 2012a, and 2012b] mischaracterize the relationship between average schooling attainment and human capital, which has led them to claim repeatedly and incorrectly that average schooling attainment is a very inaccurate proxy for human capital across countries. As an example, in HW [2012b] they state:

> "…all analyses using average years of schooling as the human capital measure implicitly assume that a year of schooling delivers the same increase in knowledge and skills regardless of the education system. For example, a year of schooling in Peru is assumed to create the same increase in productive human capital as a year of schooling in Japan."[5]

This statement is incorrect. The log-linear relationship between human capital and schooling implies that two countries with the same level of average attainment have the same level of human capital (e.g., Japan and the U.S). But each additional year of schooling does <u>not</u> increase human capital by the same amount, even within the same country. Each additional year of average attainment has an <u>exponential</u> effect on a country's human capital/adult and on its GDP/adult. Since average schooling attainment is much greater in Japan than in Peru, an additional year of schooling in Japan raises human capital by much more than an additional year in Peru.

There is no reason to expect that countries with similar levels of average schooling attainment would have similar levels of human capital. Countries that have provided their adults with the same average years of schooling could have provided very different amounts of *education* to these adults. But in practice this seems not to be the case.

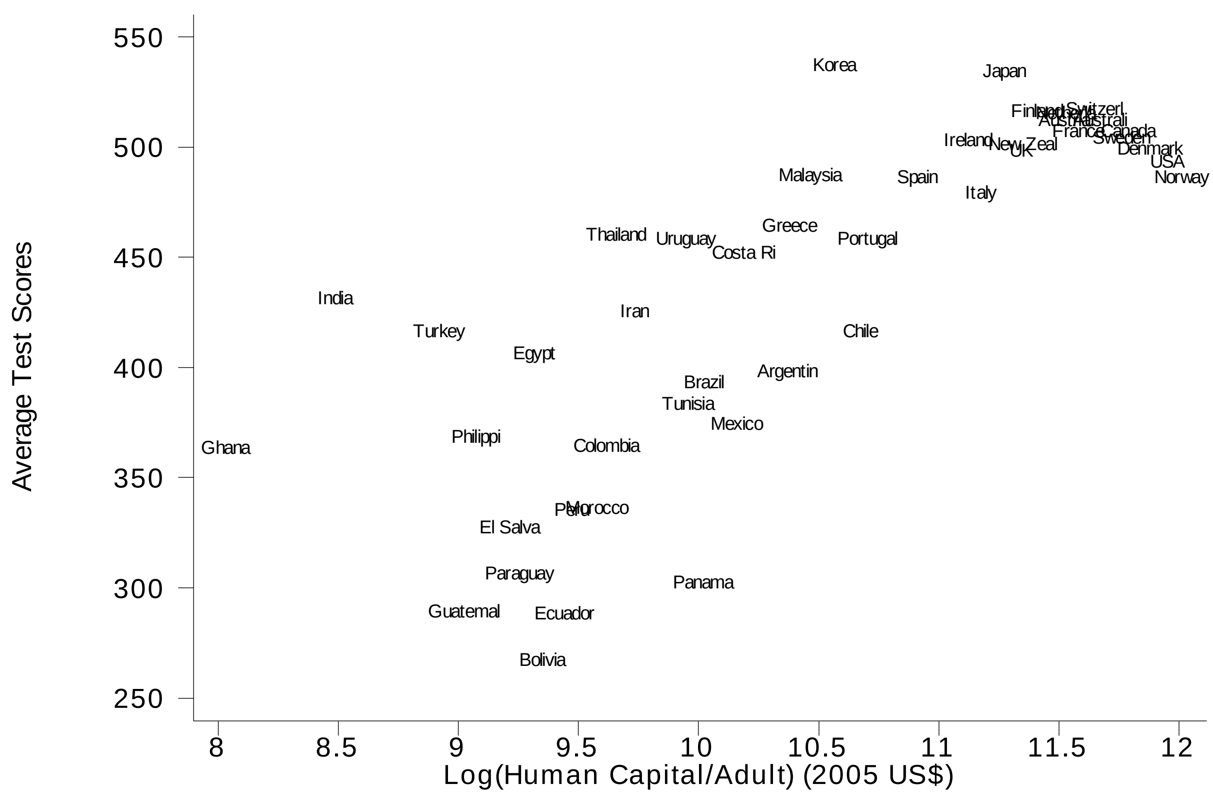
[5] HW, 2012b, p. 269.

Curriculums are very similar across the globe, even in the same year of schooling. International tests of student achievement are only possible because students of the same age study the same subjects. As a consequence, all of the countries that participate in international testing programs educate their students using relatively similar curriculums. And as shown in Figure 1, the net financial stock of human capital rises quite consistently across countries as they raise their adult population's average schooling attainment.

While the log-linear mathematical relationship between human capital/adult and average schooling attainment is well-known, the appropriate relationships for other measures of the flow or stock of human capital, such as average test scores, have not been rigorously analyzed in the literature. Figure 3 shows the relationship between average test scores and log(human capital/adult) in 2005. As with average schooling attainment, this relationship appears to be

Figure 3

Average Test Scores vs. Log(Human Capital/Adult) in 2005

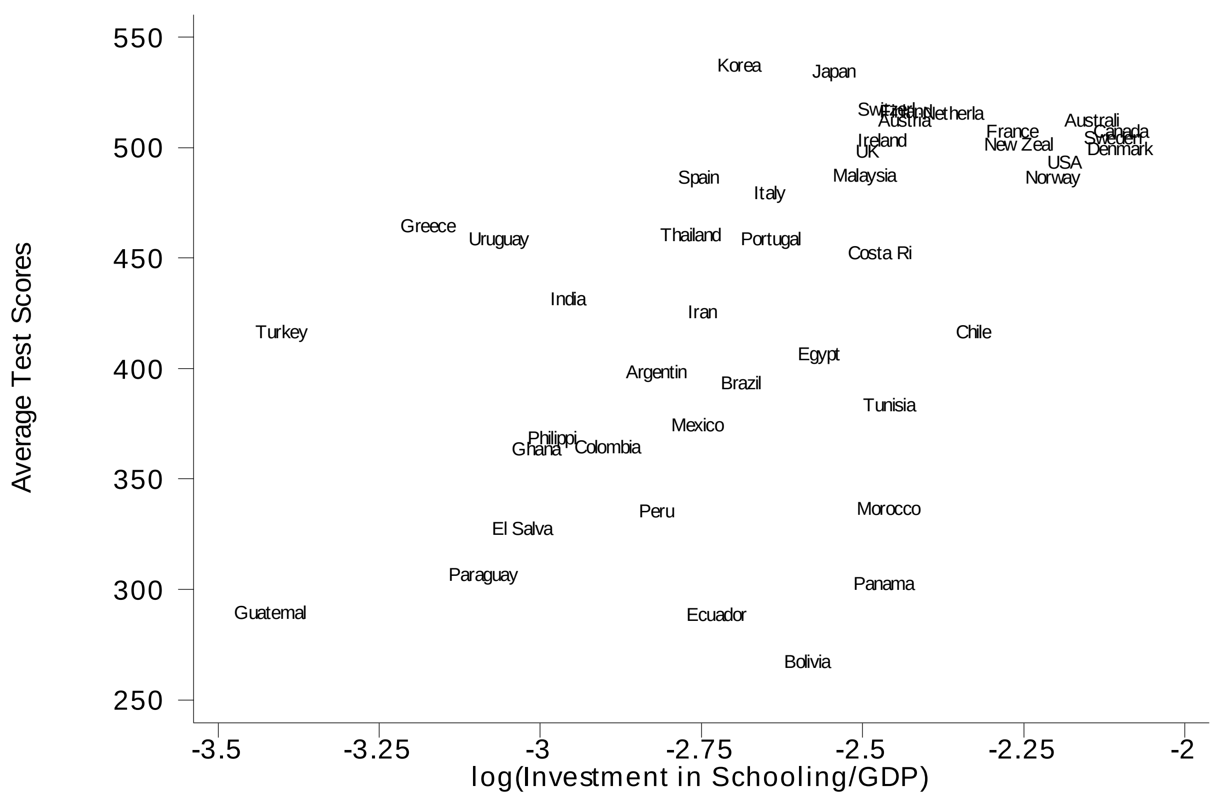


approximately log-linear. The pattern in the data shows that scores rise as national investment in schooling increases, but only up to a human capital stock of about \$100,000/adult.[6] The pattern implies that above this level, increased investment in schooling is not focused on raising students' test scores in elementary school. Nevertheless, over the entire range of countries in the data set, average test scores and log(H/adult) are highly correlated ($\rho = 0.78$), although not as highly as average schooling attainment and log(H/adult).

The mathematical relationships between the measures of human capital flows are somewhat different and not as highly correlated. Log(sh) is linearly related to average test scores ($\rho = 0.52$), as shown in Figure 4. Although it is not shown, log(sh) is linearly related to log(students' average attainment) with a similar level of correlation ($\rho = 0.54$).

Figure 4

Average Test Scores vs. Log(School Expenditures/GDP) in 1980-2000



6 Exp(100,000) = 11.5.

Based on the observed mathematical relationships between the various measures, I specify the following dynamic models for estimation:

6) $\Delta \ln(Y/L)_t = c_0 + c_1 \ln[(s_k)/(n+g+\delta_k)] + c_2 \text{ AvgTS}/\ln(n+g+\delta_h) + c_3 \ln(Y/L)_0 + \varepsilon$

7) $\Delta \ln(Y/L)_t = c_0 + c_1 \ln[(s_k)/(n+g+\delta_k)] + c_2 \ln[(s_h)/(n+g+\delta_h] + c_3 \ln(Y/L)_0 + \varepsilon$

8) $\Delta \ln(Y/L)_t = c_0 + c_1 \ln[(s_k)/(n+g+\delta_k)] + c_2 \ln(\text{StudAttain})/\ln(n+g+\delta_h) + c_3 \ln(Y/L)_0 + \varepsilon$

Physical capital and human capital are complementary in the augmented Solow model, which causes their stock levels to rise simultaneously in market economies [Breton, 2013b]. This conceptual relationship creates multicollinearity between the two variables in statistical estimation of the static model, which makes OLS estimates of the effect of each type of capital unstable. If one type of capital is poorly measured, its estimated effect is attenuated and the estimated effect of the other type is biased upward.

The static model in equation (2) can be rewritten to reduce the correlation between these two types of stocks in the econometric model and reduce the bias in OLS estimates of their effects:

9) $Y/L = (K/Y)^{\alpha/1-\alpha} (H/L)^{\beta/1-\alpha} (A)^{(1-\alpha-\beta)/(1-\alpha)}$

10) $Y/L = (K/Y)^{\alpha/1-\alpha-\beta} (H/Y)^{\beta/1-\alpha-\beta} A$

These relationships and the mathematical relationships between the human capital measures described earlier yield the following static models for estimation:

11) $\ln(Y/L) = c_0 + c_1 \ln(K/Y) + c_2 \text{ AvgTS} + \varepsilon$

12) $\ln(Y/L) = c_0 + c_1 \ln(K/Y) + c_2 \ln(H/Y) + \varepsilon$

13) $\ln(Y/L) = c_0 + c_1 \ln(K/Y) + c_2 \text{ AdultAttain} + \varepsilon$

Instrumental Variables

Human capital flows and stocks are likely to be endogenous in a growth or income model, so instruments for these variables are required to develop reliable conclusions about whether increases in human capital cause economic growth. I use three variables as instruments for the measures of human capital during the 1985-2005 period. These instruments are adults' average schooling attainment in 1980, the log of the Protestant share of the population, and the sum of the Catholic and Muslim shares of the population. HW [2012a and 2012b] use two of these instruments in their analysis.

The argument supporting the use of adults' schooling attainment in 1980 as an instrument is that the parents' level of schooling has a positive effect on student achievement and on political support for providing financial resources to schools. Juerges and Schneider [2004] and Parcel and Dufur [2009] document the positive effect of parental education on students' test scores in mathematics achievement. Rubinfeld and Shapiro [1989] show that voter support for public school expenditures in the U.S. is positively related to income and education levels.

Adults' average attainment in 1980 would be an invalid instrument if it caused growth directly, as hypothesized in endogenous growth theory, but as mentioned earlier, the evidence rejects endogenous growth theory. In the dynamic version of the neoclassical model, growth rates are affected by the change in the level of schooling, not by the initial level. The initial level of GDP in 1985 is affected by the initial level of schooling attainment in 1985, which is highly correlated with the level in 1980, but since the initial level of income in 1985 is already in the growth model, conceptually the level of schooling attainment in 1980 is not likely to have any additional direct effect.

The shares of the population affiliated with different religions are attractive instruments because these measures are not endogenous in the economic growth process and they are correlated with measures of human capital. Catholic/Muslim affiliation and the log of Protestant affiliation are inversely correlated ($\rho = -0.53$), but they have different patterns across countries, so both instruments can be used in the same model.

Most countries have some level of Protestant affiliation, and the Protestant share of the population has been positively correlated with schooling levels and with expenditures on schooling for centuries [Means, 1966, Cipolla, 1969, Johansson, 1981, Soysal and Strang, 1989, and Goldin and Katz, 1998]. The correlations apparently exist because Protestant doctrine emphasizes the responsibility of members to read the Bible and the responsibility of the community to ensure that each member develops this capability. The log of the Protestant share in 1980 is highly correlated with average schooling attainment in 2005 ($\rho = 0.55$) and with log(H/Y) in 2005 ($\rho = 0.58$).

The validity of the Protestant share of the population as an instrument for schooling is somewhat controversial because there are hypotheses that Protestant affiliation creates a "Protestant Ethic" that affects the economy in ways other than just through schooling. Despite their popularity, these hypotheses have been tested and consistently rejected [Iannocconne, 1998]. Recently, Becker and Woessmann [2009 and 2010] show that Protestant counties in the 19th century had higher incomes than Catholic counties, but they also show that differences in educational levels explain the income differences. Arruñada [2010] presents evidence rejecting the hypothesis that Protestants have a greater work ethic today than Catholics. Breton [2004] shows that Protestant affiliation is not correlated with indices for institutional characteristics that include measures of corruption.

Protestant affiliation has a positive correlation with average test scores, but the correlation is too weak for it to serve as an instrument ($\rho = 0.23$). However, Catholic/Muslim affiliation can serve as an instrument because it has a strong negative correlation with average test scores ($\rho = -0.48$). Two possible explanations for this relationship are the higher emphasis in Catholic/Muslim societies on family relationships for employment and the relatively low tolerance in the Catholic and Muslim religions for scientific or other ideas that may be perceived to contradict religious dogma. Arruñada [2010] presents evidence from 32 countries that Catholics prefer personal exchange and family-related occupations more than Protestants. Mansouri [2007] argues that Muslim theologians have opposed science because they perceive scientific ideas as a challenge to Islamic religious beliefs.

III. Data for Estimation of the Models

Two sets of data are required to estimate the models, one for the period 1985-2005 and one for 2005. Both sets include data for 49 countries which have been market economies and that are not based heavily on natural resource extraction. These restrictions increase the likelihood that the countries have production functions with similar parameters.

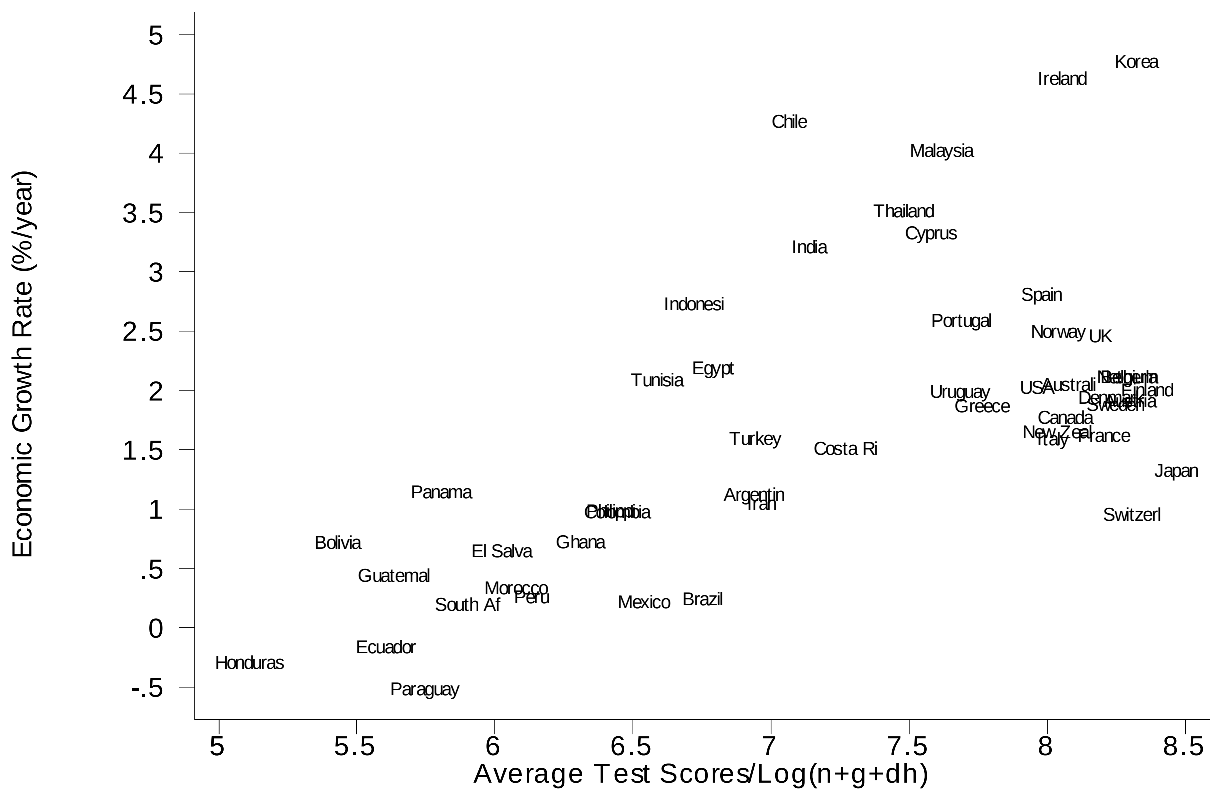
Since the primary focus of this study was on comparing HW's test score results to other measures of human capital, the availability of test scores was the initial determinant of the countries in the data set. HW [2012a] provide average test scores for 59 countries, so I began with these countries and excluded ten for various reasons. I excluded China and Romania because they were not market economies. I excluded Venezuela because its economy is dependent on oil exports. I excluded Israel, Hong Kong, Taiwan, and Iceland because Cohen and Soto [2007] do not have schooling attainment data for them. I excluded Singapore because schooling enrollment data are unavailable. Finally, I excluded Jordan and Zimbabwe because they are consistent outliers in the analytic results.

The financial measures for schooling are only available for 44 of these 49 countries due to the limited UNESCO data for historic public expenditures on schooling. In the estimations using the financial measures, the data set is limited to 44 countries.

Figure 5 shows the relationship between the growth rate over the 1960-2000 period and the average test score measure for the 49 countries in the data set. There is a strong correlation between these variables ($\rho = 0.64$), but the distribution of scores also exhibits regional patterns that could indicate that unknown factors, perhaps related to culture or development strategies, may have affected growth rates. Average test scores are relatively high in the Asian countries and are relatively low in the Latin American countries. I include dummy variables for these regions in some of the models to control for possible omitted variables.

Figure 5

Economic Growth vs. Test Scores in the Growth Model



Researchers have become increasingly aware that cross-country data have substantial measurement error. Johnson, Larson, Papageorgiou, and Subramanian [2009] show that there are substantial differences in the economic data in different versions of the Penn World Table (PWT) because the historic data are adjusted differently for purchasing power parity in each version. They report that GDP growth rates are stable across versions but the absolute level of

GDP is not. Since the dynamic and static models include data for GDP levels, these differences can affect the empirical results. Breton [2012] presents evidence that PWT 6.3, which provides data through 2007, appears to have more reliable historic data for GDP than PWT 7.0, so I use PWT 6.3 [Heston, Summers, and Aten, 2009] as my source for the economic data.

The various models all include workers (L) as one of the factors of production. I use the number of adults as my measure of the number of workers for two reasons. First, the data on the number of workers tend not to be reliable. Second, since the macro model includes the external effects of human capital, adults who are not workers can affect national income. GDP/adult is likely to provide better results than GDP/capita because children (i.e. the population under 15) are not major contributors to economic output.

I calculate GDP/adult from GDP/capita (rgdpch) and GDP per equivalent adult (rgdpeqa) and then calculate the adult population from these rates and the population data. I calculate the average investment rate for physical capital (s_k) over 1985-2005 as the average of the annual rate ci from 1985 to 2004. I calculate K/adult in 2005 using the perpetual inventory method, investment rates from 1965 to 2004, and a geometric depreciation rate (δ_k) of 0.06. I use the growth rate of the adult population as the growth rate (n) for the labor force.

I calculate students' average schooling attainment from the shares of the school age population enrolled in primary, secondary, and tertiary schooling from gross enrollment rates in the World Bank [2013] data base. The assumptions for these calculations are shown in Appendix I. I estimated average schooling attainment in 2005 by averaging the estimates in Cohen and Soto [2007] for the population age 15 to 64 in 2000 and 2010.

I estimate the average share of GDP invested in schooling for the period 1980-2000 using UNESCO data on the expenditures for public education (% of GDP), increased by a factor to account for private schooling and for the implicit cost of capital while students are in school. I estimate the net stock of human capital in 2005 using the perpetual inventory method, these estimates of investment over the 1960 to 2000 period, and a linear depreciation rate (δ_h) of 0.025. Students' foregone earnings do not affect the econometric estimates because the models are estimated in log form and foregone earnings are a similar share of schooling expenditures across countries. The methodology for these estimates is documented in Breton [2013b].

In the creation of the variables for the growth model, I assume g = 0.01, δ_h = .025, and δ_k = .06. The rate g is the estimate of the average steady state rate between 1910 and 2000 from

Breton [2013a]. The depreciation rate for human capital is from Breton [2013b]. The depreciation rate for physical capital is from Caselli [2004].

The data on average test scores are from HW [2012a and 2012b]. The data for Protestant affiliation are from Barrett [1982] and the data for Catholic and Muslim affiliation are from La Porta, Lopez-de-Silanes, Shleifer, and Vishny [1999].

The schooling measures have varying amounts of measurement error. Cohen and Soto's [2007] data on adults' average schooling attainment appear to be relatively accurate. In contrast, the data on *students'* average schooling attainment are not very accurate, since gross enrollment and net attendance can be very different and the magnitude of the discrepancy varies across countries.

The data on rates of investment in schooling and human capital/adult have similar levels of measurement error, since they are calculated from the same underlying data and the human capital data is used as the ratio H/Y in the estimation. These data are likely to be less accurate than the data on adults' average schooling attainment, but more accurate than the data on students' average schooling attainment.

IV. Empirical Results for the Econometric Models

Table 1 presents the results for the growth models specified in equations (6), (7), and (8). The first six columns show the OLS estimates of the model with the three measures of human capital flows, with and without dummy variables for Asia and Latin America. The results for all of these models are consistent with expectations for an augmented Solow model. In this model α is the share of income that accrues to physical capital, which Bernanke and Guykarnak [2001] estimate to be about 0.35 across countries. The implied values of α for the three models range from 0.28 to 0.41, which are acceptable. The implied values of β are acceptable and are statistically significant at the one percent level. The speed of convergence on the steady-state ranges from 0.016 to 0.021, which is consistent with expectations.

Columns 7 presents the results with all three measures in the same model. In this model the estimated coefficients on schooling expenditures and average test scores are both statistically significant at the one percent level. Column 8 shows the model with only these two measures and the estimated coefficients on both continue to be statistically significant. The estimated coefficients for these two measures are very similar, which indicates that students' test scores in elementary school and overall national expenditures on schooling are equally important contributors to economic growth. The financial measure may be capturing the cross-country differences in university schooling, since this takes place after students are tested.

Table 1
OLS Effect of Human Capital Measures on Growth Rates 1985-2005
[Dependent variable is log(GDP/adult)]

	1	2	3	4	5	6	7	8
Observations	49	49	44	44	49	49	44	44
	Test Scores		**Expenditures**		**Student Attain**		**Mixed**	
$Ln(sk/ng\delta_k)$	0.20 (.08)	0.18 (.09)	0.48* (.09)	0.35 (.15)	0.34* (.10)	0.21 (.09)	0.30* (.09)	0.30* (.09)
$Ln(sh/(ng\delta_h)$			0.33* (.08)	0.27 (.11)			0.19 (.09)	0.17 (.08)
$Ln(attain/ng\delta_h)$					0.46* (.16)	0.38* (.14)	-0.08 (.18)	
$Ln(exptest/ng\delta_h)$	0.23* (.03)	0.22* (.05)					0.20* (.05)	0.18* (.04)
Ln(Y/L-1985)	-0.28* (.04)	-0.25* (.09)	-0.36* (.06)	-0.27 (.13)	-0.33* (.07)	-0.23 (.10)	-0.35* (.07)	-0.37* (.06)
Latin America Dummy		-0.00 (.08)		-0.08 (.08)		-0.12 (.07)		
Asia dummy		0.05 (.15)		0.13 (.16)		0.17 (.15)		
R^2	.62	.62	.50	.54	.44	.54	.64	.64
Implied α	.28	.28	.41	.29	.30	.41	.31	.29
Implied β	.32	.34	.29	.32	.41	.32	.32	.34
Implied λ	.016	.014	.021	.016	.020	.013	.022	.023

*Statistically significant at the 1 percent level.
Note: Robust standard errors in parentheses

The inclusion of the regional dummy variables affects the estimated coefficients on the capital variables, but these coefficients continue to be acceptable. The Asian dummy has a positive effect on growth rates, while the Latin American dummy has a negative effect in models using measures other than test scores. These results are consistent with HW's observation that students' cognitive skills are lower than expected relative to schooling attainment in Latin America. The results also show that test scores are higher than expected relative to schooling in Asia, but these results are not statistically significant.

Students' average schooling attainment can explain growth rates across countries, but not as well as the other two measures. This result is not surprising, since the estimates of student attainment are clearly less accurate than the data for the other two measures. The important thing about these results is that all of the measures provide reasonable, similar estimates of the effect of human capital on economic growth, even measures that are known to be relatively inaccurate.

Since the human capital variables in the growth model are endogenous, the estimated coefficients in Table 1 could be biased. Table 2 presents 2SLS estimates of the same models using average schooling attainment in 1980 and the sum of the Catholic and Muslim shares of

Table 2
2SLS Effect of Human Capital Measures on Growth Rates 1985-2005
[Dependent variable is log(GDP/adult)]

	1	2	3	4	5	6	7	8	9	10
Instrument	Att80	Ctms	Att80 Ctms	Att80	Ctms	Att80 Ctms	Att80	Ctms	Att80 Ctms	Att80 Ctms Iprot
Observations	49	49	49	44	44	44	49	49	49	44
	Test Scores			Expenditures			Student Attainment			Mixed
$Ln(sk/ng\delta_k)$	0.18 (.13)	0.18 (.14)	0.17 (.10)	0.48* (.09)	0.48* (.09)	0.36 (.16)	0.33* (.08)	0.26 (.12)	0.21 (.09)	0.29 (.22)
$Ln(sh/ng\delta_h)$				0.46 (.19)	0.41 (.23)	0.32 (.25)				0.09 (.41)
$Ln(attain/ng\delta_h)$							0.51 (.21)	0.87 (.44)	0.40 (.25)	
$Ln(exptest/ng\delta_h)$	0.25 (.12)	0.25 (.10)	0.25 (.17)							0.19 (.20)
Ln(Y/L-1985)	-0.29* (.09)	-0.29* (.06)	-0.27 (.17)	-0.43* (.11)	-0.40* (.12)	-0.30 (.18)	-0.35* (.10)	-0.48* (.17)	-0.24 (.13)	-0.33 (.14)
Latin America Dummy			0.02 (.16)			-0.07 (.11)			-0.12 (.08)	
Asia dummy			0.04 (.18)			0.12 (.17)			0.18 (.15)	
R^2	.62	.62	.62	.47	.49	.53	.44	.35	.54	.63
Implied α	.25	.25	.25	.35	.37	.37	.28	.16	.25	.32
Implied β	.35	.35	.36	.34	.32	.33	.46	.54	.47	.31
Implied λ	.017	.017	.016	.026	.026	.018	.022	.033	.014	.020

*Statistically significant at the 1 percent level.
Note: Robust standard errors in parentheses

the population as instruments. I estimate each model with each instrument alone and then with both instruments and the dummy variables for Asia and Latin America.

As shown in columns 1 to 9, the estimates of the effects of the measures with each instrument are very consistent and similar to the OLS estimates. The consistency of the 2SLS estimates with different instruments provides reassurance that the instruments are valid, even though from a conceptual standpoint it is possible that either one could affect growth directly.

The model with average test scores explains the most variation in growth rates, but the model with schooling expenditures provides the most accurate estimates of α. The model with *student* attainment provides the worst results. The estimated coefficients are similar for all the measures when the regional dummies are included in the models, but they all lose statistical significance. These results again confirm the importance of accurate data to obtain robust estimates of the effect of human capital on growth.

Column 10 presents the 2SLS results using three instruments, with both average test scores and schooling expenditures in the model. The estimated coefficients are all positive, but none of them are statistically significant.

Table 3 presents the results for the first stage regressions for the 2SLS estimates in Table 2. The results show that the estimated coefficients on the individual instruments are statistically significant in the absence of the regional dummies. When the dummies are included these coefficients lose their significance, most likely because the religious affiliation measures are correlated with the regional dummies.

Overall the results for the dynamic growth model provide strong support for the validity of the augmented Solow model and the validity of average test scores at ages 9 to 15 as a measure of a nation's human capital. This measure consistently explains more of the variation in growth than the other measures.

But the positive empirical results for all the measures also indicate that average test scores are a proxy for human capital, so the estimated coefficient on average test scores when it is the only measure in a model cannot be interpreted to be the effect of cognitive skills in elementary school alone. The actual effect of changes in test scores on growth appears to be about half of the estimated coefficient on test scores in these models, with expenditures on schooling accounting for the rest of the effect.

Table 3 First Stage of 2SLS Effect of Human Capital Measures on Growth Rates [Dependent variable is log(measure/(n+g+δh))]									
	1	2	3	4	5	6	7	8	9
Observations	49	49	49	44	44	44	49	49	49
	Test Scores			**Expenditures**			**Student Attainment**		
Ln(sk/ngδ$_k$)	0.92* (.26)	0.85* (.31)	0.44 (.34)	0.01 (.13)	-0.11 (.12)	-0.11 (.19)	0.17* (.06)	0.17 (.08)	0.20 (.08)
Ln(Y/L-1985)	0.03 (.21)	0.51* (.17)	0.37 (.30)	0.24 (.12)	0.50* (.06)	0.30 (.18)	0.18* (.05)	0.37* (.05)	0.12 (.08)
Attain 1980	0.14* (.26)		0.09 (.04)	0.07* (.02)		0.05 (.04)	0.06* (.01)		0.06* (.01)
Catholic Muslim Share in 1980		-0.65* (.24)	0.09 (.22)		-0.33* (.12)	-0.11 (.20)		-0.15 (.06)	-0.02 (.07)
Asia dummy			0.45 (.23)			-0.02 (.18)			-0.12 (.10)
Latin America Dummy			-0.76* (.21)			-0.18 (.11)			-0.10 (.07)
R^2	.67	.69	.81	.68	.67	0.72	.84	.79	.85

*Statistically significant at the 1 percent level.
Note: Robust standard errors in parentheses

Table 4 presents the OLS estimates for the static models in equations (11), (12), and (13) in 2005. Again all of the measures provide reasonable estimated coefficients. In these models each measure explains about the same variation in national income. Adults' average schooling attainment performs well, slightly better than the other two measures. When all of the measures are included in the model, the coefficients on average test scores and on average schooling attainment are both statistically significant. When the regional dummies are included, the estimated coefficients on all three measures are statistically significant.

Table 5 presents the 2SLS estimates of the static models in 2005. All of these models are estimated using both religious affiliation instruments. I do not use adults' average attainment in 1980 as an instrument because arguably it could affect national income in 2005 directly since it is very highly correlated with adults' average schooling attainment in 2005 ($\rho = 0.96$).

In these results the average test score measure does not perform as well as the other measures. It continues to have an estimated coefficient that is statistically significant when it is included alone, but when regional dummies are added or when it is included with the other measures, it is not statistically significant. In contrast, the average attainment and cumulative investment measures have estimated coefficients that are always statistically significant.

Table 4
OLS Effect of Test Scores and School Inputs on National Income in 2005
[Dependent variable is log(GDP/adult)]

	1	2	3	4	5	6	7	8
Observations	49	49	44	44	49	49	44	44
	Test Scores		**Expenditures**		**Adult Attainment**		**Mixed**	
Log(K/Y)	0.78* (.22)	0.72* (.19)	1.21* (.16)	1.18* (.17)	0.71* (.17)	0.73* (.16)	0.66* (.18)	0.64* (.17)
School Attainment					0.18* (.02)	0.16* (.02)	0.11* (.03)	0.06* (.02)
Test Score /100	0.55* (.07)	0.64* (.11)					0.25* (.08)	0.44* (.09)
HPY			0.82* (.16)	0.70* (.17)			0.12 (.11)	0.27* (.10)
Latin America Dummy		0.07 (.18)		-0.28 (.14)		-0.28 (.12)		0.22 (.11)
Asia		-0.60* (.14)		-0.21 (.23)		-0.39* (.13)		-0.53* (.15)
R^2	.78	.84	.77	.79	.82	.86	.88	.92
Implied α	.44	.31	.40	.41	.42	.42	.28	.25
Implied β	.31	.27	.27	.24	.31	.29	.30	.35

*Statistically significant at the 1 percent level.
Note: Robust standard errors in parentheses

These results support the argument that all of these measures are proxies for a nation's human capital and that whichever measure has the least measurement error provides the best statistical results. As discussed earlier, average test scores is a more accurate measure of human capital flows during the period 1985-2005 than of the stock of human capital in 2005. And consistent with this, in the 2SLS estimates it provides the best measure of human capital during 1985-2005 and the worst measure in 2005.

Similarly, *students'* average attainment is the least accurate measure of human capital flows, while adults' average attainment is the most accurate measure of human capital stocks. And consistent with this, adults' average schooling attainment is the best measure of human capital in 2005 and students' average attainment is the worst measure during 1985-2005.

Table 5 2SLS Effect of Human Capital on National Income in 2005 [Dependent variable is log(GDP/adult)]								
	1	2	3	4	5	6	7	8
Instruments	Ctm80 Lprot	Ctm80 Lprot	Ctm80 Lprot	Ctm80 Lprot	Ctm80 Lprot	Ctm80 Lprot	Ctm80 Lprot	Ctm80 Lprot
Observations	49	49	44	44	49	49	49	44
	Test Scores		**Expenditures**		**Adult Attainment**		**Mixed**	
Ln(K/Y)	0.80 (.40)	0.12 (.69)	1.24* (.19)	1.13* (.19)	0.88* (.20)	0.86* (.19)	0.82* (.27)	1.02* (.25)
Avg School Attainment					0.15* (.04)	0.15* (.04)	0.13* (.05)	
Test Score /100	0.55 (.24)	1.32 (.55)					0.09 (.27)	0.16 (.25)
Ln(H/Y)			0.95* (.32)	1.05* (.35)				0.80 (.39)
Latin America Dummy		0.74 (.49)		-0.16 (.17)		-0.26 (.14)		
Asia Dummy		-0.61* (.18)		0.12 (.30)		-0.26 (.07)		
R^2	.78	.66	.72	.72	.80	.82	.83	.82
Implied α	.44	.11	.39	.36	.47	.46	.45	.34
Implied β	.31	1.17	.30	.33	.25	.25	.27	.32
*Statistically significant at the 1 percent level. Note: Robust standard errors in parentheses								

Table 6 shows the first stage regressions for the 2SLS regressions in the static models. These results show that the instrument for Catholic and Muslim affiliation loses significance when the regional dummies are included in the model. When the regional dummies are not included, one or the other instrument is highly correlated with all of the human capital measures.

V. Importance of Schooling Expenditures

The estimated effect of average test scores on economic growth is much lower when average schooling expenditures are included in the growth model. It is not clear whether this occurs because schooling expenditures affect test scores or because schooling expenditures are a better proxy than test scores for human capital created after students are tested at ages 9 to 15.

HW [2008] state that their assessment of the evidence is that increases in financial resources for schools are unlikely to raise test scores in the absence of institutional change. But their assessment does not appear to be correct under all circumstances. Particularly at the primary level, there is considerable evidence that class size matters, and class size is inversely related to expenditures for schools.

Table 6
First Stage of 2SLS Effect of Human Capital on National Income in 2005
[Dependent variable is log(GDP/adult)]

	1	2	3	4	5	6
Instruments	Ctm80 LProt	Ctm80 LProt	Ctm80 LProt	Ctm80 LProt	Ctm80 LProt	Ctm80 LProt
Observations	49	49	44	44	49	49
	Test Scores		**Resources**		**Adult Attainment**	
Ln(K/Y)	1.07* (.22)	0.91* (.18)	0.27 (.11)	0.25 (.12)	3.37* (.65)	3.16* (.69)
Catholic Muslim Share in 1980	0.82* (.28)	-0.06 (.26)	0.06 (.14)	-0.06 (.23)	-1.34 (.82)	-0.97 (.75)
Ln(Protestant Share) in 1980	-0.02 (.04)	0.06 (.03)	0.08* (.03)	0.07 (.04)	0.44* (.11)	0.47* (.10)
Latin America Dummy		-0.92* (.23)		-0.19 (.11)		-1.35 (.60)
Asia Dummy		0.17 (.18)		-0.41* (.17)		-1.10 (.61)
R^2	.50	.68	.37	.51	.61	.66

*Statistically significant at the 1 percent level
Note: Robust standard errors in parentheses

Hanushek and Luque [2003] show that class size is negatively related to student achievement in mathematics in 14 of 17 countries in TIMSS 1995 at age 9. Breton [2013c] shows that in primary school classes of mathematics in Colombia, each incremental student reduces scores on TIMSS 2007 by 2.4 points (relative to an OECD average of 500). Fredriksson, Oeckert, and Oosterbeek [2013] present evidence that reductions in class size from 30 to 15 in Sweden in the last three years of primary school have continuing positive effects on student achievement as they progress through school and on their levels of income and employment at ages 27 to 42.

Figure 6 shows the relationship between average test scores and the pupil-teacher ratio (PTR) in primary school in 1998. The PTR data are from the UNESCO [2013] web site. These data are highly correlated, but this does not mean that the relationship between the pupil-teacher ratio and average test scores is causal. Breton's [2013c] estimates of the effect of changes in class size on Colombian students' scores on TIMSS tests of mathematics skills in 4th grade are also shown.

Figure 6

Average Test Scores vs. Pupil-Teacher Ratio

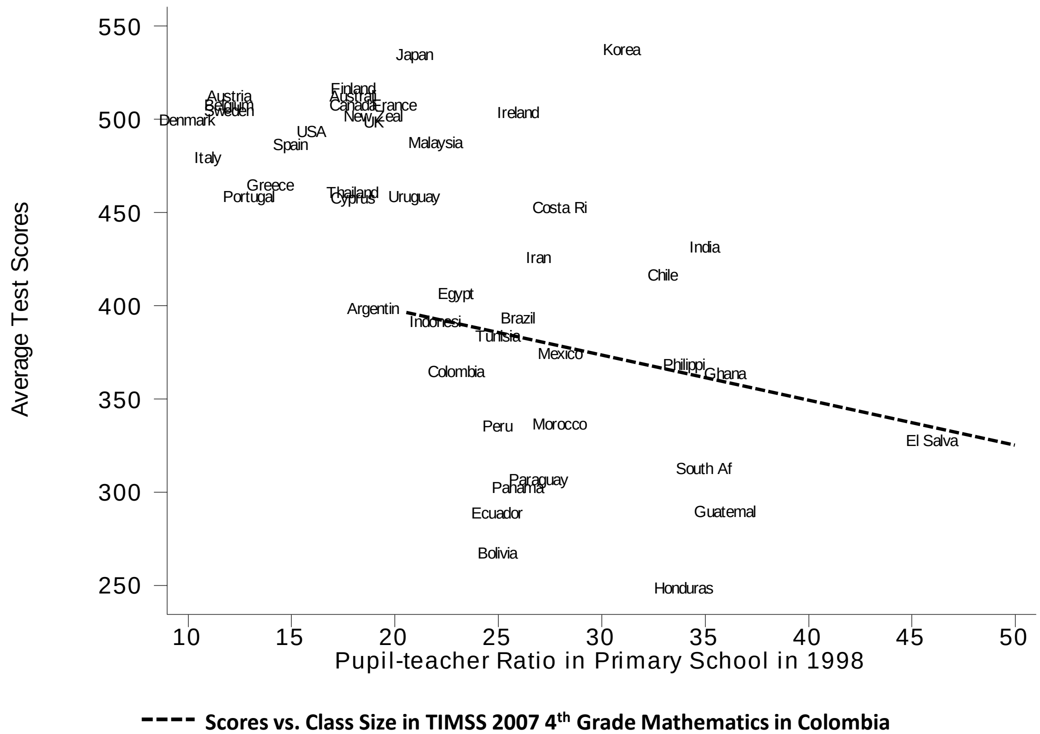


Table 7 presents OLS estimates of the effect of pupil-teacher ratios, average schooling attainment in 1980, and regional dummies in Asia and Latin America on average test scores. These estimates may not be causal since there are no formal controls for endogeneity, but the relationship between the pupil-teacher ratio and average test scores across countries is about the same as the relationship in Breton's results for Colombia, which are likely to be causal.

Overall the empirical results in this study are consistent with the evidence elsewhere that increases in parents' average schooling attainment and in expenditures on primary schooling raise students' cognitive skills and these increases in students' cognitive skills raise economic growth. The implication is that increases in schooling attainment and increases in schooling expenditures are intimately linked to increases in students' test scores. As a consequence, it is not surprising that the empirical results in this paper show that increases in average schooling attainment, increases in school expenditures, and increases in students' test scores all cause economic growth.

Table 7
Effect of Class Size in Primary School on Average Test Scores
[Dependent variable is Average Test Scores]

	1	2	3	4	5	6
Technique	OLS	OLS	OLS	OLS	OLS	OLS
Observations	45	45	45	45	36	36
Sample	All	All	All	All	Att 1980<10	Att 1980<10
Pupil-teacher ratio	-6.50* (.98)	-3.66* (1.07)	-3.75* (.86)	-2.34 (1.03)	-3.80* (.93)	-2.31 (1.12)
Adult 1980 Attainment		12.8* (2.8)	13.5* (2.4)	12.3* (1.9)	14.2* (4.2)	15.0* (3.0)
Asia Dummy			75.5* (18.4)	48.0* (16.2)	80.5* (21.4)	48.5 (18.5)
Latin America Dummy				-62.7* (20.4)		-65.5* (21.4)
R^2	.41	.55	.65	.74	.53	.66

*Statistically significant at the 1 percent level
Note: Robust standard errors in parentheses

VI. Conclusions

In this paper I estimate the effect of three measures of the flow of human capital on the rate of economic growth during the 1985-2005 period. These measures are students' average test scores, students' average schooling attainment, and average schooling expenditures. I estimate growth models with each measure separately and with combinations of these measures.

I also estimate the effect of three related measures of the stock of human capital in a static model of national income in 2005. These measures are the adult population's (earlier) average test scores, adults' average schooling attainment, and the cumulative investment in the schooling of adults of working age.

Since the relative measurement error differs in the human capital flow and stock data, the results from the two sets of models provide information on whether the statistical differences in the estimated coefficients for the different measures are due to conceptual differences in the measures or to differences in measurement error.

Overall my empirical results differ substantially from HW's results. I confirm their findings that increases in students' cognitive skills, as measured on standardized tests, cause economic growth, but I also find that the other two measures of human capital also cause growth. The estimated effects are similar with all three measures.

The results for the two sets of models indicate that whichever measure of human capital has the least measurement error provides the best results. The average test score measure provides the best results for the dynamic growth model and the worst results for the static model.

I also show that adults' average years of schooling attainment is a valid and surprisingly accurate measure of the financial stock of human capital across countries. It provides the best results for the static model in 2005. These results contradict HW's claim that adults' average schooling attainment is not a good measure of human capital across countries.

Since the different measures of human capital quantify different aspects of a nation's human capital, the effects of the measures are not mutually exclusive. I show that when two or more measures are included in the same model, generally at least two are statistically significant. These results indicate that the various components of human capital created through schooling all contribute to economic growth. These results provide very strong support for the validity of the augmented Solow growth model and for the causal relationship between increases in human capital and economic growth.

The empirical results in this study also suggest that it may not be possible to raise students' cognitive skills without raising average schooling attainment and schooling expenditures. More schooling, more expenditures, and higher test scores appear to go together. These measures of human capital are highly correlated, and clearly it has been principally through many generations of schooling, with slowly rising total investment/pupil and increasing average schooling attainment, that nations have slowly raised their average level of cognitive skills.

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Appendix I

Students' Average Schooling Attainment 1980-2000

The average schooling attainment of the students entering the work force during 1985-2005 is estimated by estimating average enrollment rates in primary, secondary, and tertiary schooling during the 1980-2000 period and multiplying these rates times a standard assumed number of years of schooling at each level of schooling. The enrollment rates are based on gross enrollment rates in World Bank [2013], but they are limited to a maximum of 100%. These estimates of students' average attainment in each country are not very accurate, but they are indicative of relative levels across countries.

	Primary			Secondary			Tertiary			Average
	Years	Enroll	Total	Years	Enroll	Total	Years	Enroll	Total	Attain
Argentina	6	1.00	6.0	6	0.70	4.2	4	0.35	1.40	11.6
Australia	6	1.00	6.0	6	1.00	6.0	4	0.45	1.80	13.8
Austria	6	1.00	6.0	6	1.00	6.0	4	0.35	1.40	13.4
Belgium	6	1.00	6.0	6	1.00	6.0	4	0.40	1.60	13.6
Bolivia	6	1.00	6.0	6	0.50	3.0	4	0.20	0.80	9.8
Brazil	6	1.20	7.2	6	0.60	3.6	4	0.10	0.40	11.2
Canada	6	1.00	6.0	6	1.00	6.0	4	0.70	2.80	14.8
Chile	6	1.00	6.0	6	0.75	4.5	4	0.25	1.00	11.5
Colombia	6	1.00	6.0	6	0.55	3.3	4	0.15	0.60	9.9
Costa Rica	6	1.00	6.0	6	0.50	3.0	4	0.25	1.00	10.0
Cyprus	6	0.95	5.7	6	0.85	5.1	4	0.15	0.60	11.4
Denmark	6	1.00	6.0	6	1.05	6.3	4	0.40	1.60	13.9
Ecuador	6	1.00	6.0	6	0.55	3.3	4	0.25	1.00	10.3
Egypt	6	0.80	4.8	6	0.65	3.9	4	0.20	0.80	9.5
El Salvador	6	0.90	5.4	6	0.40	2.4	4	0.15	0.60	8.4
Finland	6	1.00	6.0	6	1.10	6.6	4	0.45	1.80	14.4
France	6	1.00	6.0	6	0.95	5.7	4	0.35	1.40	13.1
Ghana	6	0.75	4.5	6	0.35	2.1	4	0.02	0.08	6.7
Greece	6	0.95	5.7	6	0.85	5.1	4	0.30	1.20	12.0
Guatemala	6	0.80	4.8	6	0.25	1.5	4	0.08	0.32	6.6
Honduras	6	1.00	6.0	6	0.30	1.8	4	0.10	0.40	8.2
India	6	0.90	5.4	6	0.35	2.1	4	0.10	0.40	7.9
Indonesia	6	1.00	6.0	6	0.40	2.4	4	0.10	0.40	8.8
Iran	6	1.00	6.0	6	0.55	3.3	4	0.30	1.20	10.5
Ireland	6	1.00	6.0	6	0.95	5.7	4	0.30	1.20	12.9

Italy	6	1.00	6.0	6	0.80	4.8	4	0.35	1.40	12.2
Japan	6	1.00	6.0	6	0.95	5.7	4	0.35	1.40	13.1
Korea	6	1.00	6.0	6	0.90	5.4	4	0.40	1.60	13.0
Malaysia	6	0.95	5.7	6	0.55	3.3	4	0.10	0.40	9.4
Mexico	6	1.00	6.0	6	0.55	3.3	4	0.15	0.60	9.9
Morocco	6	0.75	4.5	6	0.35	2.1	4	0.10	0.40	7.0
Netherlands	6	1.00	6.0	6	1.10	6.6	4	0.40	1.60	14.2
N. Zealand	6	1.00	6.0	6	0.95	5.7	4	0.45	1.80	13.5
Norway	6	1.00	6.0	6	1.00	6.0	4	0.45	1.80	13.8
Panama	6	1.00	6.0	6	0.60	3.6	4	0.25	1.00	10.6
Paraguay	6	1.00	6.0	6	0.35	2.1	4	0.10	0.40	8.5
Peru	6	1.05	6.3	6	0.65	3.9	4	0.25	1.00	11.2
Philippines	6	1.00	6.0	6	0.70	4.2	4	0.25	1.00	11.2
Portugal	6	1.10	6.6	6	0.75	4.5	4	0.25	1.00	12.1
South Africa	6	0.95	5.7	6	0.60	3.6	4	0.10	0.40	9.7
Spain	6	1.00	6.0	6	0.95	5.7	4	0.35	1.40	13.1
Sweden	6	1.00	6.0	6	1.05	6.3	4	0.40	1.60	13.9
Switzerland	6	1.00	6.0	6	0.95	5.7	4	0.25	1.00	12.7
Thailand	6	0.95	5.7	6	0.35	2.1	4	0.20	0.80	8.6
Tunisia	6	1.00	6.0	6	0.45	2.7	4	0.10	0.40	9.1
Turkey	6	1.00	6.0	6	0.50	3.0	4	0.15	0.60	9.6
UK	6	1.00	6.0	6	0.90	5.4	4	0.30	1.20	12.6
Uruguay	6	1.00	6.0	6	0.80	4.8	4	0.25	1.00	11.8
USA	6	1.00	6.0	6	0.95	5.7	4	0.65	2.60	14.3