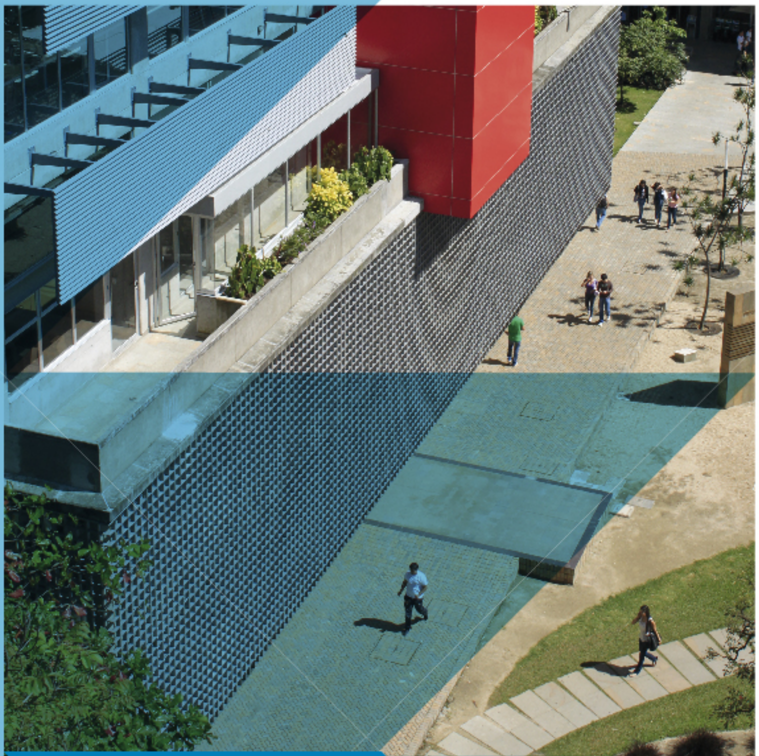

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Documentos de trabajo

Economía y Finanzas

Centro de Investigación Económicas y Financieras

No. 13-34
2013

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Breton, Theodore R.

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Centro de Investigaciones Económicas y Financieras
Universidad EAFIT

Higher Test Scores or More Schooling? Another Look at the Causes of Economic Growth

Theodore R. Breton[a]

November 5, 2013

Abstract

I use a dynamic augmented Solow model to estimate the effects of students' test scores and investment in schooling on economic growth rates in 49 countries during 1985-2005. In the complete data set, either average test scores or investment in schooling explain economic growth rates, and more of either causes growth. Further analysis reveals that higher test scores only raised growth rates in countries with low average levels of schooling. In countries with more than 7.5 years of schooling attainment in 1985, more investment in schooling raised growth rates, but higher average test scores did not.

Key Words: Education Expenditures; Human Capital; Test Scores; Economic Growth

JEL Codes: O41; I25

[a]Universidad EAFIT, Carrera 49#7 Sur-50, avenida Las Vegas, Medellin, Colombia

ted.breton@gmail.com and tbreton@eafit.edu.co

574-250-5322 (home) 574-261-9334 (office) 574-261-9294 (fax)

I. Introduction

In a series of articles, Hanushek and Kimko [2000] and Hanushek and Woessmann [2008, 2011a, 2011b, 2012a, and 2012b] use an innovative measure of human capital, students' average scores on international tests, to estimate the effect of human capital on rates of economic growth. In all of their articles, Hanushek and Woessmann (hereafter HW) use a similar model to compare the effect of students' average test scores and adults average schooling attainment and obtain similar results. In HW [2008 and 2012b] they show that during 1960-2000 average test scores explain three times the variation in growth explained by average schooling attainment (73% vs. 25%). Further, when test scores and schooling attainment are included in the same model, test scores explain all of the variation in growth. HW conclude from these results that higher cognitive skills at ages 9 to 15 cause growth and that more schooling often does not.

Breton [2011] argues that the comparison of the effect of test scores and schooling in HW [2008] is invalid because the methodology used in the growth model is flawed. Since the methodology in HW [2012a and 2012b] is the same, his criticism is applicable to these analyses as well.

The most evident flaw in the analysis is that HW compare students' test scores from 1964-2003, and primarily from 1990-2003, to adults' average schooling in 1960. These two measures are not comparable. Due to the lag between the testing of the students and their entry into the work force, average test scores from 1990-2003 are a proxy for a nation's human capital in about 2020, or 60 years after adults' schooling attainment in 1960.[1]

[1] HW [2008] argue that students' average test scores during 1990-2003 are a proxy for the cognitive skills of the work force during 1960-2000, under the assumption that the students' skills have not changed during the last 60 years. Breton [2011] points out that a large share of workers in 1960 never attended school, so they could not have had the same level of cognitive skills as students in the 1990s.

The less evident flaw is that HW's growth model is mis-specified. HK [2000] claim the model is an endogenous growth model, but it includes initial income, which is included in dynamic neoclassical growth models to control for conditional convergence. The empirical results in HK [2000] and in HW [2008, 2011a, 2011b, 2012a, and 2012b] support the lagged income variable and reject the initial level of schooling, implicitly rejecting the endogenous model and accepting the neoclassical model.[2]

In the dynamic neoclassical growth model, the capital variables are the flow of capital into the economy during the growth period, not the initial capital stock [Breton, 2011]. The implication is that in the HK/HW model, students' average test scores during 1964-2003 (or during 1990-2003) represent the *flow* of human capital into the economy during 1960-2000. The comparable schooling measure is average investment in schooling during 1960-2000, not the average schooling attainment of adults in 1960. As a consequence, HK/HW's growth model is seriously mis-specified, and their estimates of the effects of test scores and schooling attainment on growth are severely biased.

In this paper I reexamine whether higher tests scores or more schooling cause growth, using a properly-specified growth model, comparable measures for test scores and schooling, and data for these measures that are appropriate for the period of estimation. I begin my analysis by examining the quantitative relationships between three measures of a nation's human capital: adults' average schooling attainment, the financial stock of human capital/adult, and students' average test scores. I show that while these measures are correlated, they have very different patterns across countries, which suggests that they quantify different aspects of a nation's human capital.

[2] HW [2012a] include the initial level of physical capital in their growth model, as prescribed by endogenous growth theory. Their empirical results reject the validity of this variable and implicitly, which implicitly rejects the validity of the endogenous growth model.

Subsequently, I estimate the effects of higher test scores and more schooling on growth rates, using a methodology that corrects the specification errors in HK's [2000] and HW's [2008, 2011a, 2011b, 2012a, and 2012b] growth model. I use Mankiw, Romer, and Weil's [1992] (hereafter MRW) dynamic version of the augmented Solow model for this estimation. This version of the MRW model has a structure that is compatible with HK's and HW's empirical results, and the validity of the model is supported by considerable recent empirical evidence [Cohen and Soto, 2007, Ding and Knight, 2009, Breton, 2010, 2013a, and 2013b, and Gennaioli, La Porta, Lopez-de-Silanes, and Shleifer, 2013]. In particular, Breton [2013b] demonstrates that Klenow and Rodriguez-Clare's [1997] and Hall and Jones' [1999] critiques of the MRW model are incorrect and that the estimated effect of schooling on national income in the MRW model is consistent with the estimated effect of schooling on workers' salaries in 36 countries.

Since the MRW model is a well-defined, structural model, the nature, the form, and the vintage of the data required for its estimation are clear. I use the average rate of investment in schooling and students' average test scores as two measures of the flow of human capital. Since most of HW's test scores for less-educated countries were obtained after 1990, I estimate the growth model over the 1985-2005 period.

I confirm HW's findings that average test scores explain cross-country growth rates in the complete sample of countries, but I find that investment in schooling explains growth rates equally well. Using an instrument for investment in schooling and test scores, I find that more schooling and higher test scores both cause growth during 1985-2005. Both measures of human capital yield similar estimated parameters for the augmented Solow model, and these estimates are consistent with theoretical expectations and with estimates in other cross-country studies.

These results reject HK's [2000] and HW's [2008, 2011a, 2011b, 2012a, and 2012b] findings that more schooling does not cause growth.

Perhaps more importantly, when I analyze the effect of higher test scores and more investment in schooling in countries with different levels of schooling, I find that investment in schooling explains growth rates at all levels of schooling, but average test scores do not. In countries with more than 7.5 years of schooling in 1985, average test scores do not explain any of the variation in growth during 1985-2005. These results are consistent with the data patterns for these measures across countries, which show that the financial stock of human capital and average schooling attainment both rise as countries become wealthier, but average test scores do not. This evidence challenges HW's [2011b] argument that raising students' test scores at ages 9 to 15 is an attractive growth strategy for OECD countries. .

The paper is organized as follows: Section II examines the quantitative relationship between the various measures of human capital. Section III presents the growth model and provides the data sources. Section IV presents the results. Section V concludes.

II. Measures of Human Capital

Human capital is analogous to physical capital, but it is more difficult to measure because it is often created in informal settings, such as in the home or on the job. Additionally, while the cost of formal schooling or tutoring can be measured, historically schools and tutors have taught many subjects (e.g., catechism, Latin, civics, or embroidery) that were considered irrelevant for the production of goods and services.

Economists have come to use adult's average years of schooling attainment as a measure of a country's human capital because it is the only quantitative indicator of human capability available for most countries for long historic periods. The measure has acquired a certain legitimacy because the effect of an additional year of schooling on workers' income (the Mincerian return) is relatively consistent across countries. Typically an additional year of schooling raises income by about 10 percent [Psacharopoulos and Patrinos, 2004].

HK and HW accept the legitimacy of academic learning as a measure of human capital, but they claim that average schooling attainment is a less accurate measure than students' test scores because a year of schooling is not a uniform quantity of learning. For example, in HW [2012b] they assert,

> "…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 educational system. For example, a year of schooling in Peru is assumed to create the same increase in productive capacity as a year of schooling in Japan."[3]

They make this claim as part of their explanation of why years of schooling have relatively little effect on growth in their analyses, but like their results, their claim is incorrect.

Virtually all growth analyses utilize the standard, Mincerian log-linear relationship between national income and average schooling attainment, in which each additional year of schooling implicitly raises human capital by an *exponential* amount. As a result, a year of schooling provides much more education in countries with higher average schooling attainment, like Japan, than in countries with lower average schooling attainment, like Peru.

The only implicit assumption in these analyses is that a year of schooling has the same quality in countries that have the same average schooling attainment, e.g., in Australia and Canada. Arguably, this assumption is not unreasonable since a nation's average attainment and its average quality of schooling generally rise together. So while average schooling attainment

[3] HW, 2012b, P. 269.

does not account explicitly for cross-country differences in schooling quality, differences in quality that vary with a country's average level of schooling attainment are taken into account in the estimate of the effect of attainment on national income.

One method to determine how much schooling quality might vary in countries with the same schooling attainment is to examine the relationship across countries between average schooling attainment and cumulative investment in schooling per adult. Implicitly, countries that invest more in each year of schooling are likely to provide higher quality schooling, so the cumulative investment measure arguably captures differences in schooling quality to a greater degree than the average attainment measure.

Figure 1 shows the relationship between Breton's [2013c] estimates of the financial stock of human capital per adult of working age and Cohen and Soto's [2007] estimates of the average schooling attainment of the population age 15 to 64 in 56 countries in 2005.[4] Breton's measure of human capital is analogous to the standard financial measure of the stock of physical capital. It is created from the sum of the prior 40 years of investment in schooling and a depreciation rate of 2.5%/year.

The data in the figure provide clear evidence that the relationship between average schooling attainment and the financial stock of human capital is exponential. These data show that in 2005 countries with two years of schooling had invested about $2,000/adult. Countries with 13 years of schooling had invested about $130,000/adult, *or ten times as much per year of schooling*. The data also indicate that across countries there is a consistent tendency for investment per year of schooling to rise as average attainment rises. 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

[4] The estimates of average schooling attainment in 2005 are the average of schooling attainment in 2000 and 2010.

expenditures on schooling [Dang and Rogers, 2008]. The stock of human capital is underestimated in Japan for the same reason, although not by as much.

Figure 1

Human Capital/Adult vs. Average Schooling Attainment in 2005

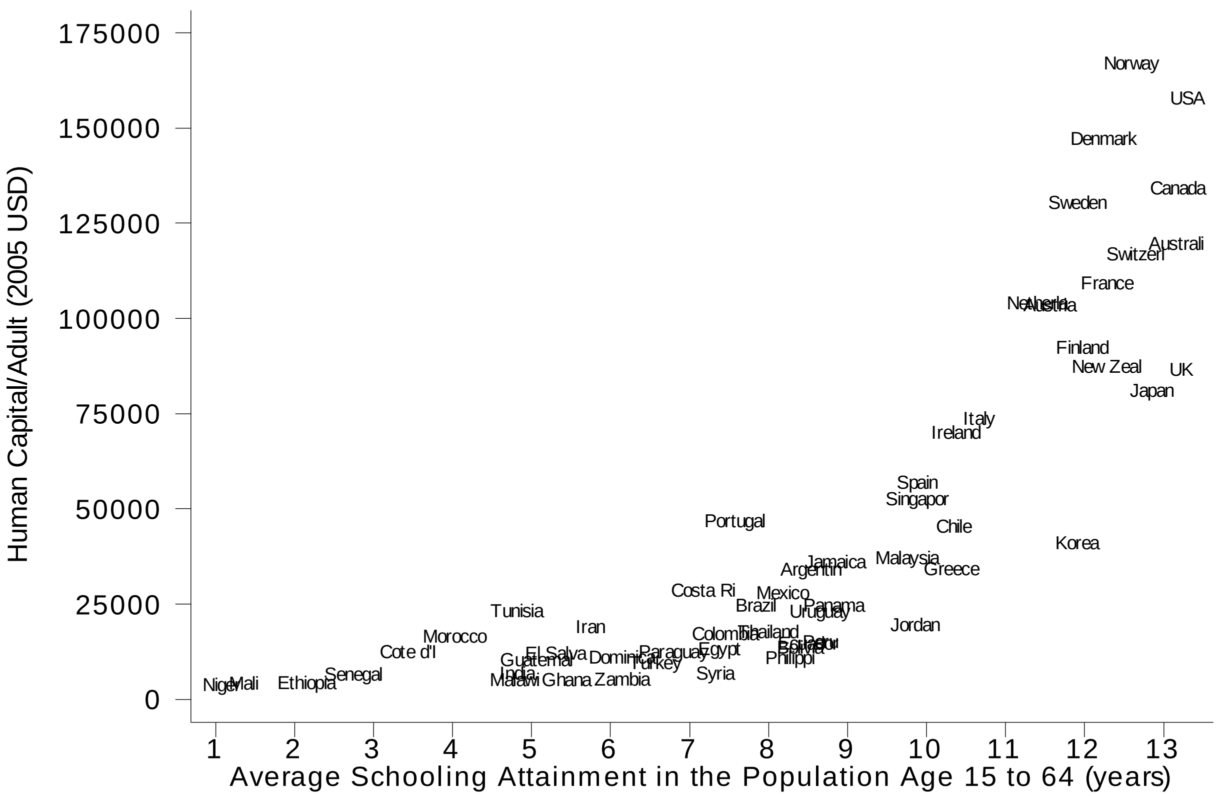
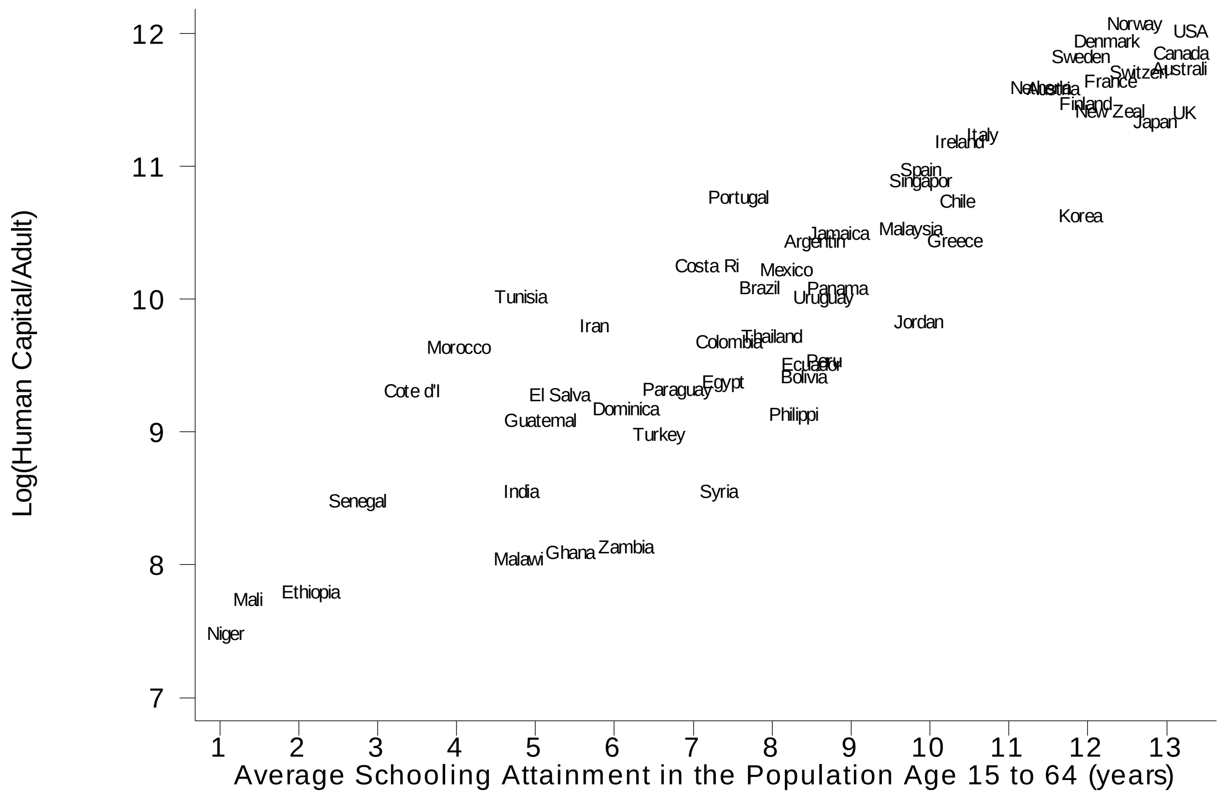


Figure 2 shows the relationship between log(human capital/adult) and average schooling attainment. This relationship is clearly linear, and the two data sets are highly correlated (ρ = 0.91). If a nation's cumulative investment in schooling accounts for the quality of its schooling, then the very high correlation between the log of human capital/adult and average schooling attainment indicates that average attainment also accounts for the higher average quality of schooling in more educated countries. But as shown in this figure, the differences in human capital/adult can be quite large in countries with the same average schooling attainment, and the range is particularly wide in countries in which average schooling attainment is between four and nine years. These data suggest that the quality of schooling is much higher in Argentina than in the Philippines and much higher in Costa Rica than in Syria.

Figure 2

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



Breton [2013b] estimates the augmented Solow model across countries in 1990 using both human capital/adult and average schooling attainment. Both measures explain the variation in national income quite well, but the financial measure explains more of the variation, suggesting that it accounts for more of the differences in schooling quality across countries than the average schooling attainment measure.

HW assert that average test scores in science and mathematics at ages 9 to 15 provide a better measure of a nation's human capital than average schooling attainment. Breton's [2011] empirical results challenge their assertion, since in his analysis average schooling attainment explains cross-country differences in national income somewhat better than average test scores. If the financial stock of human capital/adult is a more accurate measure of human capital than average schooling attainment, then it is also likely to be a more accurate measure of human capital than average test scores.

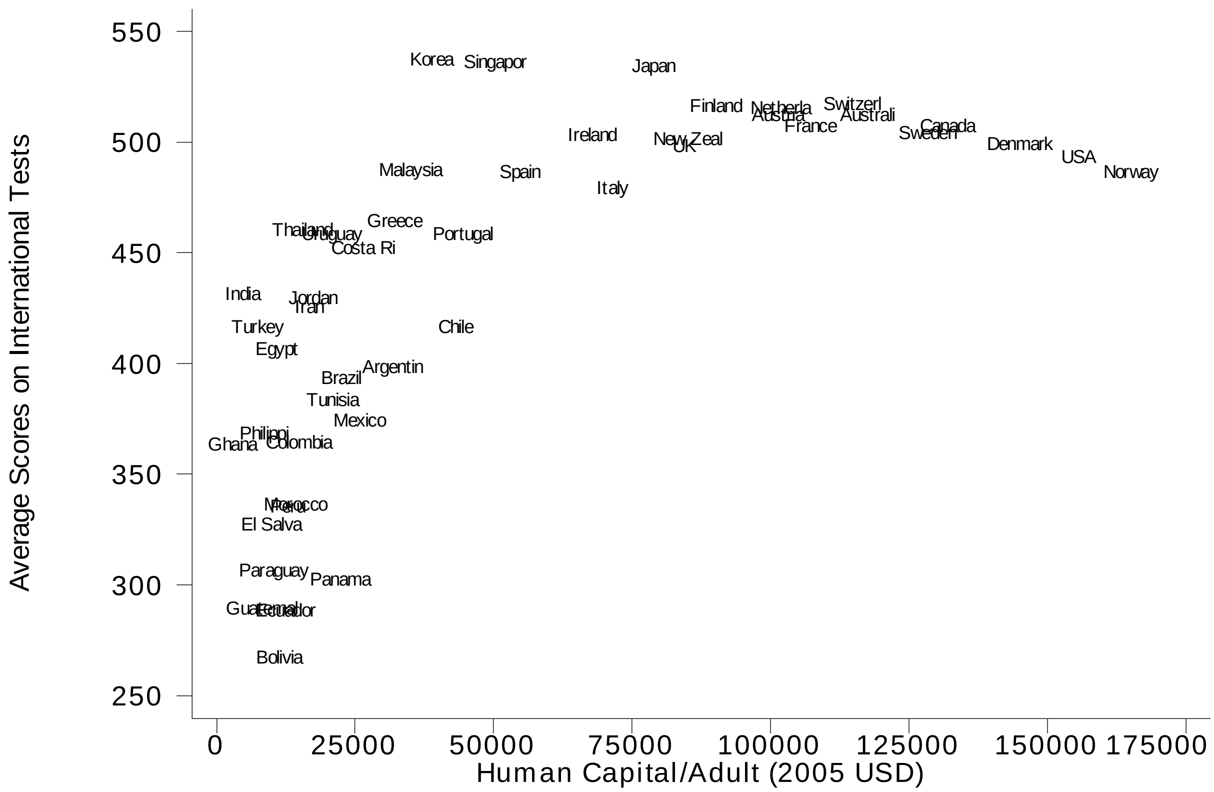
Figure 3 shows the relationship between HW's measure of average test scores and the financial stock of human capital/adult in 2005 in 46 countries. These two measures are correlated ($\rho = 0.70$), but the mathematical relationship between them is not linear or log-linear. The data show that average test scores at ages 9 to 15 rise as countries raise their investment in human capital/adult, but only up to about $100,000/adult (2005 USD). Beyond that level of investment, average scores tend to decline, although not by a substantial amount.

Figure 4 shows the relationship between HW´s measure of average test scores and average schooling attainment in 2005. The pattern is similar in that average test scores rise with increases in schooling attainment up to a level of 10-11 years and then stabilize at a mean of about 500.

These patterns suggest that a nation's average test scores at ages 9 to 15 and its average schooling attainment or cumulative investment in schooling are measuring different aspects of its human capital. This difference is not unexpected since average test scores measure students' competence in basic skills, while average attainment and total investment measure the overall educational level of the adult population. These measures rise together in countries with limited post-secondary schooling, but they diverge in more educated countries. The data in Figures 3 and 4 demonstrate that the average test score measure cannot discern the differences in human capital in countries with widely differing levels of post-secondary schooling.

Figure 3

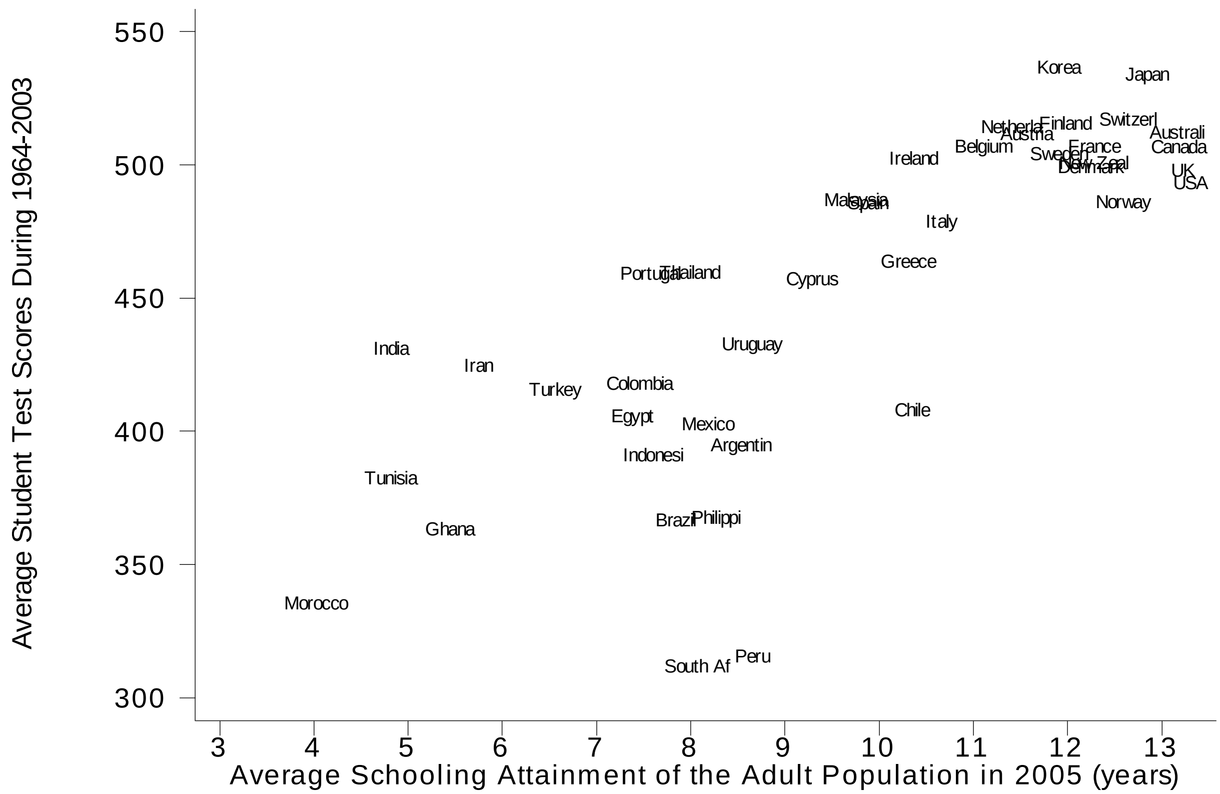
HW's Average Test Scores vs. Human Capital/Adult in 2005



The average test score measure also has limitations in countries where many students do not complete secondary schooling. In these countries average test scores are not representative of the skills of the entire school-age population. As an example, in HW's data India has relatively high average scores, but in the testing period its secondary school enrollment ratio was under 50% [World Bank, 2013]. As a consequence, India's average test scores overestimate the skills of the school-age population. Although there is no way to eliminate this measurement error, it can be minimized by using HW's average test scores to estimate growth in the latest possible time period when a larger share of the school-age population attended school.

Figure 4

Average International Test Scores vs. Average Schooling Attainment in 2005



These patterns in the data suggest that students cognitive skills at ages 9 to 15 are an important component of human capital, but that they are an incomplete measure in countries with human capital/adult above $100,000, or with more than 11 years of schooling attainment. As a consequence, they may not be a sufficiently accurate measure to determine the effect of human capital on economic growth rates in more educated countries. Since all measures of human capital have their limitations, which measure best represents cross-country human capital in is an empirical issue that can only be determined in a properly-specified income or growth model.

III. Model Specification and Data Sources

In this analysis I utilize MRW's augmented Solow model to compare the effect of higher average test scores and more investment in schooling on national output:

1) $(Y/L)_t = (K/L)_t^{\ \alpha} (H/L)_t^{\ \beta} (A_0 e^{gt})^{1-\alpha-\beta}$

In this model output (Y) changes 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.[5]

Hall and Jones [1999] specify a slightly different model, in which $\beta = 1-\alpha$. This model has become popular for growth accounting exercises [Caselli, 2005], but it is inappropriate for econometric analyses because it does not permit the data to determine the value of β. Breton [2013b] shows that when H/L is defined as the financial stock of human capital, $\beta = 0.36$ and $\alpha + \beta = 0.7$. Breton's empirical results support MRW's assumption that $\alpha + \beta < 1$.

MRW derive a dynamic version of their model, in which economic growth is modeled as convergence to the steady state $y_t = y^*$, where $y_t = Y/(e^{gt} L)$:

2) $\log(y_t) - \log(y_0) = (1-e^{-\lambda t}) \log(y^*) - (1-e^{-\lambda t}) \log(y_0)$

They show that y* is a function of the shares of GDP invested in physical and human capital (s_k and s_h), the labor growth rate (n), and the capital depreciation rates (δ_k and δ_h):

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

[5] I utilize MRW's model rather than Hall and Jones' [1999] model because the MRW model assumes that $\alpha+\beta < 1$, which is consistent with Breton's [2013b] estimates and with HW's findings that their growth rates exhibit conditional convergence. Hall and Jones [1999] assume that $\alpha+\beta = 1$, which implicitly makes their model an AK model, which does not exhibit income convergence.

Substitution of equation (3) into equation (2) and rearrangement creates a growth model, which contains a lagged income variable, similar to the one in the HK and HW analyses:

4) $\log(Y/L)_t - \log(Y/L)_0 = c + (1-e^{-\lambda t}) (\alpha/(1-\alpha-\beta) [\log (s_k)/(n+g+\delta_k)] + (1-e^{-\lambda t}) \beta/(1-\alpha-\beta) [\log (s_h)/(n+g+\delta_h)] - (1-e^{-\lambda t}) \log(Y/L)_0 + \varepsilon$

When this model is estimated over a period t, s_k, s_h, and n are the average of these rates during the period. The shares of investment s_k and s_h measure the *flow* of physical and human capital resources into the economy.

The average test score for a cohort of students age 9 to 15 can be employed as a measure of the human capital flowing into the economy 5-10 years later. HW's [2012b] data for average test scores are based on international tests taken between 1964 and 2003, but most of the tests in the less-educated countries were taken between 1990 and 2003. As a consequence, HW's average test scores for developed countries are representative of the flow of human capital in about 1990, while most of their international test scores for developing countries are representative of the flow of human capital into the work force after 1995.

Since at least twenty years is required for a growth analysis, I estimate MRW's growth model over the 1985-2005 period. This period corresponds relatively well to the period when most of the test scores were obtained and certainly much better than the 1960-2000 period that HW used in their analyses.

HW [2012a] create average test score data for 15 Latin American countries from scores on regional tests of mathematics and reading skills in 4th and 6th grade between 1997 and 2006. They combine these scores with their international scores to increase the number of countries in their data set. These expanded data are less reliable, since the regional scores relate to tests of different subjects, the scores were obtained later, and the merging of the scores required subjective adjustments to make them compatible. I estimate the growth model using HW's expanded data set, including the Latin American scores, and using a smaller data set that includes only the international scores.

For average investment in schooling (s_h) during 1985-2005, I use average schooling expenditures during 1980-2000, adjusted for the higher implicit financing cost in countries with longer periods of schooling. I use an investment period that is five years earlier than the growth period to account for the delay between the expenditures on students' schooling and the entry of these students into the work force.[6]

Figure 5 shows the relationship between the growth rate over the 1985-2005 period and the average test score for the 49 countries in the data set. The scores exhibit regional patterns that could indicate that unknown factors 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 models to control for possible omitted variables.

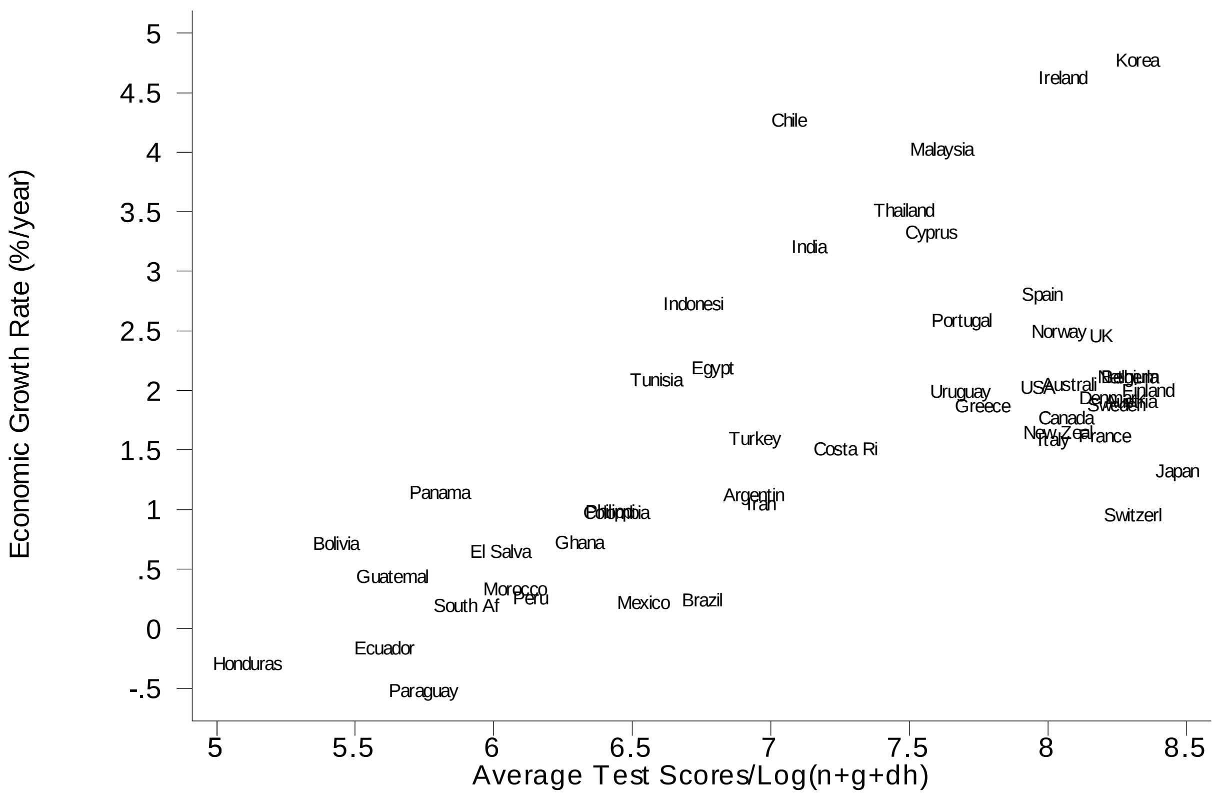
The human capital flows in the growth model could be endogenous. I use adults' average schooling attainment in 1980 as an instrument for average test scores and for investment in schooling. Average attainment in 1980 is positively correlated with schooling expenditures during 1980-2000 and with the average test scores. The rationale for this instrument is that parents' level of schooling has a positive effect on student achievement and on investment in their children's schooling. Juerges and Schneider [2004] and Parcel and Dufur [2009] document the positive effect of parental education on students' test scores in mathematics and reading skills.

[6] Five years is a reasonable average lag from a financial standpoint since unit schooling costs rise with the level of schooling and the delay between expenditures and entry into the work force is shorter at higher levels of schooling.

Average attainment in 1980 is a valid instrument for investment in schooling because it does not have a direct effect on growth rates during 1985-2005. The growth model controls for the initial level of output in 1985 and, therefore, implicitly controls for the level of schooling attainment in 1985. There is no reason to expect that attainment in 1980 would affect growth directly during 1985-2005 once the level of attainment in 1985 is taken into account.

Figure 5

Economic Growth vs. Test Scores in the Growth Model

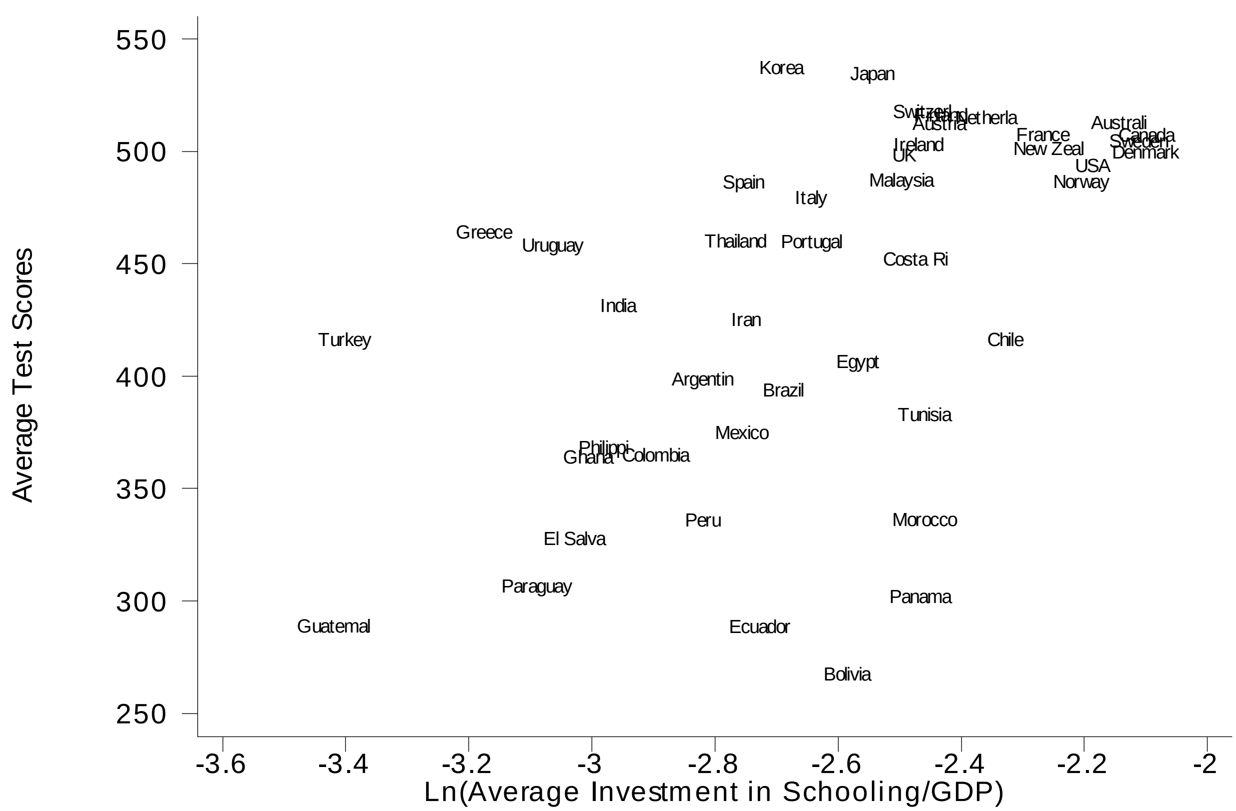


I developed data for 49 countries, beginning with the 59 countries which have test scores in HW [2012a and 2012b]. I excluded China and Romania because they were not market economies. I excluded Venezuela, Singapore, Jordan, and Zimbabwe because they have characteristics that distort the normal economic relationship between capital inputs and economic output. I excluded Israel, Hong Kong, Taiwan, and Iceland because Cohen and Soto [2007] do not provide schooling attainment data for them. The data are shown in the Appendix.

Figure 6 shows the relationship between average test scores and log(s_h) in 2005. Although the correlation between these two data sets is not very high, the pattern in the data indicates that the relationship between investment in schooling and average test scores is approximately log-linear. This relationship indicates that log(s_h) in equation (4) is best represented by the average test score rather than by the log of the average test score.

Figure 6

Average Test Score vs. Log(Investment in Schooling/GDP) in 1980-2000



I use economic data from Penn World Table (PWT) 6.3 [Heston, Summers, and Aten, 2009] because these data appear to be more reliable than the data in PWT 7.0 [Breton, 2012]. I use the rate ci in the PWT 6.3 data to estimate s_k over 1985-2005. I use adults as the proxy for workers and estimate n from the growth in the adult population.

I estimate the average share of GDP invested in schooling for the period 1980-2000 using UNESCO data on expenditures for public education (% of GDP), increased by factors to account for private schooling, the cost of financing while students are in school, and students' foregone earnings. Each of these cost components may exhibit considerable measurement error, as explained in the documentation of these estimates in Breton [2013b]. Due to the limitations of the UNESCO data, I estimate investment rates for only 44 of the 49 countries in the data set.

I assume $g = 0.01$, $\delta_h = 0.025$, and $\delta_k = 0.06$. The rate g is the average rate for 1910-2000 estimated in Breton [2013a]. The depreciation rate for human capital is from Breton [2013b]. The depreciation rate for physical capital is from Caselli [2005]. The data for average schooling attainment is from Cohen and Soto [2007].

IV. Empirical Results

Table 1 presents the OLS estimates of the growth model, divided into four categories. The first category presents the results using the expanded HW test score data set, including the regional test scores from Latin America. The second shows the results using the international test scores. The third shows the results using investment in schooling. The fourth shows the results using both measures.

The estimated parameters for the effect of physical capital and human capital and for the rate of convergence are consistent with expectations in all of the models. In the MRW 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 estimated models range from 0.29 to 0.41. The implied values of β range from 0.27 to 0.40, which are consistent with cross-country estimates [Breton, 2013b]. The estimated coefficients on the human capital measures are all statistically significant at the one percent level. The implied values of λ, the rate of convergence to the steady state, range from 0.014 to 0.026, which are consistent with expectations [MRW, 1992].

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

	1	2	3	4	5	6	7	8
Observations	49	49	41	41	44	44	44	37
	Test Scores w/LA		**Test Scores**		**Schooling**		**Comparison**	
$Ln(s_k/n+g+\delta_k)$	0.21* (.08)	0.19* (.09)	0.25* (.10)	0.22 (.12)	0.50** (.09)	0.36* (.15)	0.31** (.09)	0.32** (.11)
$Ln(s_h/(n+g+\delta_h)$					0.34** (.08)	0.28* (.11)	0.18* (.08)	0.21 (.12)
Ln(exptestscore/ $n+g+\delta_h$)	0.23** (.03)	0.22** (.05)	0.20** (.06)	0.19** (.06)			0.18** (.04)	0.18* (.08)
Ln(Y/L-1985)	-0.28** (.05)	-0.25** (.09)	-0.28** (.05)	-0.25* (.10)	-0.37** (.06)	-0.28* (.13)	-0.38** (.06)	-0.40** (.07)
Latin America Dummy		0.00 (.08)		0.01 (.10)		-0.08 (.08)		
Asia dummy		0.06 (.14)		0.05 (.15)		0.13 (.16)		
R^2	.62	.63	.52	.52	.50	.54	.64	.55
Implied α	.29	.29	.34	.33	.41	.39	.30	.31
Implied β	.32	.33	.27	.29	.28	.31	.34	.38
Implied λ	.016	.014	.016	.014	.023	.016	.024	.026

*Statistically significant at the 5 percent level.
**Statistically significant at the 1 percent level.
Note: Robust standard errors in parentheses

The results using HW's expanded test score data set (columns 1 and 2), explain more of the variation in growth rates than the human capital measures in the other models (62% versus

50-54%). The results using only the more reliable international scores (columns 3 and 4) explain the same share of the variation in growth rates as investment in schooling (columns 5 and 6). The superior results with the expanded data may be due to the method HW used to combine the Latin American regional scores and the international scores. Alternatively, if average test scores are a poor measure of human capital in more educated countries, the expanded data may explain more of the variation in growth because they include a smaller share of more educated countries.

Excluding the less reliable expanded test score data, average test scores and investment in schooling have a similar capability to explain growth during 1985-2005. The coefficients on the regional dummies have little statistical significance, and the inclusion of these dummies in the growth model has little effect on the estimated effect of the human capital measures.

Columns 7 and 8 show the results when both international test scores and investment in schooling are included in the growth model. This model explains somewhat more of the variation in growth rates, indicating that the two measures of human capital are capturing somewhat different aspects of human capital. The changes in the estimated coefficients on the two measures relative to the other models are difficult to interpret because the estimated rate of convergence is higher when both human capital measures are in the model. The statistical significance of the estimated coefficients on each measure is lower, no doubt due to the correlation between them. In these results the estimated coefficient on test scores is slightly more statistically significant than the coefficient on investment in schooling, but overall the various estimates of the model indicate that either students' cognitive skills in primary and secondary school or a nation's overall investment in schooling can explain its rates of economic growth about equally well.

Table 2 presents the 2SLS estimates of the same models, using schooling attainment in 1980 as an instrument for the human capital measures. In these results the estimated coefficients in the basic model are statistically significant at the 5% level with HW's expanded test score data and with investment in schooling. The estimated coefficients are not statistically significant at the 5% level with the international test score data and when dummy variables are included for Asia and Latin America. The estimated coefficients and the share of the variation in growth rates explained in these models are similar to the OLS results, indicating that the OLS estimates are unbiased.

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

	1	2	3	4	5	6
Observations	49	49	41	41	44	44
	Test Scores w/LA		**Test Scores**		**Schooling**	
$Ln(s_k/n+g+\delta_k)$	0.19 (.12)	0.18 (.10)	0.21 (.14)	0.20 (.12)	0.50** (.09)	0.39* (.17)
$Ln(s_h/(n+g+\delta_h)$					0.45* (.18)	0.37 (.25)
$Ln(exptestscore/ n+g+\delta_h)$	0.25* (.11)	0.24 (.17)	0.23 (.13)	0.22 (.16)		
Ln(Y/L-1985)	-0.29** (.09)	-0.26 (.16)	-0.29** (.07)	-0.27 (.14)	-0.43** (.11)	-0.33 (.19)
Latin America dummy		0.01 (.15)		0.02 (.13)		-0.06 (.11)
Asia dummy		0.05 (.17)		0.04 (.16)		0.12 (.16)
R^2	.62	.62	.51	.52	.48	.53
Implied α	.26	.26	.29	.29	.36	.36
Implied β	.34	.35	.32	.32	.33	.34
Implied λ	.017	.015	.017	.016	.028	.020

*Statistically significant at the 5 percent level.
**Statistically significant at the 1 percent level.
Note: Robust standard errors in parentheses

In the 2SLS results, the model with investment in schooling provides estimated coefficients for the physical and human capital variables that are much more statistically significant than the model with international test scores. The estimated coefficient on investment in schooling is significant at the 5% level, while the estimated coefficient on international test scores is only significant at the 10% level. This lower significance appears to be due to the high correlation between international test scores and the rate of investment in physical capital (ρ = 0.83), since the overall variation in growth rates explained by the human capital and physical capital measures is the same in the models using both human capital measures.

Given all of the statistical results and the consistency between the OLS and 2SLS estimates, average tests scores and investment in schooling have a similar capability to explain economic growth over the 1985-2005 period. Importantly, using either measure, increases in human capital appear to cause growth. Either an increase of 100 points on the international tests or an increase of 70% in the share of GDP invested in schooling raises national output by 25% over 20 years. This increase is equivalent to an average increase in economic growth of 1.1%/year over the 20-year period.

Despite the similar estimated effect of β using either measure, the data patterns in Figures 3 and 4 suggest that the similar effect associated with the two measures may be the average of different effects in different subsets of countries. Since test scores do not continue to rise with income in countries with high test scores, growth in these countries may be caused by more investment in schooling rather than by increases in test scores. To investigate this possibility I split the countries into subsets with more or less than 7.5 years of average schooling in 1985.[7]

[7] I estimate attainment in 1985 by averaging Cohen and Soto's [2007] data for 1980 and 1990. I use schooling attainment to define the two groups because the test score data are not related to the adult population.

The data set with less than 7.5 years of schooling includes from 18 to 25 countries, depending on the measure(s) of human capital employed in each model. The average test scores in these countries range from 309 to 484. The data set with more than 7.5 years of schooling includes 21-23 countries. The average scores in these countries range from 392 to 534, but only four countries have scores below 470. Most countries have test scores clustered around 500, so there is less variation in the test scores in this group.

The reduced variation in the human capital measures in each subset makes it impossible to control for endogeneity estimates of the growth model. In these small subsets of countries, average schooling attainment in 1980 is insufficiently correlated with either measure to permit its use as an instrument.

Table 3 presents OLS estimates of the models for the two sets of countries. The estimated effect of average test scores on growth rates differs dramatically in these results. Test scores are very highly correlated with growth rates in the countries with less than 7.5 years of schooling. In these countries average test scores explain a very high share of the variation in growth rates: 77% with the Latin American regional scores and 73% in the data set containing only international scores. In contrast, the model using the investment in schooling measure explains only 51% of the variation in growth rates.

In the countries with more than 7.5 years of schooling, the results are the opposite. The effect of average test scores is small, and it is never close to statistically significant. When test scores and investment in schooling are both included in the model (column 7), average test scores do not explain any of the variation in growth rates. These results confirm that the effect of average test scores in the full data set is actually due to its effect in the countries with low levels of adult schooling and low student test scores.

Table 3
Effect of Human Capital Measures on Growth Rates 1985-2005
[Dependent variable is Δln(GDP/adult)]

	1	2	3	4	5	6	7
	Schooling in 1985 < 7.5 years				**Schooling in 1985 > 7.5 years**		
Observations	25	18	22	22	23	22	21
Ln(sk/ngδ_k)	0.12 (.07)	0.09 (.09)	0.43** (.09)	0.20* (.08)	0.22 (.20)	0.47** (.15)	0.38 (.21)
Ln(sh/ngδ_h)			0.35* (.13)	0.15 (.10)		0.22* (.10)	0.25* (.10)
Ln(exptest/ngδ_h)	0.27** (.04)	0.32** (.07)		0.24** (.05)	0.09 (.13)		-0.01 (.13)
Ln(Y/L-1985)	-0.20** (.06)	-0.18* (.07)	-0.36** (.05)	-0.27** (.05)	-0.49** (.13)	-0.45** (.15)	-0.58** (.11)
R^2	.77	.73	.51	.79	.55	.42	.60
Implied α	.20	.15	.38	.23	.28	.41	.32
Implied β	.46	.54	.31	.45	.11	.19	.20
Implied λ	.011	.010	.022	.016	.034	.030	.043

*Statistically significant at the 5 percent level.
**Statistically significant at the 1 percent level.
Note: Robust standard errors in parentheses

The effect of investment in schooling on growth rates is much more consistent between the two groups of countries. When this measure is included alone, its estimated effect is higher in the countries with less schooling, but it is statistically significant in both subgroups of countries at the five percent level. In countries with lower levels of schooling, the estimated effect of investment in schooling shrinks and it loses its statistical significance when test scores are also included in the model. In the countries with higher levels of schooling, the estimated effect of investment in schooling and its statistical significance are unaffected when test scores are included in the model.

These results do not control for endogeneity bias, but since there is no evidence of bias in the full sample, the bias in these two subsamples is likely to be small. The clear implication is that higher test scores raise growth rates in countries with low levels of schooling, but not in countries with high levels of schooling. More investment in schooling raises growth rates in all countries, but evidently in different ways. In the countries with low levels of schooling, more schooling seems to affect growth predominantly by raising cognitive skills at ages 9 to 15, but not entirely, since almost half of the total effect of investment is still in evidence after controlling for average test scores. In the countries with high levels of schooling, more investment in schooling has no effect on cognitive skills at ages 9 to 15, so it must raise growth rates by raising levels of post-secondary schooling.

The results indicate that human capital is by far the most important determinant of growth rates in countries with low levels of schooling. In countries with high levels of schooling human capital is still a very important determinant, but differences in physical and human capital explain less of the variation in growth rates than in countries with less schooling (60% vs. 79%).

Another interesting result is that the estimated speed of convergence (λ) is higher in countries with higher levels of human capital, and the difference is statistically significant. This result may occur because capital depreciation rates are higher in more educated countries, which presumably are much closer to the technological frontier.

These empirical results provide no indication that increases in test scores at ages 9 to 15 raise economic growth rates in countries that already have average scores above 470. The implication is that intensive efforts, including tutoring, to raise average scores from 470 to 530 may not have much or any effect on economic growth.

Secondary school students in successive grades have taken the same international tests in mathematics, science, and reading. The test results consistently indicate that average scores increase by about 32 points if students remain in school for an additional year [Fuchs and Woessmann, 2006, Juerges and Schneider, 2004, and Woessmann, 2003]. The implication is that the extensive tutoring in Asian countries accelerates the improvement in skills that normally occurs during the schooling process by about one year.

It is not clear whether this increase in skills is temporary, or whether this improvement carries forward during further schooling. Given that there is no noticeable effect on economic growth in the model results, the improvement in skills may be temporary. Alternatively, it may be that if students in a country achieve average scores of at least 470, there are enough students with high skills to meet the economy's requirement for these highly-skilled workers.

VI. Conclusions

Hanushek and Woessmann [2008, 2011a, 2011b, 2012a, and 2012b] argue that students' cognitive skills at ages 9 to 15, as measured on international tests, determine a nation's rate of economic growth, and they show that increased schooling attainment explains only one third of the variation in growth rates explained by higher average test scores. Breton [2011] presents evidence that their results are severely biased because their measures of schooling and test scores are not comparable and their growth model is mis-specified.

In this paper I re-examine the effects of higher test scores and more schooling using a properly-specified growth model, an appropriate measure of schooling, and a time period more appropriate for the vintage of their test scores. I find that higher average test scores and more investment in schooling both cause higher economic growth rates over the 1985-2005 period and that the estimated effect of either measure on growth is similar. These results support HW's finding that increases in students' test scores cause growth, but they reject their finding that increases in schooling do not reliably cause growth.

When I examine the effect of higher test scores and more investment in schooling in subsets of countries with high and low levels of average schooling, I find that average test scores have a very large effect on growth rates in countries with low levels of schooling and no effect in countries with high levels of schooling. In contrast, the results show that additional schooling raises economic growth rates in countries at all levels of schooling. These results confirm Hanushek and Woessmann's conclusions that increases in human capital cause economic growth, but they demonstrate that students' cognitive skills at ages 9 to 15 are not the only component of human capital that matters.

Acknowledgements

I thank Richard Rogerson, Mikael Lindahl, George Psacharopoulos, Andrew Breton, and an anonymous referee for helpful comments on earlier versions of this manuscript.

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Appendix

Data Used in the Analysis

country	dlnya	lnskngd	lnshngd	lnya85	testngd	testngdxLA	attain85
Argentina	0.212	0.671152	0.165448	9.612741	6.936596	6.903596	7.61
Australia	0.397	1.247324	0.826342	10.26628	8.06328	8.06328	12.48
Austria	0.368	1.312362	0.763147	10.224	8.286293	8.286293	10.63
Belgium	0.410	1.299402		10.14377	8.294996	8.294996	9.64
Bolivia	0.130	0.100697	0.244768	8.517889	5.468852		6.65
Brazil	0.035	0.441511	0.137596	9.391448	6.726364	6.462364	5.4
Canada	0.341	1.123917	0.915946	10.30438	8.052129	8.052129	11.98
Chile	0.840	0.940259	0.584518	9.189778	7.037747	6.959747	8.66
Colombia	0.183	0.399188	-0.10611	9.054819	6.402243	6.940243	5.46
Costa Rica	0.290	0.820881	0.27546	9.328547	7.2335		5.3
Cyprus	0.653	1.36316		9.634167	7.599345	7.599345	7.57
Denmark	0.374	1.299627	1.158645	10.2123	8.218607	8.218607	11.29
Ecuador	-0.046	0.75372	0.007608	9.104218	5.584049		6.73
Egypt	0.424	-0.11349	0.177265	8.538795	6.772388	6.772388	3.94
El Salvador	0.116	0.533758	-0.17785	8.912055	6.091401		4.07
Finland	0.387	1.339292	0.77988	10.10438	8.33801	8.33801	10.11
France	0.311	1.166422	0.892581	10.1602	8.199491	8.199491	11.46
Ghana	0.131	-0.39881	-0.31874	7.700253	6.289207	6.289207	4.59
Greece	0.361	1.217776	-0.05503	9.939602	7.726655	7.726655	8.22
Guatemala	0.075	0.649844	-0.63332	9.121902	5.638829		3.29
Honduras	-0.071	0.888399		8.711511	5.096589		4.37
India	0.628	0.491327	-0.10299	7.885294	7.133697	7.133697	2.88
Indonesia	0.532	0.744995		8.308831	6.687291	6.687291	4.89
Iran	0.196	0.977986	-0.05183	9.25999	6.914383	6.914383	3.01
Ireland	0.912	1.23938	0.604389	9.882119	8.067202	8.067202	9.24
Italy	0.305	1.350426	0.583262	10.08097	7.983074	7.983074	8.53
Japan	0.251	1.50906	0.566256	10.19843	8.418996	8.418996	11.57
Korea	0.941	1.583808	0.221125	9.273177	8.249508	8.249508	9.52
Malaysia	0.791	1.011615	0.279838	9.31857	7.613081	7.613081	7.1
Mexico	0.031	0.858422	0.029243	9.608402	6.496652	6.782652	6.48
Morocco	0.054	0.423823	0.288955	8.868413	6.073793	6.073793	1.96
Netherlands	0.409	1.182184	0.783248	10.18674	8.255679	8.255679	10.5
N. Zealand	0.317	1.098914	0.799186	10.03382	8.033364	8.033364	10.87
Norway	0.486	1.441099	0.987466	10.46266	8.021009	8.021009	11.94
Panama	0.216	0.837476	0.321657	9.127715	5.771438		7.37
Paraguay	-0.116	0.377595	-0.37193	9.022554	5.74615		5.59
Peru	0.039	0.674068	-0.03418	8.993235	6.108306	5.909306	6.93

Philippines	0.184	0.46427	-0.2183	8.577427	6.40851	6.40851	6.72
Portugal	0.504	1.403134	0.487326	9.547281	7.691679	7.691679	5.74
South Africa	0.026	-0.05391		9.513802	5.839589	5.839589	5.4
Spain	0.549	1.388587	0.341332	9.888076	7.922959	7.922959	7.95
Sweden	0.363	1.045869	1.126125	10.15845	8.249744	8.249744	11.65
Switzerland	0.178	1.411867	0.689762	10.47382	8.293355	8.293355	12.72
Thailand	0.690	1.338312	0.045967	8.631466	7.376121	7.376121	5.19
Tunisia	0.404	0.477844	0.283752	9.023318	6.536824	6.536824	3.03
Turkey	0.306	0.848588	-0.62859	8.900937	6.899992	6.899992	4.69
UK	0.479	1.021637	0.752382	10.03668	8.193908	8.193908	11.93
Uruguay	0.386	0.558768	0.090501	9.201221	7.701337	7.452337	7.26
USA	0.392	1.070665	0.882339	10.47981	7.970066	7.970066	12.37