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

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I use a dynamic augmented Solow model to estimate the effect of international test scores and investment in schooling and tutoring on economic growth rates in 55 countries during 1985–2005. Either test scores or investment in schooling and tutoring can explain growth rates in the full data set or in countries that had less than 8 years of schooling in 1985. In countries with more schooling in 1985, investment in schooling has a small effect and test scores have no effect on growth rates. In the 24 countries with scores above 470, higher scores have no effect on growth rates.

I. Introduction

Analyses of the effect of human capital on national income and growth rates using aggregate cross-country data are valuable because they estimate the external as well as the direct effects of human capital (Krueger and Lindahl 2001). Until relatively recently, these analyses relied almost entirely on school enrollment rates and average years of schooling to represent the flow and the stock of human capital in an economy.

In a series of articles, Hanushek and Kimko (2000) and Hanushek and Woessmann (2008, 2011a, 2011b, 2012a, 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. They argue that average test scores provide a much more accurate measure of a nation's human capital than adults' average years of schooling attainment (hereafter schooling attainment).

In all of their articles, Hanushek and Woessmann compare the effect of test scores and schooling attainment on growth rates and obtain similar results. Hanushek and Woessmann (2008, 2012a) show that over the pe-

I thank Richard Rogerson, Mikael Lindahl, George Psacharopoulos, Michael Jetter, Andrew Breton, and four anonymous referees for helpful comments on earlier versions of this manuscript.

[*Journal of Human Capital,* 2015, vol. 9, no. 2]
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riod 1960–2000, average test scores explain three times the variation in growth explained by schooling attainment (73 percent vs. 25 percent). They also show that when test scores and schooling attainment are included in the same model, test scores explain all the variation in growth. They conclude from these results that higher cognitive skills at ages 9–15 cause growth and more schooling often does not.

Breton (2011) challenges the validity of these results. He argues that Hanushek and Woessmann's (2008) comparison of the effect of test scores and schooling attainment is flawed. Since Hanushek and Woessmann (2008, 2011a, 2011b, 2012a, 2012b) use the same methodology to estimate the effect of these measures, his criticism is applicable to the more recent analyses as well.

The most evident flaw in the methodology is that Hanushek and Woessmann compare the effect of students' test scores from 1964–2003, and primarily from 1990–2003, to the effect of adults' schooling attainment in 1960. These two measures are not remotely comparable. As an example, students who were tested at age 9 in 2003 and remained in school until they were 18 would have entered the workforce in 2012. Because of the lag between the testing of the students and their entry into the workforce and their subsequent 40-year working life, average test scores from 1964–2003 are a proxy for a country's human capital in about 2010, or 50 years later than adults' schooling attainment in 1960. The average scores from 1990–2003, which they use for most of the less educated countries, are a proxy for a country's human capital around 2020.

The less evident flaw in the methodology is that their growth model is misspecified. The model includes the initial level of human capital, which is included in some endogenous growth models, but it also includes initial income, which is included in dynamic neoclassical models to control for conditional convergence. The empirical results in Hanushek and Kimko (2000) and Hanushek and Woessmann (2008, 2011b, 2012a, 2012b) support the lagged income variable and reject the initial level of schooling. Hanushek and Woessmann (2012b) include the initial level of physical capital in the model, and this variable is also rejected. So their results consistently reject the initial levels of capital found in some endogenous growth models and accept the lagged income variable included in the dynamic neoclassical growth model.

The capital variables in the dynamic neoclassical growth model 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 Hanushek-Kimko/Hanushek-Woessmann model, students' average test scores at ages 9–15 during 1964–2003 represent the flow of human capital into the economy during 1970–2010, or about 6–7 years after the testing period. The comparable schooling measure is the average rate of enrollment or the rate of investment in schooling during 1964–2003, not the schooling attainment of adults in 1960. Their model also lacks an analogous flow of physical capital into the economy. As a consequence, Hanushek and

Kimko's and Hanushek and Woessmann's estimates of the effects of test scores and schooling attainment on growth are likely to be severely biased.

In this paper I reexamine whether higher test scores or more schooling causes growth, using a dynamic augmented Solow growth model, comparable measures for test scores and investment in schooling, and data for these measures that are appropriate for the period of estimation.[1] I also examine whether private tutoring affects growth and whether there are nonlinearities in the education-growth relationship that lead to different results in the complete data set than in subsets of countries with different levels of schooling.[2] As far as I know, these analyses have not been performed in the existing empirical literature.

I begin my analysis by examining the quantitative relationships between three measures of a nation's human capital stock: average adult schooling attainment, the financial stock of human capital per adult, and students' average test scores. I examine the relationship between stocks rather than flows because stocks measure the cumulative effect of flows over a long period.

I show that while these three measures are correlated, they have very different patterns across countries, which suggests that they quantify different aspects of a nation's human capital. The measures increase together in countries with relatively little schooling, but test scores stabilize once countries have more than 9 years of schooling attainment or have invested more than $100,000 per adult (2005 US$) in schooling. As a result, these measures relate to growth rates differently in countries with different levels of schooling.

Subsequently, I estimate the effects of higher test scores and more investment in schooling on growth rates, using Mankiw, Romer, and Weil's (1992) dynamic version of the augmented Solow model. This model has a structure that is compatible with Hanushek and Woessmann's test score data and their empirical results, and the validity of this model is supported by considerable recent empirical evidence (Cohen and Soto 2007; Ding and Knight 2009; Breton 2010, 2011, 2013b, 2013c, 2015; Gennaioli et al. 2013).[3] Since the Mankiw et al. model is a well-defined structural model, the nature, the form, and the vintage of the data required for its estimation are clearly specified. Since most of Hanushek and Woessmann's test scores for less educated countries were obtained after 1990, I estimate the growth model over the 1985–2005 period to ensure consistency with the vintage of their data.

[1] The flow of human capital into the economy is exogenous in the Solow growth model. Ehrlich and Kim (2007) specify a complex endogenous growth model in which human capital determines economic growth.

[2] Castelló-Climent (2010) finds evidence that human capital inequality affects rates of investment in human capital differently in high- and low-income countries.

[3] Breton (2013b) challenges Klenow and Rodriguez-Clare's (1997) and Hall and Jones's (1999) arguments that Mankiw et al.'s empirical results overestimate the effect of schooling on national output.

I confirm Hanushek and Kimko's and Hanushek and Woessmann's findings that average test scores explain cross-country growth rates quite well in the complete sample of countries. But I find that investments in schooling (and private tutoring) also explain growth rates quite well. In both models the estimated parameters for the augmented Solow model are consistent with theoretical expectations and with estimates in other cross-country studies. These results reject Hanushek and Kimko's and Hanushek and Woessmann's findings that more schooling is not reliably correlated with 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 these measures explain growth rates well only in countries with relatively low levels of schooling and test scores. Average test scores cannot explain growth rates during 1985–2005 in countries that had more than 8 years of schooling attainment in 1985 or in countries that had average test scores over 470. These results call into question Hanushek and Woessmann's (2011a) claim that raising students' test scores at ages 9–15 is an attractive growth strategy for OECD countries. In contrast, rates of investment in schooling can explain growth rates in countries with more than 8 years of schooling, but its estimated effect is smaller than in countries with less schooling.

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 used in the analysis, and Section IV describes the data used in this analysis. Section V presents the results. Section VI presents conclusions.

II. Measures of Human Capital

A country's human capital is analogous to its physical capital but is much more difficult to measure. A large fraction of human capital is created through the formal schooling process, particularly in higher-income countries, but human capital is also created in informal settings, such as in the home or on the job. Expenditures on formal schooling or on tutoring can be measured, but historically such data have not been collected as carefully or as regularly as expenditures on physical capital. The earnings that students forgo while in school are an additional, unmeasured investment in schooling. And some kinds of schooling are an element of consumption rather than an investment in productive capital.[4] Owing to all these complications, estimates of a country's rate of investment in human capital or of its human capital stock inherently have more measurement error than analogous estimates for physical capital.

[4] The United Nations system of national accounts classifies education as an element of consumption.

There are three measures of human capital that have been used in cross-country income and growth studies. The first is the average years of schooling attainment of the adult population for the ages 15–64, over 15, or over 25. The second is the average international score on tests of different skills for a student population with ages between 9 and 15. The third is the net cumulative investment in formal schooling of the population of working age, assuming a 40-year working life after the completion of schooling.

Most cross-country growth studies use schooling attainment as a proxy for a country's human capital because it is the only quantitative measure of workers' skills available for most countries for long historic periods.[5] Despite its limitations, this measure has acquired legitimacy because the effect of an additional year of schooling on workers' incomes (the Mincerian return) is relatively consistent across countries (Psacharopoulos and Patrinos 2004). The other two measures are available for many fewer countries and only for recent time periods.

Growth analyses using the average schooling attainment measure almost always utilize the Mincerian log-linear relationship between income and schooling. In these models, each additional year of schooling has an exponential effect on income. As a consequence, the marginal contribution of an additional year of schooling to a nation's productivity and output is much greater in a country with higher average attainment (like Japan) than in a country with lower average attainment (like Peru). These models implicitly take into account the higher average investment per year of schooling and the related higher schooling quality in countries with higher average schooling attainment.

The main weakness in these analyses is that they implicitly assume that a year of schooling has the same quality in countries that have the same schooling attainment, for example, in the United States and Canada. One indicator of how much schooling quality might vary in countries with the same schooling attainment is the variation in cumulative investment in schooling per adult in countries with the same average schooling attainment. Countries that invest more in each year of schooling (adjusted for differences in purchasing power) are more likely to provide higher-quality schooling. The cumulative investment measure of human capital could capture differences in schooling quality to a greater degree than the average attainment measure, although there are differences in investment due to institutional characteristics that are not related to schooling quality.

Figure 1 shows the relationship in 2005 between the log of Breton's (2013a) estimates of the financial stock of human capital per adult of working age and Cohen and Soto's (2007) estimates of the schooling attainment of the population aged 15–64.[6] Breton's measure of human capital

[5] Morrisson and Murtin (2009) present average schooling attainment data for 74 countries for the period 1870–2010.

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

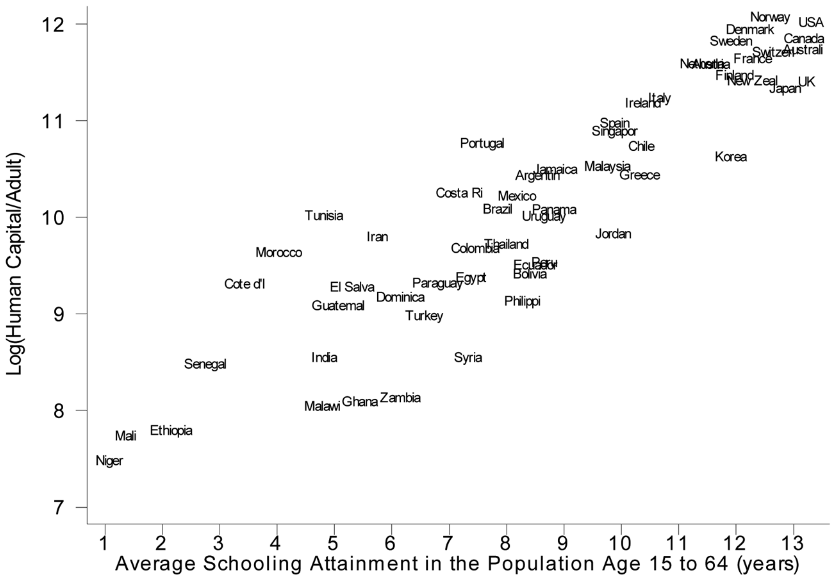

Figure 1.—Log(human capital per adult) versus average schooling attainment in 2005

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 percent per year. Since the investment is calculated from national income in Penn World Table 6.3 (Heston, Summers, and Aten 2009), the estimates of the stocks of human capital are adjusted for purchasing power differences across countries.

The relationship in the figure is clearly linear, and the two data sets are highly correlated ($\rho = .91$). 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 per adult and average schooling attainment indicates that a log-linear relationship between income and average schooling implicitly accounts for the higher average quality of schooling in more educated countries.[7]

The data in figure 1 show that South Korea, Japan, and the United Kingdom have invested less per year of schooling than other highly educated countries, but their investment in schooling does not include their expenditures on private tutoring, which are substantial (Dang and Rogers 2008). As will be addressed later, stocks or flows of human capital calculated from investment in schooling are underestimated in countries that spend considerable amounts on private tutoring.

As also shown in the figure, the differences in the financial measure of human capital per adult can be quite large in countries with the same av-

[7] The trend in the relationship shows that countries with 2 years of schooling in 2005 had invested about $2,000 per adult, and countries with 13 years of schooling had invested about $130,000 per adult, or 10 times as much per year of schooling.

erage schooling attainment, and the range is particularly large in countries in which average schooling attainment is between 4 and 9 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.

Breton (2013b) estimates Mankiw et al.'s (1992) static version of the augmented Solow model across countries in 1990 using the financial stock of human capital per adult and schooling attainment. Both measures explain the variation in national income quite well, but the financial measure explains more of the variation, suggesting that across countries it accounts for differences in schooling quality somewhat better than the schooling attainment measure.

If the financial stock of human capital per adult is a more accurate measure of human capital than average schooling attainment, then it could be a more accurate measure of human capital than average test scores, particularly in countries with high average levels of schooling. Figure 2 shows the relationship between Hanushek and Woessmann's measure of average test scores and the financial stock of human capital per adult in 2005 in 46 countries. These two measures are correlated ($\rho = .70$), but the mathematical relationship between them is not linear or log linear. The data show that average test scores at ages 9–15 rise as countries raise their investment in human capital per adult, but only up to about \$100,000 per adult (2005 US\$). Beyond that level of investment, average scores tend to decline, although not by a substantial amount.

Figure 3 shows the relationship between Hanushek and Woessmann's measure of students' average test scores obtained over the period 1964–

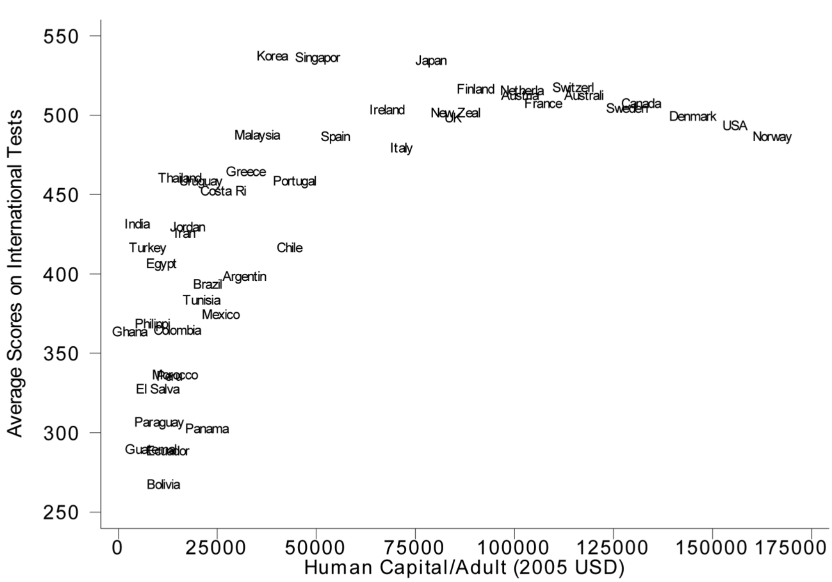

Figure 2.—Hanushek and Woessmann's average test scores versus human capital per adult in 2005.

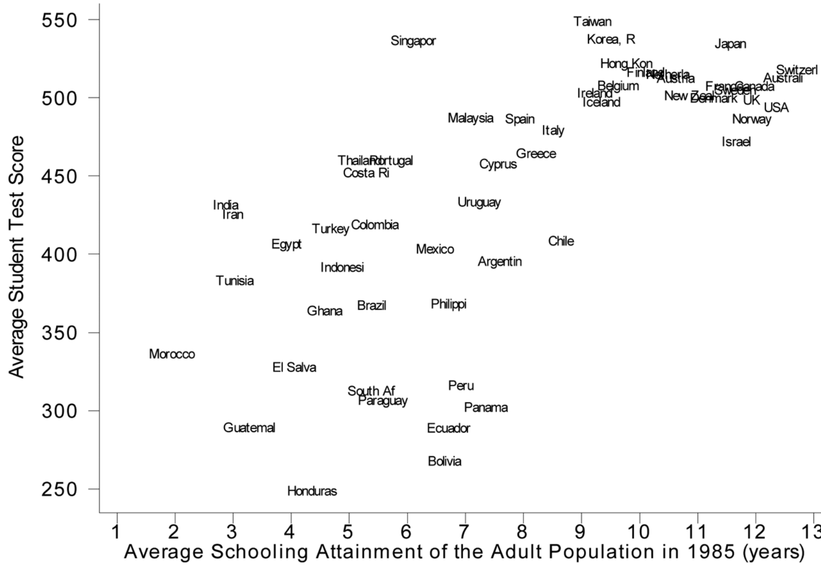

Figure 3.—Average student test score versus average schooling attainment in 1985

2006 and the average schooling attainment of the adult population in 1985, the midpoint of the testing period. Average scores on international tests at ages 9–15 increase across countries as the average schooling of the population aged 15–64 rises to a level of about 9 years, and then scores stabilize at a mean of about 500.

These patterns suggest that a nation's average test scores at ages 9–15 and its average schooling attainment are measuring different aspects of its human capital. Average test scores measure students' competence in basic skills, while schooling attainment and the financial stock of human capital measure the overall educational level of the adult population. These measures rise together in countries with limited postsecondary schooling, but they diverge in more educated countries. The data in figures 2 and 3 demonstrate that the test score measure cannot discern the differences in human capital in countries with widely differing levels of postsecondary schooling.

The 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 Hanushek and Woessmann's data, India has relatively high average scores, but in the testing period, its secondary school enrollment rate was under 50 percent.[8] 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 in countries with low

[8] World Bank data used are school enrollment, primary (% gross), secondary (% gross), and tertiary (% gross).

enrollment rates, it can be minimized by using Hanushek and Woessmann's average test scores to estimate growth during the latest possible period when a larger share of the school-age population attended secondary school.

These patterns in the data suggest that students' cognitive skills at ages 9–15 are an incomplete measure in countries with a financial stock of human capital per adult above $100,000 or with more than 9 years of average schooling attainment. As a consequence, test scores may not be a sufficiently accurate measure to permit estimation of the effect of human capital on national income or on economic growth in more educated countries. Since all measures of human capital have their limitations, which measure best represents cross-country human capital is an empirical issue that can be determined only in a properly specified income or growth model.

III. Growth Model Specification

In this analysis I utilize Mankiw et al.'s (1992) augmented Solow model to compare the effect of higher test scores and more investment in schooling on national output:

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

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 $g(1 - \alpha - \beta)$. Breton (2013b) shows that when H/L is defined as the financial stock of human capital per adult, $\beta = 0.36$ and $\alpha + \beta = 0.7$. His results support Mankiw et al.'s assumption that $\alpha + \beta < 1$, and they are consistent with Mankiw et al.'s results, in which human capital has large external effects on national income.

Mankiw et al. (1992) derive a dynamic version of their model in which economic growth is modeled as convergence to the steady state $y_t = y^*$, where $y_t = Y/(e^{gt}L)$ and λ is the rate of convergence to the steady state:

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

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):

$$\begin{aligned} y^* = {} & \alpha/(1 - \alpha - \beta)[\log(s_k)/(n + g + \delta_k)] \\ & + \beta/(1 - \alpha - \beta)[\log(s_h)/(n + g + \delta_h)]. \end{aligned} \tag{3}$$

Substitution of equation (3) into equation (2) and rearrangement creates a growth model, which contains a lagged income variable, similar to the variable in the Hanushek-Kimko and Hanushek-Woessmann analyses:

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

When this model is estimated over a period 0 to t, s_k, s_h, and n are the averages of these rates during the growth period. The shares of investment s_k and s_h measure the flow of physical and human capital resources into the economy during this period.

The average test score for a cohort of students aged 9–15 can be employed as a measure of the human capital flow into the economy in each country 5–10 years later. Hanushek and Woessmann's (2012a) data for average test scores are based on international tests taken between 1964 and 2003, but as described below, most of the scores in the less educated countries were obtained between 1990 and 2003. As a consequence, their average scores for developed countries and a few developing countries are representative of the flow of human capital during 1970–2010, while most of their average scores for developing countries are representative of the flow of human capital into the workforce during 1995–2010.

I estimate Mankiw et al.'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 earlier 1960–2000 period that Hanushek and Woessmann use in their analyses. The test scores also are more representative of the flow of human capital in the less educated countries in the later period because a much higher fraction of students remained in school until age 15 in these countries in 1985 than in 1960. As a consequence, there is less measurement error in Hanushek and Woessmann's test score measure when it is used to explain growth during 1985–2005 than when it is used to explain growth during 1960–2000.

Figure 4 shows the relationship between average test scores and $\log(s_h)$ in the data set. 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 could be log-linear. I represent $\log(s_h)$ in equation (4) by the average test score rather than by the log of the average test score because it provides better results. Hanushek and Woessmann (2012b) use a linear-exponential relationship between growth rates and test scores in their analyses for the same reason.

As mentioned earlier, a limitation of the rate of investment in schooling measure is that some countries expend considerable resources on private tutoring to improve students' cognitive skills. Since rates of investment in schooling do not include these expenditures, they underestimate the rate of investment in human capital in these countries, and as shown later in the empirical results, the failure to include the tutoring expenditures in the growth model substantially changes the estimated effect of investment

Figure 4.—Average test score versus log(investment in schooling/GDP)

in schooling. Since cross-country time-series data on expenditures on tutoring are not available, I control for the effect of tutoring by including a dummy variable for countries with high expenditures on tutoring.

Figure 5 shows the relationship between the growth rate over the 1985–2005 period and the average test score variable for the 55 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 relatively low in the Latin American countries. I include dummy variables for these regions in some models to test for possible omitted variables.

IV. Data Creation and Selection

Mankiw et al.'s growth model assumes that investment in physical capital and human capital, growth in workers, and the initial level of income are the only factors that affect growth. The model also assumes that factors of production are paid their marginal products. Countries that have centrally planned economies, have income largely determined by oil exports, have serious civil conflicts, or are tax havens have characteristics affecting income and growth rates that are not included in the model. These countries are likely to be outliers in the model's growth-investment relationships. Particularly in estimates of the model with small data samples, these outliers can substantially bias the estimated coefficients and reduce their statistical significance.

Hanushek and Kimko and Hanushek and Woessmann had similar concerns when they estimated their growth models, so they excluded many

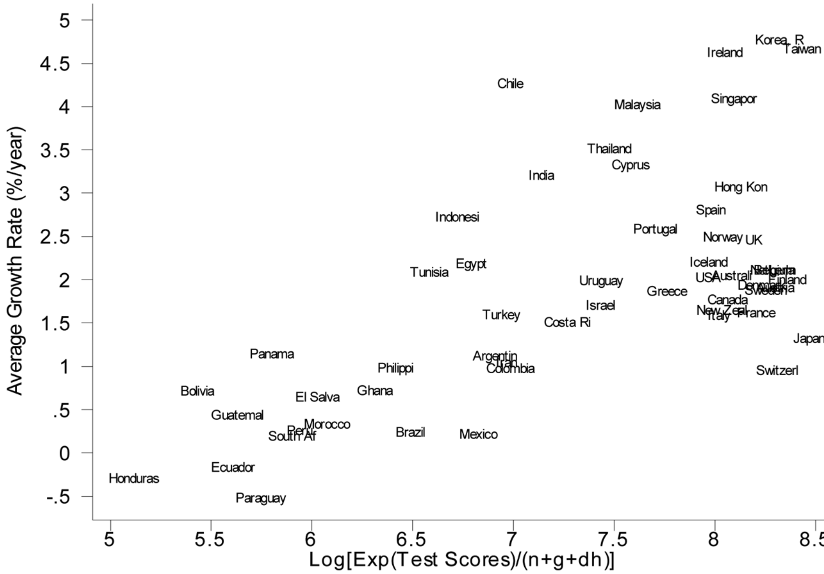

Figure 5.—Economic growth rate in 1985–2005 versus test the score variable in the growth model.

countries from their data sample. Hanushek and Woessmann (2008) report that 77 countries participated in international tests of mathematics and science during the 1964–2003 period. They excluded 27 of these countries from their sample because 15 were communist countries; three were predominantly oil exporters; six were small, were newly created, or lacked output data; and two were outliers in their growth regressions. Their remaining data set includes 50 countries.

Hanushek and Woessmann (2012b) create average scores for an additional nine Latin American countries based on regional tests of mathematics and reading skills in fourth and sixth grades taken during 1997 and 2006. These scores are less reliable since they correspond to tests of different subjects, correspond to a later period, and had to be adjusted to merge them with the international scores. I use most of these scores, but I test whether their use changes the regression results.

I began with these 59 countries and excluded four for the same reasons as Hanushek and Woessmann. I excluded China and Romania because they were communist countries and Venezuela because it was predominantly an oil exporter.[9] I excluded Jordan because it is an outlier in the growth regressions as a result of the heavy migration of refugees from Israel and Iraq during the 1985–2005 period. Since these refugees add human capital to the labor force that is not measured in the test scores or the investment rates, the inclusion of Jordan in the data set would bias

[9] China's average test scores correspond to tests taken in Shanghai, which is a relatively educated region.

the results. So my initial estimates of the effect of test scores on growth are based on the scores in 55 countries.

Hanushek and Woessmann's international test scores are the simple arithmetic average of any available scores on tests of mathematics and science for students between 9 and 15 during the 1964–2003 period. The age distribution of the students tested may be different in each country, but they argue that this is not a problem because scores on different tests within the same country are highly correlated (Hanushek and Woessmann 2008, 2012a). Another concern is that the students participating in international tests are not always a representative sample of the school population in the less educated countries. But Hanushek and Woessmann (2011b) present analyses showing that sample selectivity problems have not unduly biased their results.

Since the international tests began as a means to compare students' skills in the more educated countries, there are few scores for less educated countries prior to 1990. My data set with test scores includes 18 highly educated countries and 37 less educated countries. Only seven of the less educated countries have test scores prior to 1990 (Hanushek and Woessmann 2008), and eight of the 37 countries have scores only for the period 1997–2006 (Hanushek and Woessmann 2012b).

The shares of GDP invested in physical capital and human capital are conceptually identical in the growth model, but obtaining estimates of the investment rate for human capital is much more difficult. Time-series data on the investment/GDP ratio in non-OECD countries are available only for public schooling and are intermittent or unreliable in many countries. In addition, there is a considerable lag between the investment in a student's schooling and the student's entry into the workforce. This lag varies across countries, depending on the amount of schooling provided, the structure of the economy, and practices related to child employment.

For the average rate of investment in schooling variable (s_h) during 1985–2005, I use the average rate of investment during 1980–2000. I use an investment period that is 5 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 workforce.[10]

Breton (2013b) estimates human capital per adult in 1990 for 61 market economies from the shares of GDP invested in schooling from 1950 to 1985, using UNESCO data on expenditures for public education (percentage of GDP), increased by factors to account for private schooling, the opportunity cost of capital while students are in school, and students' forgone earnings. I use the data elements from these estimates to calculate

[10] 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 workforce is shorter at higher levels of schooling.

the average rate of investment in schooling, but with additional UNESCO data on expenditures in public education for the period 1990–2000.[11]

Dang and Rogers (2008) survey the extent of private tutoring in 23 countries, including estimates of either total expenditures or shares of the student population that participate in private tutoring. I include a dummy variable for tutoring expenditures in the eight countries that expend at least 0.5 percent of GDP on tutoring or that provide tutoring to at least 25 percent of the student population (Egypt, Greece, Hong Kong, Japan, South Korea, Singapore, Turkey, and the United Kingdom).

Hanushek and Woessmann's (2012a, 2012b) data provide test scores for 47 of the 61 countries in Breton's data set. After Jordan is excluded, the sample of countries with data for both test scores and investment rates is reduced to 46. These countries provide the basis for the initial comparison of the effect of average test scores and investment in schooling on growth rates.

I use Cohen and Soto's (2007) data on average schooling attainment in the population aged 15–64 to calculate average attainment in 1985, and I then separate the countries into subsets with more and less than 8 years of schooling attainment at the beginning of the growth period. Four of the 55 countries with test score data (Hong Kong, Iceland, Israel, and Taiwan) are not included in Cohen and Soto's average schooling attainment data. I estimate average attainment for these countries from Barro and Lee's (2013) data on average attainment in the population over 15.

I use economic data from Penn World Table 6.3 (Heston et al. 2009). I use the population over 15 as the proxy for workers, which I estimate from data on GDP per capita (rgdpch) and GDP per equivalent adult (rgdpqa). I then calculate n from the growth in this population over the 1985–2005 period. I use the average investment rate (ci) over the period 1985–2004 as the investment share s_k during the growth period. I assume $g = 0.01$, $\delta_h = 0.025$, and $\delta_k = 0.06$. The rate g is the average rate derived from the Solow residual during 1910–2000 in Breton (2013c). The depreciation rate for human capital is based on a 40-year work life, as described in Breton (2013b). The depreciation rate for physical capital is from Caselli (2005). The data used in the models are shown in the Appendix.

V. Empirical Results

The mathematical structure of the Mankiw et al. (1992) model implies that α and β are the shares of national income that accrue to the stock of physical capital (K) and human capital (H), and the rate of income convergence λ is mathematically related to the values of α, β, n, g, δ_k, and δ_h. One of the desirable features of their model relative to unstructured models, such as those specified by Hanushek and Woessmann, is that the

[11] I use the investment/GDP ratio in 1980, 1985, 1990, 1995, and 2000 to estimate the average ratio in each 5-year period and then average these four ratios to obtain the 20-year average.

validity of the Mankiw et al. model can be evaluated on the basis of whether the estimated parameters of the model are consistent with its theoretical predictions.

Table 1 presents ordinary least squares (OLS) estimates of the growth model in equation (4) and shows the implied values of α, β, and λ in the estimated coefficients. The first two columns in the table present the model's results with the test score data. Column 1 shows the effect with the 55-country data set, and column 2 shows the effect with the 46-country data set used to estimate the effect of investment in schooling in columns 3–5.

The estimated coefficients for the two models with the test score measure are very similar, have estimated coefficients that are highly statistically significant, and have implied parameters for the effect of physical capital, human capital, and the rate of convergence that are consistent with expectations for the Mankiw et al. model. The implied values of α are 0.35–0.37, which are very consistent with Bernanke and Gurkaynak's (2001) and Gollin's (2002) estimates of the share of national income accruing to physical capital, which is about 0.35 across countries. The implied values of β are 0.27, which is consistent with, but somewhat lower than, Breton's (2013b) estimates. The implied values of λ, the rate of convergence to the steady state, range from 0.016 to 0.018, which are consistent with theoretical expectations and with Barro's (2012) estimates of actual average convergence rates (1.7 percent) in 80 countries since the 1960s. Although not shown, the calculated parameter values are statistically significant at the 1 percent level.

TABLE 1
EFFECT OF HUMAN CAPITAL MEASURES ON GROWTH RATES, 1985–2005
DEPENDENT VARIABLE Δ LOG(GDP per Adult)

	Test Scores		Investment/GDP		Both	
	(1)	(2)	(3)	(4)	(5)	(6)
Countries	55	46	46	46	46	44
$\ln[s_k/(n+g+\delta_k)]$	.29*	.28**	.51**	.46**	.31**	.31**
	(.12)	(.09)	(.10)	(.07)	(.08)	(.08)
$\ln[s_h/(n+g+\delta_h)]$			.21*	.30**	.13	.21*
			(.10)	(.07)	(.09)	(.09)
Tutoring dummy				.22**	.11	.05
				(.08)	(.08)	(.08)
$\ln[\text{exptest}/(n+g+\delta_h)]$	.22**	.22**			.18**	.16**
	(.04)	(.03)			(.05)	(.05)
$\ln(Y/L - 1985)$	−.28**	−.30**	−.29**	−.32**	−.34**	−.37**
	(.05)	(.04)	(.08)	(.06)	(.06)	(.06)
R^2	.49	.60	.42	.52	.62	.64
Implied α	.37	.35	.50	.43	.32	.30
Implied β	.27	.27	.21	.28	.32	.35
Implied λ	.016	.018	.017	.019	.021	.023

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

Columns 3 and 4 present the OLS estimates of the effects of investment in schooling and private tutoring on growth rates. The results in column 3 without the tutoring dummy are all statistically significant and acceptable conceptually except the value of α, which is too high. When the tutoring dummy is added in column 4, the results become acceptable. All the coefficients, including the coefficient on the dummy variable, are statistically significant at the 1 percent level.

The results in columns 2 and 4, which are based on the same 46 countries, show that the model with test scores and the model with investment in schooling and tutoring provide very similar empirical results, although the model with test scores explains somewhat more of the variation in growth rates (R^2 = .60 vs. .52).

Columns 5 and 6 show the results when test scores and investment in schooling (and tutoring) are included in the same model. In column 5 the effects of investment in schooling and tutoring are positive, but only the effect of test scores is statistically significant. The effect of tutoring is only half as large when test scores are included, indicating that tutoring affects growth in part through its effect on test scores.[12]

In the 46-country sample, Hong Kong and Singapore are outliers in that they have high economic growth rates but relatively low rates of investment in schooling. Hong Kong became a Special Administrative Region of China in 1997, with additional legal protection for private investment destined for mainland China. Singapore is considered a tax haven. So the high growth rates in these jurisdictions may be due in part to the reporting of income that is earned elsewhere.

Column 6 shows the results for both measures in a 44-country sample that excludes Hong Kong and Singapore. In these results the effect of both test scores and investment in schooling is large and statistically significant. The implied values of the parameters in these models continue to be consistent with the expectations for the Mankiw et al. model.

Table 2 presents additional tests of the same models. Columns 1 and 4 show the results when dummy variables for the Asian and Latin American regions are included in the model. Hanushek and Woessmann (2012b) show that the effect of a Latin America dummy is negative in models that included adult schooling attainment in 1960, and they argue that this is due to the low quality of schooling in this region. In the results with the investment in schooling measure (col. 4), the coefficient on the Latin America dummy is negative, but it is small and not statistically significant, suggesting that Hanushek and Woessmann's (2012b) results were due to the misspecification of their growth model. The effect of the Asia dummy is larger and positive but not statistically significant with both measures. The estimated coefficients on the physical capital and human capital variables

[12] Alternatively, large investments in tutoring may be an indicator that the educational system is test based. If students work harder to raise their skills in these countries, it may be that the coefficient on tutoring is capturing the effect of the additional effort students expend in a test-based system rather than just the effect of the tutoring.

TABLE 2
SENSITIVITY TESTS: EFFECT OF HUMAN CAPITAL MEASURES ON GROWTH RATES, 1985–2005
DEPENDENT VARIABLE: Δ LN(GDP per Adult)

	Test Scores			Investment/GDP	
	(1)	(2)	(3)	(4)	(5)
Countries	55	46[a]	59	46	47
$\ln[s_k/(n+g+\delta_k)]$	.24*	.22*	.33*	.34**	.53**
	(.118)	(.10)	(.13)	(.10)	(.09)
$\ln[s_h/(n+g+\delta_h)]$				.27*	.30**
				(.10)	(.07)
Tutoring dummy				.15	.22**
				(.09)	(.08)
$\ln[\text{exptest}/(n+g+\delta_h)]$	.21**	.24**	.21**		
	(.05)	(.06)	(.04)		
$\ln(Y/L - 1985)$	−.22**	−.28**	−.29**	−.24*	−.35**
	(.07)	(.05)	(.06)	(.09)	(.07)
Latin America dummy	.05			−.04	
	(.09)			(.09)	
Asia dummy	.14			.14	
	(.10)			(.12)	
R^2	.51	.53	.51	.55	.54
Implied α	.33	.30	.40	.40	.45
Implied β	.29	.33	.25	.32	.27
Implied λ	.012	.016	.017	.014	.022

Note.—Robust standard errors are in parentheses.
[a] Excludes Latin America.
* Statistically significant at the 5 percent level.
** Statistically significant at the 1 percent level.

continue to be statistically significant, and the parameters continue to be acceptable when the regional dummies are included in the models.

Column 2 shows the results for the test score measure when the Latin American countries whose scores were calculated from regional tests are removed from the data set. These results are almost identical to the results for the full 55-country data set (col. 1 of table 1). Column 3 shows the model results for Hanushek and Woessmann's complete 59-country data set, including the four countries I had eliminated. The effect of test scores is smaller, but the results continue to provide acceptable, statistically significant parameters. Column 5 shows the model results for the investment in schooling measure when Jordan is included in the data set. The estimated parameters are similar to the parameters in the 46-country data set, but the effect of investment in schooling is slightly smaller.

The data patterns for the human capital measures in figures 2, 3, and 4 suggest that the estimated effects of test scores in table 1 could be the average of different effects in countries with high and low levels of schooling. Since test scores do not continue to rise once countries achieve 9 years of schooling attainment or a financial stock of human capital of $100,000 per adult, growth in the more educated countries may be caused by more investment in schooling rather than by increases in test scores.

To investigate this possibility, I separate the countries into two groups with less and more than 8 years of schooling attainment in 1985. I split the groups at 8 rather than 9 years to increase the sample size of the more educated countries. I use schooling attainment in 1985 to divide the countries because the flow measures during the growth period do not provide any indication of the level of education in the countries at the beginning of the growth period.

Table 3 presents the results for three subsets of the countries, those with less and more than 8 years of schooling in 1985 and those with test scores above 470 during 1964–2003. The results in the two subsets of countries with less and more schooling attainment show that the effects of higher test scores and more investment in schooling in the complete data set are due to the effects in countries that had less than 8 years of schooling in 1985. The implied values of the parameters are acceptable in this subset of countries, and all the human capital measures continue to be highly statistically significant.

The results for the more educated countries in columns 4 and 5 are very different. None of the measures of human capital have any statistical significance. The 24 countries with more than 8 years of schooling have an average test score of 498, with a range from 405 to 545, so there should be enough variation to explain growth rates if there were a strong relationship. As shown in column 4, there is no evidence that higher test scores affected growth rates in these countries during the 1985–2005 period. There are 20 countries with more than 8 years of schooling in 1985 that had data on rates of investment in schooling, and again there is no evidence that these rates affected growth rates.

The growth model explains about 60 percent of the variation in growth rates in these countries, but this variation is explained by the rate of income convergence, which is quite rapid. Since test scores and investment rates have no effect, the convergence effect is absolute rather than conditional. In these two subsets of countries, the results show slow conditional income convergence in the less educated countries and rapid absolute income convergence in the more educated countries.

In such a small data set, outliers can seriously affect the results. A review of the residuals in the regressions with investment rates reveals that three countries, Hong Kong, Ireland, and Norway, are outliers. Hong Kong has an unusual legal status in China, Ireland is a tax haven for companies in the European Union, and Norway's GDP is substantially affected by oil prices. These characteristics raised reported GDP growth rates beyond what can be explained by the variables in the model.

Columns 6 and 7 show the results when a dummy variable is included to control for the omitted factors contributing to higher growth rates in these three countries. In these two models the rate of investment in schooling is statistically significant at the 5 percent level, but the effect is relatively small and investment in physical capital still has no effect. In column 7 the effect of test scores on growth rates continues to be small and insignificant.

TABLE 3

EFFECT OF HUMAN CAPITAL MEASURES ON GROWTH RATES, 1985–2005

DEPENDENT VARIABLE: Δ LN(GDP per Adult)

	Schooling < 8 Years			Schooling > 8 Years				Test Score > 470
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Countries	31	26	26	24	20	20	20	24
$\ln[s_k/(n+g+\delta_k)]$	.27*	.46**	.25**	−.04	.04	.01	−.05	.08
	(.14)	(.07)	(.05)	(.17)	(.18)	(.15)	(.13)	(.18)
$\ln[s_h/(n+g+\delta_h)]$		.36**	.20		−.16	.12*	.11*	
		(.10)	(.11)		(.16)	(.04)	(.04)	
Tutoring dummy		.32**	.17*		−.05			
		(.10)	(.07)		(.11)			
$\ln[\text{exptest}/(n+g+\delta_h)]$	.22**		.21**	.07			.06	−.14
	(.06)		(.04)	(.07)			(.08)	(.17)
High-income dummy						.32**	.32**	
						(.05)	(.05)	
$\ln(Y/L - 1985)$	−.21**	−.30**	−.26**	−.52**	−.48**	−.56**	−.59**	−.54**
	(.06)	(.07)	(.04)	(.07)	(.10)	(.09)	(.11)	(.08)
R^2	.49	.63	.82	.64	.59	.86	.86	.66
Implied α	.39	.41	.27			.01		
Implied β	.31	.32	.45			.17		
Implied λ	.012	.018	.015	.037	.033	.041	.045	.039

Note.—Robust standard errors are in parentheses.

* Statistically significant at the 5 percent level.

** Statistically significant at the 1 percent level.

Column 8 shows the effect of test scores on growth in countries with average scores above 470. Again what we see in the results is absolute convergence in income levels, regardless of the level of test scores. Since the data sets for highly educated countries are so small (20–24 countries), these results cannot be considered definitive, but they call into question Hanushek and Woessmann's (2011a) claim that highly educated OECD countries can raise their growth rates by raising their students' average test scores.

It is instructive to examine why Hanushek and Woessmann (2011a) found a positive effect from test scores on growth in 24 OECD countries during 1960–2000, while this analysis does not find this effect in two slightly different sets of 24 countries during 1985–2005. There are several reasons for the different results, but two stand out. First, two OECD countries with high test scores, Japan and Switzerland, had much lower growth rates during 1985–2005 than during 1960–2000. Second, Mexico and Turkey, two OECD countries with low test scores and low growth rates during 1960–2000, are not included in the current analysis, while one non-OECD country, Chile, which had low test scores and a high growth rate during 1985–2005, is included in this analysis. In such small data sets, these changes are sufficient to completely change the statistical relationships in the results.

Figure 6 shows the relationship between growth rates in 1985–2005 and test scores for the 28 countries included in either of these analyses. An examination of the data in this figure reveals that the more educated OECD

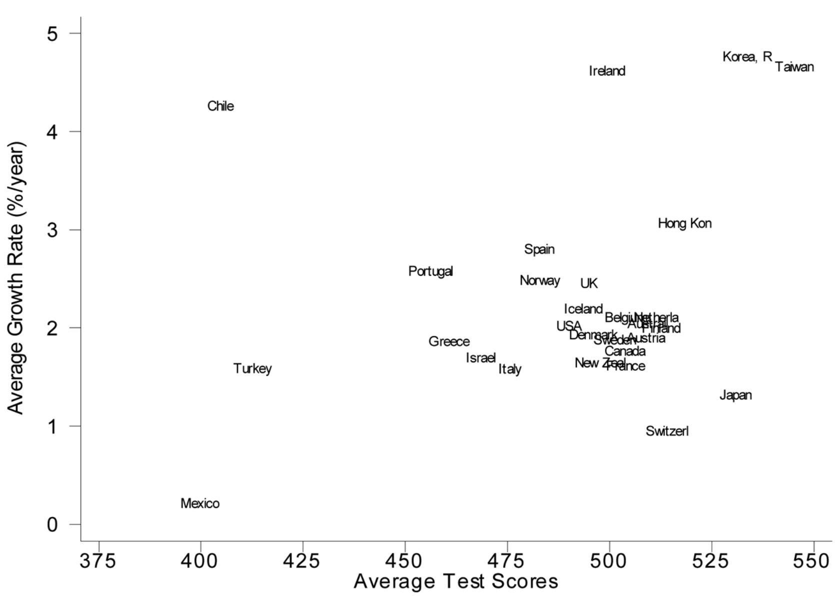

Figure 6.—Economic growth rates versus average test scores during 1985–2005

countries, excluding South Korea, had similar growth rates during this period, which were not related to their average test scores. This same pattern is evident in figure 2 in Hanushek and Woessmann (2011a) during the 1960–2000 period. In these analyses the statistical relationship between growth rates and test scores is very sensitive to the inclusion or exclusion of certain countries that are outliers relative to the traditional OECD group of highly educated countries.

There is a possible explanation for the lack of correlation between test scores and growth rates in countries with scores above 470. Experiments with students at different grade levels in the more educated countries show that average scores on the same international tests rise by about 32 points after students complete an additional year of schooling (Woessmann 2003; Jürges and Schneider 2004; Fuchs and Woessmann 2007). The implication is that intensive efforts to raise students' scores in some of the more educated countries accelerate by 1–2 years the increase in students' skills that otherwise occurs as students continue their schooling. It is not clear whether the skill advantage at ages 9–15 in the countries with higher average scores continues later or whether it diminishes with time. Since there is no noticeable effect of scores above 470 on economic growth in the results, the skill advantage may be temporary. Alternatively, it may be that in countries with average scores of at least 470, there are enough students with high skills to meet the economy's requirement for highly skilled workers.

The lack of any effect from test scores on growth rates in the more educated countries is not surprising given the data patterns in figures 2 and 3, but the small or negligible effect of investment in physical capital and human capital is unexpected. It appears that in these countries differences in other factors not included in the model had a larger effect on reported growth rates during the 1985–2005 period than differences in capital investment rates.

VI. Conclusions

Hanushek and Woessmann argue that students' cognitive skills at ages 9–15, as measured on international tests, determine a nation's rate of economic growth, and Hanushek and Woessmann (2008, 2012a) show that increased schooling attainment explains only one-third of the variation in growth rates explained by higher average test scores. Breton (2011) argues that their results are severely biased because their methodology is flawed.

In this paper I reexamine the effects of higher test scores and more schooling on growth rates using a dynamic neoclassical growth model, conceptually appropriate measures of schooling, and a time period more appropriate for the vintage of the test scores. I find that in the complete data set, either average test scores or more investment in schooling can explain growth rates over the 1985–2005 period. Test scores explain more of the variation in growth rates, but the variation explained by the two measures is similar once the effect of private tutoring is taken into account. These results are consistent with Hanushek and Woessmann'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 low and high levels of schooling attainment, I find that the effect of these measures during 1985–2005 occurs almost entirely in countries that had schooling attainment below 8 years at the beginning of the growth period. In these countries, either higher test scores or more investment in schooling and private tutoring explains a high share of the variation in economic growth rates.

I find that countries that expend considerable resources on private tutoring have higher growth rates. The results indicate that investment in schooling and private tutoring are substitutes for raising students' cognitive skills and for increasing growth rates in countries with average schooling attainment below 8 years. More research should be undertaken to determine whether it is the substantial private tutoring or the greater focus on testing (or both) in these countries that raises the scores.

In contrast, I find no evidence that increases in average test scores affect growth rates in countries with more than 8 years of schooling or in countries with average scores above 470. These results call into question Hanushek and Woessmann's (2011a) argument that OECD countries can raise their growth rates by increasing students' cognitive skills at ages 9–15.

I find some evidence that more investment in schooling raises growth rates in countries with more than 8 years of schooling, but the effect is smaller than in the less educated countries. Over the 1985–2005 period, income per adult in these countries tended to converge. Countries with lower income per adult grew faster, regardless of their rates of investment in physical capital and schooling or their level of test scores. The small effect of human capital in these results could be due to the diminishing returns to investment in human capital or to the failure of the human capital measures to adequately represent the human capital characteristics that are most relevant in highly educated countries.

Appendix

TABLE A1
DATA USED IN THE ANALYSIS

Country	dlnya	lnskngdk	testngdh	lnshngdh	lnya85	attain85	Score
Argentina	.2116	.6712	6.9127	.7861	9.6127	7.61	3.920
Australia	.3970	1.2473	8.0840	1.4971	10.2663	12.48	5.094
Austria	.3683	1.3124	8.2997	1.4167	10.2240	10.63	5.089
Belgium	.4098	1.2994	8.2981		10.1438	9.64	5.041
Bolivia	.1302	.1007	5.4342	.8415	8.5179	6.65	2.640
Brazil	.0354	.4415	6.4922	.8347	9.3914	5.40	3.638
Canada	.3409	1.1239	8.0651	1.5807	10.3044	11.98	5.038
Chile	.8398	.9403	6.9869	1.2188	9.1898	8.66	4.049
China	1.3197	1.1755	7.8849		7.6977		4.939
Colombia	.1829	.3992	6.9890	.6091	9.0548	5.46	4.152
Costa Rica	.2895	.8209	7.2695	.9067	9.3285	5.30	4.486
Cyprus	.6528	1.3632	7.5840		9.6342	7.57	4.542
Denmark	.3742	1.2996	8.2369	1.8099	10.2123	11.29	4.962
Ecuador	−.0464	.7537	5.6132	.6579	9.1042	6.73	2.852
Egypt	.4240	−.1135	6.7946	.8423	8.5388	3.94	4.030
El Salvador	.1159	.5338	6.0315	.3590	8.9121	4.07	3.243
Finland	.3873	1.3393	8.3591	1.4584	10.1044	10.11	5.126
France	.3108	1.1664	8.2062	1.5522	10.1602	11.46	5.040
Ghana	.1311	−.3988	6.3146	.3443	7.7003	4.59	3.603
Greece	.3607	1.2178	7.7638	.6352	9.9396	8.22	4.608
Guatemala	.0751	.6498	5.6343	−.0352	9.1219	3.29	2.855
Honduras	−.0713	.8884	5.1193		8.7115	4.37	2.453
Hong Kong	.6013	1.1204	8.1316	.5685	10.0968	9.78	5.185
Iceland	.4277	1.2920	7.9705		10.3711	9.35	4.936
India	.6280	.4913	7.1411	.5421	7.8853	2.88	4.281
Indonesia	.5324	.7450	6.7247		8.3088	4.89	3.880
Iran	.1959	.9780	6.9689	.5814	9.2600	3.01	4.219
Ireland	.9117	1.2394	8.0508	1.2472	9.8821	9.24	4.995
Israel	.3280	1.1021	7.4336		10.0175	11.68	4.686
Italy	.3051	1.3504	8.0235	1.2807	10.0810	8.53	4.758
Japan	.2512	1.5091	8.4690	1.2355	10.1984	11.57	5.310
Jordan	−.4545	.3033	6.7212	.8810	9.3464		4.264
Korea, Republic	.9410	1.5838	8.3232	.9367	9.2732	9.52	5.338
Malaysia	.7915	1.0116	7.6196	.9177	9.3186	7.10	4.838
Mexico	.0306	.8584	6.8286	.7073	9.6084	6.48	3.998
Morocco	.0539	.4238	6.0775	.9415	8.8684	1.96	3.327
Netherlands	.4094	1.1822	8.2874	1.4458	10.1867	10.50	5.115
New Zealand	.3171	1.0989	8.0367	1.4412	10.0338	10.87	4.978
Norway	.4857	1.4411	8.0417	1.6584	10.4627	11.94	4.830
Panama	.2159	.8375	5.8042	1.0040	9.1277	7.37	2.985
Paraguay	−.1160	.3776	5.7508	.1999	9.0226	5.59	3.031
Peru	.0387	.6741	5.9410	.6279	8.9932	6.93	3.125
Philippines	.1835	.4643	6.4181	.4231	8.5774	6.72	3.647
Portugal	.5040	1.4031	7.7078	1.1552	9.5473	5.74	4.564
Romania	−.0283	1.3161	7.7802		9.2145		4.562
Singapore	.8058	1.4634	8.0996	.7043	9.9257	6.12	5.330
South Africa	.0259	−.0539	5.9059		9.5138	5.40	3.089
Spain	.5488	1.3886	7.9823	1.0710	9.8881	7.95	4.829
Sweden	.3634	1.0459	8.2523	1.7655	10.1585	11.65	5.013
Switzerland	.1777	1.4119	8.3095	1.3467	10.4738	12.72	5.142
Taiwan	.9204	.9159	8.4317		9.3989	9.19	5.452
Thailand	.6900	1.3383	7.4796	.7715	8.6315	5.19	4.565
Tunisia	.4042	.4778	6.5832	.9768	9.0233	3.03	3.795

TABLE A1 (*Continued*)

Country	dlnya	lnskngdk	testngdh	lnshngdh	lnya85	attain85	Score
Turkey	.3062	.8486	6.9426	.0459	8.9009	4.69	4.128
United Kingdom	.4793	1.0216	8.1928	1.3926	10.0367	11.93	4.950
United States	.3920	1.0707	7.9706	1.5204	10.4798	12.37	4.903
Uruguay	.3855	.5588	7.4393	.7494	9.2012	7.26	4.300
Venezuela	−.0078	.7169	5.3923		9.7069		2.578
Zimbabwe	−.7856	.4052	6.9826		9.0107	6.18	4.107

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