Where the Education Went: Evidence that Effects of Increased Schooling on GDP are Substantially Lagged

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Abstract

We investigate why the economics literature has found no effect from increased schooling on GDP over short periods. We show that increases in GDP in 98 countries during five-year intervals from in the period 1980-2005 are positively correlated with the increases in adults´ average schooling during the prior 40 years. This relationship is similar to the relationship between increased schooling and increases in workers' earnings as they acquire experience on the job. We find that an additional year of schooling raised GDP by about 7% during the subsequent 40 years, but its effect during the initial five years was only 3%.

Key Words: Education; Economic Growth; Human Capital; Production Function; Mincer model

JEL Codes: O47; I25

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I. Introduction

For over 25 years researchers have used cross-country data to estimate the relationship between increased schooling and GDP growth. In recent studies researchers have presented evidence showing that increases in average schooling attainment across countries are associated with increases in GDP/worker that are substantially larger than the estimated effect of increased schooling on workers' earnings [Breton, 2013a, and 2015, Gennaioli, La Porta, Lopez-de-Silanes, and Shleifer, 2013, and Sunde and Vischer, 2015].

In contrast, over five or ten-year periods, researchers consistently find that there is no relationship or a negative relationship between increases in schooling and changes in GDP/worker. Pritchett [2001] presented some of these results in his well-known article, "Where Has All the Education Gone?"

Krueger and Lindahl [2001] investigated why cross-sectional and time-series estimates of the effect of schooling are so different. They concluded that the national data for schooling attainment (available at the time) had too much measurement error to permit the identification of any effect over five-year intervals. They found that over such short intervals differencing virtually eliminated any signal in the data.

Subsequently, Cohen and Soto [2007] and Barro and Lee [2013] revised the schooling data to reduce the measurement error. Recently, Delgado, Henderson, and Parmeter [2014] used a non-parametric model to again analyze the relationship between changes in schooling and economic growth over five and ten-year intervals. Over these intervals with several data sets and with different groups of countries, they again found either no relationship or a negative relationship between additional schooling and GDP growth. So if measurement error was the problem, the recent data revisions did not solve it.

Hanushek and Woessmann [2008] argue that the human capital measurement problem is much larger than simple mis-measurement of national levels of schooling. They maintain that average schooling attainment is an inherently flawed measure of human capital because schooling quality varies considerably across countries.

But their concerns appear to be exaggerated. As cited above, differences in average schooling explain cross-country differences in GDP extremely well. Moreover, Breton [2011 and 2013a] has shown that across countries schooling quality is correlated with average schooling attainment, so to some degree average attainment accounts for differences in both the quantity and the quality of schooling.[1]

More importantly, even if schooling attainment did not account for differences in schooling quality *across* countries, this limitation would not explain why researchers find no effect from increases in schooling *within* countries. If human capital created through schooling matters, schooling quality should be sufficiently stable within countries to ensure a positive correlation between increases in a country's average level of adult schooling and increases in GDP/worker over short time periods. Even with measurement error in the data, estimates using valid instruments should find an effect.

We think there is a better explanation for researchers' failure to find a positive relationship over short periods. In the existing studies researchers assume that the effect of increased schooling on GDP is immediate, so they include only recent changes in schooling when they estimate schooling's effect. If increases in schooling affect GDP over an extended period, then studies that examine only their immediate effect would find a small or negligible effect, even though the long run effect is large.

In this article we test the hypothesis that an increase in a country's average schooling attainment affects GDP gradually over an extended period. We begin by quantifying the cross-sectional relationship in middle-income countries between increased schooling and workers' earnings over their working lives. We then investigate whether this micro cross-sectional relationship explains the macro relationship over time. We find that increases in schooling in 98 countries over the prior 40 years can explain GDP growth over a series of five-year periods.

The implication of our findings is that the average schooling attainment of the population is a poor measure of human capital because it does not account for *how long* workers have had this level of schooling, and, therefore, for how many years their education and experience have interacted to improve their productivity on the job. Countries where young workers have recently raised their level of schooling could have a work force with the same average attainment as countries whose workers have been educated for a long time, but their level of human capital would be lower.

Delayed effects in macroeconomic analyses are usually estimated using VAR models. But average schooling levels within countries are so highly correlated over short intervals that VAR models cannot identify the lag pattern for schooling's effect on GDP. Estimates of

[1] Breton [2010, 2013a, and 2015] shows that across countries average schooling attainment is highly correlated with PPP-adjusted cumulative investment in schooling, so it implicitly accounts for schooling quality differences to some degree.

schooling's lagged effects in these models invariably exhibit oscillating signs on the lags that change with the number of lagged periods included in the model.

We employ an alternative strategy to identify the relationship between changes in schooling and subsequent changes in GDP over time. Workers' earnings increase withhat e experience at different rates depending on their levels of schooling. We use these relationships in workers' earnings data to convert the average schooling of the work force to an experience-weighted measure of human capital in each country.[2] We then estimate the effect on GDP/worker of changes in this measure and in physical capital/worker over five-year intervals.

We show that increases in this experience-weighted measure of human capital during five-year intervals are correlated with increases in GDP in 98 countries over the 1980-2005 period. We also show that after only minor adjustments to the experience weights, changes in this experience-weighted measure of human capital and changes in GDP are associated at a 1% level of statistical significance.

Our 2SLS estimates of a standard production function indicate that during the first five-year interval, the effect of increased schooling on GDP is only 25% of its eventual effect, which occurs after 40 years. These estimates indicate that an additional year of adult schooling increases GDP by only 3% during the first five years, even though on average it increases GDP by 7% over 40 years.

The implication of this finding is that schooling-based measures of a country's human capital that do not account for the interactive effect of schooling and experience have considerable measurement error. This error affects estimates of the effect of schooling on GDP to different degrees, depending on the structure of the growth model, the statistical technique employed, and the period of estimation. In OLS regressions using panel data and data differences over short intervals, this measurement error severely attenuates or eliminates any positive estimated effect of schooling. Since all countries experience similar lags in the effect of schooling on GDP, the failure to account for these lags does not impact the results in cross-sectional analyses as much it does in time series analyses.

Our analysis is focused entirely on the effect of increases in average schooling attainment on growth. But it is important to point out that the observed delay between increased schooling and the effect on GDP could apply equally to the effect of increases in students' skills, such as those measured in international tests.[3] Countries whose workers

[2] Thanks to Diego Restrepo-Tobon for suggesting this approach.
[3] It is important not to equate student test scores with school quality. Student test scores are substantially affected by family characteristics and cultural practices (e.g., private tutoring) both within and across countries, so differences in test scores cannot be attributed entirely to schooling quality [See Breton, 2015].

achieved high test scores only recently could have less human capital (and lower GDP) than countries whose workers obtained their high scores long ago.

This article makes several contributions to the literature. First, it quantifies the schooling-related increases in workers' earnings with experience in a group of middle-income countries. Second, it shows that the lagged relationship between increased schooling and increased earnings at the micro level is reflected at the macro level. Third, it provides an estimate of the time pattern for the initial and eventual increase in GDP resulting from an additional year of average schooling attainment. Fourth, it shows that while cross-sectional estimates of the effect of increased schooling on GDP in the literature are larger than the direct effect on workers' earnings, the difference is not at large as many researchers believe.

The rest of this article is organized as follows: Section II presents data showing the relationship between workers' earnings and experience at different levels of schooling. Section III presents the details of the methodology used in this study. Section IV presents the results. Section V compares the estimates in this study to the cross-sectional estimates in other studies. Section VI concludes.

II. Schooling and Workers' Earnings

Existing empirical studies assume that any effect of increased adult schooling on GDP occurs immediately, but they do not include any justification for this assumption. One possible rationale is that this same assumption is used for the effect of increased physical capital on GDP, and it greatly simplifies the analysis compared to an assumption that schooling has lagged effects.

The more likely rationale is that it parallels the assumption in the simplest version of the Mincer earnings function [Heckman, Lochner, and Todd, 2003]. In this function the effects of schooling and experience are independent, so the entire effect of increased schooling on worker's earnings is immediate:

1) $\text{Log(earnings)} = \alpha_0 + \alpha_1 \text{ schooling} + \alpha_2 \text{ experience} + \alpha_3 \text{ experience}^2$

This model has been estimated throughout the world, and the empirical results are similar and statistically-significant across countries [Montenegro and Patrinos, 2014]. In these studies an additional year of schooling is typically associated with a 10 percent increase in earnings.

Even though the simplest Mincer model provides results that are easy to interpret and statistically attractive, its assumption that schooling and experience are independent appears to be incorrect. There is considerable evidence that earnings increase more with experience at higher levels of schooling, which means that a conceptually-correct earnings model would include a positive interactive effect between schooling and experience. In other words, some of the effect of additional schooling on workers' earnings is lagged.

Dougherty and Jimenez [1991] test whether the effects of primary and secondary schooling on earnings are independent of experience in Brazilian survey data for 1980. They found that the coefficients on the interaction terms between primary and secondary schooling and experience and experience^2 are statistically significant at the 1% level.

Heckman, Lochner, and Todd [2003] present evidence that the effects of schooling and experience on workers' earnings in the U.S. were not independent in 1980 and 1990. Heckman, Lockner, and Todd [2008] present evidence that experience has a greater effect on U.S. workers' incomes at higher levels of schooling.

Since incomes tend to rise with experience at all levels of schooling, and since all U.S. workers have some schooling, it is not clear from the U.S. data whether the effect of experience on earnings is mostly related to schooling, or mostly independent of schooling. The magnitude of the interactive effect between schooling and experience can only be ascertained in countries, such as Brazil, where a substantial share of the work force has no schooling.

Figure 1 shows Breton's [2013a] estimate of the average relationship between workers' earnings and experience at three levels of schooling and with no schooling in four middle-income countries in 1990. The relationship is presented as an index, with the initial earnings of a worker with no schooling and no experience as the base (1.0). The patterns in the figure show very clearly that earnings rise with experience, *but only for workers who have completed at least primary schooling*. The earnings of workers with no schooling show almost no increase with experience.[4]

The implication of these patterns is that increases in earnings on the job are at least partly a *delayed effect* of an increase in a worker's level of schooling. While it is undoubtedly true that rising salaries are a result of increasing worker productivity related to experience and training on the job, the data in Figure 1 indicate that the increase in productivity with experience is dependent on having completed some level of schooling. This delayed effect of additional schooling on workers' earnings is likely to be reflected in an analogous delay in its effect on GDP.

[4] The patterns in Figure 1 are based on employee salaries in the public and private sectors. They do not include workers' earnings in the informal sector, but they are indicative of the relationships between earnings and levels of schooling and experience in the overall labor market.

Figure 1

Workers' Earnings vs. Experience by Level of Schooling

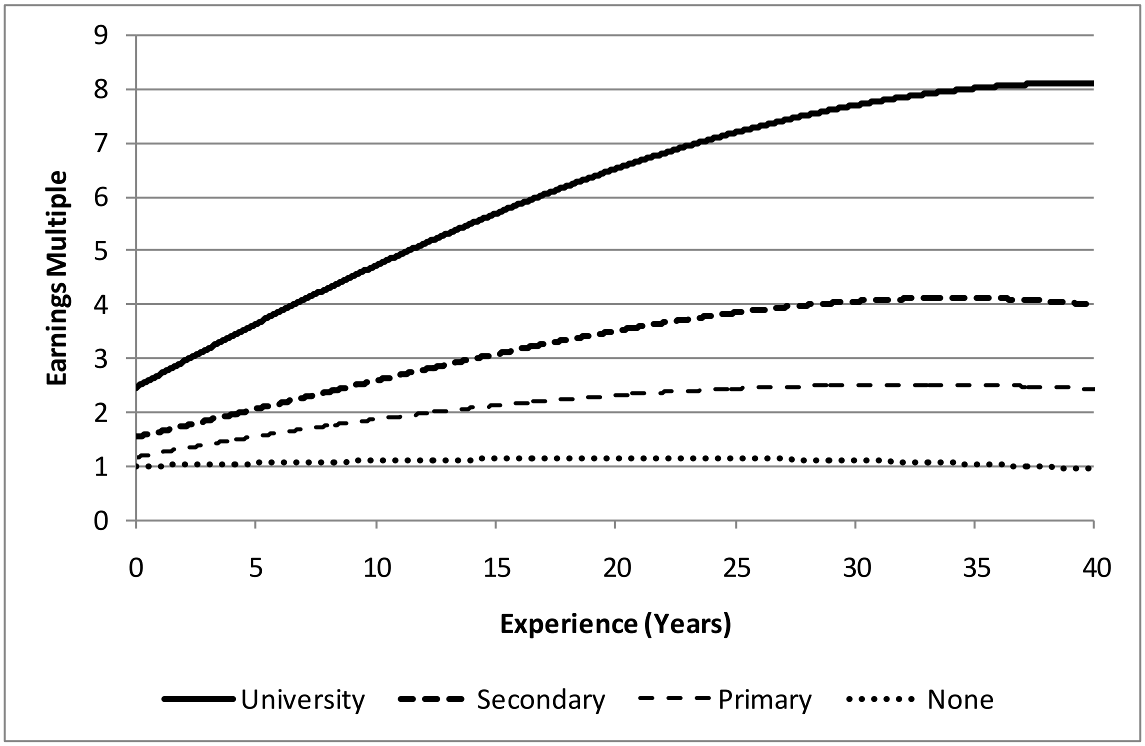
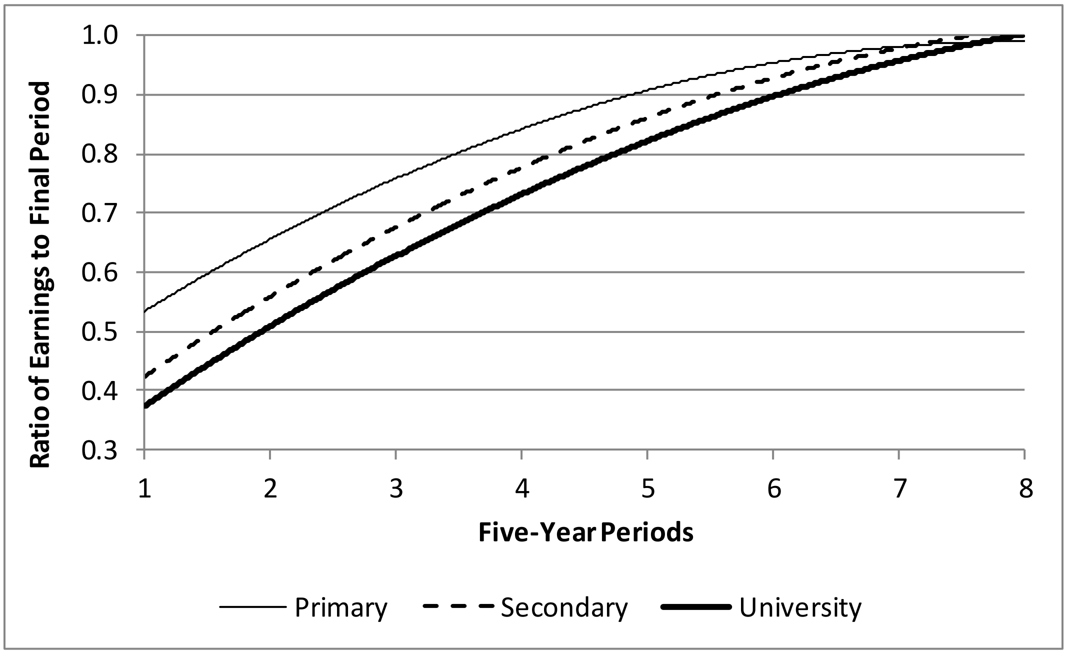


Figure 2 converts the data in Figure 1 to a ratio of a worker's incremental earnings in each five-year interval to the worker's final incremental earnings at the primary, secondary, and university levels of schooling. It shows that during the first five years on the job, a worker with a university education in 1990 earned only 37% of his/her final salary after 40 years. The Figure also shows that workers with only primary and secondary schooling have lower increases in earnings over time relative to their initial earnings.

The implication of these patterns is that the average delay in the effect of schooling on GDP could be higher in more educated countries, since these countries have a higher share of workers with more schooling. Still, the delays in the increase in earnings are similar enough across the three levels of schooling that a multi-country analysis using a single pattern to convert average schooling by age cohort to experience-weighted human capital should provide a much more accurate measure of human capital than average adult schooling with no adjustments for experience.

Figure 2

Ratio of Workers' Earnings Over Time to Final Earnings by Schooling Level



III. Methodology

The conceptual model used in the analysis is a standard Cobb-Douglas production function, in which GDP/worker (Y/L) across countries is a function of the stocks of physical capital/worker (K/L), human capital/worker (H/L), and total factor productivity (A_0e^{gt}). We estimate the model in log form:

2) $\log (Y/L)_{it} = \alpha \log (K/L)_{it} + \beta \log (H/L)_{it} (+ (1-\alpha-\beta) \log (A_0) + (1-\alpha-\beta)g\, t$

We use either average schooling attainment or the experience-weighted average attainment of the adult population (years) to represent the human capital of the work force, assuming a log-linear relationship between human capital and either measure of schooling:

3) $\text{Log}(H/L) = c + \gamma/\beta$ Schooling

Breton [2013 and 2015] shows that across countries the stock of human capital/adult (H/L) estimated from cumulative investment in schooling fits this log-linear relationship with average years of schooling very well. This relationship holds because the (average) unit costs of schooling typically rise exponentially with increases in a country's average level of schooling.[5]

Substitution of the relationship in (3) into (2) yields a log-linear "macro-Mincer" production function [Krueger and Lindahl, 2001]:

4) $\text{Log}(Y/L) = c + (1-\alpha-\beta)g\,t + \alpha \log(K/L) + \gamma\ \text{schooling}$

Estimation of this model across countries over different time periods does not provide consistent estimates of α and γ. Log (K/L) and average schooling attainment are highly correlated across countries (0.81 - 0.84 in this study), so measurement error in the variables changes the covariance matrix in econometric estimations, which causes substantial variation in the estimated coefficients.

Since estimates of K/L generally have less measurement error than the schooling proxy for human capital, OLS estimates of (4) yield estimates of α that are biased upward and estimates of γ that are biased downward. The downward bias in γ may be offset by upward bias due to the endogeneity of schooling. Both types of bias can be reduced using instruments for the physical capital and schooling variables.

Improvements in the accuracy of the schooling-based measure of human capital should lead to less attenuation bias in the OLS estimate of γ, raising γ and reducing α. Our methodology relies on this phenomenon to determine whether the effect of increased adult schooling on GDP is delayed and to identify the lag pattern. Superior specifications of the lag pattern should increase the estimate of γ and reduce the variance in its estimate, particularly in differenced estimates of the model over short time intervals.

We estimate the production function using cross-country data for GDP/adult, physical capital/adult and schooling/adult for the period 1975-2005. Since the estimated coefficient on the schooling variable is sensitive to measurement error in the physical capital data, the estimate differs when the production function is estimated with different sets of economic data. We estimate the production function using economic data from Penn World Table (PWT) 6.3, 7.1, and 8.1 [Heston, Summers, and Aten, 2009 and 2012, and Feenstra, Inklaar, and Timmer, 2015] to provide a thorough test of our hypothesis. We use the na version of PWT 8.1 for this test, because Feenstra et. al recommend this version for use in growth analyses.

Even though the three PWT data sets are all based on very similar National Accounts data, they adjust these data for differences in purchasing power in different ways. The PWT 6.3

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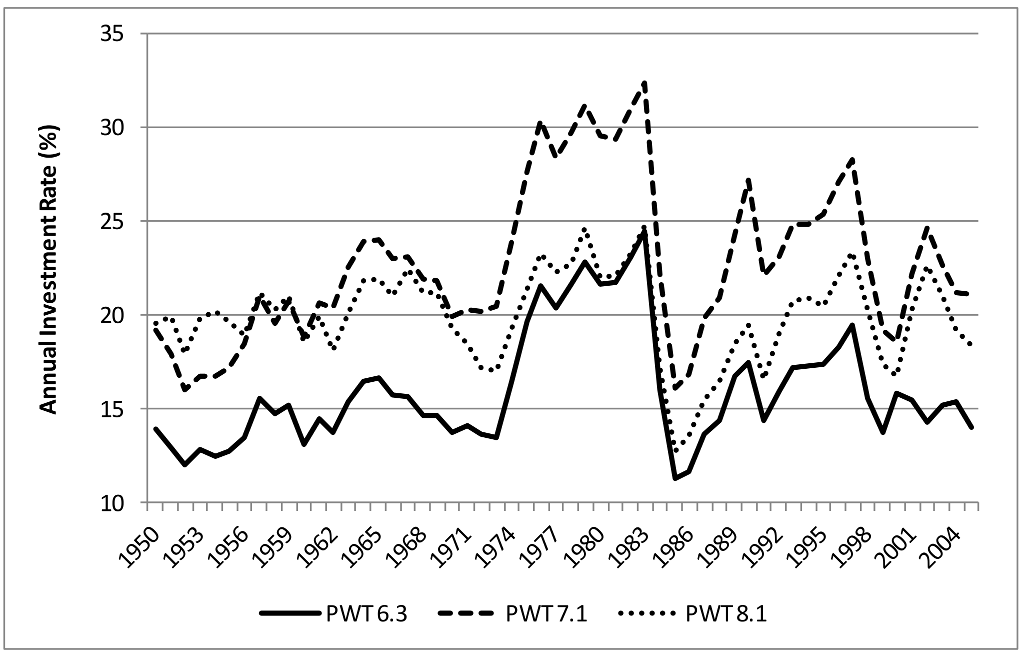
[5] It is this log-linear relationship between GDP and average schooling that permits cross-country analyses to find a large effect of schooling on GDP even though the quality of schooling is higher in countries with higher average schooling attainment.

data are adjusted using International Comparison Program (ICP) prices collected between 1970 and 1996. The PWT 7.1 and 8.1 (na) data are adjusted using ICP prices collected in 2005, which for investment in lower-income countries were very different from earlier prices [Breton, 2012]. Breton and Garcia [2016] present evidence that the new methodology used in ICP 2005 underestimates construction prices in lower-income countries, which caused an overestimate of investment rates. As an example, Figure 3 shows investment rates for the Philippines for 1950-2005. The investment rates are much higher in PWT 7.1 and 8.1 than in PWT 6.3.

Figure 3

Investment Rates for the Philippines in PWT 6.3, 7.1, and 8.1



Most of the analyses in the literature use versions PWT 6.1 to 6.3. In addition, since *a priori* the PWT 6.3 investment rates appear to have less non-random measurement error, we use the PWT 6.3 data to determine the most appropriate experience weights for our weighted-schooling measures of human capital. We then check the robustness of our weighting pattern by estimating the production function with the same experience-weighted schooling data and with economic data from PWT 7.1 and 8.1.

PWT 6.3 and 7.1 include the same data series and the same countries. PWT 8.1 has different data series and a different set of countries, so we use the data from these series in different ways. With the data in PWT 6.3 and 7.1, we calculate the physical capital stock in 1975, 1985, 1990, 1995, 2000, and 2005 using the PWT investment rates (ci) during the prior 25 years and a 0.05 annual depreciation rate. We limit the calculation period for these stocks to 25 years because the investment data begin in 1950. The PWT 8.1 data include estimates of the physical capital stock, so we use these stock estimates in our analysis.

We create the experience-weighted human capital data from the Barro and Lee [2015] data for the schooling of the population over age 25 during 1975-2005. We use these data rather than the over age 15 data because in most countries many students are still in school between the ages of 15 and 25.

Barro and Lee's over-25 data are excellent for our purpose because they include the average schooling in each five-year age cohort and the size of each cohort for the population between the ages of 25 and 64 in five-year intervals. These data permit a very accurate calculation of the experience-weighted level of human capital across countries as each five-year cohort increases its productivity with experience on the job. We use the age 25-64 schooling data to represent the schooling of the work force in each country over our estimation period. Each five-year cohort's human capital in each country is estimated as its fraction of schooling's eventual full effect on productivity. The fraction in the age 60-64 final cohort is equal to 1.0 and the fractions in the earlier, less-experienced cohorts are less than 1.0. The end result of these adjustments is a proxy for the human capital of the work force in each country measured in units of average years of schooling of workers with 40 years of experience.

We would not expect to find a statistically significant empirical relationship between factor inputs and GDP in economies whose production is not determined primarily by profit maximization in markets for inputs and outputs. For this reason we exclude countries from the analysis that were not market economies throughout the period. We also exclude countries that lacked sufficient data to calculate the physical capital stock during at least the 1985-2005 period or that were not included in the Barro and Lee [2015] data.

This left us with three panels of data with two compositions. The data sets created from PWT 6.3 and 7.1 are unbalanced panels that include 98 countries. Since PWT 6.3 and 7.1 do not have investment rates for some low-income countries prior to 1960, only 57 of the 98 countries in these panels have capital stock data in 1975 and only 66 have these data in 1980. The data are complete for 1985-2005. The data set created from PWT 8.1 is a balanced panel of 94 countries for the full period 1975-2005.

We began the analysis by specifying an experience-weighted pattern for human capital similar to the pattern of increases in workers' earnings in Figure 2. In this pattern the human capital in each five-year cohort of workers is about 40, 55, 65, 75, 85, 93, 98, and 100 percent of the human capital in the 60-64 age cohort. We examined the effect of this experience-weighted measure of schooling on GDP and then examined the effect of slightly different patterns until we identified a pattern that provides an estimate of the effect of additional schooling with higher statistical significance.

We found that patterns beginning with a lower fraction of eventual productivity have slightly larger estimated effects on GDP and/or higher statistical significance than the earnings pattern in Figure 2. The pattern with the best statistical results has productivity levels of 25, 45,60,75,85,93, 98, and 100 percent of human capital in the 60-64 age cohort. Since the experience-weighting adjustment reduces the average years of schooling in the first seven cohorts of the work force, the average values of the experience-weighted human capital measures are lower than a country's average years of schooling attainment. These lower average values increase the estimated effect of a year of schooling in the regressions that use these measures. We adjust the average effect of a year of schooling on GDP for the experience-adjusted measures (downward) so the comparison with the effect of average schooling is comparable in the results.

Economic time series typically are non-stationary of degree one. Although the number of time periods in our panel is short, the time series components could have unit roots, which could create bias in the estimated coefficients.

Since our interest is in examining whether changes in schooling affect GDP over five-year periods, we estimate our models in differences. This differencing has the added benefit that it eliminates any linear trends in the data that could bias the estimated effects of physical capital and schooling. We tested the differenced data using the Im-Pesaran-Shin test and confirmed that for the three variables in the model the null hypothesis that all the data series contain a unit root is rejected at the 1% level. Our physical capital and schooling variables could be endogenous, so we estimated them first with RE GLS and then with 2SLS using instruments created from lagged values of the physical capital and schooling variables. Conceptually, growth in GDP during a five-year period is unlikely to cause growth in the physical capital stock during a period five years earlier. Growth in GDP during a five-year period is even more unlikely to cause growth in levels of schooling in cohorts educated up to 40 years earlier.

IV. Results

Table 1 presents estimates of the model with the PWT 6.3 data, using different assumptions and statistical techniques with three human capital measures. The measures are average schooling attainment and the two experience-weighted schooling measures described above. The first experience-weighted measure assumes human capital in the first five-year cohort is 40 percent of the human capital in the age 60-64 cohort. The second measure assumes the first cohort is 25 percent of the human capital in the age 60-64 cohort. The table is organized to facilitate a comparison of the effects, with the three measures side by side for each estimation method.

Table 1
Effect of Schooling on GDP with PWT 6.3 Data
[Dependent variable is D.log(GDP/adult]

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Observations	515	515	515	417	417	417	417	417	417
Technique	RE GLS	RE GLS	RE GLS	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS
	AvSch	**405565**	**254560**	**AvSch**	**405565**	**254560**	**AvSch**	**405565**	**254560**
Instruments				L1DS L3DS L1DK	L1DLS L3DLS L1DK	L1DLS L3DLS L1DK	L1DK	L1DK	L1DK
D.Log(K/A)	0.48* (.06)	0.48* (.06)	0.47* (.06)	0.33* (.08)	0.28* (.09)	0.27* (.09)	0.30* (.09)	0.29* (.09)	0.28* (.09)
D.Schooling Measure	0.03 (.01)	0.06* (.02)	0.07* (.02)	0.01 (.03)	0.10 (.04)	0.12* (.04)	0.02 (.01)	0.06* (.02)	0.08* (.02)
R^2	.26	.27	.27	.22	.21	.21	.21	.22	.22
α	.48*	.48*	.47*	.33*	.28*	.28*	.30*	.29*	.28*
Adj. γ[a]	.03	.04*	.04*	.01	.07	.08*	.02	.04*	.05*

*Statistically significant at the 1 percent level.
[a]The average of the 25-45-60 weighted measure is 0.61 and the average of the 40-55-65 weighted measure is 0.67 of average schooling.

Note: Robust standard errors in parentheses

In our production function α is the share of national income that accrues to physical capital, which Gollin [2002] estimates to be about 0.35 on average across countries. We include our estimate of this measure in the table to show whether each model provides acceptable estimates of α. We also include our estimate of γ, adjusted to account for the lower average value of our experience-weighted measures. Since micro earnings studies show that each year of schooling raises workers' earnings about 10%, and these earnings in the aggregate are about 65% of GDP, we expect adjusted γ to be at least 0.065.

The first three columns show the results for random effects generalized least squares. The estimates of α are similar for all three measures (0.47-0.48), and they substantially exceed the expected level of 0.35. The estimates of γ are all positive, but they are lower than the expected level of 0.065. The effect with the two experience-weighted measures is larger (.04) than with the average schooling measure, and both experience-weighted measures are statistically significant at the 1% level.

The next three columns (4-6) show the results with 2SLS, using the first lag of the change in physical capital/adult and the first and third lags of the change in the schooling measures as instruments. We do not use the second lag of the change in schooling measures because a Sargan test showed that it is not a valid instrument. Using the first lag of the capital variable as an instrument shortens the estimation period by five years to 1980-2005, reducing the sample size from 515 to 417. Including the lags for the schooling measures as instruments does not affect the sample size because the schooling data are available for a longer historic period.

The 2SLS model provides much more acceptable values for α (0.27 -0.33), and these estimates continue to be statistically significant. This model finds no effect from average schooling attainment, but it finds an effect larger than the expected effect (0.065) for the experience-weighted schooling measures. The estimate with the 40-55-65 measure is statistically significant at the 5% level, and the estimate with the 25-45-60 measure is larger (8%) and statistically significant at the 1% level.

We interpret these results to indicate that the effect of increased schooling on GDP is substantially delayed and the effect in the initial five-year interval is only 25% of its eventual effect. With the 25-45-60 measure, the final effect of a year of additional schooling on GDP at age 60-64 is 12.4%, the initial effect at age 25-29 is 25% of this effect, or 3.1%, and the average effect is 12.4/.61 = 7.6%.

The standard STATA post-estimation tests for 2SLS estimation indicate that the physical capital variable is endogenous and the schooling-based variables are not. The tests also indicate that the three instruments are strong (F>10) and that they are valid. In theory the rejection of the null for the endogeneity of the schooling-based variables means that they do not require instrumentation to control for endogeneity bias.

Columns 7-9 show the 2SLS results that include an instrument only for the physical capital variable. The estimates of α are similar and statistically significant, but the estimates of γ with the experience-based measures are lower (0.05) than the instrumented estimates. Again the estimates using the experience-weighted measures are larger than with the average schooling measure and are statistically significant at the 1% level. The adjusted estimate of γ with the 25-45-60 measure is larger than with the 40-55-65 measure, which we interpret to mean that the 25-45-60 measure has less measurement error, so its estimated coefficient exhibits less attenuation bias.

Since instruments reduce attenuation bias, we interpret the entire set of results to indicate that the 25-45-60 experience-weighted measure is the most accurate measure of human capital of the three measures and that the 2SLS estimate of its effect is the least biased.

This measure indicates than an additional year of schooling raises GDP by 8% over the working life of a cohort of workers.

Table 2 shows the same model estimates using PWT 7.1 data. The estimates of α and γ are slightly different, but they exhibit the same patterns for the three human capital measures as in the PWT 6.3 data, with the 25-45-60 measure again providing the best results. These estimates show that the effect of the experience-weighted schooling variables is robust to changes in the economic data series used for the analysis.

Table 2
Effect of Schooling on GDP with PWT 7.1 Data
[Dependent variable is D.log(GDP/adult]

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Observations	515	515	515	417	417	417	417	417	417
Technique	RE GLS	RE GLS	RE GLS	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS
	AvSch	**405565**	**254560**	**AvSch**	**405565**	**254560**	**AvSch**	**405565**	**254560**
Instruments				L1DS L3DS L1DK	L1DLS L3DLS L1DK	L1DLS L3DLS L1DK	L1DK	L1DK	L1DK
D.Log(K/A)	0.44* (.05)	0.43* (.05)	0.43* (.05)	0.28* (.08)	0.22* (.08)	0.21* (.08)	0.26* (.08)	0.23* (.08)	0.23* (.08)
D.School Attainment	0.03 (.01)	0.06* (.02)	0.07* (.02)	0.03 (.03)	0.12* (.05)	0.15* (.05)	0.03 (.01)	0.07* (.02)	0.09* (.02)
R^2	.23	.24	.24	.19	.17	.17	.18	.19	.19
A	.44*	.43*	.43*	.28*	.22*	.21*	.26*	.23*	.23*
Adj. γ^a	.03	.04*	.04*	.03	.08*	.09*	.03	.05*	.05*

*Statistically significant at the 1 percent level.
[a]The average of the 25-45-60 weighted measure is 0.61 and the average of the 40-55-65 weighted measure is 0.67 of average schooling.

Note: Robust standard errors in parentheses

Nevertheless, the estimates of the models using the PWT 7.1 data are less satisfactory from a conceptual standpoint. The estimates of α are consistently lower by about 0.06 compared to the PWT 6.3 data, so they are considerably lower than expected. In addition, all of the models explain less of the variation in GDP/adult than the models using the PWT 6.3 data.

The estimates of γ are higher using the PWT 7.1 data. In the 2SLS estimate of the 25-45-60 experience-weighted measure, each additional year of schooling raises GDP by 9%. This estimate appears to be biased upward, because the estimated coefficient on physical capital (0.21) is so low that it must be biased downward. This low estimate of the effect of changes in physical capital on GDP during 1980-2005 is consistent with the very high PWT 7.1 rates of investment in lower-income countries during this period, as shown for the Philippines in Figure 3.

Table 3 shows the same model estimates using PWT 8.1 data. The estimates of α and γ are different, but they exhibit patterns for the three human capital measures that are similar to those obtained with the PWT 6.3 and 7.1 data. The 25-45-60 measure again provides the best results.

Table 3
Effect of Schooling on GDP with PWT 8.1 Data
[Dependent variable is D.log(GDP/adult]

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Observations	658	658	658	564	564	564	564	564	564
Technique	RE GLS	RE GLS	RE GLS	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS
	AvSch	**405565**	**254560**	**AvSch**	**405565**	**254560**	**AvSch**	**405565**	**254560**
Instruments				L1DS L3DS L1DK	L1DLS L3DLS L1DK	L1DLS L3DLS L1DK	L1DK	L1DK	L1DK
D.Log(K/A)	0.60* (.04)	0.59* (.04)	0.57* (.04)	0.35* (.06)	0.32* (.07)	0.32* (.07)	0.33* (.06)	0.32* (.07)	0.32* (.07)
D.Schooling Measure	0.01 (.01)	0.03 (.01)	0.04* (.02)	0.03 (.03)	0.07 (.03)	0.08* (.03)	0.02 (.01)	0.05* (.02)	0.06* (.02)
R^2	.36	.36	.36	.29	.28	.29	.28	.28	.32
Α	.60*	.59*	.59*	.35*	.32*	.32*	.33*	.32*	.32*
Adj. γ^a	.01	.02	.03	.03	.05	.05*	.02	.04*	.04*

*Statistically significant at the 1 percent level.
[a]The average of the 25-45-60 weighted measure is 0.61 and the average of the 40-55-65 weighted measure is 0.67 of average schooling.

Note: Robust standard errors in parentheses

The estimates of α in the models using the PWT 8.1 data are higher and the standard errors are lower than in the estimates obtained using PWT 6.3 and 7.1. The 2SLS estimates of α using the PWT 8.1 data are the best estimates from a conceptual standpoint, in that they are closer to 0.35. All of the models using PWT 8.1 explain more of the variation in changes in GDP/adult than the models using the PWT 6.3 and 7.1 data.

The estimates of γ are lower using the PWT 8.1 data than in the other data sets. In the 2SLS estimate of the 40-55-65 and 25-45-60 experience-weighted measures, each additional year of schooling is associated with an increase in GDP of 5%. The estimate for the 25-45-6- measure is statistically significant at the 1% level. The estimate with average schooling attainment is much smaller and again not statistically significant.

Overall the three PWT data sets provide adjusted estimates of γ with the experience-weighted schooling data that range from 0.05 to 0.09. All of these estimates using the 25-45-60 measure are statistically-significant at the 1% level. After adjusting for labor's share of national income, these estimates of the effect of additional schooling on GDP ($\gamma \approx 0.07$) are similar to the typical effect on workers' earnings (10%) in labor market studies.

V. Comparison with Cross-Sectional Estimates

Earlier we observed that cross-sectional estimates of the relationship between schooling and GDP typically are larger than the estimates of the effect of additional schooling on workers' personal earnings. However, the cross-sectional estimates often are not comparable because their magnitude is affected by the form of the growth model and the human capital data used in the estimation. Reduced forms of the production function and models that do not include physical capital provide larger estimates of the effect of schooling on GDP. The estimates from these models must be adjusted to compare them to the effect of schooling in the standard production function.

The estimated production functions in the literature using schooling attainment data are typically in two forms, the standard form shown in (4) and a reduced form that is a function of the capital/output ratio:

5) $\text{Log}(Y/L) = C + (1\text{-}\alpha\text{-}\beta)g/(1\text{-}\alpha)\ t + \alpha/(1\text{-}\alpha)\ \log(K/Y) + \gamma/(1\text{-}\alpha)\ \text{schooling}$

In this model the coefficient on schooling is $\gamma/1\text{-}\alpha$, so estimates of the effect of schooling using this function must be reduced by the factor $1\text{-}\alpha$ to compare them to the estimated coefficient in the standard function.

Some analyses omit the physical capital variable altogether. These models are mis-specified unless they have explanatory variables that substitute for physical capital. The estimated coefficient on schooling in these models is biased upward quite substantially because schooling is highly correlated with the missing physical capital variable. In these models a rough estimate of the coefficient on schooling is 2γ. Mankiw, Romer, and Weil [1992]] showed that when one type of capital is excluded from the production function in a cross-sectional analysis, the estimated coefficient on the remaining capital variable approximately doubles.

Breton [2013a and 2015] used financial measures of human capital stocks and flows to estimate the production function. These measures correspond to the standard production function in (2) or to a dynamic version of this model. These models produce an estimate of β that must be converted to a comparable estimate of the effect of average schooling attainment.

Table 4 presents the estimated coefficients on schooling in six recent cross-sectional estimates of the effect of increased schooling on GDP. The period and form of the model used for these estimates varies, but all of the estimates are cross-sectional or panel estimates that include the cross-country relationship. As a consequence, all of these estimates implicitly estimate the long-run effect of schooling.

Table 4
Estimated Coefficients on Schooling in Cross-Sectional Income Models

Study	Period	Coefficient Estimated				Implied
		β	γ	γ/(1-α)	2γ	γ
Gennaioli, et. al, 2013	2005				.24*	.12
Cohen & Soto, 2007	1960-90			.13		.08
Breton, 2013a	1990	.36				.12
Breton, 2013b	2000			.16		.10
Sunde & Vischer, 2015	1970-2000		.13			.13
Breton, 2015	1985-2005	.28				.09

*Adjusted down from 0.28 to account for their lower measure of average schooling attainment.

Gennaioli, et. al. [2013] found that each additional year of schooling is associated with a 28% increase in regional income. Their estimate is not comparable to the other estimates because their measure of average schooling attainment only includes years related to completion of a degree. Since their average schooling level is 16% lower than Cohen and Soto's estimate of average schooling, a comparable estimate of the effect of an additional year of schooling on income in their study is 24%. Since they did not include physical capital in their model, this estimate could be about double the implied value of γ, which would be 0.12.

Breton [2013a and 2015] estimates the effect of human capital (β) on GDP, rather than the effect of years of schooling (γ), but Breton [2013a] presents evidence that for the Cohen and Soto [2007] schooling data, $\beta/\gamma = 0.32$. Using this conversion ratio his estimates of the effect of a year of schooling are 0.09 and 0.12.

Cohen and Soto [2007] and Breton [2013b] estimated the reduced form model in (5), so their estimated coefficients are higher by a factor of 1-α. The implied values of γ in these estimates are only slightly larger than the estimate in workers' earnings studies.

Sunde and Vischer [2015] obtain a variety of results with different data sets, but their results are not exactly comparable to the others. They include additional variables in their model, including a lagged income variable. The inclusion of this variable with a negative coefficient in their results may bias the effect of additional schooling in their estimates.

So while estimated coefficients in the recent literature vary considerably, the implied values of γ in these estimates range from 0.08 to 0.13. These estimates are larger than the estimates of the effect of schooling on GDP in workers' earnings studies (0.065) and larger than the less biased estimates in this study (.05-.08), so they imply that the external effects of schooling are 20-100% of the direct effects.

Acemoglu, Gallego, and Robinson [2014] argue that cross-sectional estimates of the effect of schooling are likely to be biased upward because they include effects that should be attributed to differences in institutions. They cite several studies within countries that find small or non-existent external effects of schooling on workers' incomes to support their argument.

Our estimates of the effect of increased schooling on GDP exclude any erroneous effects actually due to institutions in the cross-sectional estimates because estimates of the effects of changes in schooling over time eliminate the effects of relatively stable institutions. As a consequence, our lower estimates of the effect of increased schooling support Acemoglu et al.'s argument.

VI. Conclusions

For over 25 years researchers have failed to find a positive effect from increases in schooling on GDP over five-year periods. After performing one of these analyses and finding only negative correlations, Pritchett [2001] famously asked, "Where has all the education gone?" In this paper we provide an answer to this question.

The existing analyses assume that the entire effect of schooling on GDP is immediate. We examine whether the effect of schooling on GDP may be substantially delayed to determine whether this delay can explain the difference between the short run and long run estimates of the effect of increased schooling on GDP in the literature.

We first show that workers' earnings in middle-income countries only increase with experience if the workers have prior schooling. We conclude that increases in worker productivity on the job are at least partly a delayed effect of their prior schooling.

We then examine whether a delayed effect of schooling on productivity may also characterize the relationship between increased schooling and GDP in 98 countries. We find that this pattern can explain changes in GDP that an assumed immediate effect cannot. But we also find that a steeper pattern in which the initial effect of schooling on GDP is slightly lower than in the earnings studies (25% of its eventual effect) yields an estimated effect on GDP that is slightly larger and slightly more statistically significant. The clear implication is that the increase in GDP during a five-year period is affected by the increase in the average schooling attainment of the population during the prior 40 years.

We find that an additional year of schooling in the population age 25 raises GDP across 98 countries by about 7% on average over 40 years, but the effect in the initial five-year period is only 3%. Since average schooling typically increases by less than a year over a five-year period, the effect of an increase in the average schooling of adults age 25 on GDP during the initial five-year period is very small.

So this is where the education went. It had a positive effect on GDP about equal to the aggregate effect on workers' earnings, but as with workers' earnings, this effect is not immediate. As a consequence, it is appropriate to consider worker productivity improvements on the job as partly a delayed effect of the workers' earlier schooling.

The estimated effect of schooling on GDP in this article do not provide any evidence to support the existence of external effects from schooling. The estimated effects on GDP are very similar to the aggregate estimated effect of increased schooling on workers' personal incomes. But we also show that the estimates of the effect of increased schooling on GDP in cross-sectional analyses are not as large or as varied as they appear to be, once these estimates are adjusted for differences in the structure of the model used in their estimation.

Overall the empirical research now indicates that an additional year of schooling, holding physical capital/worker constant, increases GDP by about 3% in the short run and 7-13% in the long run. While the magnitude of the long-run effect is still uncertain, the micro and macro literatures are much more consistent and much closer to a consensus now than 15 years ago when Pritchett [2001] concluded that an increase in average schooling attainment reduces economic growth.

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