A Note on Schooling in Development Accounting

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September 2011

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Abstract

How much would output increase if underdeveloped economies were to increase their levels of schooling? We describe a non-parametric upper bound on the increase in output that can be generated by more schooling. Our upper bound is valid for an arbitrary number of schooling levels with arbitrary patterns of substitution/complementarity, as long as the aggregate production function remains weakly concave. We also quantify this upper bound for all economies with the necessary data. Upper bound output increases are fairly sizable as percentages of the initial output, but they are tiny compared to the output gap with the US.

1 Introduction

Low GDP per worker goes together with low schooling. For example, in the country with the lowest output per worker in 2005, half the adult population has no schooling at all and only 5% has a college degree (Barro and Lee, 2010). In the country with output per worker at the 10th percentile, 32% of the population has no schooling and less than 1% a college degree. In the country at the 25th percentile, the population shares without schooling and with a college degree are 22% and 1% respectively. On the other hand, in the USA, the share of the population without schooling is less than 0.5% and 16% have a college degree.

How much of the output gap between developing and rich countries can be accounted for by differences in the quantity of schooling? A robust result in the development-accounting literature, first established by Klenow and Rodriguez-Clare (1997) and Hall and Jones (1999), is that only a relatively small fraction of the output gap between developing and rich countries can be attributed to differences in the quantity of schooling. This result is obtained assuming that workers with different levels of schooling are perfect substitutes in production (e.g. Klenow and Rodriguez-Clare, 1997; Hendricks, 2002). Perfect substitution among different schooling levels is necessary to explain the absence of large cross-country differences in the return to schooling if technology differences are assumed to be Hick-neutral.

There is by now a consensus that differences in technology across countries or over time are generally not Hicks-neutral and that perfect substitutability among different schooling levels is rejected by the empirical evidence, see Katz and Murphy (1992), Angrist (1995), Goldin and Katz (1998), Autor and Katz (1999), Krusell et al. (2000), Ciccone and Peri (2005), and Caselli and Coleman (2006) for example. Once the assumptions of perfect substitutability among schooling levels and Hicks-neutral technology differences are discarded, can we still say something about the output gap between developing and rich countries attributable to schooling?

The parametric production function approach taken in the development accounting literature becomes impractical when imperfect substitutability among different schooling levels is allowed for. Estimating elasticities of substitution is notoriously difficult (e.g. McFadden et al, 1978; Angrist, 1995; Duffy et al., 2004). As a result, most estimates assume that there are only two imperfectly substitutable production factors. Recent microeconomic evidence suggests that dividing the labor force in just two skill groups misses out on important margins of substitution (Autor et al., 2006; Goos and Manning, 2007). The available cross-country data on schooling attainment is quite detailed by now, see

Barro and Lee (2010). Hence, it is desirable to use an approach that allows for more than two differentiated types of labor without restricting patterns of substitutability/complementarity.

We therefore abandon the parametric production function approach and instead exploit that when aggregate production functions are weakly concave in inputs, assuming perfect substitutability among different schooling levels yields an upper bound on the increase in output that can be generated by more schooling. Hence, although the assumption of perfect substitutability among different schooling levels is rejected empirically, the assumption remains useful in that it yields an upper bound on the output increase through increased schooling no matter what the true pattern of substitutability/complementarity among schooling levels may be. This basic observation does not appear to have been made in the development accounting literature. It is worthwhile noting that the production functions used in the development accounting literature satisfy the assumption of weak concavity in inputs. Hence, our approach yields an upper bound on the increase one would obtain using the production functions in the literature. Moreover, the assumption of weakly concave aggregate production functions is fundamental for the development accounting approach as it is clear that without it, inferring marginal factor productivities from factor prices cannot yield interesting insights into the factors accounting for differences in economic development.

The intuition for why the assumption of perfect substitutability yields an upper bound on the increase in output generated by more schooling is easiest to explain in a model with two schooling levels, schooled and unschooled. In this case, an increase in the share of schooled workers has, in general, two types of effects on output. The first effect is that more schooling increases the share of more productive workers, which increases output. The second effect is that more schooling raises the marginal productivity of unschooled workers and lowers the marginal productivity of schooled workers. When assuming perfect substitutability between schooling levels, one rules out the second effect. This implies an overstatement of the output increase when the production function is weakly concave, because the increase in the marginal productivity of unschooled workers is more than offset by the decrease in the marginal productivity of schooled workers. The result that increases in marginal productivities produced by more schooling are more than offset by decreases in marginal productivities continues to hold, as long as the production function is weakly concave, for an arbitrary number of schooling types with any pattern of substitutability/complementarity. As a result, assuming perfect substitutability among different schooling levels yields an upper bound on the increase in output generated by more schooling.

From the basic observation that the assumption of perfect substitutability among schooling levels yields an upper bound on output increases and with a few ancillary assumptions – chiefly, that physical capital adjusts to the change in schooling so as to keep the interest rate unchanged – we derive a formula that computes the upper bound using exclusively data on the structure of relative wages of workers with different schooling levels. We apply our upper-bound calculations to two data sets. In one data set of approximately 90 countries we use evidence on Mincerian returns to proxy for the structure of relative wages among the seven attainment groups. In a smaller data set of four Latin American countries we have detailed wage data by attainment group, so we can estimate relative wages exactly.

Some highlights of the results are as follows. The upper-bound on a typical developing country's income gain from reaching a distribution of schooling attainment similar to the US is sizeable when seen as a proportion of initial income. For example, the country at the 90th percentile of the distribution of (upper bound) income gains experience a doubling of income per worker. However these gains appear nearly trivial when measured as a proportion of the existing income gap with the US. For example for the country at the 10th percentile of the income distribution would bridge *at most* 5% of its income gap with the US by achieving the US education distribution.

The latter result is clearly similar to current conclusions from development accounting (e.g. Klenow and Rodriguez-Clare, 1997; Hall and Jones, 1999; Caselli, 2005). The similarity is not surprising because these studies assume that workers with different schooling attainment are perfect substitutes, and thus end up working with a formula that is very similar to our upper bound.[1] In this sense, our paper could be seen as a reinterpretation of existing development accounting studies as upper bound calculations on the role of schooling capital.

The rest of the paper is organized as follows. Section 2 derives the upper bound. Section 3 shows the results from our calculations. Section 4 concludes.

[1] Our calculations are closest in spirit to Hall and Jones, who conceive the development accounting question very much in terms of counterfactual output increases for a given change in schooling attainment. Other studies use mostly variance decompositions. Such decompositions are difficult once skill-biased technology and imperfect substitutability among skills are allowed for.

2 Derivation of the Upper Bound

Suppose that output Y is produced with physical capital K and workers with different levels of schooling attainment,

$$Y = F(K, L_0, L_1, ...L_m) \tag{1}$$

where L_i denotes workers with schooling attainment $i = 0, .., m$. The (country-specific) production function F is assumed to be increasing in all arguments, subject to constant returns to scale, and weakly concave in inputs. Moreover, F is taken to be twice continuously differentiable.

The question we want to answer is: how much would output per worker in a country increase if workers were to have more schooling. Specifically, define s_i as the share of the labor force with schooling attainment i, and $\mathbf{s} = [s_0, s_1.., s_{i,...}s_m]$ as the vector collecting all the shares. We want to know the increase in output per worker if schooling were to change from the current schooling distribution $\mathbf{s}^1$ to a schooling distribution $\mathbf{s}^2$ with more weight on higher schooling attainment. For example, $\mathbf{s}^1$ could be the current distribution of schooling attainment in India and $\mathbf{s}^2$ the distribution in the US. Our problem is that we do not know the production function F.

To start deriving an upper bound for the increase in output per worker that can be generated by additional schooling, denote physical capital per worker by k and note that constant returns to scale and weak concavity of the production function in (1) imply that changing inputs from $(k^1, \mathbf{s}^1)$ to $(k^2, \mathbf{s}^2)$ generates a change in output per worker $y^2 - y^1$ that satisfies

$$y^2 - y^1 \leq F_k(k^1, \mathbf{s}^1)(k^2 - k^1) + \sum_{i=0}^{m} F_i(k^1, \mathbf{s}^1)(s_i^2 - s_i^1) \tag{2}$$

where $F_k(k^1, \mathbf{s}^1)$ is the marginal product of physical capital given inputs $(k^1, \mathbf{s}^1)$ and $F_i(k^1, \mathbf{s}^1)$ is the marginal product of labor with schooling attainment i given inputs $(k^1, \mathbf{s}^1)$. Hence, the linear expansion of the production function is an upper bound for the increase in output per worker generated by changing inputs from $(k^1, \mathbf{s}^1)$ to $(k^2, \mathbf{s}^2)$.

We will be interested in percentage changes in output per worker and therefore divide both sides of (2) by y^1,

$$\frac{y^2 - y^1}{y^1} \leq \frac{F_k(k^1, \mathbf{s}^1)k^1}{y^1}\left(\frac{k^2 - k^1}{k^1}\right) + \sum_{i=0}^{m} \frac{F_i(k^1, \mathbf{s}^1)}{y^1}(s_i^2 - s_i^1). \tag{3}$$

Assume now that factor markets are approximately competitive. Then

(3) can be rewritten as

$$\frac{y^2-y^1}{y^1} \leq \alpha^1\left(\frac{k^2-k^1}{k^1}\right)+(1-\alpha^1)\left(\sum_{i=0}^{m}\left(\frac{w_i^1}{\sum_{i=0}^{m} w_i^1 s_i^1}\right)(s_i^2-s_i^1)\right) \quad (4)$$

where α^1 is the physical capital share in income and w_i^1 is the wage of workers with schooling attainment i given inputs $(k^1, \mathbf{s}^1)$. Since schooling shares must sum up to unity we have $\sum_{i=0}^{m} w_i^1(s_i^2-s_i^1) = \sum_{i=1}^{m}(w_i^1 - w_0^1)(s_i^2 - s_i^1)$ and $w^1 = w_0^1 + \sum_{i=1}^{m}(w_i^1 - w_0^1)\, s_i^1$ and, (4) becomes

$$\frac{y^2-y^1}{y^1} \leq \alpha^1\left(\frac{k^2-k^1}{k^1}\right)+(1-\alpha^1)\left(\frac{\sum_{i=1}^{m}\left(\frac{w_i^1}{w_0^1}-1\right)(s_i^2-s_i^1)}{1+\sum_{i=1}^{m}\left(\frac{w_i^1}{w_0^1}-1\right)s_i^1}\right). \quad (5)$$

Hence, the increase in output per worker that can be generated by additional schooling and physical capital is below a bound that depends on the physical capital income share and the wage premia of different schooling groups relative to a schooling baseline.

2.1 Optimal Adjustment of Physical Capital

In (5), we consider an arbitrary change in the physical capital intensity. As a result, the upper bound on the increase in output that can be generated by additional schooling may be off because the change in physical capital considered is suboptimal given schooling attainment. We now derive an upper bound that allows physical capital to adjust optimally (in a sense to be made clear shortly) to the increase in schooling. To do so, we have to distinguish two scenarios. A first scenario where the production function is weakly separable in physical capital and schooling, and a second scenario where schooling and physical capital are not weakly separable.

2.1.1 Weak Separability between Physical Capital and Schooling

Assume that the production function for output can be written as

$$Y = F(K, G(L_0, L_1, ...L_m)) \quad (6)$$

with F and G characterized by constant returns to scale and weak concavity. This formulation implies that the marginal rate of substitution in production between workers with different schooling is independent of the physical capital intensity. While this separability assumption is not innocuous, it is weaker than the assumption made in most of the development accounting literature.[2]

We also assume that as the schooling distribution changes from the original schooling distribution $\mathbf{s}^1$ to a schooling distribution $\mathbf{s}^2$, physical capital adjusts to leave the marginal product of capital unchanged, $MPK^2 = MPK^1$. This could be because physical capital is mobile internationally or because of physical capital accumulation in a closed economy.[3] With these two assumptions we can develop an upper bound for the increase in output per worker that can be generated by additional schooling, that depends on the wage premia of different schooling groups only. To see this, note that separability of the production function implies

$$\frac{y^2 - y^1}{y^1} \leq \alpha^1 \left(\frac{k^2 - k^1}{k^1}\right) + (1 - \alpha^1)\left(\frac{G(\mathbf{s}^2) - G(\mathbf{s}^1)}{G(\mathbf{s}^1)}\right). \tag{7}$$

The assumption that physical capital adjusts to leave the marginal product unchanged implies that $F_1(k^1/G(\mathbf{s}^1), 1) = F_1(k^2/G(\mathbf{s}^2), 1)$ and therefore $k^2/G(\mathbf{s}^2) = k^1/G(\mathbf{s}^1)$. Substituting in (7),

$$\frac{y^2 - y^1}{y^1} \leq \frac{G(\mathbf{s}^2) - G(\mathbf{s}^1)}{G(\mathbf{s}^1)}. \tag{8}$$

Weak concavity and constant returns to scale of G imply, respectively, $G(\mathbf{s}^2) - G(\mathbf{s}^1) \leq \sum_{i=0}^{m} G_i(\mathbf{s}^1)(s_i^2 - s_i^1)$ and $G(\mathbf{s}^1) = \sum_{i=0}^{m} G_i(\mathbf{s}^1) s_i^1$, where G_i denotes the derivative with respect to schooling level i. Combined with (7), this yields

$$\frac{y^2 - y^1}{y^1} \leq \frac{\sum\limits_{i=0}^{m} G_i(\mathbf{s}^1)(s_i^2 - s_i^1)}{\sum\limits_{i=0}^{m} G_i(\mathbf{s}^1) s_i^1} = \frac{\sum\limits_{i=1}^{m} \left(\frac{w_i^1}{w_0^1} - 1\right)(s_i^2 - s_i^1)}{1 + \sum\limits_{i=1}^{m} \left(\frac{w_i^1}{w_0^1} - 1\right) s_i^1} \tag{9}$$

where the equality makes use of the fact that separability of the production function and competitive factor markets imply

$$\frac{G_i(\mathbf{s}^1)}{G_0(\mathbf{s}^1)} = \frac{F_2(k^1, G(\mathbf{s}^1)) G_i(\mathbf{s}^1)}{F_2(k^1, G(\mathbf{s}^1)) G_0(\mathbf{s}^1)} = \frac{w_i^1}{w_0^1}. \tag{10}$$

[2] Which assumes that F in (6) is Cobb-Douglas, often based on Gollin's (2002) finding that the physical capital income share does not appear to vary systematically with the level of economic development.

[3] See Caselli and Feyrer (2007) for evidence that the marginal product of capital is not systematically related to the level of economic development.

Hence, assuming weak separability between physical capital and schooling, the increase in output per worker that can be generated by additional schooling is below a bound that depends on the wage premia of different schooling groups relative to a schooling baseline.

2.1.2 Non-Separability between Physical Capital and Schooling

Since Griliches (1969) and Fallon and Layard (1975), it has been argued that physical capital displays stronger complementaries with high-skilled than low-skilled workers (see also Krusell et al., 2000; Caselli and Coleman 2002, 2006; and Duffy et al. 2004). In this case, schooling may generate additional productivity gains through the complementarity with physical capital. We therefore extend our analysis to allow for capital-skill complementarities and derive the corresponding upper bound for the increase in output per worker that can be generated by additional schooling.

To allow for capital-skill complementarities, suppose that the production function is

$$Y = F(Q\left[U(L_0, .., L_{\tau-1}), H(L_\tau, .., L_m)\right], G\left[K, H(L_\tau, .., L_m)\right]) \tag{11}$$

where F, Q, U, and H are characterized by constant returns to scale and weak concavity, and G by constant returns to scale and $G_{12} < 0$ to ensure capital-skill complementarities. This production function encompasses the functional forms by Fallon and Layard (1975), Krusell et al.(2000), Caselli and Coleman (2002, 2006), and Goldin and Katz (1998) for example (who assume that F, G are constant-elasticity-of-substitution functions, that $Q(U, H) = U$, and that U, H are linear functions).[4] The main advantage of our approach is that we do not need to specify functional forms and substitution parameters, which is notoriously difficult (e.g. Duffy et al., 2004).

To develop an upper bound for the increase in output per worker that can be generated by increased schooling in the presence of capital-skill complementarities, we need an additional assumption compared to the scenario with weak separability between physical capital and schooling. The assumption is that the change in the schooling distribution from $\mathbf{s}^1$ to $\mathbf{s}^2$ does not strictly lower the skill ratio H/U, that is,

$$\frac{H(\mathbf{s}_2^2)}{U(\mathbf{s}_1^2)} \geq \frac{H(\mathbf{s}_2^1)}{U(\mathbf{s}_1^1)}, \tag{12}$$

[4] Duffy et al. (2004) argue that a special case of the formulation in (11) fits the empirical evidence better than alternative formulations for capital-skill complementarities used in the literature.

where $\mathbf{s}_1 = [s_0, ..., s_{\tau-1}]$ collects the shares of workers with schooling levels strictly below τ and $\mathbf{s}_2 = [s_\tau, ..., s_m]$ collects the shares of workers with schooling levels equal or higher than τ (we continue to use the superscript 1 to denote the original schooling shares and the superscript 2 for the counterfactual schooling distribution). For example, this assumption will be satisfied if the counterfactual schooling distribution has lower shares of workers with schooling attainment $i < \tau$ and higher shares of workers with schooling attainment $i \geq \tau$. If U, H are linear function as in Fallon and Layard (1975), Krusell et al.(2000), Caselli and Coleman (2002, 2006), and Goldin and Katz (1998), the assumption in (12) is testable as it is equivalent to

$$\frac{\sum_{i=0}^{\tau-1} \frac{w_i^1}{w_0^1}(s_i^2 - s_i^1)}{\sum_{i=0}^{\tau-1} \frac{w_i^1}{w_0^1} s_i^1} \leq \frac{\sum_{i=\tau}^{m} \frac{w_i^1}{w_\tau^1}(s_i^2 - s_i^1)}{\sum_{i=\tau}^{m} \frac{w_i^1}{w_\tau^1} s_i^1}, \tag{13}$$

where we used that competitive factor markets and (11) imply $w_i^1/w_0^1 = F_1 Q_1 U_i / F_1 Q_1 U_0 = U_i/U_0$ for $i < \tau$ and $w_i^1/w_\tau^1 = (F_1 Q_2 + F_2 G_2) H_i$ $/ (F_1 Q_2 + F_2 G_2) H_\tau = H_i/H_\tau$ for $i \geq \tau$.

It can now be shown that the optimal physical capital adjustment implies

$$\frac{k^2 - k^1}{k^1} \leq \frac{H(\mathbf{s}_2^2) - H(\mathbf{s}_2^1)}{H(\mathbf{s}_2^1)}. \tag{14}$$

To see this, note that the marginal product of capital implied by (11) is

$$MPK = F_2 \left(1, \frac{G\left[\frac{k}{H(\mathbf{s}_2)}, 1\right]}{Q\left[\frac{U(\mathbf{s}_1)}{H(\mathbf{s}_2)}, 1\right]}\right) G_1 \left[\frac{k}{H(\mathbf{s}_2)}, 1\right]. \tag{15}$$

Hence, holding k/H constant, an increase in H/U either lowers the marginal product of capital or leaves it unchanged. As a result, k/H must fall or remain constant to leave the marginal product of physical capital unchanged, which implies (14).

Using steps that are similar to those in the derivation of (9) we obtain

$$\frac{U(\mathbf{s}_1^2) - U(\mathbf{s}_1^1)}{U(\mathbf{s}_1^1)} \leq \frac{\sum_{i=0}^{\tau-1} \frac{w_i^1}{w_0^1}(s_i^2 - s_i^1)}{\sum_{i=0}^{\tau-1} \frac{w_i^1}{w_0^1} s_i^1}, \tag{16}$$

where we used $w_i^1/w_0^1 = (F_1Q_1U_i)/(F_1Q_1U_0) = H_i/H_\tau$ for $i < \tau$, and

$$\frac{k^2 - k^1}{k^1} \leq \frac{H(\mathbf{s}_2^2) - H(\mathbf{s}_2^1)}{H(\mathbf{s}_2^1)} \leq \frac{\sum_{i=\tau}^{m} \frac{w_i^1}{w_\tau^1}(s_i^2 - s_i^1)}{\sum_{i=\tau}^{m} \frac{w_i^1}{w_\tau^1} s_i^1}, \tag{17}$$

where we used $w_i^1/w_\tau^1 = (F_1Q_2H_i + F_2G_2H_i) / (F_1Q_2H_\tau + F_2G_2H_\tau) = H_i/H_\tau$ for $i \geq \tau$ and (14). These last two inequalities combined with (11) imply

$$\frac{y^2 - y^1}{y^1} \leq \beta^1 \left(\frac{\sum_{i=0}^{\tau-1} \frac{w_i^1}{w_0^1}(s_i^2 - s_i^1)}{\sum_{i=0}^{\tau-1} \frac{w_i^1}{w_0^1} s_i^1} \right) + (1 - \beta^1) \left(\frac{\sum_{i=\tau}^{m} \frac{w_i^1}{w_\tau^1}(s_i^2 - s_i^1)}{\sum_{i=\tau}^{m} \frac{w_i^1}{w_\tau^1} s_i^1} \right), \tag{18}$$

where β^1 is the share of workers with schooling levels $i < \tau$ in aggregate income. Hence, with capital-skill complementarities, the increase in output per worker that can be generated by additional schooling is below a bound that depends on the income share of workers with schooling levels $i < \tau$ and the wage premia of different schooling groups relative to two schooling baselines (attainment 0 and attainment τ).

To get some intuition on the difference between the upper bound in (9) and in (18), note that the upper bound in (18) would be identical to the upper bound in (9) if, instead of β^1, we were to use the share of workers with schooling levels $i < \tau$ in aggregate wage income. Hence, as the share of workers with low schooling in aggregate wage income is greater than their share in aggregate income, (18) puts less weight on workers with low schooling and more weight on workers with more schooling than (9) (except if there is no physical capital). This is because of the stronger complementarity of better-schooled workers with physical capital.[5]

Because obtaining estimates of β^1 is beyond the scope of the present paper in the rest of the paper we focus on the upper bound in (9) rather than in (18).

[5]The main difficulty in estimating β^1 is defining threshold schooling τ. If τ was college attainment, the upper bound could be quite large because developing countries have very low college shares and the increase in college workers would be weighted by the physical capital income share plus the college-worker income share (rather than the much smaller college-worker income share only). If τ is secondary school, the difference with our calculations would be small.

2.2 The Upper Bound with a Constant Marginal Return to Schooling

The upper bound on the increase in output per worker that can be generated by additional schooling in (9) becomes especially simple when the wage structure entails a constant return to each additional year of schooling, $(w_i - w_{i-1})/w_{i-1} = \gamma$. This assumption is often made in development accounting, because for many countries the only data on the return to schooling available is the return to schooling estimated using Mincerian wage regressions (which implicitly assume $(w_i - w_{i-1})/w_{i-1} = \gamma$). In this case the upper bound for the case of weak separability between schooling and physical capital in (9) becomes

$$\frac{y^2 - y^1}{y^1} \leq \frac{\sum_{i=1}^{m}((1+\gamma)^{x_i} - 1)(s_i^2 - s_i^1)}{1 + \sum_{i=1}^{m}((1+\gamma)^{x_i} - 1)s_i}. \tag{19}$$

where x_i is years of schooling corresponding to schooling attainment i (schooling attainment 0 is assumed to entail zero years of schooling).

2.3 Graphical Intuition and Link to Development Accounting

At this point it is worthwhile discussing the relationship between our analysis of schooling's potential contribution to output per worker differences across countries and the analysis in development accounting. Following Klenow and Rodriguez-Clare (1996), development accounting usually assesses the role of schooling for output per worker under the assumption that workers with different schooling attainment are perfect substitutes in production. This assumption has been made because it is necessary to explain the absence of large cross-country differences in the return to schooling when technology is Hick-neutral (e.g. Klenow and Rodriguez-Clare, 1996; Hendricks, 2002). But there is now a consensus that differences in technology across countries or over time are generally not Hicks-neutral and that perfect substitutability among different schooling levels is rejected by the empirical evidence, see Katz and Murphy (1992), Angrist (1995), Goldin and Katz (1998), Autor and Katz (1999), Krusell et al. (2000), Ciccone and Peri (2005), Caselli and Coleman (2006). Moreover, the elasticity of substitution between more and less educated workers found in this literature is rather low (between 1.3 and 2, see Ciccone and Peri, 2005 for a summary).

Hence, the assumption of perfect substitutability among different schooling levels often made in development accounting should be discarded. But this does not mean that the findings in the development accounting literature have to be discarded also. To understand why note that the right-hand side of (9) —our upper bound on the increase in output per worker generated by more schooling assuming weak separability between physical capital and schooling—is exactly equal to the output increase one would have obtained under the assumption that different schooling levels are perfect substitutes in production, $G(L_0, L_1, ...L_m) = a_0L_0 + a_1L_1 + ... + a_mL_m$. Hence, although the assumption of perfect substitutability among different schooling levels is rejected empirically, the assumption remains useful in that it yields an upper bound on the output increase that can be generated by more schooling.

While weak concavity of the production function implies that the increase in output generated by more schooling is always smaller than the output increase predicted assuming perfect substitutability among schooling levels, it also implies that the decrease in output generated by a fall in schooling is always greater than the decrease predicted under the assumption of perfect substitutability. To develop a graphical intuition for these results, consider the case of just two labor types, skilled and unskilled, and no capital,

$$Y = G(L_U, L_H) \tag{20}$$

where G is taken to be subject to constant returns to scale and weakly concave. Suppose we observe the economy at a skilled-labor share s^1 and want to assess the increase in output per worker generated by increasing the skilled-worker share to s^2. The implied increase in output per worker can be written as

$$\begin{aligned} y(s^2) - y(s^1) &= G(1 - s^2, s^2) - G(1 - s^1, s^1) \\ &= \int_{s^1}^{s^2} \frac{\partial G(1 - s, s)}{\partial s} ds \\ &= \int_{s^1}^{s^2} \left[G_2(1 - s, s) - G_2(1 - s, s)\right] ds \end{aligned} \tag{21}$$

where weak concavity of G implies that $G_2(1 - s, s) - G_1(1 - s, s)$ is either flat or downward sloping in s. Figure 1 illustrates the calculation in (21). The downward sloping curve is $G_2(1 - s, s) - G_1(1 - s, s)$. The area under the curve between s^1 and s^2 is $G(1 - s^2, s^2) - G(1 - s^1, s^1)$. Our upper bound on the increase in output in (9) exploits (i) that $G_2(1 - s, s) - G_1(1 - s, s)$ is downward sloping and (ii) that the difference between the observed skilled and observed unskilled wage in the economy is equal to $G_2(1-s^1, s^1)-G_1(1-s^1, s^1)$ when factor markets are perfectly competitive. As a result, the area under the curve between s^1 and s^2 is smaller than the rectangle with thick borders, which is the output increase one would have obtained under the assumption that the two skills types are perfect substitutes. The difference between our upper bound and the true increase in output becomes larger the harder it is to substitute between the two skills.

Now suppose that we observe the economy at a skilled-worker share s^2 and want to assess the decrease in output per worker generated by a fall in the skilled-worker share to s^1. The difference between the observed skilled and unskilled wage in the economy is now $G_2(1-s^2, s^2)-G_1(1-s^2, s^2)$, the height of the downward sloping curve at s^2. The fall in output obtained assuming perfect substitutability among skills is a rectangle with height $G_2(1-s^2, s^2)-G_1(1-s^2, s^2)$ and length s^2-s^1. The true decrease in output is the area under the curve between s^1 and s^2. Hence, the true decrease is greater than the the fall predicted assuming perfect substitutability between skills (and, again, the difference increases the harder it is to substitute between the two skills).

3 Estimating the Upper Bounds

We now estimate the maximum increase in output that could be generated by increasing schooling to US levels. This is done by estimating the upper bound in (19) for a large sample of countries with estimates of the Mincerian return to schooling, and by estimating the upper bound in (9) for a very small set of countries with data on wages by schooling attainment.

3.1 Using Mincerian Returns

In order to implement equation (19) we need to begin by choosing a reference year to constitute our starting point, i.e. the year where we observe $\mathbf{s}^1$ as well as γ. We choose 1990. We then need a *country specific* measure of the initial Mincerian return, γ, as well as employment shares of different schooling groups for each country and for a reference country (the stand-in for $\mathbf{s}^2$).

For Mincerian returns we use a collection of published estimates assembled by Caselli (2010). This starts from previous collections, most recently by Bils and Klenow (2003), and adds additional observations from other countries and other periods. Of course only very few of the estimates apply exactly to the year 1990, so for each country we pick the estimate *prior and closest* to 1990. In total, there are approximately 90 countries with an estimate of the Mincerian return prior to 1990 (the oldest being 1972). These country-specific Mincerian returns (and their date) are shown in Appendix Table 1. For schooling attainment, we use the latest installment of the Barro and Lee data set [Barro and Lee (2010)]. As already mentioned, this breaks the labor force down into seven attainment groups: No education, Some primary, Primary completed, Some secondary, Secondary completed, Some college, and College completed and more. These are observed in 1990 for all countries. For the reference country, we take the United States.[6]

Figure 2 shows the results of implementing (19) on our sample of 90 countries. For each country, we plot the upper bound on the right side of (19) against real income per worker in PPP in 1995 (from the Penn World Tables). Not surprisingly, poorer countries experience larger upper-bound increases in income when bringing their educational attainment in line with US levels. The detailed country-by-country numbers are reported in Appendix Table 1.

Table 1 shows summary statistics from the implementing of (19) on our sample of 90 countries. In general, compared to their starting point, several countries have seemingly large upper bound increases in income associated with attaining US skill levels (and the physical capital that goes with them). The largest upper bound is 3.66, meaning that income almost quadruples. At the 90th percentile of income gain income roughly doubles, and at the 75th percentile there is still a sizable increase by three quarters. The median increase is roughly by 45%. The average country has an upper bound increase of 60%.

These numbers are significantly less impressive, however, when viewed as a percentage of the initial income with the US. this is plotted against initial income in Figure 3.[7] Clearly the upper-bound income gains for the poorest countries in the sample are almost trivial in terms of bridging the gap with the US. For the poorest country the upper-bound income gain is less than 1% of the gap with the US. For the country with the 10th percentile level of income the upper-bound gain covers about 5% of the income gap. At the 75th percentile of the income distribution it is about 7%, and at the median it is in the order of 20%. The average upper bound closing of the gap is 74%, but this is driven by some very large outliers. Country-specific details on these calculations are, again , in Appendix Table 1.

Our upper-bound calculation using (19) is closely related to analogous calculations in the development accounting literature. In develop-

[6]To implement (19) we also need the average years of schooling of each of the attainment groups. This is also avaiable in the Barro and Lee data set.

[7]For the purpose of this figure the sample has been trimmed at an income level of $60,000 because the four countries above this level had very large values that visually dominated the picture.

ment accounting, a country's human capital is typically calculated as

$$(1+\gamma)^S \tag{22}$$

where S is average years of schooling and the average marginal return to schooling γ is calibrated off evidence on Mincerian coefficients.[8] For example, several authors use $\gamma = 0.10$, where 0.10 is a "typical" estimate of the Mincerian return. One difference with our approach is therefore that typical development accounting calculations identify a country's schooling capital with the schooling capital of the average worker, while our upper-bound calculation uses the (more theoretically grounded) average of the schooling capital of all workers. The difference, as already mentioned, is Jensen's inequality.[9] Another difference is that we use country-specific Mincerian returns instead of a common value (or function) for all countries. In Table 1 we also report summary statistics on the difference between our upper bound measure and the equivalent measure based on (22). While the difference is typically not huge, the measure based on (22) tends to be larger than our theory-based calculation. Since the latter is an upper bound, we can conclude that the standard calculation overstates the gains from achieving the attainment levels of the US.

3.2 Using Group-Specific Wages

In this section we implement the "full" upper bound calculation in equation (9) for a small group of countries for which we were able to estimate wages by education sub-group. Specifically, we look at countries for which microeconomic data from national censa is available from IPUMS (Minnesota Population Center, 2011), containing reasonably detailed information on both schooling attainment and labor income. The countries are Brazil, Mexico, Panama, and Venezuela. We present results

[8] More accurately, human capital is usually calculated as $\exp(\gamma S)$, but the two expressions are approximately equivalent and the one in the text is more in keeping with our previous notation.

[9] To see the relation more explicitly, for small γ, $(1+\gamma)^{x_i}$ is approximately linear and the right-hand side of (19) can be written in terms of average years of schooling $S = \sum_{i=1}^{m} x_i s_i$, as we do not miss much by assuming that $\sum_{i=o}^{m} (1+\gamma)^{x_i} s_i \approx (1+\gamma)^S$ (ignoring Jensen's inequality). As a result, if the Mincerian return to schooling is small, the upper bound on the increase in output per worker that can be generated by more schooling depends on the Mincerian return and average schooling only

$$\frac{y^2 - y^1}{y^1} \leq \frac{(1+\gamma)^{S^2} - (1+\gamma)^{S^1}}{(1+\gamma)^{S^1}}.$$

Another approximation of the right-hand side of (19) for small γ that is useful for relating our upper bound to the development accounting literature is $\gamma(S^2 - S^1)/\left(1+\gamma S^1\right)$.

for upper-bound increases in income by attaining US schooling levels in 1990 (1995 for Mexico, due to unexplained oddities in the 1990, and 2000).

The details of the calculations vary somewhat from country to country, as (i) schooling attainment is reported in varying degrees of detail in some countries (with some countries using seven education categories and others eight); and (ii) the concept of labor income varies somewhat from country to country. Here we present the results, which are collected in the first row of Table 2.

For this group of Latin American countries applying the full upper-bound calculation leads to conclusions that vary significantly both across countries and over time. The largest computed upper-bound gain is for Brazil in 2000, which is driven in large measure by very high estimated skill premia in Brazil in that year. In that year, the upper bound income increase for Brazil implies is one and one half time the initial level. The smallest upper bound is for Venezuela in 2001, where income goes up by at most 15%. This is driven by low estimated skill premia in that country in that year.

A potentially important question is whether using the "Mincerian" approach of (19) leads to an acceptable approximation of (9). To answer this question, we first estimate Mincerian returns on each country's (and year) micro data. This is done with a simple OLS regression with no attempt to correct for endogeneity.[10] Our estimated Mincerian coefficients are reported at the bottom of Table 2. In three cases out of four they are quite close to those from the literature used in the previous subsection (cfr. Appendix Table A.1), but in the case of Brazil our estimate is much below. Once we have the Mincerian return we can apply equation (19). The results are reported in the second row of Table 2. The differences in some cases are substantial. For example, Mexico in 1990 is estimated to experience a 90% (upper-bound) increase in income using (9), but a significantly more modest 65% using the Mincerian approach. Nevertheless, the comparison does not lend itself to easy generalizations as the direction of the bias varies both quantitatively and qualitatively across countries and years. In any case the results suggest that whenever possible it would be advisable to use detailed data on the wage structure rather than a single Mincerian coefficient.

[10]We note, however, that in the empirical labor literature IV and OLS estimates of Mincerian returns tend to be pretty similar. This is doubtless the result of measurement error and endogeneity bias roughly cancelling each other out.

4 Conclusions

Can developing countries close a substantial part of the output gap with rich countries by increasing the quantity of schooling? Our approach has been to look at the best-case scenario: an upper bound for the increase in output that can be achieved by more schooling. Even in this best-case scenario the part of the output gap with rich countries than can be closed by schooling is tiny. This result is in line with previous findings in the development accounting literature. Our best case scenario does, however, involve significant increases in living standards from the current, very low levels.

It is important to note that while our upper-bound approach has allowed us to relax the strong assumption of perfect substitutability made in much of the development accounting literature, we have maintained the assumption that there are no schooling externalities, i.e. that schooling does not affect aggregate technology/efficiency. While such effects are intuitively plausible, the empirical literature tends to either find no schooling externalities or externalities that appear too small to overturn the finding that schooling accounts for a small part of the gap between developing and rich countries (e.g. Acemoglu and Angrist, 2000; Moretti, 2004; Ciccone and Peri, 2006; Peri and Iranzo, 2009).

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Figure 1: Exact and upper-bound change in income as s changes from s^1 to s^2

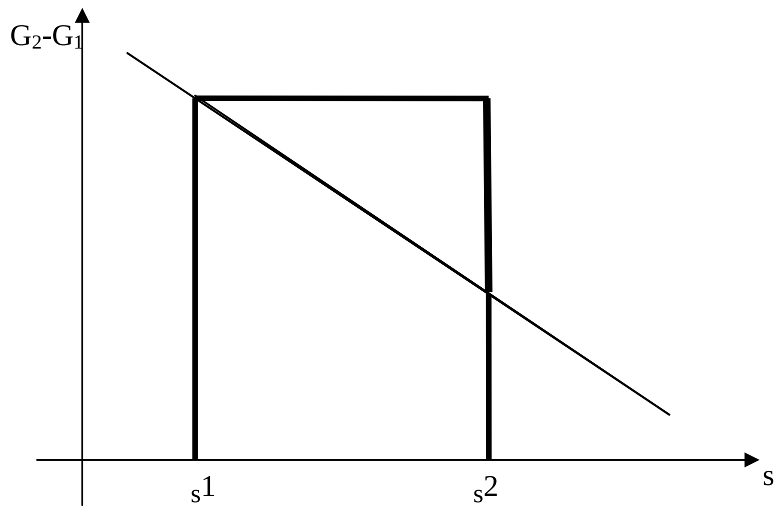

Figure 2: Upper bound income increase when moving to US attainment

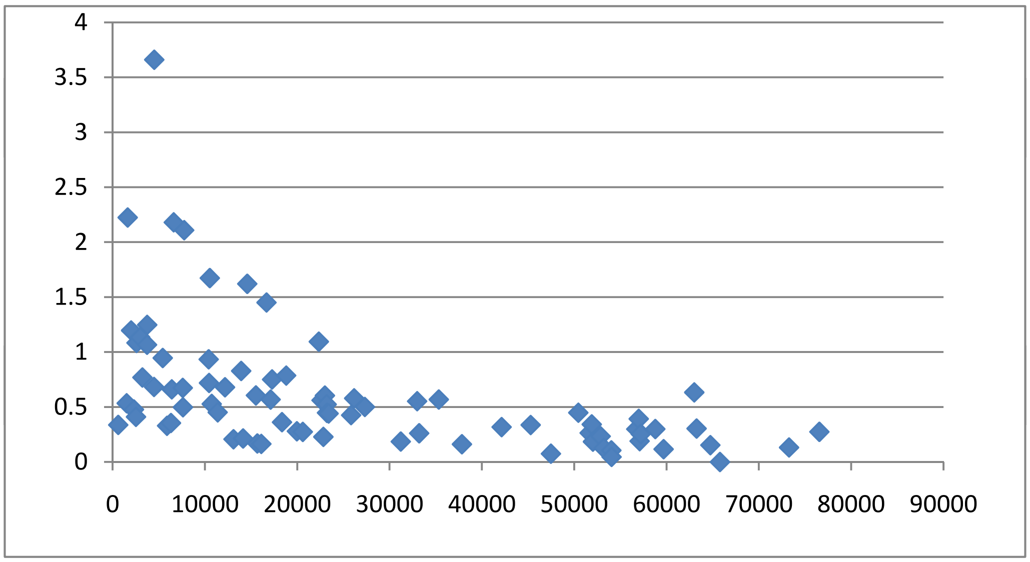

Figure 3: Upper bound income gain as percent of initial income gap with US

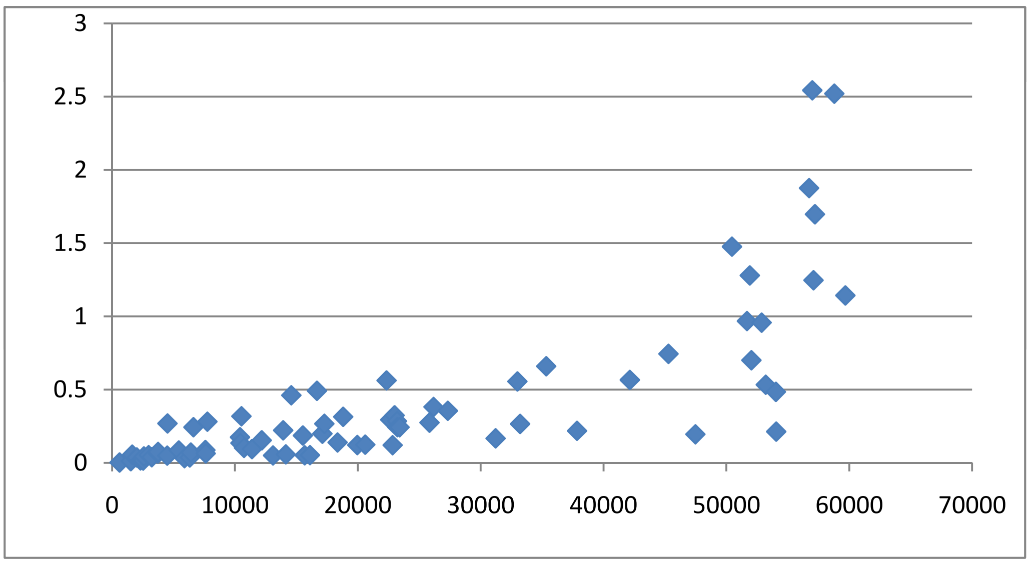

Table 1

	mean	max	90th perc.	75th perc.	median
% Income gain using (19)	0.61	3.66	1.20	0.68	0.45
% Income gain using (23)	0.80	7.59	1.48	0.82	0.54

Table 2

	% Income gain		Minceriam Return
	Using (9)	Using (19)	from IPUMS
Brazil 1991	0.292	0.215	0.028
Brazil 2000	1.480	1.266	0.154
Mexico 1990*	0.890	0.647	0.088
Mexico 2000	0.772	0.656	0.115
Panama 1990	0.721	0.628	0.130
Panama 2000	0.533	0.484	0.116
Venezuela 1990	0.551	0.660	0.096
Venezuela 2001	0.147	0.180	0.034

Appendix Table 1

	Income in 1995	% gap with US	Mincer Coeff. Estimate	Mincer Coeff. Year	% gain using (4)	% gain using (7)	% of gap closed
Kuwait	76562	-0.14	4.5	1983	0.275	0.317	-1.95
Norway	73274	-0.10	5.5	1995	0.132	0.141	-1.29
Zimbabwe	610	106.79	5.57	1994	0.337	0.370	0.00
Uganda	1525	42.13	5.1	1992	0.535	0.572	0.01
Vietnam	2532	24.99	4.8	1992	0.411	0.425	0.02
Ghana	2313	27.44	7.1	1995	0.477	0.578	0.02
Philippines	5897	10.16	12.6	1998	0.330	0.411	0.03
Nepal	2008	31.76	9.7	1999	1.197	1.518	0.04
Sri Lanka	6327	9.40	7	1981	0.355	0.408	0.04
China	3234	19.34	12.2	1993	0.769	0.964	0.04
Zambia	2595	24.35	11.5	1994	1.084	1.342	0.04
Cameroon	4490	13.65	6.45	1994	0.683	0.753	0.05
Peru	13101	4.02	5.7	1990	0.207	0.239	0.05
Estonia	15679	3.20	5.4	1994	0.169	0.181	0.05
Russian Federation	16108	3.08	7.2	1996	0.165	0.172	0.05
Kenya	2979	21.08	11.39	1995	1.135	1.353	0.05
Tanzania	1640	39.10	13.84	1991	2.225	2.676	0.06
Bulgaria	14140	3.65	5.25	1995	0.214	0.235	0.06
India	3736	16.61	10.6	1995	1.067	1.421	0.06
Bolivia	7624	7.63	10.7	1993	0.498	0.658	0.07
Indonesia	6413	9.26	7	1995	0.661	0.758	0.07
Sudan	3747	16.56	9.3	1989	1.248	1.417	0.08
Nicaragua	5433	11.11	12.1	1996	0.947	1.303	0.09
Honduras	7599	7.66	9.3	1991	0.674	0.763	0.09
Egypt	11387	4.78	5.2	1997	0.452	0.511	0.09
Dominican Republic	10739	5.13	9.4	1995	0.528	0.652	0.10
Slovak Republic	22834	1.88	6.4	1995	0.229	0.265	0.12
Poland	19960	2.30	7	1996	0.280	0.302	0.12
Croatia	20606	2.19	5	1996	0.274	0.299	0.13
Paraguay	10450	5.30	11.5	1990	0.719	0.851	0.14
Costa Rica	18352	2.58	8.5	1991	0.362	0.411	0.14
El Salvador	12182	4.40	7.6	1992	0.680	0.776	0.15
Czech Republic	31215	1.11	5.65	1995	0.186	0.210	0.17
Thailand	10414	5.32	11.5	1989	0.934	1.084	0.18
Ecuador	15528	3.24	11.8	1995	0.606	0.820	0.19
Sweden	47480	0.39	3.56	1991	0.076	0.080	0.20
Panama	17119	2.84	13.7	1990	0.568	0.770	0.20
Australia	54055	0.22	8	1989	0.046	0.038	0.21
Cyprus	37843	0.74	5.2	1994	0.162	0.178	0.22
Tunisia	13927	3.72	8	1980	0.829	1.006	0.22
Chile	23403	1.81	12.1	1989	0.442	0.546	0.24

Pakistan	6624	8.93	15.4	1991	2.180	3.439	0.24
Argentina	23222	1.83	10.3	1989	0.448	0.542	0.24
Korea, Rep.	33210	0.98	13.5	1986	0.262	0.406	0.27
Botswana	17280	2.81	12.6	1979	0.751	1.056	0.27
Cote d'Ivoire	4512	13.58	20.1	1986	3.660	7.593	0.27
Mexico	25835	1.55	7.6	1992	0.426	0.496	0.28
Morocco	7759	7.48	15.8	1970	2.109	3.550	0.28
Malaysia	23194	1.84	9.4	1979	0.524	0.657	0.29
South Africa	22638	1.91	11	1993	0.562	0.668	0.29
Colombia	18808	2.50	14.5	1989	0.787	1.044	0.32
Guatemala	10530	5.25	14.9	1989	1.674	2.193	0.32
Turkey	22996	1.86	9	1994	0.605	0.736	0.32
Hungary	27326	1.41	8.9	1995	0.501	0.588	0.36
Venezuela, RB	26164	1.51	9.4	1992	0.579	0.689	0.38
Jamaica	14588	3.51	28.8	1989	1.621	2.268	0.46
Canada	54026	0.22	8.9	1989	0.106	0.108	0.49
Brazil	16676	2.95	14.7	1989	1.451	1.903	0.49
Israel	53203	0.24	6.2	1995	0.126	0.149	0.53
Slovenia	32991	0.99	9.8	1995	0.553	0.693	0.56
Iran, Islamic Rep.	22339	1.95	11.6	1975	1.095	1.483	0.56
Greece	42141	0.56	7.6	1993	0.318	0.368	0.57
Portugal	35336	0.86	8.73	1994	0.569	0.658	0.66
Denmark	52032	0.26	5.14	1995	0.185	0.197	0.70
Finland	45289	0.45	8.2	1993	0.337	0.374	0.74
Ireland	52868	0.24	9.81	1994	0.234	0.266	0.96
Japan	51674	0.27	13.2	1988	0.264	0.333	0.97
Netherlands	59684	0.10	6.4	1994	0.117	0.127	1.14
Hong Kong	57093	0.15	6.1	1981	0.190	0.229	1.25
United Kingdom	51901	0.27	9.3	1995	0.342	0.405	1.28
Spain	50451	0.30	7.54	1994	0.449	0.541	1.48
Switzerland	57209	0.15	7.5	1991	0.255	0.314	1.70
Austria	56728	0.16	7.2	1993	0.300	0.331	1.88
France	58784	0.12	7	1995	0.300	0.347	2.52
Germany	56992	0.15	7.85	1995	0.392	0.480	2.54
Italy	63260	0.04	6.19	1995	0.305	0.344	7.63
Belgium	64751	0.02	6.3	1999	0.154	0.171	9.58
Singapore	63009	0.04	13.1	1998	0.634	0.724	14.36
United States	65788	0.00	10	1993	0.000	0.000	
Iraq			6.4	1979	0.567	0.664	
Taiwan			6	1972	0.330	0.293	