DISCUSSION PAPER SERIES

No. 8683

A NOTE ON SCHOOLING IN DEVELOPMENT ACCOUNTING

Francesco Caselli and Antonio Ciccone

DEVELOPMENT ECONOMICS and INTERNATIONAL MACROECONOMICS

Centre for Economic Policy Research

www.cepr.org

Available online at: www.cepr.org/pubs/dps/DP8683.asp

ISSN 0265-8003

A NOTE ON SCHOOLING IN DEVELOPMENT ACCOUNTING

Francesco Caselli, London School of Economics and CEPR
Antonio Ciccone, Universitat Pompeu Fabra, Barcelona

Discussion Paper No. 8683
December 2011

Centre for Economic Policy Research
77 Bastwick Street, London EC1V 3PZ, UK
Tel: (44 20) 7183 8801, Fax: (44 20) 7183 8820
Email: cepr@cepr.org, Website: www.cepr.org

CEPR Discussion Paper No. 8683

December 2011

ABSTRACT

A Note on Schooling in Development Accounting*

How much would output increase if underdeveloped economies were to increase their levels of schooling? We contribute to the development accounting literature by describing a non-parametric upper bound on the increase in output that can be generated by more schooling. The advantage of our approach is that the upper bound is valid for any number of schooling levels with arbitrary patterns of substitution/complementarity. We also quantify the upper bound for all economies with the necessary data, compare our results with the standard development accounting approach, and provide an update on the results using the standard approach for a large sample of countries.

JEL Classification: I25, O11
Keywords: development accounting, imperfect substitution and schooling

Francesco Caselli
Professor of Economics
Department of Economics
London School of Economics
Houghton Street
London WC2A 2AE

Email: f.caselli@lse.ac.uk

For further Discussion Papers by this author see:
www.cepr.org/pubs/new-dps/dplist.asp?authorid=135322

Antonio Ciccone
Department of Economics
Universitat Pompeu Fabra
Ramon Trias Fargas 25-27
08005 Barcelona
SPAIN

Email: antonio.ciccone@upf.edu

For further Discussion Papers by this author see:
www.cepr.org/pubs/new-dps/dplist.asp?authorid=121260

* We thank Marcelo Soto, Hyun Son, and very especially David Weil for useful comments.

Submitted 27 November 2011

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 US, 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?

Taking a parametric production function approach to the development accounting literature requires assuming that there are only two imperfectly substitutable skill types, that the elasticity of substitution between these skill types is the same in all countries, and that this elasticity of substitution is equal to the elasticity of substitution in countries where instrumental-variable estimates are available (e.g. Angrist, 1995; Ciccone and Peri, 2005). These assumptions are quite strong. For example, the evidence indicates 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). Once there are more than 3 skill types, estimation of elasticities of substitution becomes notoriously difficult for two main reasons. First, there are multiple, non-nested ways of capturing patterns of substitutability/complementarity and this make it difficult to avoid misspecification (e.g. Duffy et al., 2004). Second, relative skill supplies and relative wages are jointly determined in equilibrium and estimation therefore requires instruments for relative supplies. It is already challenging to find convincing instruments for two skill types and we are not aware of instrumental-variables estimates when there are 3 or more imperfectly substitutable skills groups.

We explore an alternative to the parametric production function approach and 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 productivities from market 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 for an arbitrary number of schooling types with any pattern of substitutability/complementarity as long as the production function is weakly concave. Hence, 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 assuming perfect substitutability among schooling levels yields an upper bound on output increases and with a few ancillary assumptions – mainly 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 9 countries we have detailed wage data for up to 10 schooling-attainment groups for various years between 1960 and 2005. In another data set of about 90 countries we use evidence on Mincerian returns to proxy for the structure of relative wages among the 7 attainment groups. Our calculations yield output gains from reaching a distribution of schooling attainment similar to the US that are sizeable as a proportion of initial output. However these gains are much smaller when measured as a proportion of the existing output gap with the US. This result is in line with the conclusions from development accounting (e.g. Klenow and Rodriguez-Clare, 1997; Hall and Jones, 1999; Caselli, 2005). This is not surprising as these studies assume that workers with different schooling attainment are perfect substitutes and therefore end up working with a formula that is very similar to our upper bound.[1]

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.

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

[1] Our calculations are closest in spirit to Hall and Jones (1999), who conceive the development accounting question 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.

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

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

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,

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

Assume now that factor markets are approximately competitive. Then (3) can be rewritten as

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

where α^1 is the physical capital share in output 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,

[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.

$MPK^2 = MPK^1$. 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

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

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

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

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.

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

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

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

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,

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

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

[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.

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).

The upper-bound calculation using (19) is closely related to analogous calculations in the development accounting literature. In development accounting, a country's human capital is typically calculated as

$$(1+\gamma)^S \tag{20}$$

where S is average years of schooling and the average marginal return to schooling γ is calibrated off evidence on Mincerian coefficients.[6] 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.[7] Another difference is that we use country-specific Mincerian returns instead of a common value (or function) for all countries.

[6] 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.

[7] 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

2.3 Link to Development Accounting and Graphical Intuition

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 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 – is exactly equal to the output increase one would have obtained under the assumption that different schooling levels are perfect substitutes in production, $G(L_0, L_1, ..., L_m) = a_0 L_0 + a_1 L_1 + ... + a_m L_m$. Hence, although rejected empirically, the assumption of perfect substitutability among different schooling levels remains useful in that it yields an upper bound on the output increase that can be generated by more schooling.

To develop an intuition for these results, consider the case of just two

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 $\gamma(S^2 - S^1)/\left(1 + \gamma S^1\right)$.

labor types, skilled and unskilled, and no capital,

$$Y = G(L_U, L_H) \tag{21}$$

where G is taken to be subject to constant returns to scale and weakly concave. Suppose we observe the economy when the share of skilled labor in total employment is 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

$$\begin{aligned} y(s^2) - y(s^1) &= G(1 - s^2, s^2) - G(1 - s^1, s^1) \\ &= \int_{s^1}^{s^2} \frac{\partial G(1 - s, s)}{\partial s} ds \\ &= \int_{s^1}^{s^2} \left[G_2(1 - s, s) - G_2(1 - s, s) \right] ds. \end{aligned} \tag{22}$$

Weak concavity of G implies that $G_2(1 - s, s) - G_1(1 - s, s)$ is either flat or downward sloping in s. Hence, (22) implies that $y(s^2) - y(s^1) \leq [G_2(1 - s^1, s^1) - G_1(1 - s^1, s^1)] (s^2 - s^1)$. Moreover, when factor markets are perfectly competitive, the difference between the observed skilled and unskilled wage in the economy $w_H^1 - w_U^1$ is equal to $G_2(1 - s^1, s^1) - G_1(1 - s^1, s^1)$. As a result, $y(s^2) - y(s^1) \leq (w_H^1 - w_U^1) (s^2 - s^1)$. As $(w_H^1 - w_U^1) (s^2 - s^1)$ is also the output increase one would have obtained under the assumption that the two skill types are perfect substitutes, it follows that our upper bound is equal to the increase in output assuming perfect substitutability between skill types. Figure 1 illustrates this calculation graphically.[8] The increase in output is the pink area. The upper bound is the pink plus blue area. The figure also illustrates that the difference between our upper bound and the true output gain is larger – making our upper bound less tight – the larger the increase in schooling considered.[9]

It is worth noting that 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. Hence, our approach is not useful for developing an upper bound on the decrease in output that would be generated by a decrease in schooling.

[8] We thank David Weil for suggesting this figure.

[9] Our implementation of the upper bound below considers US schooling levels as the arrival value. As a result, the increase in schooling considered is large for many developing countries and our upper bound could be substantial larger than the true output gain.

3 Estimating the Upper Bounds

We now estimate the maximum increase in output that could be generated by increasing schooling to US levels. We first do this for a subsample of countries and years for which we have data allowing us to perform the calculation in equation (9). For these countries we can also compare the results obtained using (9) with those using (19), which assume a constant return to extra schooling. These comparisons put in perspective the reliability of the estimates that are possible for larger samples, where only Mincerian returns are available. We also report such calculations for a large cross-section of countries in 1990.

3.1 Using Group-Specific Wages

We implement the upper bound calculation in equation (9) for 9 countries for which we are able to estimate wages by education attainment level using national censa data from the international IPUMS (Minnesota Population Center, 2011). The countries are Brazil, Colombia, Jamaica, India, Mexico, Panama, Puerto Rico, South Africa, and Venezuela, with data for multiple years between 1960 and 2007 for most countries. The details vary somewhat from country to country as (i) schooling attainment is reported in varying degrees of detail across countries; (ii) the concept of income varies across countries; and (iii) the control variables available also vary across countries. See Appendix Tables 1-3 for a summary of the micro data (e.g. income concepts; number of attainment levels; control variables available; number of observations). These data allow us to estimate attainment-specific returns to schooling and implement (9) using the observed country-year specific distribution of educational attainments and the US distribution of educational attainment *in the corresponding year* as the arrival value.

It is worthwhile noting that in implementing (9) – and also (19) below – we estimate and apply returns to schooling that vary both across countries and over time. Given our setup, the most immediate interpretation of the variation in returns to schooling would be that there is imperfect substitutability between workers with different schooling attainments and that the supply of different schooling attainments varies over time and across countries. It is exacly the presence of imperfect substitutability among different schooling levels that motivates our upper-bound approach. Another reason why returns to schooling might vary could be that there are differences in technology. Our upper-bound approach does not require us to put structure on such (possibly attainment-specific) technology differences. Of course, our upper bound would be inaccurate if technology changes in response to changes in schooling. To the extent that this is an objection, it applies to all the development-accounting literature. For example, the Hall-Jones calculation would be inaccurate if total factor productivity increases in response to an increase in human capital. However, our interpretation of the spirit of development accounting is precisely to ask about the role of inputs holding technology constant.[10]

The results of implementing the upper-bound calculation in (9) for each country-year are presented (in bold face) in Table 1. For this group of countries applying the 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 1970, which is of the order of 150%. This result largely reflects the huge gap in schooling between the US and Brazil in that year (average years of schooling in Brazil was less than 4 in 1970). The smallest upper bound is for Puerto Rico in 2005, which is essentially zero, reflecting the fact that this country had high education attainment by that year (average years of schooling is almost 13). The average is 0.59.

A different metric is the fraction of the overall output gap with the US that reaching US attainment levels can cover. This calculation is also reported in Table 1 (characters in normal type). As a proportion of the output gap, the largest upper-bound gain is for Brazil in 1980 (57%), while the smallest is again for Puerto Rico in 2005 (virtually zero). On average, at the upper bound attaining the US education distribution allows countries to cover 21% of their output gap with the US.

The shortcoming of the results in Table 1 is that they refer to a quite likely unrepresentative sample. For this reason, we now ask whether using the approach in equation (19) leads to an acceptable approximation of (9). As we show in the next section, data to implement (19) is readily available for a much larger (and arguably representative) sample of countries, so if (19) offers an acceptable approximation to (9) we can be more confident on results from larger samples.

To implement (19), we first use our micro data to estimate Mincerian returns for each country-year. This is done with an OLS regression using the same control variables employed to estimate the attainment-specific returns to schooling above.[11] See Appendix Table 2 for point estimates and standard errors of Mincerian returns for each country-year. Once we have the Mincerian return we can apply equation (19) to assess the

[10] Another possible source of differences in schooling returns across countries is sampling variation. However our estimates of both attainment specific and Mincerian returns are extremely precise, so we think this explanation is unlikely.

[11] The empirical labor literature finds that OLS estimates of Mincerian returns to schooling are often close to causal estimates, see Card (1999).

upper-bound output gains of increasing the supply of schooling (assuming that technology remains unchanged). The results are reported, as a fraction of the results using (9), in the first row of Table 2 (bold type). This exercise reveals differences between the calculations in (9) and (19). On average, the calculation that imposes a constant proportional wage gain yields only 77% of the calculation that uses attainment-specific returns to schooling. Therefore, the first message from this comparison is that, on average, basing the calculation on Mincerian coefficients leads to a significant underestimate of the upper bound output increase associated with attainment gains. However, there is enormous heterogeneity in the gap between the two estimates, and in fact the results from (19) are not uniformly below those from (9). Almost one third of the estimates based on (19) are larger. The significant average difference in estimates and the great variation in this difference strongly suggest that whenever possible it would be advisable to use detailed data on the wage structure rather than a single Mincerian return coefficient. It is interesting to note that the ratio of (19) to (9) is virtually uncorrelated with per-worker GDP. To put it differently, while estimates based on (19) are clearly imprecise, the error relative to (9) is not systematically related to per-worker output. Hence, one may conclude that – provided the appropriate allowance is made for the *average* gap between (19) and (9) – some broad conclusions using (19) are still possible.

We can also compare the results of our approach in (9) to the calculation combining average years of schooling with a single Mincerian return in (20). The results are reported in the second rows of Table 2. On average, the results are extremely close to those using (19), suggesting that ignoring Jensen's inequality is not a major source of error in the calculations. However, the variation around this average is substantial.

3.2 Using Mincerian Returns Only

The kind of detailed data on the distribution of wages that is required to implement our "full" calculation in equation (9) is not often available. However, there are estimates of the Mincerian return to schooling for many countries and years. For such countries, it is possible to implement the approximation in (19).

We begin by choosing 1990 as the reference year. 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. 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. Country-specific Mincerian returns and their date are shown in Appendix Table 3. For schooling attainment, we use the latest installment of the Barro and Lee data set (Barro and Lee, 2010), which breaks the labor force down into 7 attainment groups, no education, some primary school, primary school completed, some secondary school, secondary school completed, some college, and college completed. These are observed in 1990 for all countries. For the reference country, we again take the US.[12]

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 output per worker in PPP in 1995 (from the Penn World Tables). Not surprisingly, poorer countries experience larger upper-bound increases in output when bringing their educational attainment in line with US levels. The detailed country-by-country numbers are reported in Appendix Table 3.

Table 3 shows summary statistics from implementing (19) on our sample of 90 countries. In general, compared to their starting point, several countries have seemingly large upper bound increases in output associated with attaining US schooling levels (and the physical capital that goes with them). The largest upper bound is 3.66, meaning that output almost quadruples. At the 90th percentile of output gain, output 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%.

Figure 3 plots the estimated upper bounds obtained using (19) as a percentage of the initial output gap with the US.[13] Clearly the upper-bound output gains for the poorest countries in the sample are small as a fraction of the gap with the US. For the poorest country the upper-bound output gain is less than 1% of the gap with the US. For the country with the 10th percentile level of output per worker the upper-bound gain covers about 5% of the output gap. At the 75th percentile of the output per worker distribution it is about 7%, and at the median it is around 20%. The average upper-bound closing of the gap is 74%, but this is driven by some very large outliers.

In Table 4 we also report summary statistics on the difference between the upper bound measure obtained using (19) and the upper bound obtained using (20). While the difference is typically not huge,

[12] 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.

[13] 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.

the measure based on (20) tends to be larger than our theory-based calculation. Since the latter is an upper bound, we can conclude that the calculation in (20) overstates the gains from achieving the attainment levels of the US.

4 Conclusion

How much of the output gap with rich countries can developing countries close by increasing their 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. The advantage of our approach is that the upper bound is valid for an arbitrary number of schooling levels with arbitrary patterns of substitution/complementarity. Application of our upper-bound calculations to two different data sets yields output gains from reaching a distribution of schooling attainment similar to the US that are sizeable as a proportion of initial output. However these gains are much smaller when measured as a proportion of the existing output gap with the US. This result is in line with the conclusions from the development accounting literature, which is not surprising as many development accounting studies assume that workers with different schooling attainment are perfect substitutes and therefore end up employing a formula that is very similar to our upper bound.

REFERENCES

Angrist, Joshua, 1995. "The Economic Returns to Schooling in the West Bank and Gaza Strip." *American Economic Review*, 85, pp. 1065-1087.

Autor, David, and Lawrence Katz, 1999. "Changes in the Wage Structure and Earnings Inequality." In Orley Ashenfelter and David Card, *Handbook of Labor Economics*, Amsterdam: Elsevier.

Autor, David H., Lawrence F. Katz and Melissa S. Kearney, 2006. "The Polarization of the U.S. Labor Market," *American Economic Review Papers and Proceedings*, 96(2), pp. 189-194.

Barro, Robert and Lee, Jong-Wha, 2010. "A New Data Set of Educational Attainment in the World, 1950-2010." National Bureau of Economic Research Working Paper #15902, Cambridge, MA. Data downloadable at: http://www.barrolee.com/

Bils, Mark and Pete Klenow, 2000. "Does Schooling Cause Growth?" *American Economic Review*, 90(2), pp. 1160-1183.

Card, David, 1999. "The Causal Effect of Education on Earnings." In Orley Ashenfelter and David Card, *Handbook of Labor Economics*, Amsterdam: Elsevier.

Caselli, Francesco and Coleman, John Wilbur II, 2002. "The U.S. Technology Frontier." *American Economic Review Papers and Proceedings*, 92(2), pp. 148-152.

Caselli, Francesco and Coleman, John Wilbur II, 2006. "The World Technology Frontier." *American Economic Review*, 96(3), pp. 499-522.

Caselli, Francesco, and James Feyrer, 2007. "The Marginal Product of Capital." *Quarterly Journal of Economics*, 122(2), pp. 535-568.

Caselli, Francesco, 2010. *Differences in Technology across Time and Space*. 2010 CREI Lectures, Powerpoint Presentation.

Ciccone, Antonio, and Giovanni Peri, 2005. "Long-Run Substitutability Between More and Less Educated Workers: Evidence from US States 1950-1990."*Review of Economics and Statistics*, 87(4), pp. 652-663.

Duffy, John, Chris Papageorgiou, and Fidel Perez-Sebastian, 2004. "Capital-Skill Complementarity? Evidence from a Panel of Countries." *Review of Economics and Statistics*, 86(1), pp. 327-344.

Fallon, Peter R., and Richard G. Layard, 1971. "Capital-Skill Complementarity, Income Distribution, and Output Accounting." *Journal of Political Economy*, 83(2), pp. 279-302.

Goldin, Caudia, and Lawrence Katz, 1998. "The Origins of Technology-Skill Complementarity." *Quarterly Journal of Economics*, 113(3), pp. 693-732.

Gollin, Douglas, 2002. "Getting Income Shares Right." *Journal of Political Economy*, 110(2), pp. 458-474.

Goos, Maarten, and Alan Manning, 2007. "Lousy and Lovely Jobs: The Rising Polarization of Work in Britain." *Review of Economics and Statistics*, 89, pp. 118-133.

Griliches, Zvi, 1969. "Capital-Skill Complementarity." *Review of Economics and Statistics*, 51(1), pp. 465-468.

Hall, Robert and Charles Jones, 1999. "Why Do Some Countries Produce So Much More Output Per Worker Than Others?" *Quarterly Journal of Economics*, 114(1), pp. 83-116.

Hendricks, Lutz, 2002. "How Important is Human Capital for Development? Evidence from Immigrant Earnings." *American Economic Review* 92(3), pp. 198-219.

Katz, Lawrence, and Kevin Murphy, 1992. "Changes in Relative Wages 1963–1987: Supply and Demand Factors." *Quarterly Journal of Economics*, 107(2), pp. 35-78.

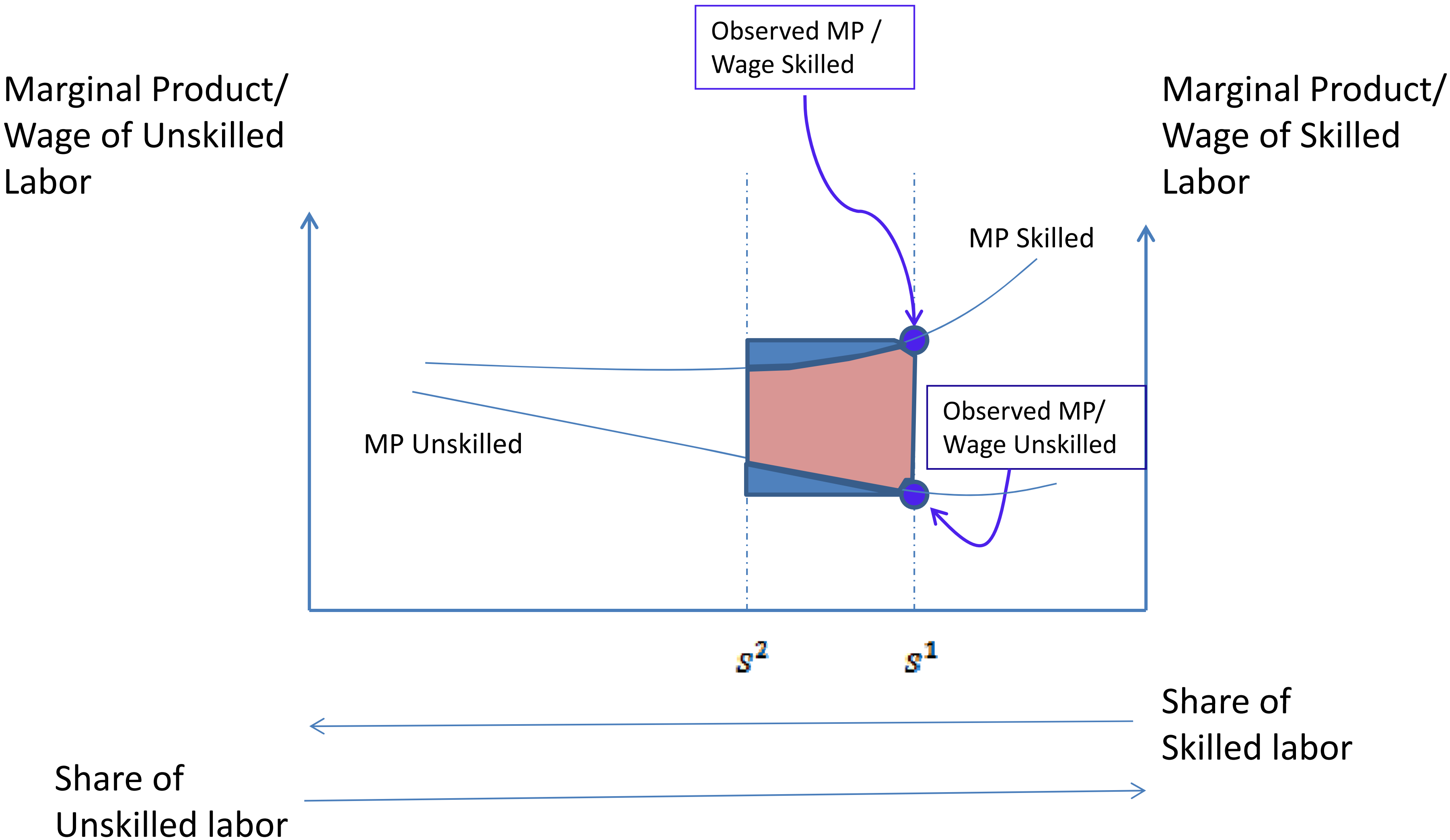
Klenow, Peter, and Andres Rodriguez-Claire, 1997. "The Neoclassical Revival in Growth Economics: Has It Gone Too Far?". In *NBER Macroeconomic Annual.* Cambridge MA: MIT Press.

Krusell, Per, Lee Ohanian, Victor Rios-Rull, and Gianluca Violante, 2002. "Capital-Skill Complementarity and Inequality: A Macroeconomic Analysis." *Econometrica* 68(4), pp. 1029-1053.

McFadden, Daniel, Peter Diamond, and Miguel Rodriguez, 1978. "Measurement of the Elasticity of Factor Substitution and the Bias of Technical Change." In Melvyn Fuss and Daniel McFadden, *Production Economics: A Dual Approach to Theory and Applications*, Amsterdam: Elsevier.

Minnesota Population Center. Integrated Public Use Microdata Series, International (IPUMS), 2011. Version 6.1 [Machine-Readable Database.]. Minneapolis: University of Minnesota. Data downloadable at: http://www.international.ipums.org

Figure 1: Change in Output from Change in Schooling



Note: Output increase when share of skilled labor grows from s^1 to s^2. Pink area: correct calculation; pink plus blue area: upper bound calculation.

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

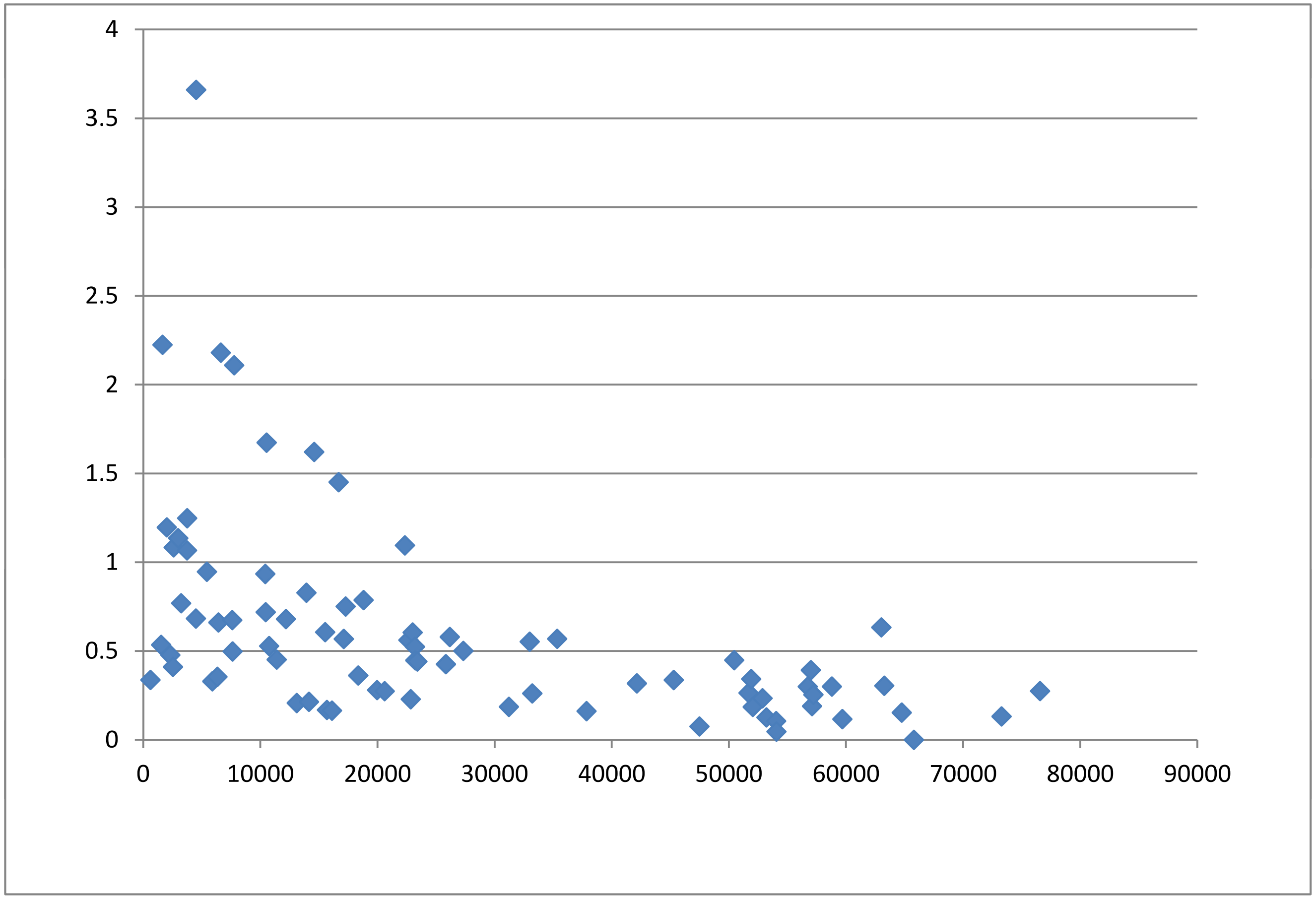


Figure 3: Upper bound income gain as percent of output per worker gap with US

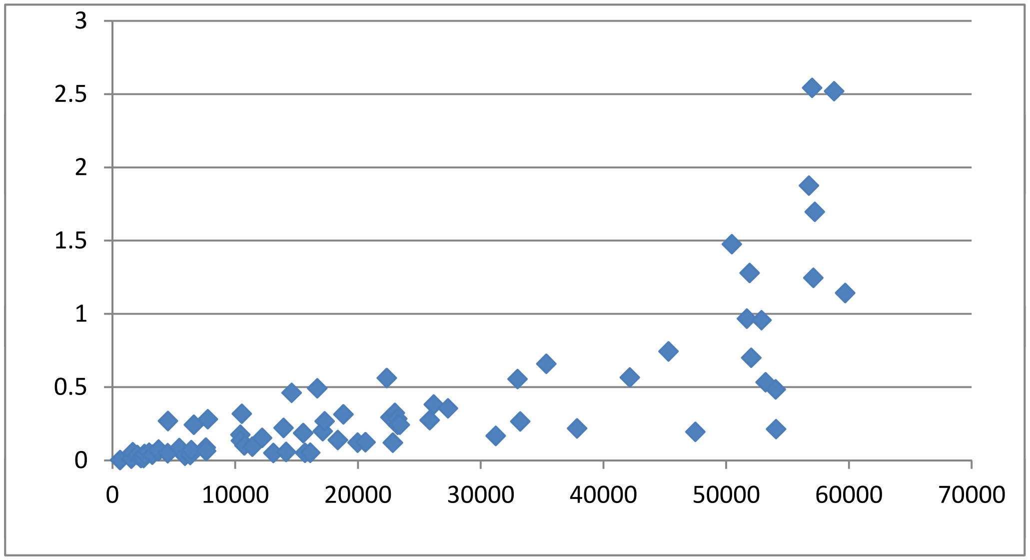


Table 1

	1960	1970	1980	1990	1995	2000	2005
Brazil		**1.576**	**1.201**	**1.020**		**0.901**	
		0.441	0.567	0.304		0.224	
Colombia		**0.901**					
		0.159					
Jamaica			**0.620**	**0.242**		**0.469**	
			0.209	0.076		0.135	
India			**0.908**	**0.945**	**0.769**	**0.792**	**0.769**
			0.053	0.056	0.047	0.054	0.06
Mexico	**1.238**	**0.916**		**0.439**	**0.543**	**0.543**	
	0.524	0.411		0.169	0.187	0.201	
Panama		**0.434**	**0.408**	**0.331**		**0.255**	
		0.088	0.109	0.072		0.055	
Puerto Rico		**0.202**	**0.108**	**0.045**		**-0.003**	**-0.012**
		0.209	0.111	0.061		-0.006	-0.019
South Africa					**0.745**	**0.708**	**0.609**
					0.140	0.129	0.130
Venezuela		**0.757**	**0.604**	**0.403**		**0.860**	
		0.568	0.353	0.132		0.235	

Note: upper bound changes in income from moving to US education distribution.
Figures in bold type are percent income increases, based on equation (19)
[i.e. Use attainment-specific returns to education]
Figures in normal type are percent income increases as share of overall income gap with US.
1970 figure refers to 1971 for Venezuela and 1973 for Colombia;
1980 figure refers to 1981 for Venezuela, 1982 for Jamaica, and 1983 for India;
1990 figure refers to 1987 for India and 1991 for Brazil and Jamaica;
1995 figure refers to 1993 for India and 1996 for South Africa;
2000 figure refers to 1999 for India and 2001 for Jamaica, South Africa, and Venezuela;
2005 figure refers to 2004 for India and 2007 for South Africa

Table 2

	1960	1970	1980	1990	1995	2000	2005
Brazil		**0.828**	**0.749**	**0.743**		**0.657**	
		0.816	0.821	0.880		0.773	
Colombia		**0.839**					
		0.873					
Jamaica			**1.052**	**1.269**		**0.439**	
			1.092	1.255		0.431	
India			**0.915**	**0.954**	**0.907**	**0.866**	**0.842**
			1.037	1.100	1.042	1.017	1.000
Mexico	**1.137**	**1.195**		**0.983**	**1.109**	**0.886**	
	1.049	1.105		1.055	1.311	1.024	
Panama		**0.934**	**0.984**	**0.978**		**1.017**	
		1.065	1.202	1.231		1.278	
Puerto Rico		**0.996**	**1.023**	**0.992**		**-1.748**	**0.134**
		1.237	1.285	1.369		-4.333	-0.479
South Africa					**0.711**	**0.612**	**0.694**
					0.861	0.739	0.855
Venezuela		**0.693**	**0.917**	**1.112**		**0.283**	
		0.612	0.958	1.172		0.283	

Note: alternative measures of upper bound changes in income from moving to US education distribution, as percent of baseline measure.

Figures in bold type assume constant returns to each additional year of schooling [based on equation (19)];

Figures in nornal type assume constant returns and assign to all workers the average years of schooling

1970 figure refers to 1971 for Venezuela and 1973 for Colombia;

1980 figure refers to 1981 for Venezuela, 1982 for Jamaica, and 1983 for India;

1990 figure refers to 1987 for India and 1991 for Brazil and Jamaica;

1995 figure refers to 1993 for India and 1996 for South Africa;

2000 figure refers to 1999 for India and 2001 for Jamaica, South Africa, and Venezuela;

2005 figure refers to 2004 for India and 2007 for South Africa

Table 3

	mean	max	90th percentile	75th percentile	median
% Output gain using (19)	0.61	3.66	1.20	0.68	0.45
% Output gain using (20)	0.80	7.59	1.48	0.82	0.54

Note: upper bound on income changes in a large cross-section,
assuming constant returns to extra schooling

Appendix Table 1: Description of Individual-Level Data

Brazil	*Income concept used in the analysis* : total income per hour worked for 1980, 1991, 2000; total income for 1970. *Other income concepts available:* earned income per hour worked for 1980, 1991, 2000 (yield nearly identical results as income concept used for 1991 and 2000 but a significantly negative return to schooling in 1980). *Control variables used in the analysis:* age, age squared, gender, marital status, age*marital status, gender*marital status, dummies for region (state) of birth, dummies for region (state) of residence, dummy for urban area, dummy for foreign born, dummies for religion, dummies for race (except 1970). *Educational attainment levels:* 8
Colombia	*Income concept used in the analysis:* total income for 1973. *Other income concepts available:* none. *Control variables used in the analysis:* age, age squared, gender, marital status, age*marital status, gender*marital status, dummies for region (state) of birth, dummies for region (municipality) of residence, dummy for urban area, dummy for foreign born. *Educational attainment levels: 9*
India	*Income concept used in the analysis:* wage income for 1983, 1987, 1993, 1999, 2004. *Other income concepts available:* none. *Control variables used in the analysis:* age, age squared, gender, marital status, age*marital status, gender*marital status, dummies for region (state) of residence, dummy for urban area, dummies for religion. *Educational attainment levels:* 8
Jamaica	*Income concept used in the analysis:* wage income for 1982, 1991, 2001. *Other income concepts available:* none. *Control variables used in the analysis:* age, age squared, gender, marital status, age*marital status, gender*marital status, dummies for region (parish) of birth, dummies for region (parish) of residence, dummy for foreign born, dummies for religion, dummies for race. *Educational attainment levels: 7*
Mexico	*Income concept used in the analysis:* earned income per hour worked for 1990, 1995, 2000; earned income for 1960; total income for 1970. Other income concepts available: total income per hour for 1995, 2000. Control variables used in the analysis: age, age squared, gender, marital status, age*marital status, gender*marital status, dummies for region (state) of birth, dummies for region (state) of residence, dummy for urban area, dummy for foreign born, dummies for religion (except 1995). *Educational attainment levels: 10*

Note: Point estimates of the Mincerian regressions and the number of observations available are summarized in Appendix Tables 2 and 3. For more details on the variables see https://international.ipums.org/international/.

Appendix Table 1: Continued

Panama	Income concept used in the analysis: wage income per hour worked for 1990, 2000; wage income for 1970; total income per hour worked for 1980. Other income concepts available: earned income per hour worked for 1990, 2000; total income per hour worked for 1990 (yield nearly identical results as income concept used). Control variables used in the analysis: age, age squared, gender, marital status, age*marital status, gender*marital status, dummies for region (state) of birth (except 1990), dummies for region (district) of residence, dummy for urban area (except 1990), dummy for foreign born (except 1980). *Educational attainment levels:* 8
Puerto Rico	*Income concept used in the analysis:* wage income per hour worked for 1970, 1980, 1990, 2000, 2005. *Other income concepts available:* total income per hour worked for 1970, 1980, 1990, 2000, 2005; earned income per hour worked for 1990, 2000, 2005 (yield nearly identical results as income concept used. *Control variables used in the analysis:* age, age squared, gender, marital status, age*marital status, gender*marital status, dummies for region (metropolitan area) of residence, dummy for foreign born, dummies for race (only 2000, 2005). *Educational attainment levels:* 8
South Africa	*Income concept used in the analysis:* total income per hour worked for 1996, 2007; total income for 2001. *Other income concepts available:* none. *Control variables used in the analysis:* age, age squared, gender, marital status, age*marital status, gender*marital status, dummies for region (province) of birth (except 1996), dummies for region (municipality) of residence, dummy for foreign born, dummies for religion (except 2007), dummies for race. *Educational attainment levels: 6*
Venezuela	*Income concept used in the analysis:* earned income per hour worked for 1971, 1981, 2001; earned income for 1990. *Other income concepts available:* total income per hour worked 2001 (yields a Mincerian return to schooling of 13.7% as compared to 4.4% using earned income). *Control variables used in the analysis:* age, age squared, gender, marital status, age*marital status, gender*marital status, dummies for region (state) of birth, dummies for region (province) of residence, dummy for foreign born. *Educational attainment levels: 10*

Note: point estimates of the Mincerian regressions and the number of observations available are summarized in Appendix Tables 2 and 3. For more details on the variables see https://international.ipums.org/international/.

Appendix Table 2

	1960	1970	1980	1990	1995	2000	2005
Brazil		0,124 (0,00005)	0,113 (0,00004)	0,115 (0,00004)		0,109 (0,00003)	
Colombia		0,0889 (0,0005)					
India			0,083 (0,00002)	0,0866 (0,00002)	0,074 (0,00002)	0,0776 (0,00001)	0,0788 (0,00001)
Jamaica			0,125 (0,002)	0,0573 (0,002)		0,0614 (0,001)	
Mexico	0,123 (0,0002)	0,0993 (0,0001)		0,0682 (0,0001)	0,114 (0,0001)	0,094 (0,0001)	
Panama		0,0879 (0,002)	0,0911 (0,0003)	0,0941 (0,0003)		0,0916 (0,0005)	
Puerto Rico		0,099 (0,0003)	0,088 (0,0005)	0,0938 (0,0005)		0,0985 (0,0005)	0,116 (0,0004)
South Africa					0,117 (0,0001)	0,11 (0,0002)	0,143 (0,0002)
Venezuela		0,0625 (0,0005)	0,0875 (0,0003)	0,0732 (0,0002)		0,0443 (0,0005)	

Note: estimated Mincerian coefficients and robust standard errors in parentheses

1970 figure refers to 1971 for Venezuela and 1973 for Colombia;

1980 figure refers to 1981 for Venezuela, 1982 for Jamaica, and 1983 for India;

1990 figure refers to 1987 for India and 1991 for Brazil and Jamaica;

1995 figure refers to 1993 for India and 1996 for South Africa;

2000 figure refers to 1999 for India and 2001 for Jamaica, South Africa, and Venezuela;

2005 figure refers to 2004 for India and 2007 for South Africa

Appendix Table 3

	1960	1970	1980	1990	1995	2000	2005
Brazil		14660440	24720720	33616046		41010810	
Colombia		3127210					
India			86928152	45901965	109703806	133891583	139597372
Jamaica			255720	409100		443629	
Mexico	4470106	6183300		14303270	18762057	21316086	
Panama		246250	367330	408540		653460	
Puerto Rico		653200	775220	698772		732668	1000738
South Africa					6775030	8299308	9360012
Venezuela		1540174	2567310	3548928		5038900	

Note: number of observations used in the individual-level Mincerian regressions

1970 figure refers to 1971 for Venezuela and 1973 for Colombia;

1980 figure refers to 1981 for Venezuela, 1982 for Jamaica, and 1983 for India;

1990 figure refers to 1987 for India and 1991 for Brazil and Jamaica;

1995 figure refers to 1993 for India and 1996 for South Africa;

2000 figure refers to 1999 for India and 2001 for Jamaica, South Africa, and Venezuela;

2005 figure refers to 2004 for India and 2007 for South Africa

Appendix Table 4

	Output in **1995**	% gap with US	Mincer Coeff. Estimate	Year	% gain using (**19**)	% gain using (**20**)	% 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	n.a.
Iraq	n.a.	n.a.	6.4	1979	0.567	0.664	n.a.
Taiwan	n.a.	n.a.	6	1972	0.330	0.293	n.a.

Note: output per worker from PWT