CHRISTIAN DAUDE

Understanding Solow Residuals in Latin America

Despite some improvements in recent years, long-term economic growth in Latin America and the Caribbean (LAC) has been rather disappointing over the past decades. Since 1960, gaps in the GDP per capita of LAC countries with respect to not only the United States but also their peers ("twin economies") have widened steadily (see table 1). While the typical Latin American country[1] was around 4.4 times poorer than the United States in 1960, as of 2008 it was 5.5 times poorer. The comparison with twin economies—countries that in 1960 had a GDP per capita comparable to that in Latin America[2]—is even more remarkable. The average LAC economy was just 20 percent poorer than its typical twin economy in 1960. In 2008, GDP per capita in Latin America was less than half that in the twin economies.

Daude is with the Development Centre at the Organization for Economic Cooperation and Development.

I would like to thank Marcela Eslava and Daniel Ortega as well as participants in the Economía panel meeting held in May 2011 in Washington, D.C., and in the Hertie School of Government seminar held in June 2012 in Berlin, Germany, for helpful suggestions and comments. Laura Alfaro, Mauricio Cárdenas, Francesca Castellani, Eduardo Fajnzylber, Eduardo Fernández-Arias, William Maloney, and participants at the October 2009 INNOVALatino Experts Meeting in Buenos Aires made insightful comments and suggestions on an earlier version of this paper. Arne Nagengast provided superb research assistance. Any errors are my sole responsibility. The opinions expressed in this paper are personal and do not necessarily reflect those of the OECD or the governments of its member countries.

1. Throughout the paper, I use the terms "typical" or "average" country to refer to the geometrical average across countries within a region.

2. Twin economies are defined as countries with similar levels of development at an initial date. In particular, I consider those that were in the second and third quartiles of the world's GDP per capita distribution in 1960—a range where most Latin American countries were at that time—and for which all data used in this paper to perform the accounting exercises are available (investment, education, and so forth). The resulting group of countries is composed of Cyprus, Greece, Iran, Ireland, Israel, Japan, Jordan, Korea, Mauritius, Portugal, South Africa, Spain, and Turkey.

TABLE 1. GDP per Capita in Latin America Relative to Benchmarks[a]

	GDP per capita relative to United States					
Country	*1960*	*1970*	*1980*	*1990*	*2000*	*2008*
Argentina	0.395	0.370	0.331	0.234	0.234	0.272
Bolivia	0.175	0.138	0.133	0.089	0.084	0.087
Brazil	0.189	0.217	0.298	0.233	0.202	0.215
Chile	0.241	0.221	0.189	0.182	0.247	0.286
Colombia	0.160	0.146	0.165	0.147	0.153	0.176
Costa Rica	0.318	0.311	0.318	0.238	0.231	0.262
Dominican Republic	0.149	0.138	0.172	0.154	0.186	0.224
Ecuador	0.177	0.155	0.219	0.156	0.129	0.144
El Salvador	0.222	0.201	0.179	0.131	0.141	0.151
Guatemala	0.193	0.194	0.220	0.151	0.140	0.143
Honduras	0.146	0.118	0.132	0.100	0.078	0.085
Jamaica	0.367	0.351	0.256	0.232	0.227	0.211
Mexico	0.293	0.305	0.364	0.279	0.264	0.289
Nicaragua	0.173	0.180	0.127	0.070	0.053	0.050
Panama	0.139	0.165	0.201	0.186	0.177	0.228
Paraguay	0.121	0.099	0.141	0.119	0.089	0.088
Peru	0.243	0.247	0.218	0.136	0.130	0.165
Uruguay	0.307	0.226	0.246	0.202	0.213	0.246
Venezuela	0.449	0.413	0.391	0.261	0.212	0.220
Average LAC country relative to						
United States	0.225	0.213	0.222	0.167	0.161	0.182
Twin economies	0.834	0.670	0.632	0.486	0.448	0.462

Source: Author's calculations based on Heston, Summers, and Aten (2011).
a. GDP per capita is purchasing power parity–adjusted and Hodrick-Prescott–filtered with smoothing parameter 6.25.

This persistent decline in relative GDP per capita has been common to all countries in the region, with some exceptions. Of the nineteen LAC economies in my sample, five managed to grow faster than the United States during the 1960–2008 period: Brazil, Chile, Colombia, the Dominican Republic, and Panama. However, progress has been quantitatively modest. For example, if benchmarked to twin economies, only the Dominican Republic and Panama managed to grow faster over the same period. Furthermore, in several cases (for example, Brazil) progress was made mainly during the 1960s and 1970s, with growth being subpar from the debt crisis in the early 1980s onward. While the 2000s have been good years in terms of relative growth performance for the region, it will still take around 27 years to cut by 50 percent the GDP per capita gap with respect to the United States if the growth differential during 2000–08 of around 1.5 percent per year is to be maintained; with respect to the twin economies, it will take around 108 years. Therefore, low potential growth continues to be a significant challenge for the region.

This paper contributes to the understanding of what drives this poor performance by using new databases and analytical tools to explore the relative importance of productivity and factor accumulation across LAC countries. With regard to analytical tools, the paper provides new evidence from three viewpoints. First, I perform a careful analysis of different ways of decomposing GDP per capita levels into physical capital, human capital, and a residual—the "Solow residual," often interpreted as a measure of total factor productivity (TFP), representing aggregate economic efficiency, but also often viewed as "a measure of our ignorance"—under different assumptions regarding the production function and measurement. Second, I present nonparametric estimations of efficiency based on a data envelope analysis that does not rely on the traditionally used Cobb-Douglas production function; instead, it recognizes that the relevant production possibilities frontier may be a function of factor endowments and thus differ across countries. With regard to new data sets, this paper uses three newly available sources. First, in contrast to previous studies focusing on Latin America, it uses the new version of the Barro and Lee (2010) data set on educational attainment, which addresses several concerns on data quality that arose over the previous version (see Cohen and Soto 2007 as well as De la Fuente and Domenech 2006). Second, I also use the latest version of the Penn World Tables (version 7.0), extending the analysis until 2008; doing so allows me to cover the 2000s, a decade that has been quite successful for the region in terms of economic growth compared with its past. Third, I use the PISA 2009 test scores from the Organization for Economic Cooperation and Development (OECD) to analyze the importance of cognitive skills and adjust human capital indicators for differences in quality.

The paper focuses on the decomposition of GDP per worker into physical capital, human capital, and the Solow residual through the use of alternative methods, as policy recommendations might differ substantially according to the source of income disparities, in particular if policymakers have to establish priorities and have limited political capital to implement reforms. While recent work on Latin America has emphasized the importance of TFP (see Daude and Fernández-Arias 2010) for the region as a whole, this paper tries to go into more detail on the differences across countries and explores in more detail some factors that traditionally fall into the residual.

The results show that the two most relevant aspects in explaining the residual are the quality of human capital and differences in the relevant production possibilities frontier. Adjusting for the quality of human capital reduces by 10 percentage points the contribution of TFP to the income per capita gap with respect to the United States. Similarly, using nonparametric estimates of a production possibilities frontier instead of the United States as a common frontier reduces the contribution of efficiency by 18 percentage points. Other issues, such as adjusting for terms of trade, using country-specific production function parameters, and considering hours worked instead of the number of workers to measure labor inputs are not found to be systematically important across countries in Latin America in terms of altering the relative contribution of production factors and measured TFP to income per capita gaps.

The paper next presents the data sets and basic definitions used herein and some preliminary evidence derived from traditional development accounting techniques. It then presents some robustness checks regarding the basic results from traditional development accounting, considering different specifications within the standard Cobb-Douglas production function framework, the effects of terms of trade and natural resources, and the quality of education. Following that, it explores an alternative nonparametric approach to examine the importance of differences in production possibilities frontiers across countries. Finally, it discusses the main policy implications of the analysis and identifies needs for future research.

Data

For aggregate production in the baseline results, I used a purchasing power parity–adjusted series at 2005 prices from the latest Penn World Tables (version 7.0) for nineteen LAC economies from 1957 to 2008 (see Heston, Summers, and Aten 2011).[3] The workforce and physical capital investments (at constant 2005 prices) are also from this database. I used the workforce instead of hours worked to proxy labor inputs, as the latter are available for only seven countries. However, I used output per hour worked as an alternative series in the robustness checks. For the construction of physical capital stocks, I followed the usual perpetual inventory method approach (see, for example, Caselli 2005). The initial capital stock (K_0) is given by $K_0 = \frac{I_0}{g+\delta}$, where I_0 is aggregate investment in the first available year, g is the geometric

3. In particular, I considered the Laspeyres series “rgdpl” (per capita) and “rgdpl2wok” (per worker). The countries in my sample are Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Uruguay, and Venezuela.

average of GDP growth rates between the first year available and 1960, and the depreciation rate (δ) is set equal to 0.07. From the initial date onward the capital stock was updated using the following equation: $K_t = I_t + (1 - \delta)K_{t-1}$.

I used the average years of schooling of the population over 15 years of age from Barro and Lee (2010) to construct the human capital series according to Hall and Jones (1999). In particular, I mapped the years of schooling (s) into human capital (h) using: $h = e^{\phi(s)}$, where $\phi(.)$ is a piecewise linear function equal to $0.134 \cdot s$ if $s \leq 4$, $0.536 + 0.101 \cdot (s - 4)$ if $4 < s \leq 8$ and $0.94 + 0.068 \cdot (s - 8)$ if $s \geq 8$. It is important to point out that this measure of human capital is based on the average quantity of formal education in the population. Therefore, it ignores differences in the quality of education as well as skills that are acquired through work experience and other types of workforce training.

Finally, as I was interested in analyzing long-term trends rather than business cycle fluctuations, I focused on Hodrik-Prescott filtered GDP, workforce, and physical and human capital series, using a smoothing parameter of 6.25 as suggested by Ravn and Uhlig (2002).

Standard Development Accounting

The differences in GDP per capita of LAC countries with respect to the United States are mainly driven by differences in output per worker. GDP (Y) per capita can be written as $\frac{Y}{N} = \frac{Y}{L}\frac{L}{N_{15-64}}\frac{N_{15-64}}{N}$, where N is the population, L is the labor force, and N_{15-64} is the working-age population. Therefore, differences in GDP per capita could be driven by differences in output per worker, differences in labor force participation rates, or demographic factors (share of the working-age population—workers between 15 and 64 years of age—in the total population). For the average LAC country in 2008, around 92 percent of the GDP per capita gap with respect to the United States is explained by the GDP per worker gap, while differences in labor participation and demographics explain less than 8 percent of the development gap.[4] Therefore, in what follows I focus on decomposing output per worker gaps.

4. However, there are differences within the region. For some economies in the region, labor participation and demographic differences are more significant contributors to the GDP per capita gap. For example, in Mexico they account for almost 16 percent of the gap (due mainly to low female labor force participation). Meanwhile, in Brazil the contribution of these factors is actually slightly negative (that is, they narrow the GDP per capita gap with respect to the United States), contributing –1.7 in 2008.

The standard development accounting approach consists of adjusting a Cobb-Douglas production function such as

(1) $$Y = AK^{\alpha}(hL)^{1-\alpha},$$

where Y is aggregate GDP, A is the Solow residual, K is the aggregate physical capital stock, and hL is the human capital–adjusted workforce. In my baseline analysis, the capital-share production function parameter α is set equal to one-third, as is usual in the literature.[5] In per worker terms, this yields human capital A:

(2) $$y = Ak^{\alpha}h^{1-\alpha}.$$

Dividing equation 2 by the benchmark's GDP per worker—denoted by y^*—and taking logs yields a decomposition of output per worker gaps given by

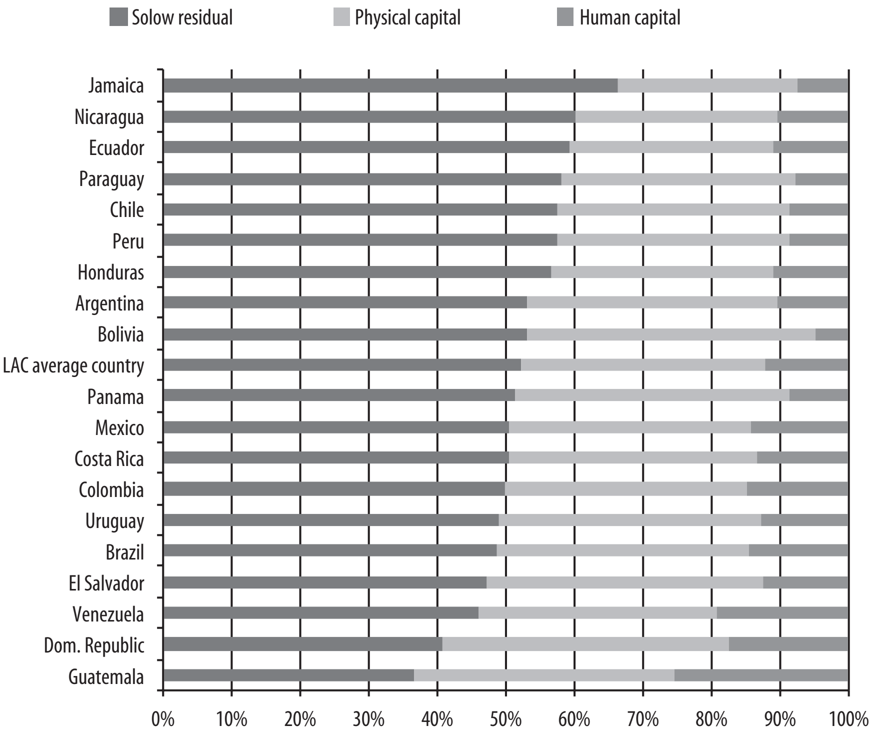
(3) $$\log y - \log y^* = \left(\log A - \log A^*\right) + \alpha\left(\log k - \log k^*\right) + (1-\alpha)\left(\log h - \log h^*\right).$$

For the frontier y^* to be a meaningful benchmark, an important implicit assumption is that all countries could in principle attain the level of aggregate efficiency A^*. In other words, if an economy is not producing at the frontier level of efficiency, it is not because of economic conditions such as relative endowments of physical and human capital but because of some type of government failure or distortions that block the efficient outcome (see Parente and Prescott 2002).

Applying this decomposition to the 2008 data across countries in the region with respect to the United States shows that on average the Solow residual accounts for around 52 percent of the output per worker gap, physical capital for nearly 36 percent, and human capital for the remaining 12 percent (see figure 1). However, there are significant differences regarding the relative contribution of each factor within the region. While the residual explains

5. While Gollin (2002) shows a large variation across countries in this parameter, after adjustments have been made for informal labor markets and self-employment, there are no significant trends in terms of economic development (GDP per capita level) and labor income shares. Thus, the assumption of a constant and equal parameter across countries does not seem too restrictive to begin with. However, some authors argue that capital shares are higher in developing countries (see, for example, Rodriguez and Ortega 2006).

FIGURE 1. 2008 GDP per Worker Decomposition for LAC Countries Relative to the United States



Source: Author's calculations based on Barro and Lee (2010) and Heston, Summers, and Aten (2011).

just around one-third of the gap in Guatemala, its contribution amounts to almost two-thirds in Jamaica. There is no clear pattern in terms of the level of development and the contribution of the different factors to the output per worker gap. For example, in Guatemala and El Salvador physical and human capital factors contribute between 63.5 and 53 percent, while in Nicaragua and Honduras the Solow residual is the main factor (60.2 and 56.7 percent, respectively). Finally, Costa Rica and Panama—two economies with higher income per capita levels than the rest of the region—are in between in terms of the relative contribution of factors and the residual. In the Southern Cone a similar picture emerges. For example, countries like Chile and Paraguay have very similar relative contributions of the residual, physical capital, and human capital to their gaps with respect to the United States, despite the fact that Chile's GDP per capita is more than 3 times that of Paraguay.

Another interesting finding is that today the contribution of human capital is rather limited—on average, it accounts for just 12 percent of the 2008 output per worker gap with respect to the United States. As table 2 shows, the relative contributions of the residual, physical capital, and human capital have changed significantly over time. During the 1960s and 1970s human capital accounted for almost one-third of the gap, physical capital for a similar amount, and the Solow residual for slightly more. However, during the 1980s the contribution of the residual increased to around 50 percent, while that of human capital started to decline steadily from 30 percent in 1980 to just above 12 percent in 2008. The residual's contribution to the gap has remained slightly above 50 percent since the 1980s, while that of physical capital has increased from around 29 percent to around 36 percent. Again, patterns differ across countries within the region over time. During the 1980–2008 period, the contribution of aggregate productivity remained roughly the same for

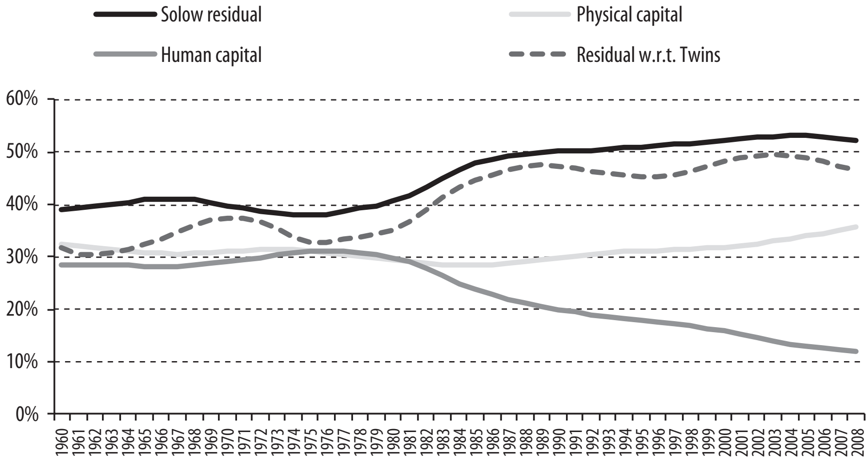
TABLE 2. Contributions to the Output per Worker Gap vis-à-vis the United States, by Country[a]

	1980			*2008*			*2008–1980*		
Country	*Solow residual*	*Physical capital*	*Human capital*	*Solow residual*	*Physical capital*	*Human capital*	*Solow residual*	*Physical capital*	*Human capital*
Argentina	0.56	0.20	0.24	0.53	0.36	0.10	−0.03	0.16	−0.13
Bolivia	0.46	0.35	0.19	0.53	0.42	0.05	0.07	0.07	−0.14
Brazil	0.14	0.31	0.56	0.49	0.37	0.15	0.35	0.06	−0.41
Chile	0.53	0.28	0.19	0.58	0.34	0.09	0.04	0.06	−0.10
Colombia	0.37	0.33	0.29	0.50	0.35	0.15	0.13	0.02	−0.15
Costa Rica	0.22	0.41	0.37	0.50	0.36	0.14	0.29	−0.05	−0.24
Dominican Rep.	0.38	0.36	0.25	0.41	0.42	0.18	0.03	0.05	−0.08
Ecuador	0.56	0.17	0.27	0.59	0.30	0.11	0.03	0.13	−0.16
El Salvador	0.28	0.37	0.35	0.47	0.40	0.12	0.20	0.03	−0.23
Guatemala	0.18	0.36	0.46	0.36	0.38	0.25	0.18	0.02	−0.21
Honduras	0.38	0.34	0.29	0.57	0.32	0.11	0.19	−0.01	−0.18
Jamaica	0.54	0.22	0.24	0.66	0.26	0.07	0.12	0.05	−0.17
Mexico	−0.07	0.33	0.74	0.50	0.35	0.14	0.57	0.02	−0.59
Nicaragua	0.46	0.25	0.29	0.60	0.29	0.11	0.14	0.04	−0.19
Panama	0.47	0.31	0.22	0.51	0.40	0.09	0.04	0.09	−0.13
Paraguay	0.44	0.35	0.21	0.58	0.34	0.08	0.14	−0.01	−0.14
Peru	0.51	0.24	0.25	0.57	0.34	0.09	0.06	0.10	−0.16
Uruguay	0.50	0.29	0.20	0.49	0.38	0.13	−0.02	0.09	−0.07
Venezuela	0.29	0.08	0.64	0.46	0.35	0.19	0.17	0.27	−0.44
Average LAC country	0.41	0.30	0.30	0.52	0.36	0.12	0.12	0.06	−0.18

Source: Author' calculations based on Barro and Lee (2010) and Heston, Summers, and Aten (2011).

a. GDP per capita is purchasing power parity–adjusted and Hodrick-Prescott–filtered with smoothing parameter 6.25.

FIGURE 2. Evolution of Contributions to the GDP per Worker Gap between the Average LAC Country and the United States



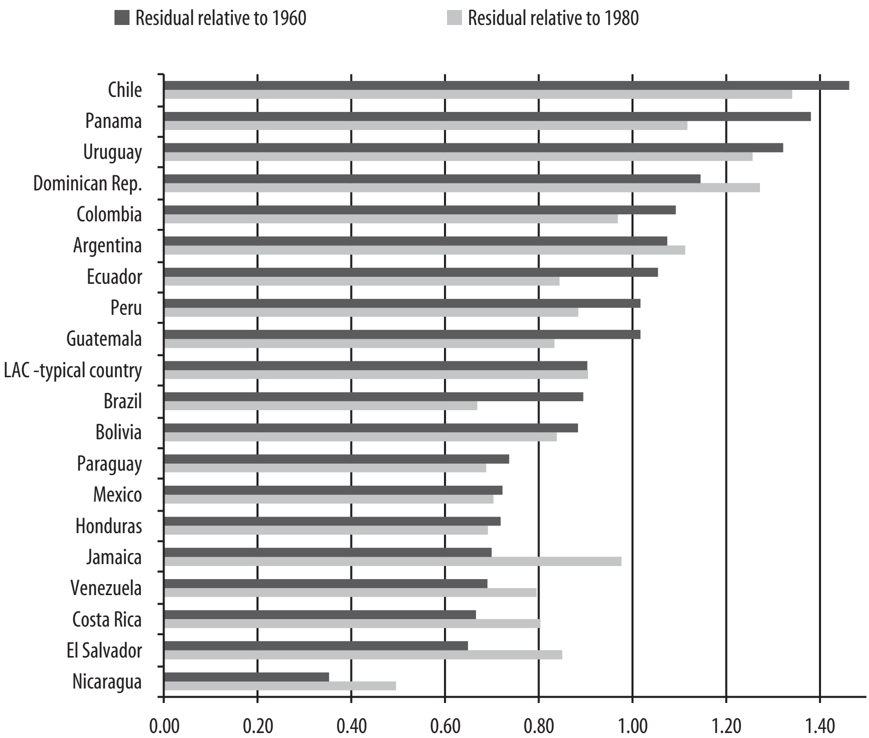
Source: Author's calculations based on Barro and Lee (2010) and Heston, Summers, and Aten (2011).

Argentina, Bolivia, Chile, Dominican Republic, Ecuador, Panama, Peru, and Uruguay, while it increased significantly in the remaining countries. The increase has been particularly steep in Brazil and Mexico, where the contribution of aggregate productivity to the output per worker gap with respect to the United States was negative or minor in 1980 and accounted for around half of the gap in 2008. While it could be argued that these trends are specific to the benchmark—the U.S. economy—the dotted line in figure 2 shows that this is not the case. Similar trends emerge when one considers the contribution of LAC aggregate productivity with respect to that of the twin economies.

Not only did the Solow residual grow relatively more slowly in LAC than in benchmark countries—as shown by the widening income per capita gaps (table 1) and the increasing contribution of the residual to the gap (figure 2)—but in many countries the residual levels in 2008 were actually below those of the early 1980s.[6] While nine countries presented levels in 2008 that were higher than or similar to levels in 1960, only three countries (Chile, Panama, and Uruguay) managed to have levels that were 20 percent—the cumulative growth rate of the Solow residuals in the United States during the same period—or more above their 1960 levels (figure 3). On average, the residual

6. Daude and Fernández-Arias (2010) also highlight this fact.

FIGURE 3. Ratio of 2008 Solow Residual to 1960 and 1980 Solow Residuals



Source: Author's calculations based on Barro and Lee (2010) and Heston, Summers, and Aten (2011).

was around 10 percent lower in 2008 than in 1960. Furthermore, for many countries the picture is more acute when compared with that in the 1980s. For example, Brazil's level in 2008 was just two-thirds of its level in 1980. That contrasts somewhat with other economies in the Southern Cone, such as Argentina, Chile, and Uruguay, which managed to raise the levels of their Solow residuals. In Central America and the Caribbean, Panama and the Dominican Republic—and to some degree Jamaica—stand out as the relatively successful economies in terms of raising their Solow residual levels from 1980 onward. Other economies reached TFP levels that were just half of those in 1980 (for example, Nicaragua).

Declines in levels are difficult to understand if the Solow residual is given a narrow technological interpretation. Alternative interpretations, which can be sorted into two groups, could be offered. First, the residual—as measured here—captures the overall efficiency at which inputs map into aggregate output; therefore distortions in the allocation of factors across sectors or firms can result in lower levels of output per unit of input if resources are reallocated to inefficient sectors or firms. That would be also in line with the finding in McMillan and Rodrik (2011) that in Latin America structural change—the reallocation of resources across sectors of economic activity—has had a negative contribution to output per worker growth. The question then is what drives the distortions—which policies, politics, market failures, or structural characteristics. The second group of interpretations holds that the residual only captures all measurement and specification errors in equation 2. Some of these concerns are addressed below.

Next, I investigate what drives the dispersion in income per worker across countries in the region. In particular, I emphasize the role of physical and human capital versus the Solow residual. Let $y_{kh} = k^{\alpha}h^{1-\alpha}$ be the level of income if all countries had the same level of efficiency, such that differences across countries would be explained only by differences in production factors. The following indicator can be computed to quantify the power of production factors to explain the differences in GDP per worker within the region (see Caselli 2005):

$$(4) \qquad VR_1 = \frac{var(\log(y_{kh}))}{var(\log(y))}.$$

Alternatively, as the Solow residual and production factors are correlated, Klenow and Rodriguez-Clare (1997) proposed using the following measure:

$$(5) \qquad VR_2 = \frac{var(\log(y_{kh})) + cov(\log A, \log y_{kh})}{var(\log(y))}.$$

Table 3 shows the evolution over time of the components of equations 4 and 5 as well as the variance of the Solow residual (in logs). The dispersion within the region in output per worker has increased significantly (by 60 percent) since the 1980s. That has not been the case for the dispersion in factors, which declined somewhat during the 1980s and remained constant from the 1990s through 2009. In the meantime, there has been an increase in the dispersion of the Solow residuals (by around 56 percent between 1980 and 2008) and also in the covariance between the residual and production factors. Regarding the

TABLE 3. Evolution of Variances across LAC Countries[a]

	1960	*1970*	*1980*	*1990*	*2000*	*2008*
GDP per worker	0.150	0.180	0.129	0.138	0.176	0.209
Factors (y_{kh})	0.067	0.064	0.045	0.038	0.036	0.038
Solow residual	0.092	0.089	0.064	0.071	0.088	0.100
Covariance (residual, factors)	–0.005	0.014	0.010	0.014	0.026	0.036
Variance ratio 1 (VR_1)	***0.445***	***0.353***	***0.346***	***0.276***	***0.207***	***0.183***
Variance ratio 2 (VR_2)	***0.415***	***0.430***	***0.425***	***0.380***	***0.353***	***0.353***

Source: Author's calculations based on Barro and Lee (2010) and Heston, Summers, and Aten (2011).
a. The first three rows refer to the variance of the logs between the 19 LAC countries in the sample.

relative importance of factors and the residual in explaining the dispersion in output per worker, according to the indicator VR_1, physical and human capital have been continuously losing ground, falling from a ratio of 44 percent in 1960 (35 percent in 1980) to below 19 percent in 2008. If we consider VR_2, the ratio was around 35 percent in 2008, below the 43 percent of 1980 but still significantly above the VR_1 measure.[7] Thus, the conclusion regarding what explains income per worker differences within the region depends to a certain degree on the treatment of the covariance term. The VR_1 indicator points clearly toward the declining importance of physical and human capital, with more than 80 percent of the variation in output per worker in 2008 being explained by other drivers (Solow residuals and the covariance term). The VR_2 indicator would still assign two-thirds of the output per worker gap to differences in Solow residuals and just one-third to physical and human capital. Therefore, according to the traditional development accounting approach, the Solow residual not only contributes to explaining a large share (52 percent in 2008) of the average output per worker gap with respect to the United States but also seems to account for a significant share of the differences in output per worker within the region. I explore next the robustness of these and the previous results.

Exploring Some Explanations

This section explores some possible explanatory factors behind the Solow residuals that are related to the production function parameters and specifications that might affect the results of the standard development accounting

7. Interestingly, these latter levels of relative dispersion are similar to those found in Caselli (2005) for the whole world.

presented so far. I do not focus on every possible source of variation but rather on new ones or some not highlighted in the literature so far.[8] In particular, I analyze four different topics. First, I consider country-specific labor shares instead of a uniform share across countries. Second, I investigate the influence of the terms of trade on Solow residuals. Third, I explore the robustness of my results when considering output per hour worked instead of output per worker. Fourth, I explore the importance of differences in the quality of education.

Country-Specific Labor Shares

A first consideration is to relax the assumption that all labor shares are the same across countries. Therefore, while each country's production function is still assumed to be a Cobb-Douglas function, it can differ across countries in terms of its key parameter. In particular, I consider the country-specific estimates of labor shares in Bernanke and Gürkaynak (2002), which follows the methodology proposed in Gollin (2002).[9] The resulting subsample of LAC countries is presented in the appendix (table A1). In terms of decomposing the output per worker ratios, equation 3 would now look like this:

$$\text{(6)} \qquad \log y - \log y^{*} = \left(\log A - \log A^{*}\right) + \alpha \log k - \alpha^{*} \log k^{*} + (1-\alpha)\log h - \left(1-\alpha^{*}\right)\log h^{*}.$$

The previous decompositions into factor and efficiency gaps are not that straightforward anymore. While the contribution of A could in principle be computed by focusing the first term on the right-hand side of equation 6, the other terms are a mix of differences in the production function (that is, in principal technological differences) and factor gaps. For example, I

8. For an overall survey on these issues from a global perspective, see Caselli (2005). Daude and Fernández-Arias (2010) show that decompositions are not very sensitive to changing the capital share from one-third to 0.5 and give alternative ways to compute the physical capital stock.

9. Although in principle one could also consider changes in the shares over time, the evidence provided in Bernanke and Gürkaynak (2002) and Gollin (2002) shows that in general there are no time trend or important fluctuations in labor shares over time for a large sample of developed and developing countries. In order to maximize coverage, I consider first the labor share, adjusting it for the operating surplus and private unincorporated enterprises (OSPUE). If that information is not available, I use the *imputed* OSPUE. Finally, if the information required to compute the imputed OSPUE is not available, I use the labor force corrected share (see Bernanke and Gürkaynak 2002 for more details).

could rewrite the right-hand side as the sum of a productivity gap, as two factor gaps if all countries had the same production function, and as a fourth term that reflects the differences in the production function parameters as follows:

$$\log\frac{A}{A^*}+\alpha^*\log\frac{k}{k^*}+\left(1-\alpha^*\right)\log\frac{h}{h^*}+\left(\alpha-\alpha^*\right)\log\frac{k}{h}. \tag{7}$$

Thus, the last term could be considered a technology factor, which depends on the country's relative factor endowments (physical to human capital), and therefore it could be attributed to the Solow residual or to part of the gap driven by factors. As shown in table 4, this term makes a large contribution to the output per worker gap. On average, it accounts for –29 percent of the output per worker gap. Therefore the Solow residual's contribution to GDP per capita gaps increases significantly if this last term is not considered part of it. As the country-by-country exercise shows, the changes in the relative contributions are very large. For example, in the case of Ecuador, Mexico, and Venezuela, the Solow residual contributes now more than 100 percent of the output per worker gap. At the other end of the spectrum, the contribution of the residual is now slightly negative for Costa Rica and Panama. Thus, differences in the production function parameters do not help to explain the

TABLE 4. Decomposition of 2008 Output per Worker Gap between LAC Countries and the United States, with Country-Specific Labor Shares

Country	*A/A* /a*	*k/k**	*h/h**	*Interaction term*	*Equal labor shares = 1/3 /b*	*Difference /a–/b*
Bolivia	0.52	0.42	0.05	0.01	0.53	–0.01
Chile	0.98	0.34	0.09	–0.41	0.58	0.41
Colombia	0.60	0.35	0.15	–0.10	0.50	0.11
Costa Rica	–0.07	0.36	0.14	0.58	0.50	–0.58
Ecuador	1.78	0.30	0.11	–1.19	0.59	1.19
El Salvador	0.95	0.41	0.13	–0.49	0.47	0.48
Mexico	1.24	0.36	0.14	–0.74	0.50	0.74
Panama	–0.13	0.41	0.09	0.64	0.51	–0.64
Paraguay	1.13	0.34	0.08	–0.55	0.58	0.55
Peru	1.00	0.34	0.09	–0.43	0.57	0.42
Uruguay	1.03	0.39	0.13	–0.54	0.49	0.54
Venezuela	1.28	0.36	0.20	–0.84	0.46	0.82
Average LAC	0.81	0.36	0.12	–0.29	0.52	0.29

Source: Author's calculations based on Barro and Lee (2010) and Heston, Summers, and Aten (2011).

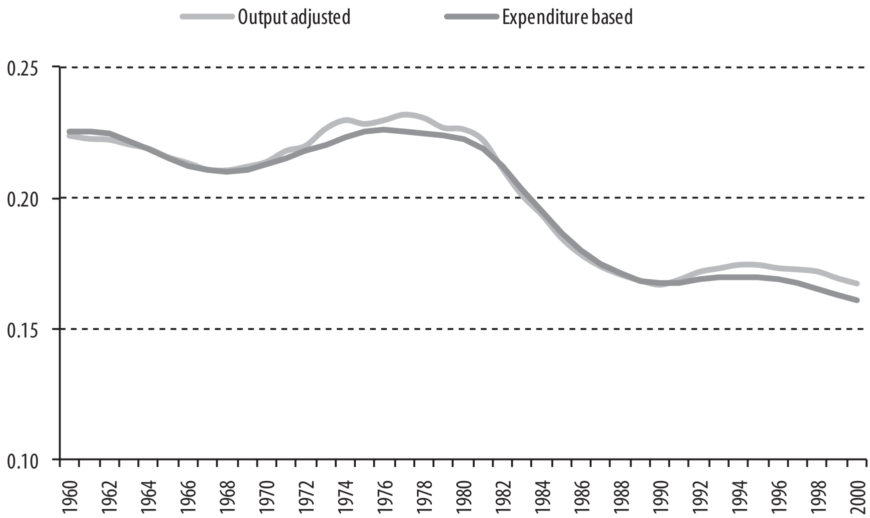
average Solow residual, as the "measure of our ignorance" actually increases its contribution from 52 percent to 81 percent of the output per worker gap. Furthermore, the country-level results show the sensitivity of the results to the assumption that the production function parameters are the same across countries. Of course, this depends on how the last term in equation 7 is interpreted, as it could be thought of as differences in productivity induced by the difference in technologies related to the relative factor endowments $\frac{k}{h}$. Therefore, again the issue of how efficiency and productive factors interact seems to be important in understanding further what drives output per worker gaps. Moreover, relaxing the assumption increases also the heterogeneity across countries in the region in terms of the relative importance of factors and the Solow residual. In the next section, I explore these issues further.

Terms of Trade

Another concern is the influence of commodity prices on the measurement of productivity. In my sample, the simple correlation coefficient between the growth rate of the terms of trade and the Solow residual for the average LAC economy for the 1980–2008 period is 0.64 and statistically significant. This positive correlation between the residual and terms of trade growth could be driven by economic fundamentals or could simply be due to a measurement problem, such that price effects account for part of the increase in GDP growth, in terms of purchasing power parity (PPP).[10] This problem relates to the issue of how GDP is measured in the Penn World Tables database—following the "expenditure side" rather than the "output side," as Feenstra and others (2009) put it. The PWT data measure real (PPP-adjusted) income with deflators constructed using expenditure data that are influenced by the terms of trade rather than output-based deflators. These expenditure and output deflators can be very different, especially in small open economies, due to the terms of trade. Unfortunately, the required deflators are not available from 2001 onward. Therefore, to assess the robustness of results, I looked at the differences in trends from 1960 to 2000. Figure 4 plots the GDP per worker ratio of the average LAC country compared with that of the United States

10. For example, if it is very difficult to move resources across sectors, fluctuations in the terms of trade can induce fluctuation in aggregate measured TFP, as the movements in relative prices could induce fluctuations in factor utilizations. However, as I focus here on trends—that is, filtered series—such effects should not be driving the correlation. See also Kehoe and Ruhl (2008) on this issue.

FIGURE 4. Ratio of LAC GDP per Worker to U.S. GDP per Worker According to Alternative Deflators



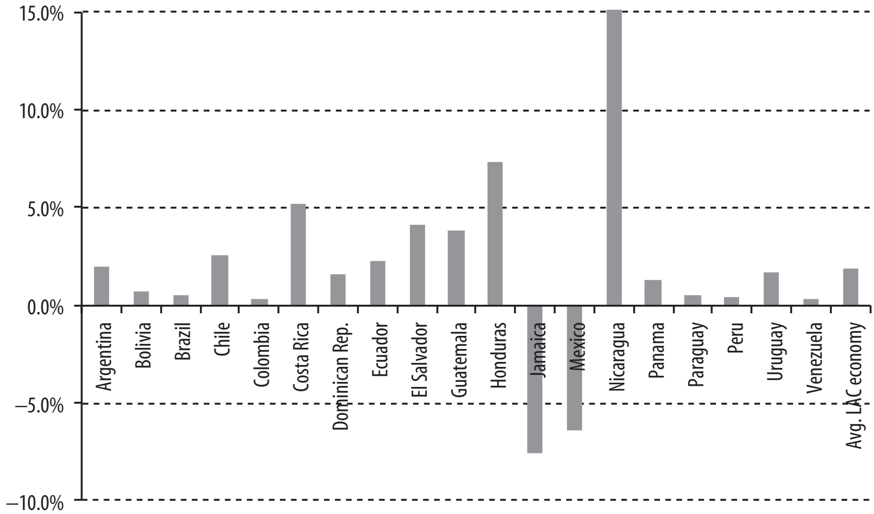
Source: Author's calculations based on Feenstra and others (2009) and Heston, Summers, and Aten (2011).

using both alternative deflators.[11] As can be seen, despite some differences between both series, the trends coincide and deviations never rise above 4 percent. Such small differences therefore cannot affect the overall trends and facts presented above for the LAC region as a whole.

However, figure 5 shows that the differences for individual countries can be significant. In fact, the contribution of the residual to the output per worker gap in 2000 for Nicaragua increases by more than 15 percent, from around 51 percent to above 66 percent. The differences in the contributions are also significant for Honduras, Jamaica, Mexico, and Costa Rica. Although I cannot infer from this that the influence of terms-of-trade measurement problems invalidates my results presented above, terms of trade seem likely to have first-order effects and should therefore be taken into account. For example, while overall regional trends seem to be relatively robust to this problem, country-specific diagnosis—a fundamental tool for evidenced-based policy—

11. The data were downloaded from Feenstra's website. See www.econ.ucdavis.edu/faculty/fzfeens/papers.html.

FIGURE 5. Differences in the Contribution of Solow Residuals to the Output per Worker Gap between Selected LAC Countries and the United States in 2000, According to Alternative Deflators[a]



Source: Author's calculations based on Barro and Lee (2010), Feenstra and others (2009), and Heston, Summers, and Aten (2011).
a. Output-adjusted minus expenditure-based.

seems to be more sensitive to this issue and therefore should be used to carefully review the issue in detail.

Differences in Labor Intensity

Significant differences in labor intensity could affect my results regarding trends as well as the levels of Solow residual differences across countries. To address this issue, I compared the contribution of the residual to the gap in output per worker and output per hour worked with respect to the United States for the seven countries for which the information on hours is available in the PWT database. Table 5 shows that changing the measure of labor input does not have significant consequences for the relative importance of physical and human capital versus the residual. On average, the impact for 1980 and 2008 is almost negligible, while in 1960 it accounted for a marginal increase of 2 percentage points in the residual's contribution to the gap. The main differences can be observed for Mexico in 1960 (with hours increasing the

TABLE 5. Contribution of Solow Residuals to Output per Hour or per Worker Gap between Selected LAC Countries and the United States

	1960		1980		2008	
Country	*Hours*	*Workers*	*Hours*	*Workers*	*Hours*	*Workers*
Argentina	0.54	0.54	0.56	0.56	0.53	0.53
Brazil	0.32	0.31	0.16	0.14	0.49	0.49
Chile	0.67	0.66	0.53	0.53	0.57	0.58
Colombia	0.45	0.43	0.39	0.37	0.50	0.50
Mexico	0.08	0.03	−0.05	−0.07	0.51	0.50
Peru	0.62	0.60	0.52	0.51	0.58	0.57
Venezuela	0.10	0.10	0.29	0.29	0.46	0.46
Average LAC country	0.44	0.42	0.38	0.38	0.52	0.52

Source: Author's calculations based on Barro and Lee (2010) and Heston, Summers, and Aten (2011).

contribution of the Solow residual by 5 percentage points), but as of 2008, the impact for all countries was not greater than 1 percentage point.[12]

Differences in the Quality of Education

The analysis so far has considered human capital as a mapping of the quantity of formal skills (average years of schooling) through the returns to education into the index h that affects the productivity of labor. I assume that for all countries an additional year of education increases the productivity of labor by the same amount. However, that assumption seems very unrealistic considering the large differences in cognitive skills suggested by student scores on international tests such as the OECD's Program for International Student Assessment (PISA) test. For example, the average score on the 2009 PISA test for the eight LAC countries was 408 points, almost 100 points below the OECD average (500 points). Such a difference is large, equivalent to a gap in knowledge of more than two years of schooling (OECD 2009). Thus, a part of the Solow residual might be capturing shortfalls in the quality of education. Next, I consider estimates of how adjusting for differences in the quality of the labor force can change my results. As there are no time series of comparable test scores long enough to adjust the working-age population's human capital accordingly, I used the 2009 PISA score to adjust the average

12. These results are similar to those in Restuccia (2009), which finds that labor intensity and participation are not a major driver of the output gap with respect to the United States for the aggregate LAC region.

TABLE 6. Decomposition of 2008 Output per Worker Gap between Selected LAC Countries and the United States, Adjusting for Differences in the Quality of Education

	Decomposition with quality-adjusted years of schooling			
Country	*Solow residual*	*Physical capital*	*Human capital*	*Change in Solow residual vs. baseline*
Argentina	0.41	0.37	0.22	−0.12
Brazil	0.39	0.37	0.24	−0.10
Chile	0.53	0.34	0.14	−0.05
Colombia	0.40	0.35	0.25	−0.10
Mexico	0.39	0.36	0.25	−0.11
Panama	0.37	0.41	0.23	−0.14
Peru	0.45	0.34	0.21	−0.12
Uruguay	0.40	0.39	0.22	−0.09
Average	0.42	0.36	0.22	−0.10

Source: Author's calculations based on Barro and Lee (2010), Heston, Summers, and Aten (2011), and OECD (2010).

years of schooling.[13] Table A2 presents the PISA test scores for the eight LAC countries that participated in the 2009 PISA round. For the adjustment, I consider 39 points equivalent to one year of schooling to map the test score gap with respect to the United States (which had a score of 500) into years of schooling. Then I subtracted the resulting years from the original Barro and Lee (2010) data. For example, while Chile had 9.99 years of schooling in 2008, given Chile's PISA score of 449, the quality-adjusted years of schooling would be 8.69.[14]

The adjustment for differences in the quality of schooling has a significant impact on the relative importance of the Solow residual and human capital. Table 6 presents the decomposition of the output per worker gap for the eight LAC countries that participated in the PISA 2009 round. On average, human capital shortfalls now explain almost one-fourth of the output per worker gap. The Solow residual now accounts on average for approximately 42 percent of the gap, just marginally above physical capital. This result is consistent with recent regression-based evidence, which argues that the disappointing growth performance of LAC countries can be explained by the low quality of schooling (Hanushek and Woessmann 2009). Differences in the quality of education also help explain why educational attainment, which has been increasing in

13. Therefore, I am implicitly assuming that the differences in quality were the same in the past.

14. Calculated as $8.69 = 9.99 - (500 - 449)/39$.

most countries of the region, has done little to close the income per capita gap. The results have also important policy implications. Almost two-thirds of the contribution of human capital to the income gap of Latin America with respect to the United States is driven by the lower quality of education and just one-third due to lower quantity. Therefore, focusing growth policies in this area on educational quality—putting the emphasis on increasing skills and knowledge rather than just expanding coverage—would bring the biggest payoff in terms of GDP growth.[15]

Summing up, traditional development accounting techniques might mask very different realities and policy implications, as they are especially sensitive to changes in the production function parameters, the terms of trade, and the quality of schooling. Therefore, the results should be taken with caution, and to better understand the drivers of country-specific income gaps they should be complemented with an in-depth analysis of these issues at the country level.

Data Envelope Analysis

So far, I have assumed that all countries—regardless of their relative endowments of physical and human capital—could reach the same level of efficiency as the most developed countries. In this sense, the use of the same benchmark—for example, the U.S. economy—is the right way to understand the relative contribution of production factors and efficiency gaps to development gaps. Furthermore, the most efficient technologies—used and developed at the frontier—would in principle be available to developing countries, at least in the medium term.[16] This view of technological progress requires an explanation for why developing countries "choose" more inefficient production. In line with this interpretation, a series of papers in the literature have focused on barriers to entry and monopoly rights (see Parente and Prescott 2002). However, this approach assumes that technological progress is factor neutral, which is a long-debated issue from a theoretical and empirical viewpoint (Caselli 2005). For example, the theory of appropriate

15. Of course, in the short term extending education to lower-income households often brings with it a reduction in the average test scores as students from weaker family backgrounds are incorporated into the system. The challenge for Latin American schools is therefore to become more inclusive while also increasing their effectiveness.

16. See Bernard and Jones (1996) on the issue of productivity convergence.

technology presented in Atkinson and Stiglitz (1969) puts emphasis on the technological process being “local” and therefore not easily transferable to different activities and countries with different factor endowments. In a similar way, Basu and Weil (1998) presents a model in which technologies depend on the capital-labor ratio, such that technological transfers do not occur in the short run due to the inappropriateness of using the advanced technologies in advanced (capital-intensive) economies in developing countries, which have lower capital-labor shares. A related literature deals with the implications—especially for labor income inequality—of technological change that is more skill intensive (see, for example, Acemoglu 1998 and 2002; Caselli and Colman 2006).

In order to explore the implications of relaxing my assumption, I used a nonparametric estimation based data envelope techniques (DEA). This approach, pioneered in Koopmans (1951) and Farell (1957), has been applied more recently in Färe and others (1994) and Kumar and Russell (2002) to growth accounting and in Jermanowski (2007) to development accounting across countries. It allows imposing fewer constraints on the elasticity of substitution between factors and moves away from the assumption of a factor-neutral technological frontier. Above, I used the twin economies as an alternative benchmark of countries that in the 1960s had a similar level of development. However, this group of countries might still have had different factor endowments and possibilities for upgrading their technologies. The DEA estimation of production possibilities frontiers therefore enables me to consider country-specific benchmarks.

In particular, I assume that output in a given country can be written as $Y = E\,F(K,H)$, where $F(.)$ has constant returns to scale. Therefore, country n could in principle replicate the economies of the whole universe of countries at scale λ as long as the required aggregate factor inputs in this combination do not exceed the available stocks of factor inputs (K_n, H_n). Consequently, the frontier is the linear combination that would yield the highest output. Given N countries and inputs in per worker terms (k, h), country n's maximization program is given by

$$\max_{\theta_n,\lambda_1,\ldots\lambda_N} \theta_n$$

$$\text{subject to} \tag{8}$$

$$\theta_n y_n \leq \lambda \cdot y, k_n \geq \lambda \cdot k,$$

$$h_n \geq \lambda \cdot h, \lambda_{1\times N} \geq 0.$$

The resulting solution to this maximization problem is generally upward biased due to the fact that the frontier is a linear combination of the relevant best-in-sample performers whose efficiency levels are likely to be below their own potential. Thus, as the potential is not observed, assuming that some countries in the sample are on the frontier means that the inferred efficiency levels are higher than the real ones. While the analysis is deterministic in nature, it is done with respect to an estimate of the underlying unobserved variable of interest, the true production possibilities frontier (Simar and Wilson 1998). Therefore, I also present a bias-corrected estimate of the efficiency index (E) using a bootstrapping procedure.[17] The basic idea of using this approach is that it is a good method—under reasonable assumptions regarding the data generating process—to "analyze the sensitivity of the efficiency scores relative to the sampling variations of the estimated frontier" (Simon and Wilson 1998). The underlying resampling process of the bootstrapping correction is therefore a useful tool to reduce one problem related to the DEA techniques, which is the potential influence of outliers and measurement errors in estimating the frontier.

Finally, it is also important to highlight some limitations of DEA techniques. The main advantage of DEA techniques is their nonparametric nature, which allows accommodating differences in the elasticity of substitution between physical and human capital and therefore reduces the potential of misspecification. However, DEA techniques also share with parametric production function or frontier models the disadvantage of potential endogeneity bias, as causality between physical and human capital and productivity can go both ways. Although it could be argued that their nonparametric nature partly reduces the problem, simulations show that endogeneity bias can also be large in DEA analysis, in particular in the presence of measurement errors and small samples (Orme and Smith 1996).

I solved the problem presented in equation 8 by using a sample of sixty-five economies, all of which have all data available for the 1960–2008 period.[18] I excluded two clear outliers, Luxembourg and Iran, as they would heavily influence the estimation of the frontier due to extremely high income, in the case of Luxembourg, and the 1970s oil price hikes, in the case of Iran. To increase the accuracy of my estimates, I computed the annual frontiers recursively by

17. Daude and Fernández-Arias (2010) present similar estimates but for the aggregate of Latin America and without considering the bias correction.

18. Estimations were made in *R* using Paul Wilson's FEAR 1.13 software package. It can be downloaded at no charge at www.clemson.edu/economics/faculty/wilson/Software/FEAR/fear.html.

TABLE 7. Contributions of Efficiency to Output per Worker Distance to Frontier, 2008

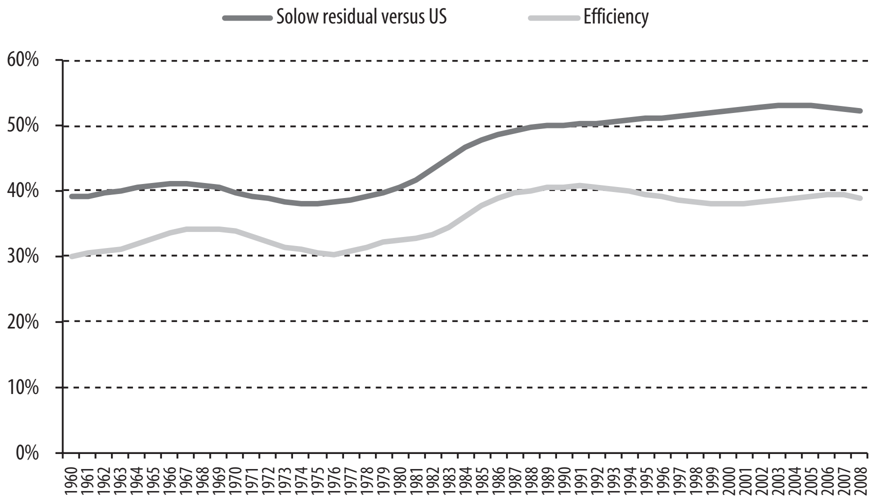
Country	*Efficiency*	*Bias-adjusted efficiency*	*Cobb-Douglas (United States benchmark)*
Argentina	0.42	0.37	0.53
Bolivia	0.35	0.34	0.53
Brazil	0.35	0.30	0.49
Chile	0.37	0.30	0.58
Colombia	0.35	0.30	0.50
Costa Rica	0.32	0.26	0.50
Dominican Rep.	0.29	0.23	0.41
Ecuador	0.48	0.44	0.59
El Salvador	0.29	0.24	0.47
Honduras	0.44	0.40	0.57
Jamaica	0.52	0.46	0.66
Mexico	0.33	0.25	0.50
Nicaragua	0.48	0.45	0.60
Panama	0.39	0.37	0.51
Paraguay	0.45	0.42	0.58
Peru	0.47	0.44	0.57
Uruguay	0.37	0.32	0.49
Venezuela	0.32	0.27	0.46
Average LAC	0.39	0.34	0.52

Source: Author's calculations based on Barro and Lee (2010) and Heston, Summers, and Aten (2011).

using all available observations up to that date. For example, for 1970 I used 650 observations: 65 countries times 10 years. Table 7 presents the resulting contributions of efficiency E to the output gap relative to the frontier compared with the contribution of Solow residuals for the baseline with respect to the United States. Clearly, abandoning the uniform benchmarking and Cobb-Douglas production function has important implications in terms of the diagnostic. On average, bias-corrected efficiency gaps contribute around one-third to the distance to the frontier, almost 20 percentage points less than the contribution of Solow residuals to the output per worker gap with respect to the United States, according to my baseline results. Therefore, it seems that the conclusion that Solow residuals are the main culprit of the GDP per worker gap is rather sensitive to the production possibilities frontier specification.

There are differences at the country level, but in general the reduction in the contribution of efficiency is between 15 and 27 percentage points. In no country is the contribution of bias-corrected inefficiency above 50 percent. However, it continues to represent around 40 percent or more of the gap in several economies, like Jamaica, Nicaragua, Peru, Ecuador, and Honduras.

FIGURE 6. Contribution of Efficiency to Gap between the Average LAC Country and the United States in Output per Worker Distance to the Frontier and Total Factor Productivity



Source: Author's calculations based on Barro and Lee (2010) and Heston, Summers, and Aten (2011).

Mexico and Chile have the largest differences between the efficiency and Solow residual gaps, and those differences are economically significant. For example, in the case of Mexico, according to the DEA estimates, output per worker would increase by 30 percent if the economy would operate on the production frontier. Meanwhile, according to the traditional growth accounting decomposition comparing Mexico with the United States, if Mexico were to operate at the same level of efficiency as the United States, it would almost double its output per worker. Of course, the DEA indicates that the U.S. level of TFP is not attainable for Mexico with its current factor endowments. That does not mean that TFP or technology does not matter in explaining this large gap but rather that given its factors—physical and human capital—Mexico actually has a low potential output, probably because it cannot produce more sophisticated products with its current mix of factors.

Figure 6 plots over time the contribution according to the DEA estimation and the baseline Solow residual's contribution to the GDP per worker gap between the United States and the average LAC economy. Interestingly, the time series are very similar, with a simple correlation between both series of 0.94. On average, the Solow residual's contribution is 10 percent above the efficiency-based estimation. As discussed above, the traditional approach shows that Solow residuals become the main explanation for the decline in GDP per worker from the early 1980s onward. However, according to the DEA measure, while the decline in relative GDP per worker during the 1980s was explained by a relative loss of efficiency, from the 1990s onward, efficiency's contribution to the gap has remained somewhat constant, which means that factors have been gaining ground again in explaining absolute gaps. Interestingly, this period coincides also with the increase in the correlation between the Solow residual and factors reported in table 3. It has also been associated with skill-biased technological change and increasing complementarity between capital and skilled labor (for example, computers).[19]

Thus, low levels of potential output might be explained by technological change that is not factor neutral. One way to explore this issue in my current set-up, following Jermanowski (2007), is to decompose the Solow residual (A) into the product of a pure efficiency term E, which is captured by my estimate from the DEA, and a term that depends on factors, as follows: $A = E \times T(k/h)$, such that the technological frontier for country i can be estimated as $T_i = A_i/E_i$. Using the bias-corrected DEA estimates, the contribution of the Solow residual to the output per worker gap with respect to the United States—52 percent in 2008 (table 2)—would be composed of a pure efficiency term (34 percent) and a factor-related gap in T (18 percent). That would imply that factors would be responsible for almost two-thirds (66 percent) of the output per worker gap—a direct effect of 48 percent and this indirect effect of 18 percent. Again, this exercise shows that a large part of the Solow residual—and therefore the output per worker gaps—can in principle be explained by factors rather than efficiency per se.[20]

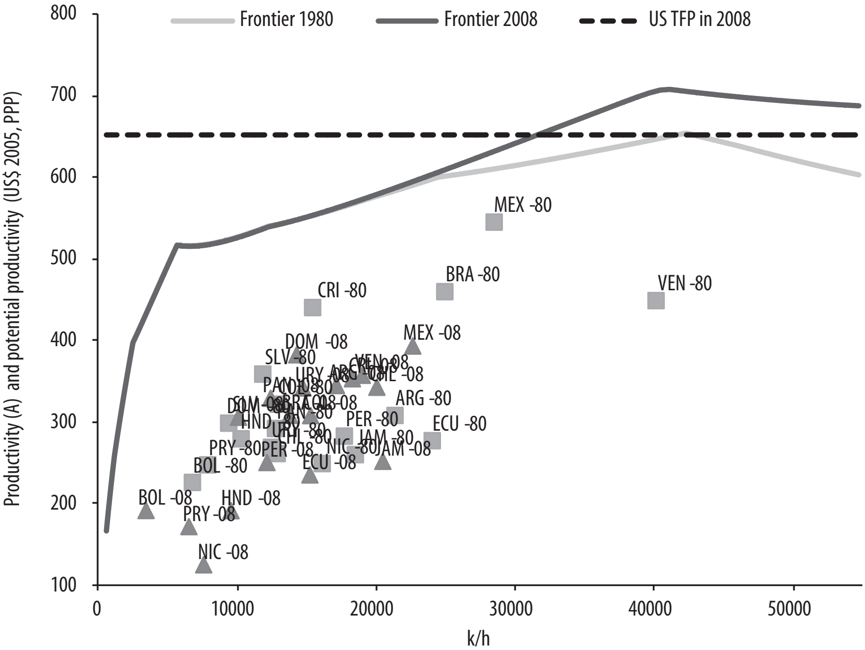
Figure 7 presents potential and observed productivity (Solow residuals) in terms of the relative endowments of physical and human capital for 2008 and 1980. This figure presents several interesting findings related to Latin America. First, the technological frontier for the countries with low relative physical capital is virtually unchanged because the frontier has expanded outward at the higher end only.[21] For most LAC countries that implies that—apart

19. See Acemoglu (1998), Bekman, Bound, and Machin (1998), and Caselli and Coleman (2006).

20. Figure 7 includes a representation of this decomposition. For a given factor mix, the vertical distance between the observed productivity and the frontier represents the pure inefficiency, while the distance between the frontier and the dotted line accounts for T.

21. This result is in line with the Jermanowski (2007) analysis, which covered just up to 1995.

FIGURE 7. Technological Frontier in 1980 and 2008



Source: Author's calculations based on Barro and Lee (2010) and Heston, Summers, and Aten (2011).

from the fact that there has been an observed decline in TFP—the potential level of TFP did not change significantly between 1980 and 2008. For example, while measured TFP declined around 12.5 percent on average during that period, potential TFP fell by just 3 percent. Second, despite different experiences across countries, there is a positive correlation between the changes in measured TFP and potential TFP. For example, within the group of countries that increased their TFP levels between 1980 and 2008 (Chile, the Dominican Republic, and to some extent Uruguay, Panama, and Argentina), all countries have experienced an increase in their potential TFP—with the exception of Argentina, which experienced a slight decline. Third, this increase is driven mainly by upgrading of the relative factor endowments rather than expansion of the technological frontier. For example, while potential TFP increased by around 6 and 5 percent for Chile and the Dominican Republic, respectively, that increase would have been basically nil if they had preserved their 1980s factor mix. However, these increases in potential TFP are small compared with the overall increases in measured TFP of 36 and 22 percent, respectively. Thus, these countries have raised TFP mainly by increasing factor-independent efficiency rather than by accessing new technological opportunities due to altering their factor mix.

Overall, the DEA presented here reinforces the argument that a development policy agenda for the region should be country-focused, because the proximate causes of low labor productivity across countries differ significantly. Furthermore, conclusions regarding the main factors driving relative GDP per worker levels for Latin America depend heavily on the functional form assumed in standard development accounting exercises. Of course, just as the Cobb-Douglas framework has its flaws, the DEA approach also suffers from the same potential measurement problems regarding human and physical capital. Furthermore, it does not solve the causality problems discussed earlier. I turn to this issue next.

Conclusions

This chapter presents a series of development accounting exercises for Latin America. The results show that conclusions regarding the relative importance of physical capital and human capital versus Solow residuals depend critically on the assumptions regarding benchmarks and functional forms. Furthermore, even within the traditional Cobb-Douglas functions approach, issues such as differences in the production function parameters across countries, the quality of education of the labor force, and changes in terms of trade tend to be captured by the Solow residual, although they would have very different implications for policy. Furthermore, assuming benchmarks that depend on a country's factor endowments, I find that differences in factor endowments can explain almost 40 percent of the gap in Solow residuals of the average LAC country with respect to the United States. Finally, another important point is that differences across countries in the relative importance of factor endowments and efficiency gaps are significant. That means that to advance understanding of the underlying constraints, a country-specific approach is needed.

While all these exercises have their limitations, I think that they provide solid evidence of the shortcomings of standard development accounting techniques in making robust predictions. Therefore, while they can be a useful exploratory tool for identifying some trends, recommendations regarding policy priorities should be based on more solid evidence. For example, traditional techniques tend to underestimate the role of human capital in explaining income gaps between Latin America and the developed world and other developing countries, because they focus only on the quantity of education rather than taking into account cognitive skills. This paper shows that cognitive differences are large and that therefore human capital formation should be high on the agenda in most countries of the region. In particular, emphasizing outcomes that improve quality, knowledge, and skills would bring larger payoffs than focusing on just extending coverage.

Of course, development accounting has also limitations in terms of its usefulness for policy purposes because the proximate causes are somewhat abstract and not directly related to policies.[22] There exist efforts, such as the OECD's Going for Growth framework, which try to remedy this issue by developing databases to benchmark policies and regulations and produce an estimate of the expected impact of each policy on productivity and growth. Combined with such an approach, development accounting would be part of the toolbox for making a diagnosis but it also would be complemented by an in-depth analysis of policy gaps that could guide prioritization and suggestions for reform. Nevertheless, such a framework should be adapted to the stage of development of LAC countries, as countries might face different constraints to development and growth at different stages and phases of their development. For example, many policies—such as competition policies and financial liberalization—that might enhance growth and productivity in developed economies because they allow for more innovation and reallocation of resources to leading sectors may do little in economies that are far away from the frontier. In those economies, institutions and policies that facilitate absorption and adoption might be more important (Acemoglu, Aghion, and Zilibotti 2006). There is some evidence in the literature that these differential and nonlinear effects of policies do exist (for example, Wölfl and others 2010; Vandenbussche, Aghion, and Meghir 2004). Thus, in addition to policy benchmarking and development accounting, a careful country-level assessment is definitely needed to understand the constraints to economic growth in each country in the region, especially given the significant heterogeneity that seems to exist within Latin America and the Caribbean even at the very aggregate and abstract level of the results presented here. Studies based on the growth diagnostics methodology pro-

22. The cross-country growth regressions popular during the 1990s have received similar criticism as they often include indirect proxies of outcomes but not policies.

posed by Hausmann, Rodrik, and Velasco (2005) seem to be a more fruitful way to guide policy (see, for example, Agosin, Fernández-Arias, and Jaramillo 2009). Combined with country-specific microeconomic evidence, this approach is flexible enough to take into account the complexity of interactions and institutions that matter in making a good diagnosis to guide growth-enhancing policies but also provide a framework to systematically assess development constraints.

Appendix

TABLE A1. Alternative Labor Shares, by Country

Country	*Labor share*
Bolivia	0.67
Chile	0.62
Colombia	0.65
Costa Rica	0.74
Ecuador	0.45
El Salvador	0.58
Mexico	0.59
Panama	0.76
Paraguay	0.52
Peru	0.59
Uruguay	0.59
Venezuela	0.55
United States	0.67

Source: Bernanke and Gürkaynak (2002).

TABLE A2. PISA 2009 scores[a]

Country	*Score*
Argentina	398.3
Brazil	411.8
Chile	449.4
Colombia	413.2
Mexico	425.3
Panama	370.7
Peru	369.7
Uruguay	425.8
United States	499.8

Source: OECD (2010).
a. OECD average = 500.

Comment

Daniel E. Ortega: Most economists are likely to agree with Paul Krugman's assertion that "productivity isn't everything, but in the long run, it is almost everything" (Krugman 1994). That idea has been underscored in the Latin American context in both policy and academic circles (Restuccia 2011). There is little doubt that providing a sustainable solution to the region's social ills requires a significant increase in the amount of output that each worker produces in a given amount of time. The question, of course, is how to do it.

Christian Daude's paper provides a useful overview of methods that seek to quantify the role of observable and mostly measurable factors such as physical capital and labor in explaining output per worker, and as a residual, also the role of technology—which includes, of course, many things. The main conclusion of the paper is that functional form assumptions about the technological frontier—and the allowance for cross-country heterogeneity in access to technologies in a general sense—have sizable effects on the estimated weight given to factors in explaining output per worker. The author suggests that the standard development accounting exercises understate the role of factors and overstate the role of total factor productivity (TFP), especially so once a measure of the quality of education is included as a complement to quantity measures alone. Finally, the paper suggests that these types of analyses need to be undertaken on a country-by-country basis, as the quantitative results may differ significantly between countries.

Certainly, efforts to better understand the sources of Latin America's low output per worker relative to that of the United States are important for gaining a general picture on the likely bottlenecks for economic development. However, and this is recognized to some extent in the paper, there are tight limits on how much guidance can be obtained for policy analysis. The large differences in the contribution of TFP to output per worker between several Central American countries underscore both the relevance of country-specific analyses and the limits of the methodology to guide understanding of the causes of low productivity. The main problem is that the levels as well as the quality of human and physical capital are outcomes in themselves, just as much as output per worker or per hours worked, and it is very difficult to know how much of each is determined by the level or trend of the others. The challenges in identifying the relationship between factors and productivity go beyond their likely reverse causation; the key identification hurdle in this case is one of omitted variables.

Although it is reasonable to assume that countries' technological possibilities differ, it is much less clear that the data envelope used in the paper provides an adequate measure of the differences. The interpretation is that whatever constraints a country faces that make it underperform relative to others are part of the efficiency gap that it must overcome. However, the nature of the constraints that each country faces may be different, and their true potential output may therefore also be different. It may well be the case that for the same capital-labor ratio in 1980, Ecuador's potential output was lower than Brazil's;[1] so, even though it would appear that Ecuador was less efficient in 1980 than Brazil, it could be exactly the opposite. The problem is that the data envelope—which for each level of capital-labor ratio compares the best performer in the sample with the rest—gives no insight into the reasons for such differences and therefore very little insight into what might be done to overcome them.

That in Nicaragua TFP accounts for 60 percent of output per worker but only 40 percent in El Salvador or that the shares are 30 percent in both economies does not really tell us much about whether we should pay attention to the quality of education, to the maintenance of public infrastructure, or to financial constraints that may be limiting the private sector's access to new machines. These issues are not resolved by making the TFP or efficiency gap estimations more flexible or sophisticated. In fact, even though these alternative methods may suggest a larger or smaller contribution of factor accumulation to productivity, it turns out that TFP/efficiency, the "measure of our ignorance" (Abramovitz 1956), invariably represents upward of 30 percent of the output gap with respect to the United States. So the real challenge faced by the less developed countries in the world is to answer the "how" question: how can we make our workers produce more given a certain amount of capital? Are there better ways of organizing production within and across

1. Note in figure 7 in the paper that Ecuador and Brazil had similar capital-labor ratios in 1980 but that Brazil had much higher output per worker.

firms? Is there something specific in each country or even city that could make it easier and more attractive to set up high-growth firms?

There is little question that productivity is the main challenge for Latin America. The problem is that we do not really know much about how to increase it. Do we need more capital? Probably—but for that, we need better financial markets; and for that, we need stronger conflict-resolution mechanisms and more trustworthy institutions; and for that, we need a better trained and socially valued civil service. Do we need more employable workers that firms can hire and keep out of the informal sector? Yes. But that requires enough available jobs to make it worthwhile for youngsters to stay in school and invest in developing their skills, but job availability, in turn, is related to the high costs of training workers on the job, which deters firms from offering such vacancies. So we may be trapped in a low-productivity, high-informality equilibrium, wherein labor market skills depreciate rapidly in the informal sector and potential employers do not invest in new machines and organizational capital due to the low quality of the labor force and lack of financing. Of course, these are central questions in development economics, and we need to bring to bear all the tools that we have available in order to answer them.

References

Abramovitz, M. 1956. "Resource and Output Trends in the United States since 1870." *American Economic Review* 46 (2): 5–23.

Acemoglu, D. 1998. "Why Do New Technologies Complement Skills? Directed Technical Change and Wage Inequality." *Quarterly Journal of Economics* 113 (4): 1055–89.

———. 2002. "Directed Technical Change." *Review of Economic Studies* 69 (4): 781–809.

Acemoglu, D., P. Aghion, and F. Zilibotti. 2006. "Distance to Frontier, Selection, and Economic Growth." *Journal of the European Economic Association* 4 (1): 37–74.

Agosin, M., E. Fernández-Arias, and F. Jaramillo. 2009. "Growing Pains: Binding Constraints to Productive Investment in Latin America." Washington: Inter-American Development Bank.

Atkinson, A. B., and J. E. Stiglitz. 1969. "A New View of Technological Change." *Economic Journal* 79 (315): 573–78.

Barro, R. J., and J. W. Lee. 2010. "A New Data Set of Educational Attainment in the World: 1950–2010." Working Paper 15902. Cambridge, Mass.: National Bureau of Economic Research.

Basu, S., and D. N. Weil. 1998. "Appropriate Technology and Growth." *Quarterly Journal of Economics* 113 (4): 1025–54.

Bekman, E., J. Bound, and S. Machin. 1998. "Implications of Skill-Biased Technological Change: International Evidence." *Quarterly Journal of Economics* 113 (4): 1245–79.

Bernanke, B. S., and R. S. Gürkaynak. 2002. "Is Growth Exogenous? Taking Mankiw, Romer, and Weil Seriously." In *NBER Macroeconomics Annual 2001,* vol. 16, edited by B. S. Bernanke and K. Rogoff, pp. 11–57. MIT Press.

Bernard, A., and C. I. Jones. 1996. "Technology and Convergence." *Economic Journal* 106 (437): 1037–44.

Caselli, F. 2005. "Accounting for Cross-Country Income Differences." In *Handbook of Economic Growth,* edited by P. Aghion and S. Durlauf. Amsterdam: Elsevier.

Caselli, F., and W. J. Coleman. 2006. "The World Technology Frontier." *American Economic Review* 96 (3): 499–522.

Cohen, D., and M. Soto. 2007. "Growth and Human Capital: Good Data, Good Results." *Journal of Economic Growth* 12 (1): 51–76.

Daude, C., and E. Fernández-Arias. 2010. "On the Role of Productivity and Factor Accumulation in Economic Development in Latin America and the Caribbean." OECD Development Centre Working Paper 290. Paris: OECD Development Centre.

De La Fuente, A., and R. Doménech. 2006. "Human Capital in Growth Regressions: How Much Difference Does Data Quality Make?" *Journal of the European Economic Association* 4 (1): 1–36.

Färe, R., and others. 1994. “Productivity Growth, Technical Progress, and Efficiency Change in Industrialized Countries.” *American Economic Review* 84 (1): 66–83.

Farell, M. J. 1957. “The Measurement of Production Efficiency.” *Journal of Royal Statistical Society* 120 (3): 253–81.

Feenstra, R. C., and others. 2009. “Estimating Real Production and Expenditures across Nations: A Proposal for Improving the Penn World Tables.” *Review of Economics and Statistics* 91 (1): 201–12.

Gollin, D. 2002. “Getting Income Shares Right.” *Journal of Political Economy* 110 (2): 458–74.

Hall, R., and C. I. Jones. 1999. “Why Do Some Countries Produce So Much More Output per Worker than Others?” *Quarterly Journal of Economics* 114 (1): 83–116.

Hanushek, E. A., and L. Woessmann. 2009. “Schooling, Cognitive Skills, and the Latin American Growth Puzzle.” Working Paper 15066. Cambridge, Mass.: National Bureau of Economic Research (June).

Hausmann, R., D. Rodrik, and A. Velasco. 2005. “Growth Diagnostics.” Unpublished paper. Harvard University.

Heston, A., R. Summers, and B. Aten. 2011. “Penn World Table Version 7.0.” University of Pennsylvania, Center for International Comparisons of Production, Income, and Prices.

Jermanowki, M. 2007. “Total Factor Productivity Differences: Appropriate Technology vs. Efficiency.” *European Economic Review* 51 (8): 2080–110.

Kehoe, T. J., and K. J. Ruhl. 2008. “Are Shocks to the Terms of Trade Shocks to Productivity?” *Review of Economic Dynamics* 11 (4): 804–19.

Klenow, P. J., and A. Rodriguez-Clare. 1997. “The Neoclassical Revival in Growth Economics: Has It Gone Too Far?” In *NBER Macroeconomics Annual 1997,* vol. 12, edited by B. S. Bernanke and J. Rotemberg, pp. 73–103. MIT Press.

Koopmans, T. C. 1951. “Efficient Allocation of Resources.” *Econometrica* 19 (4): 455–65.

Krugman, P. 1994. *The Age of Diminished Expectations.* MIT Press

Kumar, S., and R. R. Russell. 2002. “Technological Change, Technological Catch-Up, and Capital Deepening: Relative Contributions to Growth and Convergence.” *American Economic Review* 92 (3): 527–48.

McMillan, M., and D. Rodrik. 2011. “Globalization, Structural Change, and Productivity Growth.” Unpublished paper. Harvard University.

Organization for Economic Cooperation and Development (OECD). 2009. *PISA Assessment Framework: Key Competencies in Reading, Mathematics, and Science.* Paris.

———. 2010. *PISA 2009 Results: What Students Know and Can Do.* Paris.

Orme, C., and P. Smith. 1996. “The Potential for Endogeneity Bias in Data Envelopment Analysis.” *Journal of the Operational Research Society* 47 (1): 73–83.

Parente, S. L., and E. C. Prescott. 2002. *Barriers to Riches.* MIT Press.

Ravn, M. O., and H. Uhlig. 2002. "On Adjusting the Hodrick-Prescott Filter for the Frequency of Observations." *Review of Economics and Statistics* 84 (2): 371–80.

Restuccia, D. 2009. "The Latin American Development Problem." Serie Macroeconomía del Desarrollo 81. Santiago, Chile: CEPAL.

———. 2011. "The Latin American Development Problem." Working Paper 432. University of Toronto, Department of Economics.

Rodriguez, F., and D. Ortega. 2006. "Are Capital Shares Higher in Poor Countries? Evidence from Industrial Surveys." Wesleyan Economics Working Papers 2006-023. Wesleyan University.

Simar, L., and P. W. Wilson. 1998. "Sensitivity Analysis of Efficiency Scores: How to Bootstrap in Nonparametric Frontier Models." *Management Science* 44 (1): 49–61.

Vandenbussche, J., P. Aghion, and C. Meghir. 2004. "Growth, Distance to Frontier, and Composition of Human Capital." *Journal of Economic Growth* 11 (2): 97–127.

Wölfl, A., and others. 2010. "Product Market Regulation: Extending the Analysis beyond OECD Countries." Economics Department Working Paper 799. Paris: OECD.