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Kenji Moreno María Cecilia Deza

Abstract

This paper studies productivity in the Andean region in detail between 1990 and 2018. To do this, a growth accounting analysis is carried out, considering adjustments for quality and utilization of production factors. Subsequently, the paper explores whether the productivity gap between the Andean region and developed countries results from an innovation shortfall (low R&D investment level) or an accumulation problem. Several findings emerged. First, the absence of adjustments for quality and utilization of production factors generates more optimistic (and biased) estimates of TFP than when such adjustments are incorporated. Second, the link between productivity and the terms of trade has been heterogeneous across the Andean countries. Third, all Andean countries experience innovation shortfalls: innovation level is below expected due to the high cost of innovation adoption and to the policy distortions that have persisted over the last three decades. In that way, we warn of the diminishing contribution of productivity in the Andean countries' growth and highlight the need to establish more favorable conditions for innovation.

Keywords: productivity, R&D, terms of trade, economic development, Andean region.

JEL classification: O11, O30, O47, O54

1. Introduction

"Productivity isn't everything, but in the long run, it's almost everything."

Paul Krugman (1994).

In the short run, the economic growth of a country may be determined by the availability of factors of production, as well as the costs of accessing them. These elements play an essential role in economic cycles, which have been studied extensively. Nonetheless, the discussion can become more complex beyond the short term. In the long run, the dynamics of factors of production also matter, just as the degree of efficiency with which those factors are used and/or allocated. Said efficiency is usually called productivity and is often associated with the quality of factors of production, that is, with the quality of a country's capital and labor force (Céspedes et al., 2016), as well as with cross-cutting elements such as the availability of technology, market structures, external conditions, and institutional factors.[1] As such, productivity largely depends on the design of economic policies in tax, trade, finance, and labor. The wide variety of productivity drivers has led to the disaggregation of its study into several microeconomic components (Syverson, 2011). With increasing importance, the literature highlights the role of an efficient allocation of factors in business productivity and, therefore, of aggregate productivity (Foster, Haltiwanger, and Krizan (2001); Hsie and Klenow (2009)). Thus, it is reasonable that greater levels of efficiency or productivity make it possible to broaden the economy's production possibility frontier, strengthening the growth path of income per capita in a persistent manner. Therefore, following the words of Krugman, productivity is essential in defining growth in the long run.

However, calculating productivity is not free of challenges and limitations. One of the more important ones is that, while considered a residual, it is highly dependent on the adequate calculation of the contribution of physical capital and labor, as well as on the shape of the production function. Traditional measures of physical and human capital tend to overestimate the contribution of productivity to growth.

Furthermore, according to World Bank data, the GDP per worker in 2020 in the Andean region[2] was around 35% higher than its level in 2000 (Figure 1). However, no convergence is observed if we transpose this analysis to a developed country (Figure 2). This increases the need for an adequate understanding of the productivity dynamics in Andean countries.

On the other hand, the usual recipe used to increase the productivity of developing countries, such as the Andean countries, is to drive innovation through greater investment in research and development (R&D). The basis for this recommendation is that developed countries reveal higher R&D spending (OECD average: 2% of GDP[3]) than developing countries (Andean region average: 0.2% of GDP[4]), thereby setting the idea that the region presents an innovation shortfall. However, Maloney and Rodríguez-Clare (2005) warn that this type of comparison does not consider that R&D investment in a country is influenced by the economy's pattern of specialization, incentives, and distortions. On this basis, the authors question whether natural-

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[1] Ruiz-Arranz and Deza (Eds.) (2018) present an analysis of the factors that lead to an inefficient allocation of resources in the Andean region.

[2] The Andean region comprises Bolivia, Colombia, Ecuador, Peru, and Venezuela. Due to the availability and reliability of the information, this document does not consider Venezuela.

[3] Based on the latest available data from The World Bank.

[4] Based on the latest available data from The World Bank.

resource-rich countries, like those of South America, should really invest as much in R&D as countries dependent on manufacturing or services. In this sense, they question the suitability of policies promoting innovation in countries with low R&D spending when the latter could actually be the materialization of structural problems regarding capital accumulation.

Figure 1. GDP per worker in the Andean region
(2000=100)

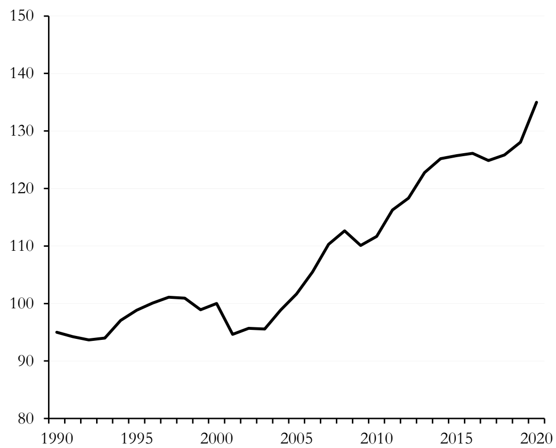
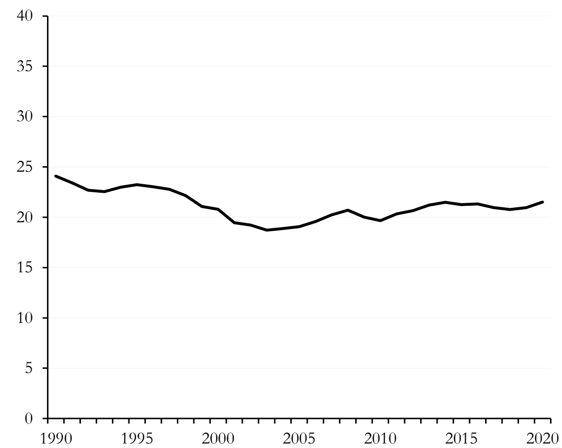


Figure 2. GDP per worker in the Andean region
(% of GDP per worker in the US)



Source: The World Bank.
Prepared by the authors. Aggregates are purchasing-power-parity GDP-weighted averages.

In this way, this study offers an analysis of productivity trends in the Andean region adjusted for the quality and utilization of production factors. Subsequently, in order to provide policy recommendations that can underpin productivity growth, we assess whether the region actually experiences an innovation shortfall. Thus, a more proactive use of the leeway that public policies have for providing sustainable long-term growth could be encouraged.

This document comprises six sections. Following this introduction, the second section discusses the relevant academic literature. The third section outlines the methodologies we will use to calculate total factor productivity (TFP) for the Andean region and identify innovation shortfalls. The fourth section offers a brief description of the evolution of relevant variables. Thus, the fifth section presents the results. There, we also perform a sensitivity analysis of the results for different values of the most relevant parameters and a brief review of the relationship between TFP and the terms of trade. Finally, the sixth section sets out the main findings.

2. Theoretical Framework

Over six decades ago, Solow (1957) developed a framework for the composition of economic growth based on an aggregate production function approach. According to this approach, a country's total production is explained by the contributions of its productive factors, which include human capital, physical capital, and TFP. In this line, the TFP, which is the subject matter of this paper, is generally known as "the Solow residual" since it is achievable after subtracting the weighted contributions of the rest of the factors of production from economic growth (Fuentes et al., 2004). In other words, it captures all the unobserved factors that explain aggregate output; therefore, its measurement is not exempt from risks and complexities. That is, given that

TFP is an unobservable indicator, it depends on the estimation method and the assumptions relating to factors of production and the production function used.

The Solow Method (1957) is also known as the primal model. As mentioned above, TFP estimations deriving from this approach rely heavily on the assumptions used concerning the production function used. An alternative methodology is Hsieh's (2002) dual approach to development that estimates total factor productivity (TFP) growth based on measurements for marginal productivities or production factor returns. Both methodologies should offer equivalent results in the context of good specification for the dual and primal approaches (Céspedes and Ramírez-Roldán, 2016). For this study, we will only delve into the analysis through the primal approach.[5]

It is also essential to discuss how to measure the other factors of production: physical capital and human capital. The standard way of measuring them is through the capital stock and the number of workers, respectively, that exist in an economy at a given time (Fuentes et al., 2004). However, this measurement strategy does not appropriately capture the effective use given to said production factors (OECD, 2001) and, therefore, would not adequately allow measuring their contribution to economic growth. Hence, not incorporating some adjustment for quality or utilization of the factors of production can lead to biased results in TFP estimation (Céspedes and Ramírez-Roldán, 2016) since changes in both adjustments (quality and utilization) would be treated as changes in TFP. Taking this into account, the literature reviewed comprises work that indeed implements some adjustments to the factors of production in order to offer more reliable estimates of TFP. For comparative purposes, this study will estimate TFP with and without adjustments for quality and utilization of the factors of production.

Luckily, the literature on growth accounting is exhaustive, even in cases comparable to the Andean region. An example is provided by Caselli (2014), who performs a development accounting analysis for a sample of 22 Latin American countries. This analysis was based on a primal approach with a production function that is expressed in its intensive form, that is, in terms of inputs and outputs per worker. On the one hand, human capital was measured through a Mincer approach, where key inputs include education, health, and cognitive skills. On the other hand, physical capital was measured as an aggregate of reproducible capital (equipment and infrastructure) and natural capital (fundamentally subsoil resources, arable land, and forest resources). The author finds that, on average, capital (human and physical) per worker in a Latin American country is well below half of the capital per worker in the United States. In addition, the efficiency of capital use per worker in an average Latin American country only ranges from 44% to 60% of the efficiency of capital use per worker in the United States.

Although using a relatively different methodological strategy, Daude and Fernández-Arias (2010) found similar results. Based on a primal approach, the authors calculated the TFP for 76 countries between 1960 and 2005 to compare Latin America's performance with other countries. In order to avoid the fluctuations arising from economic cycles, they decompose the series of output and production factors and only work with their trend components. In this sense, their results are reported in terms of trend productivity. Moreover, this specification also seeks to avoid the problem of using total production factor stocks without adjusting utilization. In this manner, only structural underemployment of production factors could be reflected as low productivity. Nonetheless, the authors do not make any quality adjustments to the factors of

[5] Céspedes and Ramírez-Roldán (2016) present an analysis of TFP in Peru using the dual approach.

production. Thereby, the estimated TFPs are influenced by aspects such as differences in the quality of education between countries. The authors find that the gaps in income per capita growth rates between countries of Latin America and other countries are due to gaps in their respective TFP growth rates. Similarly, in line with Caselli (2014), the authors mention that productivity in Latin America represents between 50% and 70% of the productivity of the United States. Among the proposed recommendations, the suggestion of greater proactivity in designing policies that aim to increase a country's aggregate productivity stands out because the policies that favor accumulated physical and human capital are insufficient. The need for a greater understanding of how well and rapidly the factors of production are allocated to more productive economic agents is underscored.

For their part, Fuentes et al. (2004) and Magendzo and Villena (2012) also study TFP dynamics in Chile under a primal approach. On the one hand, Fuentes et al. (2004) studied the determinants of TFP behavior in Chile between 1960 and 2003. The authors capture human capital using the number of hours worked and the work quality as independent factors of production. Regarding work quality, they use two alternative measurements for their calculation: years of schooling and estimated workforce weighted by educational level. Regarding physical capital, the authors provide two alternatives for the adjustment for utilization: labor employment rate and the ratio between the cyclical component of energy consumption and its trend component. Finally, the authors apply OLS regression to explain TFP according to the terms of trade; exchange rate variation; institutional indicators, macroeconomic stability and reform; and their lags. The authors find that measuring TFP is more sensitive to adjustments applied to human capital in contrast with those applied to physical capital. Additionally, they demonstrate that high TFP growth between 1990 and 2003 can mainly be explained by the improvements made to the terms of trade.

Furthermore, Magendzo and Villena (2012) provide an exhaustive literature review and propose an aggregate and sectoral growth accounting analysis. Thus, they suggest that human capital be measured as the number of workers actually employed adjusted for utilization (average of hours worked per worker) and quality (wage differences as an approximation to productivity). The physical capital is obtained for different types of physical capital and adjusted for utilization through a correction for energy consumption. The proposed methodology is used with data for Chile between 1993 and 2012. The authors point out that Chile's growth is due mainly to investment and actual hours worked, leaving behind the role of productivity. The preceding represents a risk whenever the marginal productivity of physical capital decreases and a workforce reduction is expected due to a demographic change in the country.

Most recent evidence is provided by Céspedes and Ramírez-Roldán (2016), who studied TFP in Peru between 2001 and 2012 under the primal and dual approaches. For the primal approach, they measure the labor factor as the economically active population (EAP) and apply adjustments for utilization (the employment rate) and quality (workforce by the level of education). However, as the authors warn, this approach involves a considerable source of risks as it does not consider Peruvian aspects such as underemployment, self-employment, and informal employment. Furthermore, physical capital is constructed through the perpetual inventory method and adjusted for utilization (an approximation to energy consumption) and quality (relative price between investment and consumption). According to the authors, the TFP in Peru grew at an average annual rate of 1.6% during the period under study.

Finally, to verify the existence of innovation deficits, the methodological framework developed by Klenow and Rodríguez-Clare (2005) was used, which relates productivity to R&D spending. One of the primary purposes of this methodology is to estimate the level of R&D spending a country would have if it favored innovation as much as a developed country. This model was subsequently applied to Latin America by Maloney and Rodríguez-Clare (2005). The authors find that, while Latin American countries have lower levels of R&D investment as a percentage of GDP than developed countries, not all have innovation deficits. In particular, the authors point out three groups. The first one consists of countries whose estimated levels of R&D spending broadly exceed their observed levels. These countries truly experience an innovation deficit due to policies and institutions detrimental to R&D deepening. The contrary is so for the second group, comprised of countries whose estimated R&D investments are inferior to those observed. These countries have institutions that support R&D. These countries experience a capital accumulation problem rather than one of innovation, whereby continuing R&D deepening would not generate significant returns in terms of development. Lastly, the third group involves a middle ground between the first two groups because the estimated level of R&D spending is slightly higher than the level observed. This classification does not imply that the first group does not have accumulation problems or that the second group must abandon innovation policies. However, it seeks to determine how priorities should be oriented.

3. Methodological Framework

3.1 Measuring Productivity

As shown in the previous section, a starting point for analyzing growth accounting is the economy's aggregate production function. In our evaluation, we will use the Cobb-Douglas[6] function to approximate the production function to its labor-augmenting version (Equation 1).

$$y_t = k_t^{\alpha}(A_t h_t)^{1-\alpha} \qquad (1)$$

Where y represents output, k represents physical capital and h represents human capital. For its part, A captures all unobserved factors that complete the explanation of output. To this document, A shall be understood as total factor productivity (TFP). Finally, α represents the share of physical capital in production and there is evidence to support that it is invariant across time and according to development level (Gollin, 2002). However, regarding the human capital measurement h, the most common way to measure it is the percentage of labor force employed (Solow, 1957).

Meanwhile, the construction of physical capital stock k_t is conducted through the perpetual inventory model proposed by Nehru and Dareshwar (1993), which uses the physical capital accumulation equation (Equation 2). One can observe that physical capital accumulation is a function of the initial physical capital k_0, the gross domestic investment i and the depreciation rate δ. This equation can be rewritten as Equation 3.

[6] Moreover, since the academic debate does not yet show strong evidence of extraordinary factor returns, it is acceptable to assume constant returns to scale (Caselli, 2014), which is easily achieved by using a Cobb-Douglas function.

$$k_t = (1-\delta)^t k_0 + \sum_{s=0}^{t-s} i_{t-s}(1-\delta)^s \qquad (2)$$

$$k_t = (1-\delta)k_{t-1} + i_t \qquad (3)$$

Note that it is necessary to know k_0, which is possible through the strategy proposed by Harberger (1978). This methodology assumes a steady state context where the growth rate of product g is equal to the growth rate of physical capital and points out that initial physical capital k_0 is calculated following Equation 4.

$$k_0 = \frac{i_1}{g+\delta} \qquad (4)$$

Nevertheless, it is important not to lose sight of the fact that the series defined for human capital h and physical capital k are not adjusted for quality and/or the use of those factors. As we mentioned in the literature review, estimating TFP without adjustments will generate biased results.

The adjustment method we will apply to physical capital follows Costello (1993), who suggests that physical capital consumption be identified by energy consumption. According to Céspedes and Ramírez-Roldán (2016), Costello's (1993) approach provides two important advantages as a measurement of physical capital: (i) energy has a high level of homogeneity and measures the invariant quality of physical capital; and (ii) since energy is not easily storable, its consumption is a good approximation of the amount of energy actually used in the production process. In this way, following these guidelines and Fuentes et al. (2004), our measurement of adjusted physical capital will be based on Equations 5 and 6.

$$\tilde{k}_t = k_t(1+v_t) \qquad (5)$$

$$v_t = \frac{\hat{n}_t}{\bar{n}_t} \qquad (6)$$

Where v_t, according to Equation 6, is the ratio between the cyclical component $\hat{n}_t$ and the trend component $\bar{n}_t$ of the energy consumption series. Thus $\tilde{k}_t$ is physical capital adjusted for utilization.

Furthermore, it is more realistic to recognize that human capital is also influenced by indicators such as educational level and health of the population. In this way, following Caselli (2014), our measurement of adjusted human capital is based on Equations 7 and 8.

$$\tilde{h}_t = h_t m_t \qquad (7)$$

$$m_t = \exp(\beta_e e_t + \beta_s s_t) \qquad (8)$$

Where e represents education measured as the average years of education; while s represents health measured as the survival rate at age 65. In addition, β_e and β_s are, respectively, the returns on education and health. These elements help to explain the adjustment to human capital m through $\exp(.)$, which is the exponential function. Again, h is the percentage of labor force employed.

In order to analyze the implications of the adjustments to physical and human capital measurements on TFP estimations, we will show results for Equations 9, 10, 11 and 12; where A is simple TFP or without any adjustments, A' is TFP adjusted for education and health, A'' is TFP adjusted for physical capital utilization, and A^* is TFP adjusted for education, health and physical capital utilization.

$$A_t = \left(\frac{y_t}{k_t^{\alpha} h_t^{1-\alpha}}\right)^{\frac{1}{1-\alpha}} \qquad (9)$$

$$A'_t = \left(\frac{y_t}{k_t^{\alpha} \tilde{h}_t^{1-\alpha}}\right)^{\frac{1}{1-\alpha}} \qquad (10)$$

$$A''_t = \left(\frac{y_t}{\tilde{k}_t^{\alpha} h_t^{1-\alpha}}\right)^{\frac{1}{1-\alpha}} \qquad (11)$$

$$A^*_t = \left(\frac{y_t}{\tilde{k}_t^{\alpha} \tilde{h}_t^{1-\alpha}}\right)^{\frac{1}{1-\alpha}} \qquad (12)$$

3.2. Identifying Innovation Shortfalls

To apply the methodological framework developed by Klenow and Rodríguez-Clare (2005), we will use the production function as presented in Equation 1. Regarding the factors of production, the authors do not adjust physical capital; while human capital is only adjusted for years of education, which is assumed to be constant. By contrast, in this study we will apply the adjustments presented for physical capital (Equations 5 and 6) and for human capital (Equation 7). For the latter, years of education may vary between countries and between periods. In this way, productivity for each country will be identified as A^*.

The accumulation of physical capital will follow the dynamics set out in Equation 3. It is also assumed that output can be used for consumption (c), investment (i) and R&D spending (R). This accounting is shown in Equation 13, where ρ is the relative price of investment and is assumed to be time invariant.

$$y_t = c_t + \rho i_t + R_t \qquad (13)$$

This requires the existence of a technology frontier $\bar{A}$, which is determined by R&D applied worldwide and grows at a rate of g_A. Thus, it is possible to establish a as the relationship between the levels of local productivity and worldwide productivity (Equation 14).

$$a_t = \frac{A_t^*}{\bar{A}_t} \qquad (14)$$

Furthermore, it is assumed that there is a free flow of ideas from the rest of the world to a specific country at a rate of ε; and that there is also a minimum productivity in R&D which is similar among countries and expressed as λ. The authors show that, in a steady state, it is possible to achieve the expression in Equation 15; where S_R represents R&D spending as a percentage of GDP and $\bar{k}$ is the ratio of composite capital to GDP (Equation 16).

$$a = 1 - \frac{g_A}{\lambda S_R \bar{k} + \varepsilon} \qquad (15)$$

$$\bar{k} = m \left(\frac{\tilde{k}}{y}\right)^{\frac{\alpha}{1-\alpha}} \qquad (16)$$

Under this model, a country's policies should be aimed at closing the gap between local productivity and global productivity, which implies increasing a. From Equation 15, it may be noted that spending in R&D allows achieving this objective only through an interaction with the level of accumulated aggregate capital $\bar{k}$. Therefore, pushing for higher R&D investment (increasing S_R) may not have significant results if there is a low level of $\bar{k}$ (accumulation problem). Conversely, if there is a relatively high level of $\bar{k}$ and low S_R (innovation deficit), the policies favoring increased R&D investment could generate significant results in productivity.

Furthermore, the model also considers the characterization of the innovation environment, taking into account that a country's R&D levels and productivity are the aggregate of R&D and productivity of companies operating in the country, respectively. On the one hand, the policies and institutions that affect the cost of adopting innovation measures are calibrated by ϕ. Thus, a positive value for ϕ means that there are net costs and/or limited support of innovation policies. In turn, a negative value for ϕ is related to a net subsidy and/or a more friendly environment for innovation policies. On the other hand, it is possible that R&D adoption by one company may affect the productivity of other companies. These externalities are captured by μ, whose value is between 0 and 1. If μ is 0 then there are no externalities; whereas, if μ equals 1, there are complete externalities and A^* is determined by the average of R&D performed by all the companies in the economy.

Klenow and Rodríguez-Clare (2005) also demonstrate that the problem of maximizing company profits has two first-order conditions in a steady state, which determine optimal investment in physical capital (Equation 17) and R&D (Equation 18).

$$\rho\left(\frac{\tilde{k}}{y}\right) = \alpha\left(\frac{1-\tau}{r+\delta}\right) \qquad (17)$$

$$\Omega\,(1-\alpha)\,\lambda\,\bar{k}\,(1-a) - \frac{g_A a}{1-a} + \varepsilon\,(1-a) = r \qquad (18)$$

$$\Omega = \frac{(1-\tau)\,(1-\mu)}{1+\phi} \qquad (19)$$

In Equation 17, τ represents the profit tax of companies, while r represents the real interest rate. r is assumed to be fixed in time and equal across countries due to the assumption of free capital mobility. Since r is identical for all countries, international differences in $\tilde{k}$ are explained by differences in τ.

Equation 18 allows obtaining the relative level of productivity a, and, hence, the optimal R&D level as a percentage of GDP. An adjustment factor Ω is considered that captures taxes (τ), externalities (μ) and the policy/ institutional environment for innovation (ϕ).

Based on this model, it is possible to determine the level of R&D spending as a percentage of GDP that an Andean country would have if it had a policy/institutional environment that fosters innovation (ϕ) as a developed country does. If the estimated R&D spending exceeds its observed level, then we will face a real innovation shortfall. By contrast, if the estimated R&D spending is lower than its observed level, then we will be facing a case of policies that are friendly towards innovation, but with accumulation problems.

The evaluation will also include calculating the value that ϕ would have to be for a level of R&D expenditure estimated by the model to be equal to the observed level. If the ϕ required is positive, then the country has policies/institutions that represent net costs for innovation, and we will be facing a case of innovation shortfall. In turn, if the ϕ required is negative, then the country maintains friendly regulations for adopting innovation and its problem is only one of accumulation.

It is worth highlighting that, up to this point, the Klenow and Rodríguez-Clare (2005) model assumes that differences in productivity levels between countries only respond to differences in R&D spending and/or technological adoption. Maloney and Rodríguez-Clare (2005) indicate, however, that differences in productivity could also be the consequence of trade barriers or regulations that limit technological adoption. Maloney and Rodríguez-Clare (2005) call this set of other reasons distortions, which are captured by z.

$$y_t = \tilde{k}_t^{\alpha}(zA_t\tilde{h}_t)^{1-\alpha} \qquad (20)$$

In that way, z helps to determine the magnitude of the distortions that need to be considered so that, assuming a favorable environment for innovation, the model and the data are consistent with each other. This new approach will allow us to have another estimate of R&D expenditure that we will contrast with the data. We will also perform the previously mentioned analysis for the case without distortions.

3.3 Calibration

Table 1 presents the parameters used for the Andean countries evaluated; as well as for the United States, which will serve as a reference developed country. The value employed for α was obtained from the work of Ruiz-Arranz and Deza (Eds.) (2018). For its part, δ was obtained from Céspedes and Ramírez-Roldán (2016). Then, the g rate, which will be used in Equation 4, was calculated as the historical average economic growth up to 2018 for each country. β_e and β_s were obtained from Caselli (2014). From Maloney and Rodríguez-Clare (2005), we collected their calculations for ρ, λ, r, μ and ϕ. It is worth noting that ϕ=-0.20 implies a net R&D subsidy of 20%, which seeks to replicate the favorable environment for innovation that developed countries present. Similarly to Maloney and Rodríguez-Clare (2005), our results do not vary significantly when there are changes in ϕ. Finally, the value for g_A corresponds to the average growth of OECD countries' TFP over 1960-2018, while $\varepsilon = g_A$ following Maloney and Rodríguez-Clare (2005).

Table 1. Parameters

Parameter	Bolivia	Colombia	Ecuador	Peru	United States
α	0.361698	0.361698	0.361698	0.361698	0.361698
δ	5%	5%	5%	5%	5%
g	3.21%	4. 09%	3.85%	3.78%	3.04%
β_e	0.10	0.10	0.10	0.10	0.10
β_s	0.65	0.65	0.65	0.65	0.65
ρ	1.8	1.6	1.1	1.1	0.9
λ	0.38	0.38	0.38	0.38	0.38
g_A	0.83%	0.83%	0.83%	0.83%	0.83%
ε	0.83%	0.83%	0.83%	0.83%	0.83%
r	0.086	0.086	0.086	0.086	0.086
μ	0.55	0.55	0.55	0.55	0.55
ϕ	-0.20	-0.20	-0.20	-0.20	-0.20

Source: Ruiz-Arranz and Deza (Ed.) (2018); Céspedes and Ramírez-Roldán (2016); Maloney and Rodríguez-Clare (2005); and historical data for each country.

4. Stylized Facts

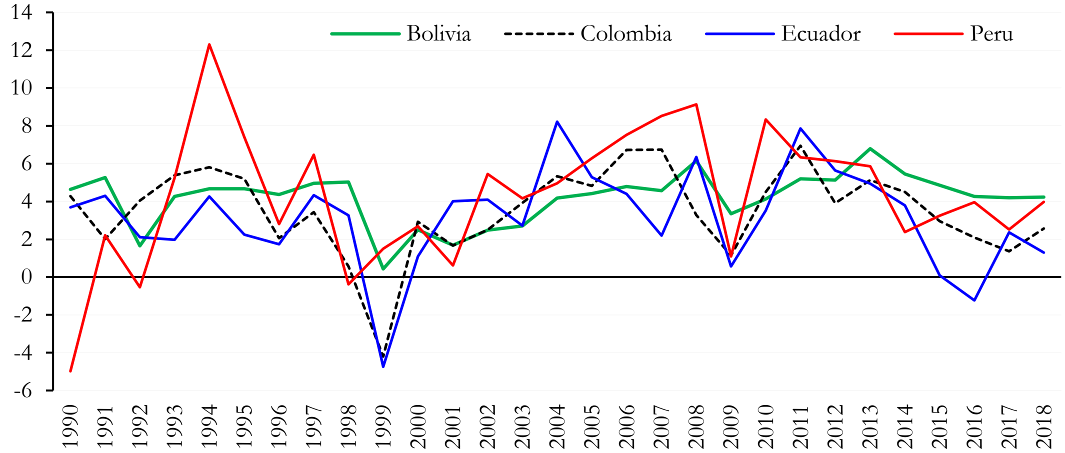
The analysis of productivity and innovation shortfalls for the Andean region is performed for the period 1990-2018 due to the availability of information on the relevant variables.

First, Figure 3 shows the Andean countries' economic growth dynamics. Three pronounced recessions in the 1990s decade stand out. The first corresponds to 1990 in Peru (-5%), which was emerging from marked economic instability in the 1980s. The other two recessions occurred in 1999. That year, Ecuador (-4.7%) experienced a combined inflationary, financial and fiscal crisis, while Colombia (-4.2%) also went through a combined financial and fiscal crisis. Since then, without accounting for Ecuador's (-1.2%) recession in 2016, the Region has shown uninterrupted growth. However, the Region's growth dynamics since 2000 have not been stable. In particular, there was an acceleration of economic growth in the Andean countries between 2002 and 2013, a period that coincides with the price boom of the Region's principal raw materials exports. Consequently, between 2014 and 2018, there was a generalized slowdown.

Furthermore, Figure 4 shows the behavior of the series linked to physical capital. On the one hand, the unadjusted physical capital series was constructed by Equations 3 and 4. Panel (a) shows the evolution of non-residential secondary energy consumption, which is a utilization adjustment factor for previously obtained physical capital. We can see that, in the last 30 years, Bolivia (323.1%) is the Andean country that has most increased its energy consumption. In contrast, Colombia shows the lowest evolution of this indicator (93.1%). Panel (b) shows the evolution of physical capital adjusted for utilization after applying the unadjusted physical capital and energy consumption in Equations 5 and 6[7]. In the last three decades, without considering the case of Ecuador (144.9%), the countries in the region have more than tripled (240%) their accumulated physical capital.

[7] The cyclical and trend components of non-residential secondary energy consumption were obtained through the Hodrick-Prescott filter. An exploration of the ideal method of series decomposition is not addressed by this study.

Figure 3. Economic growth
(percentage)

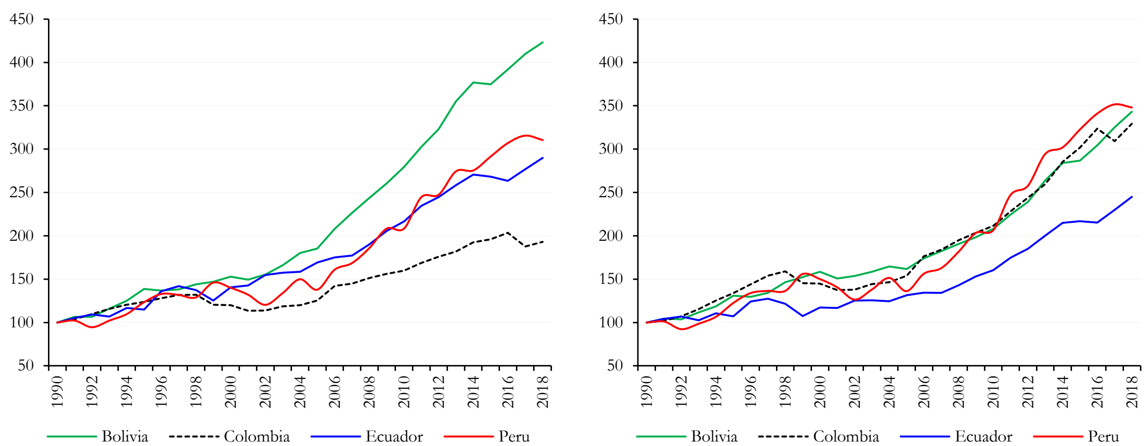


Source: International Monetary Fund.
Prepared by the authors.

Figure 4. Physical capital in the Andean region

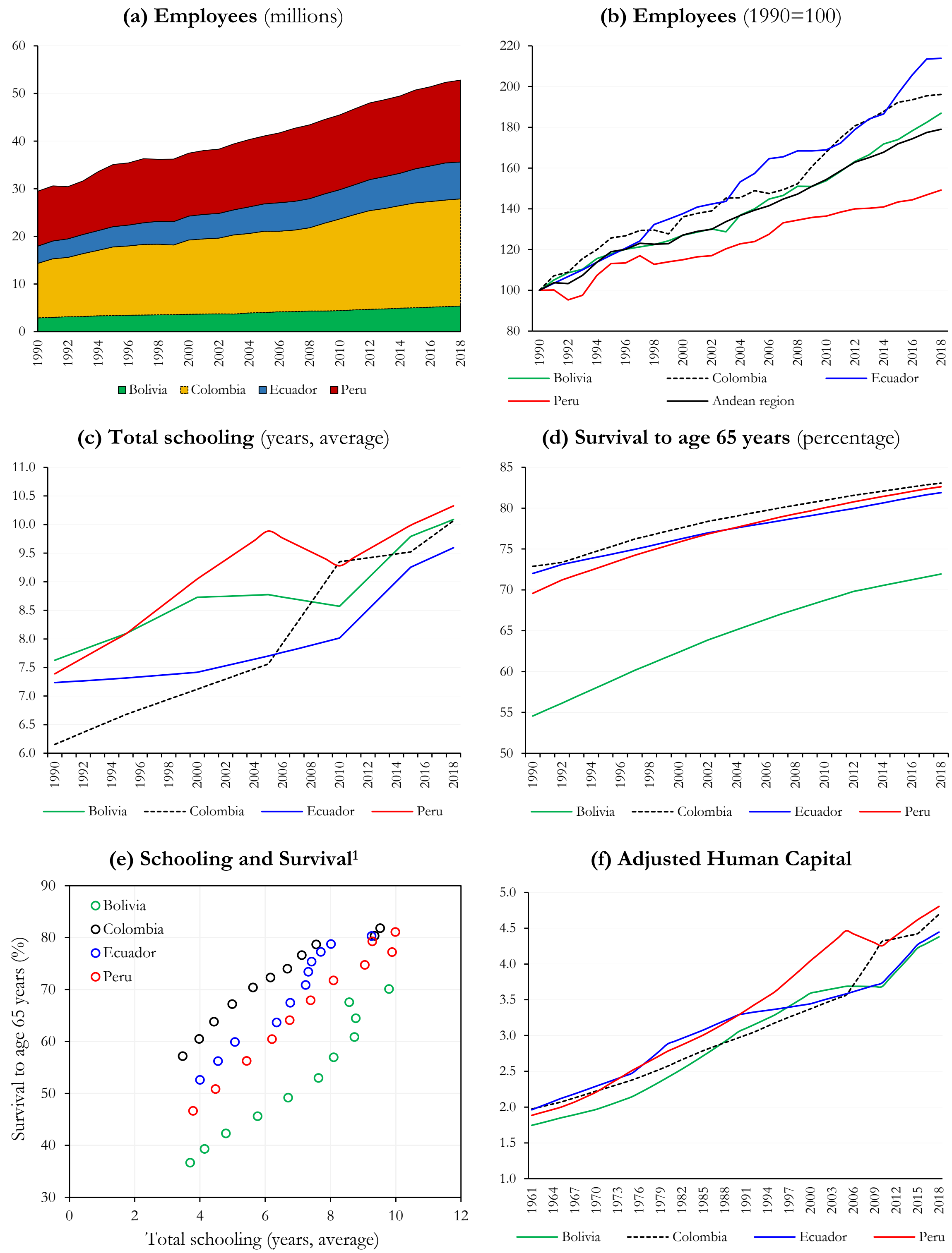
(a) Non-residential secondary energy consumption (1990=100)

(b) Physical capital adjusted for utilization (1990=100)



Source: International Monetary Fund; and government authorities of each country.
Prepared by the authors.

Figure 5. Human capital in the Andean region



1/ Data of survival to age 65 years correspond to a five-year average.
Source: Conference Board; Barro and Lee (2010) (updated database); The World Bank; and own calculations. Prepared by the authors. Aggregates are purchasing-power-parity GDP-weighted averages.

Moreover, Figure 5 presents the dynamics of the series linked to human capital. On the one hand, panels (a) and (b) show the evolution of the number of employees in each Andean country. We observe that, over the last 20 years, the number of employees in the Region has grown by 79.1%. However, this growth has been uneven across countries as Peru (49.2%) has not been able to increase the size of its workforce in the same proportion as its peers in the Region (Ecuador: 113.9%; Colombia: 96.1%; Bolivia: 86.9%). On the other hand, panels (c), (d), and (e) show the evolution of the human capital quality adjustment factors, which are positively correlated. We can see that, as of 2018, the Andean countries achieved a total average of 9.5 to 10.5 years of formal schooling. It also shows that Bolivia has a considerably lower survival rate until age 65 (10 percentage points lower) than its peers in the Region. The combination of the three components (workforce, total schooling, and survival to age 65) in Equations 7 and 8 allows us to obtain a measurement of human capital adjusted for quality. The results can be seen in panel (f) of Figure 4. It is observed that, as of 2018, the Andean country with the highest adjusted human capital is Peru, followed by Colombia, while Ecuador and Bolivia are the Andean countries with the lowest adjusted human capital.

5. Results

5.1 TFP in the Andean region between 1991 and 2018

The productivity estimates for the Andean region are shown in Table 2 and Figure 6.

Table 2. TFP estimates for the Andean region

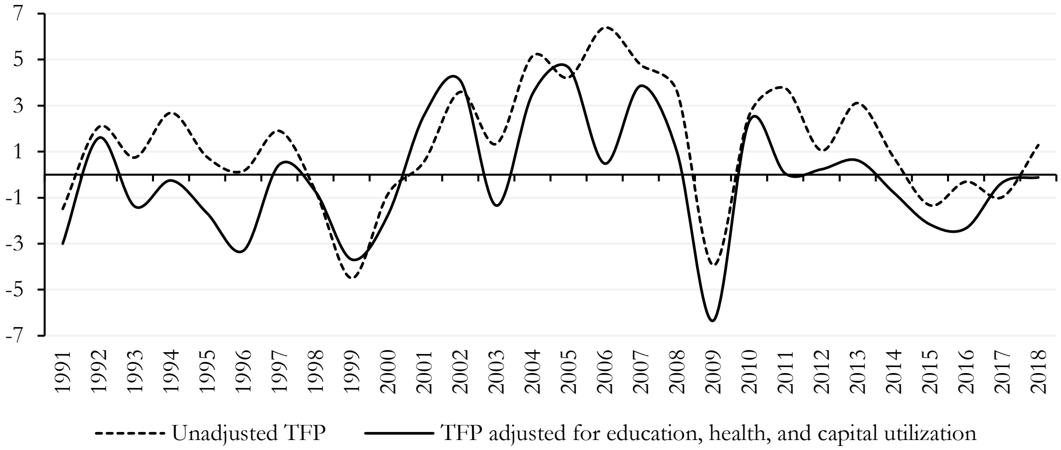
(Annual average % variation)

Period	$\boldsymbol{A}$	$\boldsymbol{A'}$	$\boldsymbol{A''}$	$\boldsymbol{A^*}$
1991-2000	0.08	-1.08	-0.03	-1.38
2001-2010	2.83	1.57	3.02	1.48
2011-2018	0.91	-0.91	0.82	-0.60
1991-2018	1.30	-0.09	1.30	-0.14
2001-2003	1.83	2.07	3.07	1.78
2004-2014	2.86	2.10	2.40	0.87
2004-2014 (Without 2008-2009)	3.53	1.40	3.14	1.66
2015-2018	-0.33	-1.40	0.31	-1.24

Where A is the simple or unadjusted TFP, A' is TFP adjusted for education and health, A'' is TFP adjusted for physical capital utilization, and A^* is TFP adjusted for education, health, and physical capital utilization.
Prepared by the authors. Aggregates are purchasing-power-parity GDP-weighted averages.

A relevant finding is that the TFP estimates without adjustment to the factors of production (A) tend to be more optimistic than estimates that consider some adjustments, especially concerning our methodological proposal (A^*), which considers all adjustments studied. This is because, as we pointed out earlier, the unadjusted TFP estimate erroneously reports the dynamics of physical and human capital adjustments as if they were productivity dynamics. In detail, 23 of the 28 periods analyzed have unadjusted TFP estimates that exceed the fully adjusted TFP estimates. This is in line with the warnings of the literature consulted, which verifies the importance of establishing adjustments for quality and utilization during productivity calculation.

Figure 6. TFP estimates for the Andean region
(annual % variation)



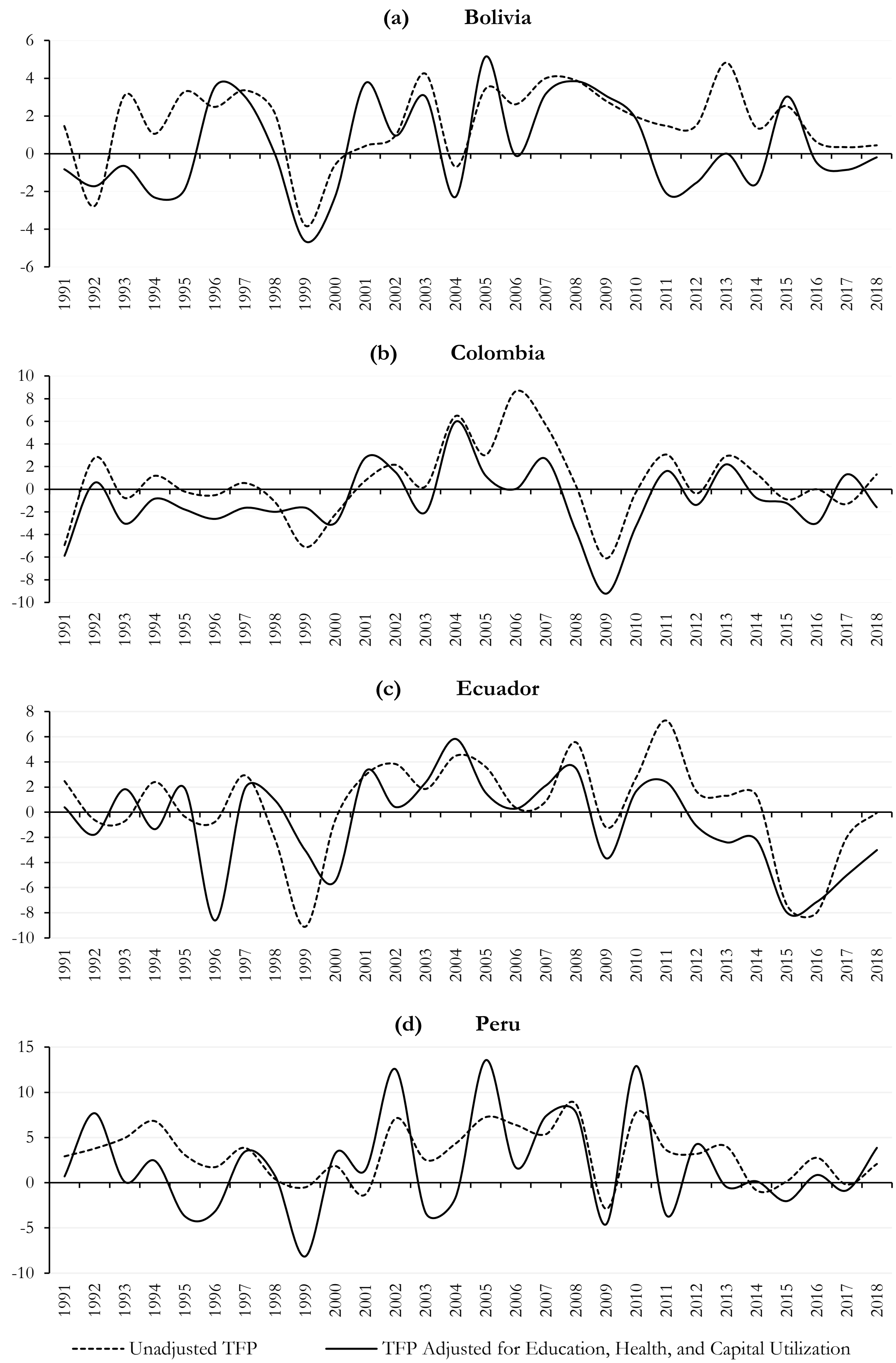
Prepared by the authors. Aggregates are purchasing-power-parity GDP-weighted averages.

Taking the fully adjusted TFP into account, we observe that TFP contracted at an average annual rate of 0.14% between 1991 and 2018. However, this dynamic shows asymmetries between different time slices. On the one hand, the 1990s are characterized by persistent regional productivity declines. On the other hand, the best performances in terms of productivity are observed as of 2000. In particular, the highest TFP growth rates coincide with the export commodity supercycle of prices (0.87% between 2004 and 2014 and 1.66% in the same period without considering the 2008-2009 financial crisis). However, the faster growth rate during this boom was not reflected in better foundations for sustainable growth in subsequent years, which is why we perceive exhaustion of TFP as a source of economic growth (average annual drop between 2015 and 2018 of 1.24%).

Figure 7 presents TFP dynamics for each Andean country, showing that unadjusted TFP tends to be more optimistic than adjusted TFP. It can also be seen that, except for Bolivia, the CAN countries saw their productivity decline significantly during the 2008-2009 financial crisis. Likewise, the evolution of TFP in each country has been more favorable between 2004 and 2014, coinciding with the export commodity price supercycle.

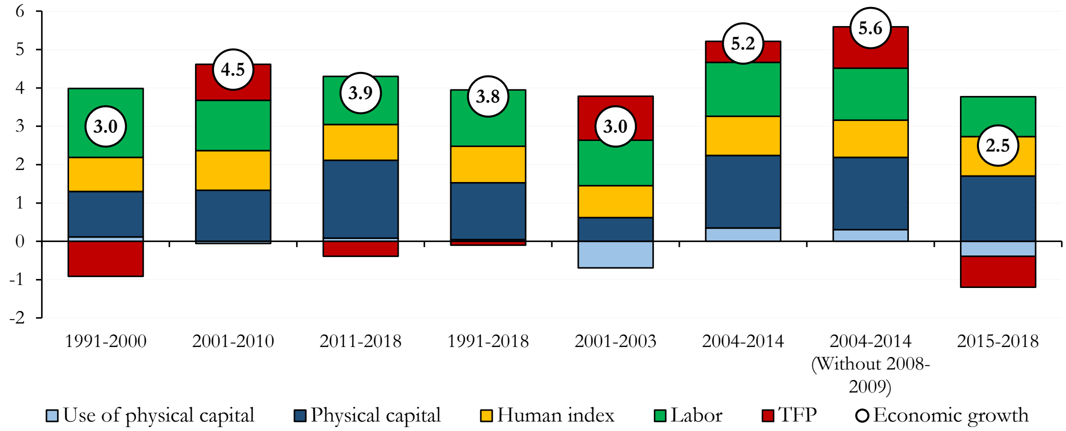
Finally, Figure 8 illustrates the decomposition of economic growth by factors of production adjusted for education, health, and capital utilization. Thus, in the 1990s, on average, TFP had contributed negatively (-0.9 percentage points) to the region's economic growth by missing out on the accumulation gains of the rest of the factors of production, especially those linked to the labor force (human index: 0.9 percentage points: labor: 1.8 percentage points). This changed radically after 2000, especially coinciding with the international price boom for primary export commodities (2004-2014: 05 percentage points: 2004-2014 without crisis 2008-2009: 1.1 percentage points). In line with the above, after the end of the commodity price boom, the average contribution of TFP to the region's growth became negative again (2015-2018: 0.8 percentage points). In this way, TFP had an average contribution of -0.1 percentage points over the entire horizon analysis.

Figure 7. TFP estimates by Andean country
(Annual % change)



Prepared by the authors.

Figure 8. Decomposition of the economic growth in the Andean region
(Percentage points)



Prepared by the authors. Aggregates are purchasing-power-parity GDP-weighted averages.

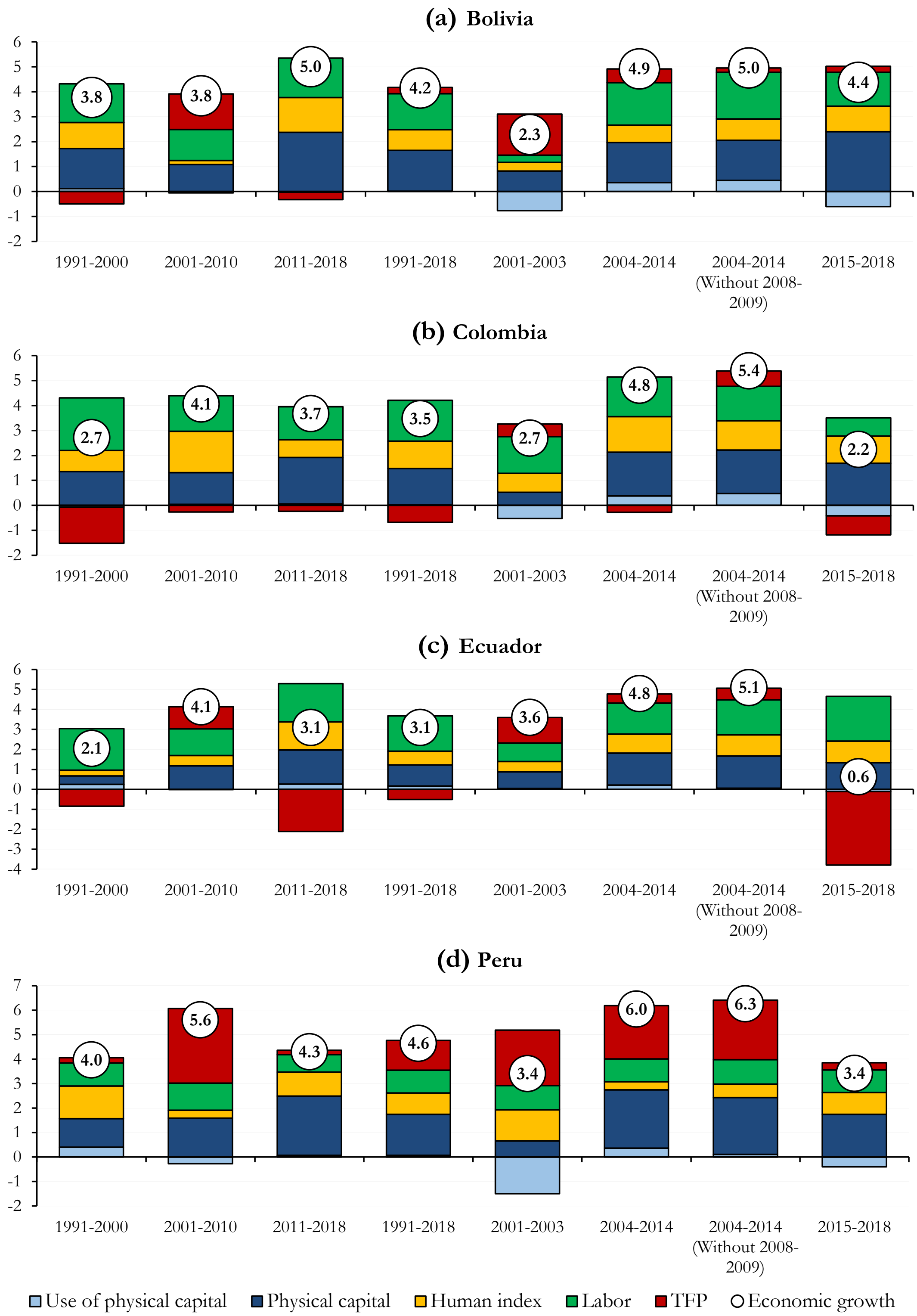
Regarding the other factors of production, on the one hand, there is a relatively constant contribution of workforce accumulation to economic growth. Between 1991 and 2000, labor contributed an annual average of 1.8 percentage points, although it decreased to 1.3 percentage points between 2000 and 2018. Furthermore, the quality of the labor force maintained a stable contribution over the analysis horizon of 1 percentage point. Moreover, physical capital accumulation also played an essential role in economic growth, especially between 2004 and 2014 (average annual contributions of 1.9 percentage points). However, this has yet to be fully exploited because physical capital utilization has had a marginal contribution on growth (0.05 percentage points as an annual average between 1991 and 2018).

Figure 9 shows the growth decomposition for each Andean country. It shows considerable dispersion among countries regarding the contribution of productive factors to their growth.

First, the four countries analyzed coincide in that they have physical capital accumulation as a decisive element for their growth in all periods. Then, unlike its peers in the region, Peru shows a low contribution to labor, which is explained by having the lowest growth rate of employed people (Figure 5, panel (6)). Furthermore, except for Peru, the countries of the Andean region show a higher contribution of the human index (which reflects the quality of the labor force) between 2004-2014 in contrast with the early 2000s (2001-2003). Concerning the contribution of TFP to growth, this factor will be particularly critical for Peru as of 2000.

From a temporal approach, it is interesting that, during the commodities price boom (2004-2014), Peru's growth has mainly been explained by an increase in productivity, while growth in the rest of the countries has mainly been explained by factors related to the workforce (labor and human index). In the years following the boom (2015-2018), one may note a depletion of the sources of growth, with particular emphasis on productivity, especially in Colombia, Ecuador, and Peru.

Figure 9. Decomposition of growth by Andean country
(Percentage points)



Prepared by the authors.

5.2 TFP and Terms of Trade

As we have seen, growth and productive factors show a differentiated behavior when we limit the time horizon to the main export commodity price boom. This raises interest in knowing the role or ties that the terms of trade have concerning the productive factors, especially with TFP. In this section, we will outline some ideas in this regard, albeit very superficial. In particular, we present an overview of the behavior of TFP (adjusted and unadjusted) and the terms of trade over the last 30 years. A more in-depth and technical review aimed at establishing causal relationships between the terms of trade and productivity in the Andean region is beyond the scope of this study and is proposed as a pending agenda.

The literature on the link between terms of trade and a country's productivity level is not extensive, especially for the Andean countries. Castillo and Rojas (2014) studied the relationship between terms of trade and TFP in Chile, Peru, and Mexico. According to the authors, terms of trade shocks are an important source of productivity gains for the short and long run. Furthermore, it is crucial to consider that favorable terms of trade can induce positive spillovers from tradable-goods sectors to non-tradable sectors (Llosa, 2013), as well as reallocations of resources in favor of more productive goods and sectors (Kehoe and Ruhl, 2007). In the specific case of Peru, Castillo and Rojas (2016) point out that between 2001 and 2007, the shocks of terms of trade contributed strongly to TFP growth. However, this contribution has decreased since then, which signals the greater relevance of domestic factors on TFP in recent periods.

Figure 10 shows the terms of trade and TFP, both in natural logarithms. For each country, the graph on the left corresponds to unadjusted TFP, while the right corresponds to TFP adjusted for education, health, and physical capital utilization. Each graph also shows the correlation coefficient between the two indicators for 1990-2018.

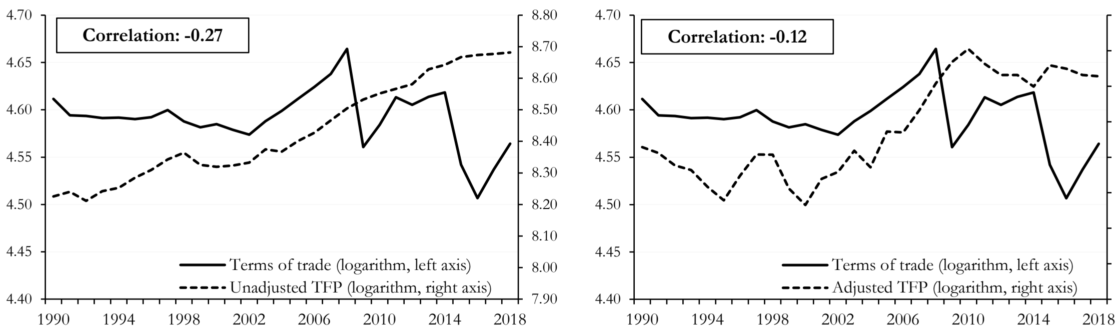
The graphs in Figure 10 do not allow for establishing a general rule for the region on the link between terms of trade and TFP. On the one hand, Bolivia shows a negative correlation that is relatively close to zero. In turn, Colombia and Ecuador show relatively high correlations, but only in the case of unadjusted TFP. Finally, Peru shows relatively high correlation coefficients for both adjusted and unadjusted TFP. Consequently, the study of the implications of the terms of trade on TFP in the Andean region will probably require a more country-specific approach rather than an aggregate regional approach. Likewise, the differences in how the terms of trade are linked to TFP in each country could respond to domestic policies and institutions that influence the dependence of productivity on external factors.

5.3 Innovation shortfalls in the Andean region

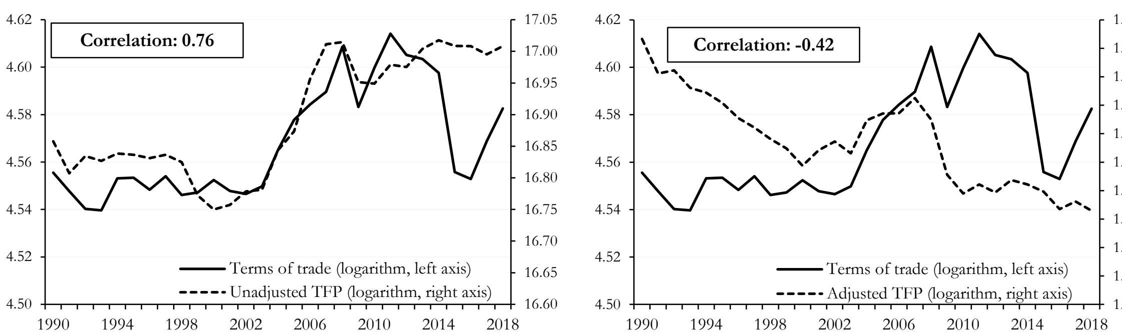
The last topic we address in this study is whether the lower level of productivity of Andean countries, compared with the productivity level of developed countries, is an outcome of innovation shortfalls or accumulation problems. Towards this aim, innovation deficits and accumulation problems will be understood as they were described in the methodological framework.

Figure 10. TFP and Terms of Trade[1,2]

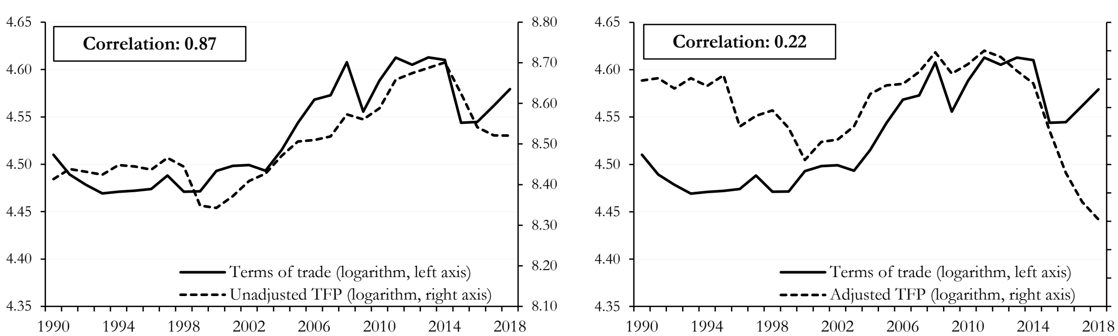
(a) Bolivia



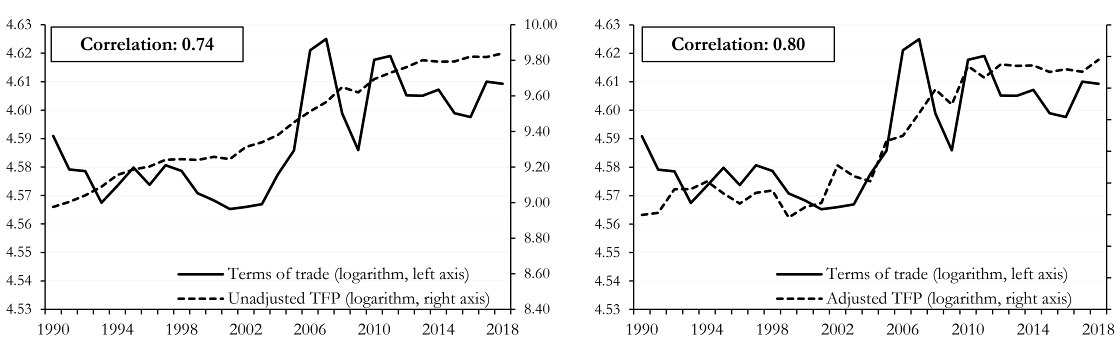
(b) Colombia



(c) Ecuador



(d) Peru



1/ The case of adjusted TFP refers to the adjustment for education, health, and physical capital utilization.
2/ Correlation calculations correspond to the period between 1990 and 2018.
Source: International Monetary Fund; and based on own estimates.
Prepared by the authors.

Figure 11 shows four versions of R&D expenditure as a percentage of GDP for Andean countries. On the one hand, the black line with marks (asterisks) is information obtained from World Bank records. For its part, the unmarked black line corresponds to observed data that was implicitly obtained from the model. As can be seen, in most cases, the implicit observed data from the model and the data reported by the World Bank are relatively similar. On the other hand, we include the model estimates for R&D expenditure as a percentage of GDP. The red line with marks (squares) represents the R&D expenditure estimates assuming a favorable policies/institutions environment for innovation (ϕ=-0.20) and without distortions. In contrast, the dashed blue line represents the estimates of R&D spending assuming an innovation-friendly policies/institutions environment (ϕ=-0.20) and with distortions.

Therefore, if we rely only on the estimates without distortions, we conclude that all Andean countries suffer from innovation shortfall. This occurs because, if Andean countries provided a net subsidy of 20% for innovation adoption, R&D investment would have to range from 1.5% to 2.5% of GDP. However, it does not happen. The data (either those obtained implicitly by the model or those obtained from the World Bank) never reach at least 0.5% of GDP.

However, it is unlikely that distortions do not exist in Andean countries that could limit innovation adoption, such as restrictions on trade or regulations that encourage suboptimal levels of innovation. For this reason, Figure 11 provides estimates for the model with distortions. In principle, if Andean countries provided a 20% net subsidy for adopting innovation and if distortions were considered, R&D investment should be relatively below 0.5% of GDP. However, in this case, the conclusions depend on what is taken as observed data. If the data observed were implicitly taken from the model, then the conclusion reached would be that all Andean countries experience innovation shortfalls. By contrast, if the data reported by the World Bank were considered, two groups could be established. The first one comprises Bolivia and Peru, whose observed data are still well below estimated data; thus, said countries present innovation shortfalls. The second group comprises Colombia and Ecuador, whose data is relatively close to the estimated data; thus, they may not be experiencing innovation shortfalls and should focus on addressing their accumulation problems.

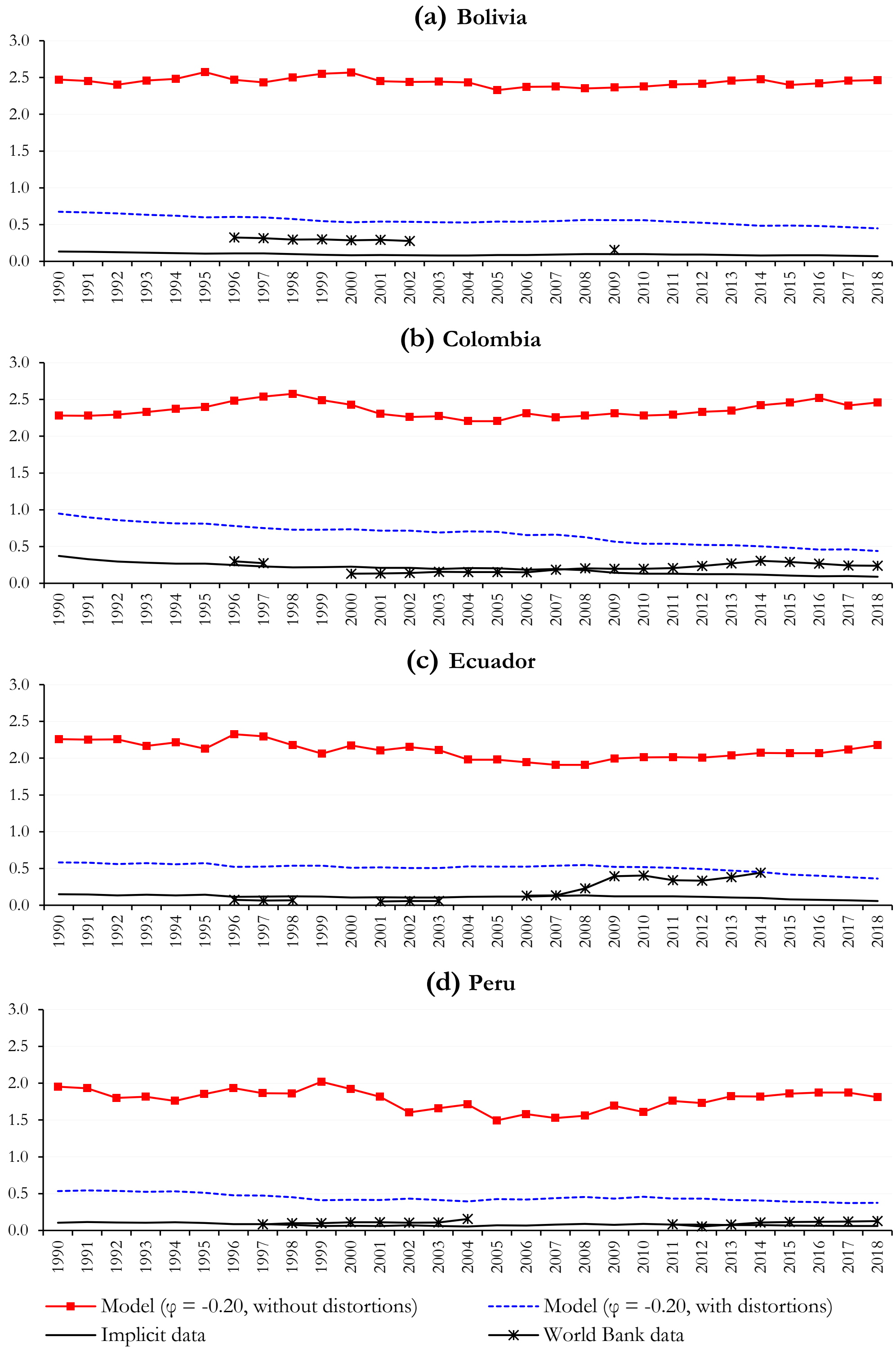
Finally, Figure 12 shows the cost of innovation adoption (ϕ) necessary for the model's estimates to coincide with the observed data implicitly obtained from it. Several interesting results are obtained from this figure.

First, the cost of adopting innovation in the Andean countries is considerably high. The estimated cost without distortions ranges from 700% to 1100%, while the estimated cost with distortions ranges from 250% to 450%. This result could suggest why innovation levels are low in the Andean region.

Second, it is possible to note three phases. First, in the 1990s, the cost of adopting innovation experienced a growing trend. Then, between 2000 and 2008, that cost remained relatively stable. Finally, since 2008, the cost has resumed a positive trend.

Third, the dynamics of the cost of adopting innovation in the model without distortions are very similar to the dynamics in the model with distortions. This finding could imply that the distortions factor (z) has persisted over the last thirty years, showing signs that they are issues that affect the structural and long-term conditions of the economy. According to the estimates, it was found that the distortions entail that the observed labor productivity in Andean countries is only between 20% to 30% of what it would be without said distortions. A more detailed exploration of the specific distortions that the Andean countries experience and how they impact productivity is beyond the scope of this study.

Figure 11. R&D Expenditure in the Andean region
(Percentage of GDP)

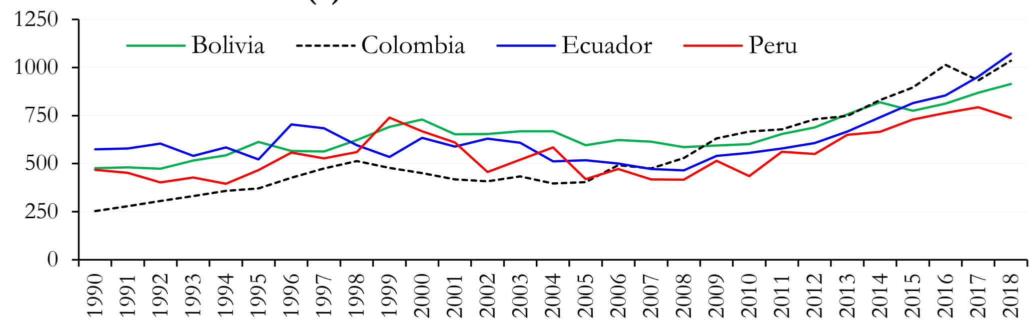


Source: The World Bank; and own estimates. Prepared by the authors.

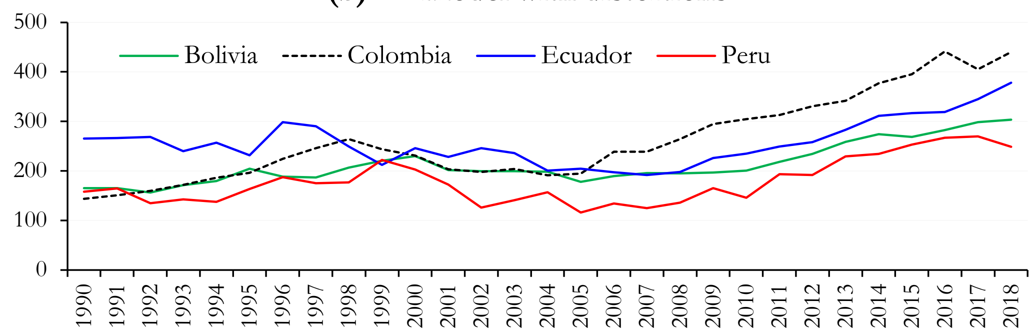
Fourth and finally, while it is true that all the Andean countries experience political, regulatory, and institutional environments that do not promote innovation, a hierarchy among countries can be established. In this way, Figure 12 shows that the lowest costs for innovation adoption are in Peru, followed by Bolivia, while the highest costs are in Ecuador and Colombia.

Figure 12. Innovation adoption cost in the Andean region
(Percentage)

(a) Model without distortions



(b) Model with distortions



Source: The World Bank; based on own estimates.
Prepared by the authors.

6. Conclusion

This document provides a detailed analysis of productivity in the Andean region. First, we presented a discussion and methodological analysis of growth accounting for the Andean countries over the last thirty years. Second, given that the productivity of Andean countries is lower than that of more developed countries, we explore whether this difference is the result of differences in levels of R&D investment, which could imply an innovation shortfall, or if it is only due to accumulation problems.

We applied Solow's (1957) method or primal approach to conducting the growth accounting analysis. Moreover, different productivity measurements were generated, with and without quality and utilization adjustments of the productive factors. Concerning these adjustments, human capital was adjusted for education (average years of schooling) and health (survival rate at age 65). Physical capital, built through the perpetual inventory method, was adjusted for utilization, which corrected the ratio between the cyclical and trend components of the energy consumption series.

In order to verify the existence of innovation deficits, we used the model developed by Klenow and Rodríguez-Clare (2005). Moreover, since this model does not consider the presence of distortions in the economy, which could limit the adoption of innovation, we also use a variation of this model proposed by Maloney and Rodríguez-Clare (2005).

Several results were obtained from the growth accounting exercise. First, the absence of adjustments for quality and utilization of production factors generates more optimistic estimates of TFP than when such adjustments are incorporated. This finding is because an estimate without adjustments would incorporate the dynamics of the adjustments of production factors as dynamics in productivity, which represents biases in the results. Also, the contribution of the factors of production and the TFP to growth has been heterogeneous across countries. Finally, the link between productivity and the terms of trade is not similar for the countries of the region. Therefore, a deeper exploration of this linkage would require an individual rather than an aggregate analysis.

Finally, we verified that all countries suffer from innovation shortfalls. Therefore, adopting a more proactive stance towards policies that favor higher levels of R&D investment is recommended. The need to promote such measures is greater in Bolivia and Peru because, although they are countries with relatively lower innovation adoption costs, their levels of R&D spending are below expected levels assuming a favorable environment for innovation. In addition, we found that distortions that limit the innovation adoption cause the observed labor productivity in the Andean region to be only between 20% and 30% of what it could be in the absence of these distortions.

With the results generated in this study, we observe a decrease in the contribution of TFP to economic growth, which has even been negative in recent years. Furthermore, we demonstrate that actions that generate an environment (policies, regulations, and institutions) more favorable to innovation could obtain significant gains in terms of productivity. Therefore, we highlight the need for public policies to focus not only on physical and human capital accumulation but also aim to raise the country's aggregate productivity. We also suggest that such policies have an approach that promotes innovation to deepen R&D in the Andean countries. That would help reduce the development gaps that have persisted in recent decades in the Andean region.

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