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Total Factor Productivity Estimation in Peru: Primal and Dual Approaches

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Abstract

In this paper we estimate total factor productivity (TFP) growth for the Peruvian economy using the primal and dual methods for the period 2003-2012. According to the primal method, a procedure that uses the Solow residual as an indicator of productivity, TFP grew at an average annual rate of 1.6%, adjusted for the quality and usage of the factors of production. According to the dual method, a procedure that considers estimations of the marginal productivities of the factors of production, TFP grew at an annual rate of 1.7%.

JEL clasification: C23, E23, 047.

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1 Introduction

Total factor productivity (TFP) can be considered as a production factor that contributes to economic growth. The main feature of this indicator is that it is not directly observable and therefore its measurement depends on the estimation methods used and on the assumptions made with respect to the number of observable production factors and also the assumption of the subjacent production function. Traditionally, TFP is estimated using the approach proposed

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by Solow (1957), a method that regards TFP as a residual after the contribution of known factors of production have been subtracted from output growth. Since there is uncertainty about the true production function, the number of factors and the factors' estimation, as well as TFP significant contribution for economic growth, the literature refers to this residual as the "size of our ignorance" (Abramovitz, 1956).

Certainly, there is disagreement in the literature about what TFP actually measures.[1] In this paper, we follow the TFP measurement approach taken by Abramovitz (1956) and Jorgensen and Griliches (1967), where TFP measures positive externalities that indirectly contribute to an increase in production. In that sense, the TFP measurement does not include the technological progress incorporated into new capital and improvements in human capital.

The Solow (1957) method, known as the production function method, is also known as the primal method. Under this method, the appropriate estimation of TFP requires the correct measurement of the two main factors of production: physical capital and labor. This method has been applied to almost all economies worldwide.[2] In the Peruvian economy, it has been implemented in diverse studies such as Vega-Centeno (1989 and 1997), Elias (1992), Seminario and Beltran (1998), Valderrama et al. (2001), Miller (2003), Loayza et al. (2005), Abusada and Cusato (2007), Ministerio de Economía y Finanzas (MEF, 2013), and Vera-Tudela (2013). The majority of these papers point out that the production factors considered correspond to the general indicators of stocks of capital and labor. Regarding the stock of labor, most of the papers consider the number of workers;[3] the physical capital factor is estimated by the perpetual inventory method. Neither of these indicators considers corrections to quality and usage of the factors of production that the relevant literature has considered (Jorgenson and Griliches (1967), Greenwood and Jovanovic (2001) and Costello (1993)).

The estimation of TFP without correcting for the quality and usage of factors of production can lead to a biased estimator. For example, if the quality of the factors has improved (worsened) at a relevant rate, then the estimates of TFP would be overestimated (underestimated) by taking into consideration the increase (decrease) in the quality of the factor as part of the increase (decrease) in productivity. Some papers have tried to correct this bias for the Peruvian economy: Valderrama et al. (2001), Carranza et al. (2005) and Loayza et al. (2005) incorporate the quality of the labor force or human capital in their estimations. In this paper we estimate the changes in TFP taking into consideration changes in the quality and usage of the stocks of capital and labor. This procedure allows us to break output growth into several components associated with the changes in quality and in the usage of factors of production.

[1] The literature considers many definitions of TFP, which makes its estimation difficult. For example, a common definition considers TFP as a measure of efficiency and technological change in the long-run of all production factors. Hulten (2001) presents an excellent literature review on TFP definitions, critiques and debates from a historical perspective.

[2] For recent studies of TFP estimates for economies worldwide, see Collins and Bosworth (1996), Easterly and Levine (2001), Loayza et al. (2005), among others.

[3] Or the economically active population in some studies.

TFP can be estimated by an alternative method called the dual approach. This method was popularized by Hsieh (2002), and, in general terms, it estimates TFP growth from indicators of the marginal productivity of the factors of production (prices of the factors of production). Ideally, TFP estimates using the primal and dual methods are equivalent. In this paper, we estimate the growth rate of TFP for the Peruvian economy by the dual method, taking into consideration indicators related to the growth of the marginal productivity of factors. The real wage is used to identify the marginal productivity of the labor factor and the real interest rate identifies the marginal productivity of capital. We consider different indicators for wages and interest rates according to the available information.

We find that the following indicators of the quality and usage of physical capital and labor factors changed significantly throughout the period 2003-2012: i) human capital, a measurement that controls for the quality of the labor factor, grew at an annual average rate of 0.9%; ii) the relative price of new capital (investment), a variable related to the quality of the capital factor (Greenwood and Jovanovic, 2001), grew at an average annual rate of 0.7%; iii) the employment rate, a variable that measures the use of the labor force stock, grew at an annual average rate of 0.2%; and iv) the installed capacity of capital (capital utilization) in the economy grew at an average rate of 0.1%.

By considering these indicators, TFP estimated through the primal method grew at an annual average rate of 1.6% throughout 2003-2012, which indicates that the factor that contributes the most to economic growth is physical capital. Additionally, we find that the quality and usage of capital and labor factors contributed 21% of the economic growth in the period studied. This last result is an indicator of the magnitude of the overestimation of the growth in TFP when changes in the quality and usage of factors of production are not taken into account. Moreover, the average annual growth rate of TFP estimated using the dual approach is 1.7% in the period studied, a rate that is close to the estimated value using the primal approach.

The rest of the paper is organized as follows: section 2 formally introduces the primal and dual estimation methods of TFP. Section 3 discusses the data used in this paper. Section 4 discusses the results, and section 5 summarizes the paper.

2 The Model

2.1 The Primal Approach

The primal approach developed by Solow (1957) identifies the growth rate of TFP from a production function that depends on the factors of production: capital (K_t), labor (L_t), and total factor productivity (A_t). The application of this method considers, in most cases, the following Cobb-Douglas-like production function with constant returns to scale

$$Y_t = A_t K_t^{\alpha} L_t^{1-\alpha}, \tag{1}$$

where Y_t is output or income, α is the physical capital share of output and t is time. If we apply logs to equation (1) and differentiate it with respect to time, this equation expresses the growth rate in the following manner

$$\Delta y_t = \Delta a_t + \alpha \Delta k_t + (1 - \alpha)\Delta l_t, \tag{2}$$

where Δy_t, Δa_t, Δk_t and Δl_t are the respective growth rates of output, productivity, physical capital and labor. From this expression, the growth rate of total factor productivity is expressed in terms of the observable variables by the following equation

$$\Delta a_t = \Delta y_t - \alpha \Delta k_t - (1 - \alpha)\Delta l_t. \tag{3}$$

The TFP growth rate is calculated in equation (3) conditional on the information about the growth rates of output, physical capital and employment. Moreover, we need to know the value of the capital share of output.

2.2 The Dual Approach

The dual approach, introduced by Hsieh (2002), allows us to estimate TFP by considering the measurement of output using the income method. Under these ideal conditions, this method reports results similar to those estimated by the primal method. The formal differentiation of the formula relates both the primal and dual methods using the income definition, that is, the sum of the payment received by each factor that participates in the productive process: capital (K_t) and labor (L_t).

$$Y_t = r_t K_t + w_t L_t, \tag{4}$$

where r_t is the return to physical capital and w_t is the return to labor. Equation (4) is expressed in terms of the growth rates such as

$$\Delta y_t = \alpha(\Delta r_t + \Delta k_t) + (1 - \alpha)(\Delta w_t + \Delta l_t), \tag{5}$$

where Δr_t and Δw_t are the growth rates of the real return to capital and the real return to labor, respectively. $\alpha \equiv rK/Y$ and $(1 - \alpha) \equiv wL/Y$ are capital and labor factor shares of income, respectively. If we rearrange equation (5) we get

$$\Delta y_t - \alpha \Delta k_t - (1 - \alpha)\Delta l_t = \alpha \Delta r_t + (1 - \alpha)\Delta w_t, \tag{6}$$

The left side of equation (6) is the primal TFP, as indicated by equation (3), while the right side of equation (6) represents the dual TFP, that is

$$\Delta a_t = \alpha \Delta r_t + (1 - \alpha)\Delta w_t. \tag{7}$$

Thus, by construction, both measurement methods deliver the same result, a coincidence that does not necessarily occur in practice because the ideal conditions or assumptions do not always hold. It is important to note that this method allows us to calculate the variation in productivity in a residual manner using the information on the variation in the prices of the factors of production (capital and labor). This feature makes the estimation of TFP using this method not dependent on the particular functional forms of the production function, and, more interestingly, by using the variation in the prices of the factors of production, this method does not depend directly on estimated indicators in the national accounts.

The two measurements of TFP could be different when the national income exceeds the payments of capital and labor, for example, if the identity of the national income is given by $Y_t = r_t K_t + w_t L_t + \pi_t$ where π_t could be interpreted as the benefits or the payments to the factors of production omitted from the growth accounting exercise. When that is the case, Hsieh (2002) shows that the primal estimates exceeds the dual estimates by $\widehat{s}_\pi(\widehat{s}_\pi - \widehat{\alpha})$, where $\widehat{s}_\pi$ and $\widehat{\alpha}$ are the growth rates of π/Y and α, respectively.

3 The Data

We implement estimation methods of TFP using data on the Peruvian economy as described in this section.

3.1 Output and Labor

The indicator of output is real Gross Domestic Product (GDP) estimated by the *Instituto Nacional de Estadística e Informática* (INEI). This series is shown in Figure 1(a). The indicator of the labor force stock is the economically active population estimated by the *Ministerio de Trabajo y Promoción del Empleo* (MTPE). This series is shown in Figure 1(b). It is important to note that the series are reported from 2001 onward, which limits the estimation of the growth rate of TFP to this period.

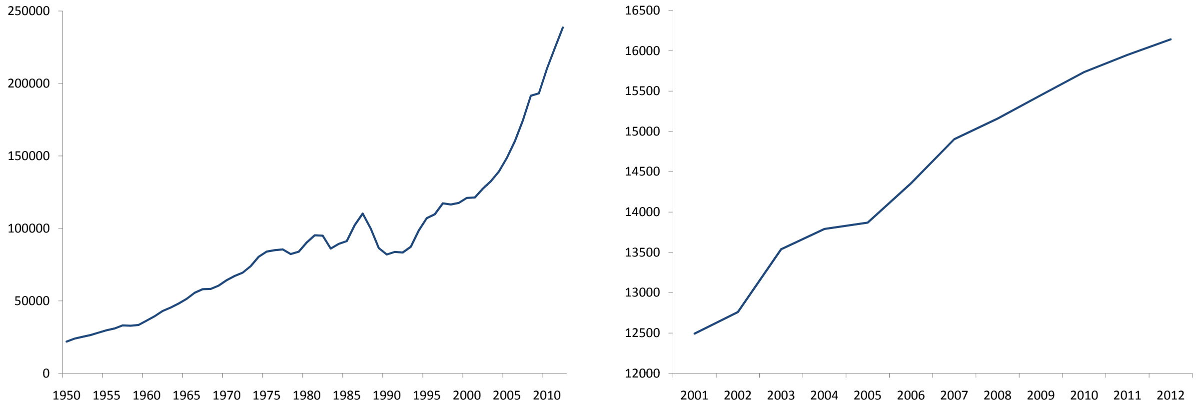
3.2 Physical Capital

The stock of physical capital is constructed using the perpetual inventory method, a procedure suggested by Nehru and Dareshwar (1993). This method uses the following law of capital accumulation, which allows us to express physical capital as a function of the initial capital stock and investment

$$K_t = (1-d)^t K_0 + \sum_{s=0}^{t-s} I_{t-s}(1-d)^s, \tag{8}$$

Figure 1: Output and Employment

(a) Output (b) Employment



Notes: Panel (a): Real gross domestic product in millions of soles from 1994 (INEI). Panel (b): Economically active population in thousands of workers (MTPE).

where K_0 is the initial stock of physical capital, I_{t-s} is gross fixed domestic investment in period $t-s$ and d is the depreciation rate. If we rewrite equation (8) we obtain

$$K_t = (1-d)K_{t-1} + I_t, \tag{9}$$

the estimation of K_t according to this method requires a previous knowledge of K_0, a value estimated by using a modified version of the technique suggested by Harberger (1978). The Harberger (1978) procedure assumes that there is a steady state through which the output growth rate (g) is equal to the physical capital growth rate. According to this approach, K_0 is calculated by the following equation[4]

$$K_0 = \frac{I_1}{g+d}. \tag{10}$$

In order to perform the appropriate calculation, we assume that the annual depreciation rate of physical capital is equal to 5% and the long-run growth rate of the economy (g) is equal to 3.9% (average annual growth rate of real GDP between 1951 and 2012). Gross fixed investment is estimated by the INEI. With these values, we estimate the value of the initial physical capital with equation (10) and the other values with equation (9). The estimated series of capital has an average annual growth rate of 4% (see Figure 2(a)). Also, note that, by construction, this indicator does not include the usage and quality of this factor.

An alternative indicator of physical capital was proposed by Costello (1993), who suggests that the consumption of physical capital is identified by the consumption of electricity. This

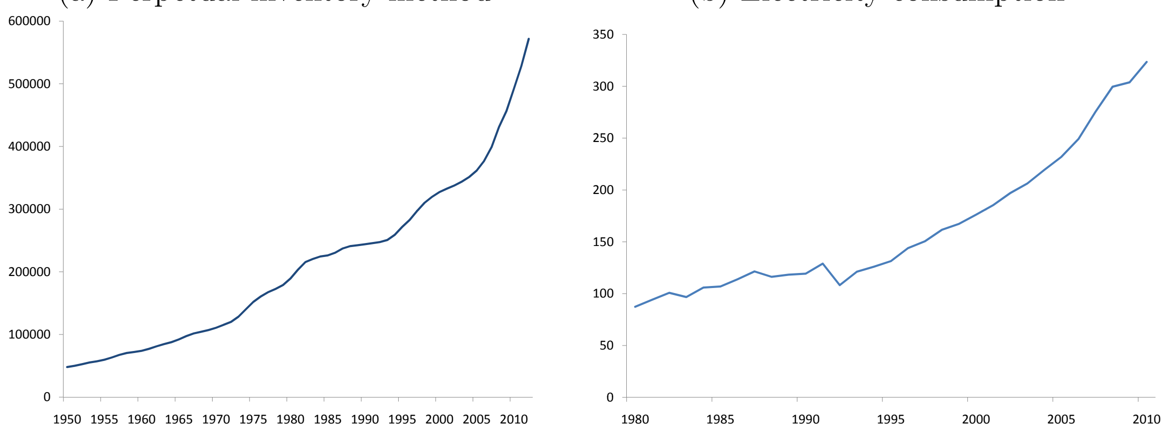
[4]From (9), the physical capital growth rate can be written as: $(K_t - K_{t-1})/K_{t-1} = -d + I_t/K_{t-1}$. In the steady state, $g = (K_t - K_{t-1})/K_{t-1}$, equation (9) gives $K_{t-1} = I_t/(g+d)$. Finally, when $t=1$ we get (10).

indicator has two advantages as a measurement of capital: i) it is perfectly homogeneous and it measures the invariant quality of capital and ii) given that electrical energy is not easily stored, the quantity of energy used in the production process corresponds to the quantity of electricity that effectively enters the production process. Therefore, unlike the measurement of capital obtained using the perpetual inventory method, this measurement of capital does not have measurement error. Nevertheless, this indicator presents an evident disadvantage by assuming that the usage of physical capital and the consumption of electricity are highly complementary.

The alternative indicator of the stock of capital is estimated by using data on electricity consumption reported by the *Organismo Supervisor de la Inversión en Energía y Minería* (OSINERGIM). The data are available for the period 2001-2012. A more complete series of this indicator (1980-2010) is obtained from the World Development Indicators (WDI) from the World Bank. Figure 2(b) shows the series that combines both sources. According to these data, physical capital displays an annual growth rate of 5.3% between 2003 and 2012.

Figure 2: Physical Capital Measures

(a) Perpetual inventory method (b) Electricity consumption



Notes: Panel (a): physical capital in millions of soles from 1994. Panel (b): Consumption of electricity in millions of gigawatts per hour (OSINERGMIN).

3.3 Usage of Factors of Production

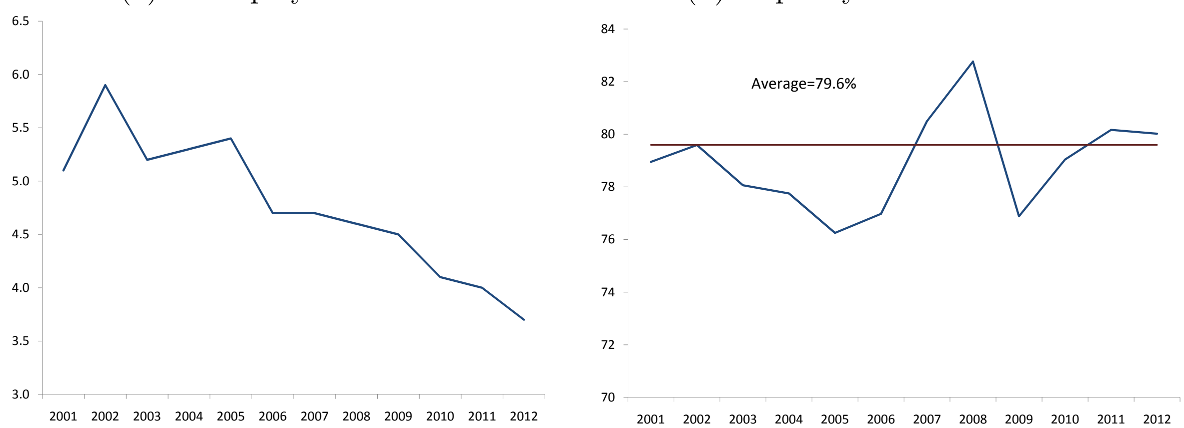
The TFP calculated by equation (3) depends on the appropriate estimation of the production factors series (physical capital and labor). The changes in the usage of factors of production can have certain influence on the growth rate of the TFP. For example, an economy with high growth rates cannot be related to the labor productivity growth if it is driven by a greater labor force participation that was previously inactive or outside of the labor force. Similarly, the stock of installed capital can be used without shifting both quality and quantity of this capital.

The usage of these production factors is approximated by indicators that represent the usage of the installed production factors. The use of the labor factor is approximated by the national unemployment rate that is estimated by the MTPE. This indicator measures the proportion of the labor force that is effectively working and is measured as one minus the unemployment rate.[5] Figure 3(a) shows the evolution of the national unemployment rate from 2001, a rate that shows a persistent decreasing trend, a fact that is consistent with the growth of the economy in these years.[6]

The usage of the capital factor is approximated by using the Fuentes et al. (2006)[7] approach. The indicator of usage of capital is constructed as the deviation of effective consumption of electricity from its long-run trend.[8] This indicator is standardized in such a way that the average in the period 1980-2012 is equal to the average of the indicator of usage of the installed capacity (79.6%) similar to the U.S. average throughout 1983-2012. Figure 3(b) shows the indicator being estimated for Peru between 2001 and 2012.

Figure 3: Usage of Factors of Production

(a) Unemployment rate (b) Capacity utilization index



Notes: Panel (a): The national unemployment rate is estimated by the MTPE. It is measured as the percentage of the economically active population. Panel (b): The capacity utilization index is the deviation of effective consumption of electricity from its long-run trend; we use the HP filter.

[5]This indicator can be limited as an indicator of labor installed capacity, since it does not include self-employment and informal employment. If GDP does not adequately account for the output generated in sectors with self-employment and informal employment, then the estimates can be sensitive to the dynamic of self-employment and informal employment. Céspedes et al. (2003) show that labor informality has shown a slight decline in the context of rapid economic growth, a fact that suggests a greater growth of formal jobs and therefore greater use of labor in formal activities.

[6]Another element we do not consider is the intensive measures of the labor force such as hours worked. In this case, the indicator of aggregate employment in intensive units corresponds to the stock of workers by the number of average hours worked. Céspedes (2011) suggests that hours worked have shown a decreasing trend during the period under study, which might compensate, at least partially, for the increase in the stock of the labor force.

[7]Other indicators are used to approximate the installed capacity of physical capital. For example, Loayza et al. (2005) used the unemployment rate as an indicator of physical capital utilization.

[8]The long-run trend of electricity consumption is calculated using the Hodrick-Prescott (HP) filter.

3.4 Quality of Factors of Production

As Hulten (2001) maintains, an important contribution to the study of TFP was made by Jorgenson and Griliches (1967), who disaggregated labor and capital into its components, to avoid any aggregation bias associated with internal changes in the composition of factors, for example, the composition bias of old technology of lower quality compared with more modern technology of better quality or the bias due to the shift to better educated workers (young workers). According to Jorgenson and Griliches (1967), output can grow due to improvements in the quality of inputs (specific to physical capital or labor). If the growth rate of the quality of inputs were positive (negative) and significant, then the growth rate of TFP estimated by equation (3) would be overestimated (underestimated). In other words, if we do not incorporate specific improvements to physical capital or to labor, those improvements would be part of the TFP growth estimate; thus, it would be incorrectly estimated if the improvements in quality were significant.

Quality of Labor

We construct a labor quality index following Collins and Bosworth (1996), Bernanke and Gurkaynak (2002) and Loayza et al. (2005). The procedure consists of estimating an index of the quality of labor, H, as the weighted average of the shares of population, E, with educational level j,

$$H = \sum_{j} W_j E_j, \tag{11}$$

where W_j is the variable that assigns a weight that is defined as the social return to educational level j.[9]

Variable H for Peru is estimated by the following procedure: the returns to education are estimated by Psacharopoulos (1994) for the following seven educational levels: no education, incomplete primary education, completed primary education, incomplete secondary education, completed secondary education, incomplete college education, and completed college education. Moreover, the proportion of the population at each educational level (E_j) is obtained from Barro and Lee (2010).[10] H is estimated from 1950, and the results emphasize the significant growth in the quality of the labor force as illustrated by Figure 4(a).

Previous studies have applied a similar procedure to estimate a labor force quality index in Peru (Valderrama et al., 2001). Our procedure differs in the weights. Valderrama et al. (2001) use the relative middle labor income in each group to assign weights. Additionally, they estimate

[9]Weights: no education = 1, incomplete primary education = 1.68, completed primary education = 2.69, incomplete secondary education = 3.91, completed secondary education = 5.53, incomplete college education = 5.87 and completed college education = 8.8.

[10]Barro and Lee (2010) estimate these indicators until 2010. For 2011 and 2012, we consider that the human capital index grows at the same rate as over the last five years (2006-2010).

the economically active population shares by educational level using data from the *Encuestas Nacional de Niveles de Vida* (ENNIV).

Quality of Physical Capital

There are many ways to construct an index of the quality of physical capital. Jorgensen and Griliches (1967), for example, construct an index by using a weighted average of the investment in machines/technology and buildings/infrastructure. Moreover, Greenwood and Jovanovic (2001) propose an alternative measurement of the quality of physical capital that is related to the relative price of investment in terms of consumption. In this paper, we follow the approach taken by Greenwood and Jovanovic (2001) mainly because the disaggregated series of investment by category were not available. In Greenwood and Jovanovic (2001), the indicator of the quality of capital appears in the equation of the accumulation of capital, which means the quality of capital appears as a technological change specific to investment. The accumulation of capital follows the following procedure

$$K_t = (1-d)K_{t-1} + q_t I_t, \tag{12}$$

where q_t represents the current state of technology to produce new equipment. This equation states that when q_t increases, you can produce more goods from physical capital by giving up one unit of output or consumption. This type of technological progress is specific to investments in the economy. Therefore, changes in q_t, could be interpreted as technological progress specific to investment, which is different from the neutral Solow (1957) technological progress approach. The change in technology specific to investment is estimated by using the relative price of investment (new physical capital) over consumption, $q_t = 1/p_t$.[11]

The p_t and q_t series are estimated for Peru by using the implicit prices of consumption and investment. The implicit deflators are calculated for each category from the available data on consumption and investment in nominal and real terms from the national account published by the Central Bank of Peru. Figure 4(b) shows the relative price estimated from new capital (investment), p_t, and technological progress specific to investment, q_t, from 2000. The graph shows the fall in the relative price of investment over consumption, which could be related to the rate of obsolescence of old physical capital caused by the arrival of new high-quality capital.[12] Such behavior is also observed in the U.S. economy, from 1940 (see Greenwood and Jovanovic, 2001).

The measurements of physical capital and labor that incorporate the indicators of the quality of the factors of production are calculated by multiplying the stock of the factor and the index of

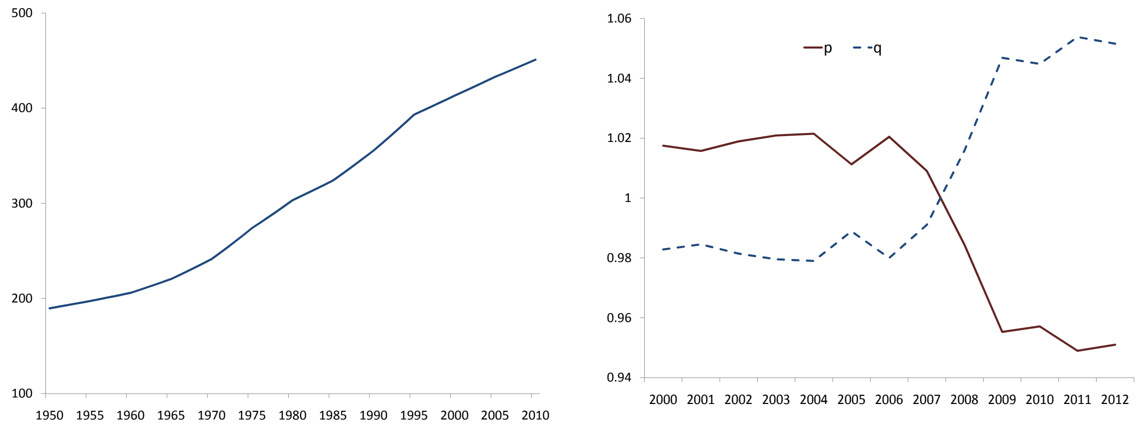
[11]This identity is based on the result of competitive markets. The relative price of investment in consumption, p_t, satisfies the following equation: $p_t = 1/q_t$ (see Greenwood and Jovanovic, 2001).

[12]The decreasing trend in the relative price of investment is observed since 1950 (year from which data are available). However, this series shows high variability before 2000, partially explained by the structural changes the Peruvian economy went through during this period.

Figure 4: Quality of Factors of Production

(a) Human capital index

(b) Price of new capital, p, and investment-specific technological progress, q



Notes: Panel (a): The human capital index is the weighted average of the shares of the population with different educational levels. The weights are based on the social returns to schooling at each educational level. Panel (b): Technological progress is measured as the ratio of the investment deflator to the consumption deflator.

quality considered. Adjustment for usage of the factors is done by following a similar procedure. It is important to note that these calculations are done at an aggregate level.

3.5 Returns to Factors of Production

The measurement of TFP by the dual method requires estimators of the variation in the interest rate and wages, indicators that represent the variation in earnings of the factors of production. Note that the market structure in which each of these prices is determined has a key influence on the evolution of dual TFP.

Return to Physical Capital

The real return rate of physical capital is estimated by using an extension of the formula suggested by Hsieh (2002). The correction for the Peruvian case incorporates the dollarization of the credit market, a key feature of the Peruvian capital market. The real interest rate net of depreciation in domestic currency (soles) is estimated by the following formula

$$r_t = \frac{P_I}{P_c}(i_t - \Delta p_t + d), \tag{13}$$

where P_I/P_C is the ratio of the price of investment with respect to the price of consumption, i_t is the active interest rate in national currency in nominal terms, Δp_t is the inflation rate, and d is the depreciation rate, which takes the value of 5%. The real net interest rate of foreign currency is calculated following a formula similar to the previous one, but by subtracting the exchange rate depreciation and by considering the active rate of foreign currency (U.S. dollars) as an indicator of the interest rate.

The indicator of the real interest rate growth is calculated as the weighted sum of the real interest rate growth in national currency and the real interest rate growth in foreign currency; the weight is the coefficient of the dollarization of the liquidity in the banking system.[13] Other levels of disaggregation could also be used, for example, by the size of the company or by the economic sector. Nevertheless, the disaggregated annual series of the interest rate are not available. The evolution of this indicator is shown in Figure 5(a). It is important to note that by separating the interest rate by currency (national currency and foreign currency), we control for the high dollarization of the Peruvian economy.

Return to Labor

Return to labor is estimated from wages, which are estimated from several sources. The first indicators are the wages of workers in firms with 10 or more workers in the Lima metropolitan area published by the MTPE. We also consider the wage estimated by the INEI according to the Permanent Employment Survey (PES). TFP estimated by this method considers the heterogeneity of the factors of production. In this manner, the wage growth rate is estimated as the weighted sum of average wages in each sector and between blue-collar and white-collar workers,

$$\Delta w_t = \sum_{j=1}^{n} s_{Lj} \Delta w_{jt}. \tag{14}$$

Figure 5(b) shows the evolution of the wages of blue-collar and white-collar workers during the period studied. The weights s_{Lj}, in this case, are the participation of each sector over the hired population, values that are estimated by the Permanent Employment Survey (PES) elaborated by the INEI.[14]

Return as an Indicator of Marginal Productivity

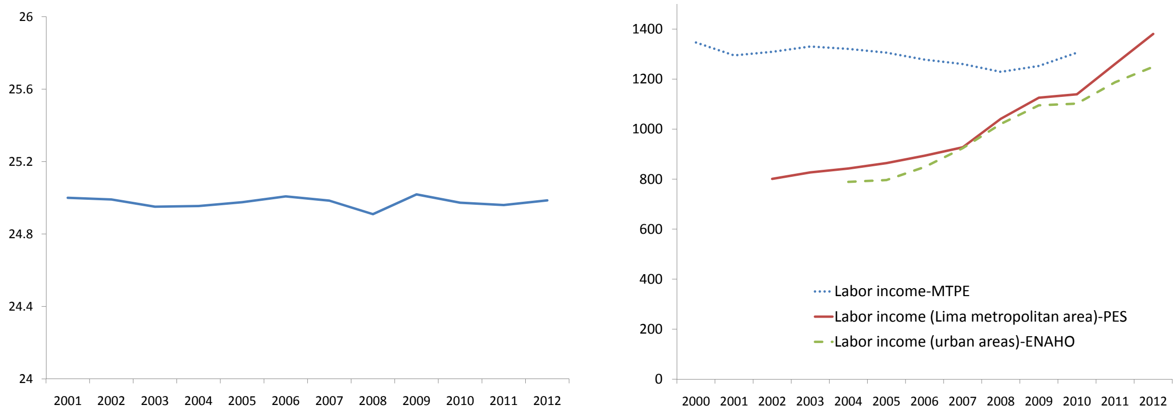
The calculation of TFP by the dual method uses the core assumption that the change in marginal productivity is highly correlated with changes in price (interest rate and wages). This assumption is true in economies where the factors of production are determined in a highly competitive environment. The relevant literature on developed economies relates the existence of wedges between the terms considered, with frictions in the factor market. Among the frictions responsible for these wedges we mention taxes, mark-up, labor unions, and credit rationing. This subject is

[13] The weights capture the reduction of credit dollarization during the period under study.

[14] It is assumed that the weights do not change over time. This assumption is based on the low dynamic of income distribution between labor categories during the period studied.

Figure 5: Returns to Production Factors

(a) Physical capital returns (b) Labor returns



Notes: Panel (a): Capital returns are the average weight of the real interest rates growth in domestic and foreign currency. The weights are the coefficients of dollarization of the liquidity in the banking system. Panel (b): Labor returns by source of information in nominal terms.

important because the earnings of productivity could be due to changes in those frictions. However, there are no published papers that document the importance of frictions as determinants of the inefficiency of the Peruvian economy, which could be a subject for future investigation.

The minimum wage is the other variable related to the inefficiency of the Peruvian economy. Céspedes and Sánchez (2013) show that the minimum wage has effects on middle labor income; they argue that the labor market reports a relevant mass of workers who receive salaries in the neighborhood of the minimum wage. We consider that the size of the elasticity that captures this correlation in aggregate terms is not big enough to argue that the changes in wages captured by the available data respond to changes in frictions of this type. Moreover, the Peruvian economy exhibits a high degree of an informal labor market and a financial sector in the process of development, both of which must be taken into consideration as factors that contribute to inefficiency. The effects of these factors are difficult to calculate and could be significant in highly dynamic markets. In our case and during the period studied, the Peruvian economy has experienced a period of persistent growth, with the development of the financial market[15] and a gradual reduction in the amount of labor informality (Céspedes et al. 2013). These facts could bias the TFP results obtained using the dual method.

[15] The loans and deposits markets of the Peruvian economy have shown a slight change during the period under study. However, banking sector shows low levels of competition. See Céspedes and Orrego (2013) for a diagnosis of the degree of competition in the Peruvian banking sector.

4 Results

4.1 Results of the Primal Method

According to the primal method, TFP grew[16] at an annual average rate of 1.6% between 2003 and 2012, a value inferior to that reported in previous research (2.5%) for a similar period (MEF, 2013).[17] By decomposing the quality and usage of factors, we find that the contribution of these two elements could reach 21% of output growth (0.8%) in the period studied.

Table 1: Total Factor Productivity: Primal Method

	2003-2007	2008-2012	2003-2012
GDP growth	6.3	6.3	6.3
Capital contribution	1.9	4.1	3.0
Capital stock	1.7	3.6	2.6
Capital quality index	0.1	0.6	0.3
Capital utilization index	0.1	-0.1	0.0
Labor contribution	2.1	1.3	1.7
Employment stock	1.6	0.8	1.2
Employment quality index	0.4	0.4	0.4
Employment rate	0.1	0.1	0.1
TFP growth	2.3	0.8	1.6
Capital contribution 1/	3.4	3.1	3.3
TFP growth 1/	0.6	1.8	1.2

Note: 1/ is when consumption of electricity is considered as the capital stock and the corresponding estimates of TFP growth take into account this second measure of capital stock.

A result that follows from the previous exercise is that capital is the factor that contributes the most to GDP growth. This result is highlighted by the second sub-period, as shown in Table 1. We can argue that the high growth rate of investment in physical capital goods (foreign and

[16] We use a value of $\alpha = 0.5$, close to the one used in Miller (2003) and also close to the estimate using data from the national accounts in the period 1950-2000 (see Table 3 for the available estimated values for Peru). The value of this parameter is consistent with recent estimates using data on formal enterprises; see Céspedes et al. (2014). Also, a depreciation rate of physical capital of 5% is considered in the estimations.

[17] The MEF's (2013) estimates do not incorporate the suggested corrections. The MEF (2013) reports that output growth has the following composition: capital (2%), labor (1.7%) and productivity (2.5%). Notice that the MEF (2013) assumes a value of 0.42 for the capital share of output and an economic depreciation rate of 3%.

domestic) that was registered in those years drives the results. Moreover, the labor factor makes a reduced contribution because the employment indicators show low and stable growth rates in the second sub-period of this research.

As an alternative exercise, we estimate TFP growth by taking the consumption of electric energy as an indicator of physical capital. As we previously mentioned, this indicator does not have measurement error problems, because it incorporates the quality and usage of that factor. If we use this indicator, TFP grew at an annual average rate of 1.2% in the period studied. Nevertheless, this indicator has a problem in that it assumes strong complementarity between electricity consumption and physical capital in the economy.

The main disadvantage of the primal method lies in the potential errors of the estimation of the growth rate of the factors of production. Also, the specification assumes that the production function could introduce a certain bias; this would be the case with the Cobb-Douglas production function if the factor shares of aggregate output change over time and if the assumption of constant returns to scale in the production function does not hold.

4.2 Results of the Dual Method

According to the dual method, TFP grew at an annual growth rate of 1.7% in the period 2003-2012, a value estimated by using data on wages from the INEI. We consider two alternative estimators of the TFP growth rate for sub-samples only due to the availability of wage data. Using the wage indicator from the MTPE,[18] the average annual growth rate of TFP is -0.1%, for the period 2003-2007. Additionally, by using the wage indicator for urban areas from the *Encuesta Nacional de Hogares* (ENAHO),[19] TFP grew at an annual average rate of 1.5% for the period 2008-2012.

The difference between these two methods (dual and primal) is due to the discrepancy between the marginal productivities of each factor of production with its respective price. The two methods report results equivalent if the tendencies of the marginal productivities are similar to the tendency of the prices. Moreover, the presence of frictions and other distortions in the labor and capital markets could create differences in these two methods. For the Peruvian case, interest rates have shown a decreasing tendency in the period studied, which could result in a lack of consistency in the returns to productivity. Also, the wage indicators have remained relatively stable during the period 2002-2007, which reflects a rigid labor market with a wage dynamic not necessarily consistent with the reported earnings of labor productivity. From 2007 onward, labor income show a significant (see Figure 5b) growth rate; which is consistent with a

[18] It considers wage and salary data in companies with 10 or more workers by economic sector in the Lima metropolitan area, information published by the MTPE and available since 2004. With these data, the indicator of the variation in wages is constructed as a weighted average of the variation in wages in different categories (sectors and occupational categories).

[19] This wage considers the labor income series published by the INEI using the Permanent Employment Survey (PES), available since 2002.

Table 2: Total Factor Productivity: Dual Method

	2003-2007	2008-2012	2003-2012
Wages and salaries from INEI-PES			
Return to capital contribution	-0.2	0.1	-0.1
Return to labor contribution	0.4	2.9	1.7
TFP growth	0.2	3.0	1.6
Wages and salaries from MTPE			
Return to capital contribution	-0.2	-	-
Return to labor contribution	0.1	-	-
TFP growth	-0.1	-	-
Wages and salaries from INEI-ENAHO			
Return to capital contribution	-	0.1	-
Return to labor contribution	-	1.4	-
TFP growth	-	1.5	-

minor effect of distortions on the wage dynamics.[20]

4.3 Robustness Analysis

Physical Capital Share of Output

Previous calculations assume that the physical capital share of output (α) is 0.5. The capital share is usually estimated by two methods: i) the first method uses data from the national accounts, specifically the measurement of GDP by the income method. According to this method, α is estimated as the portion of GDP that goes to the payment of the physical capital factor. ii) The second method estimates the α parameter using econometric methods. Traditionally, the cointegration method is used, which suggests that there is a long-run relationship between output and the production factors (labor and capital). The available research for Peru considers the values of α to be between 0.33 and 0.69, as shown in Table 3.

To measure the robustness of the results, we consider distinct capital shares; we estimate the growth rate of TFP for values of this parameter on a reasonable interval. The values of α are considered to be 0.4, 0.5, and 0.6. The results indicate that TFP growth estimated using the primal method during the period 2003-2012 is between 1.3% and 1.8%, while, according to the dual method, TFP growth ranges between 1.2% and 1.9% (see Tables 4 and 5). The values are close to the mean with $\alpha = 0.5$.

[20]Céspedes and Rendón (2012) found that the elasticity of labor supply in the Peruvian economy has experienced a significant change. This change suggests greater wage dynamics in the late 2000s, in a context of persistent economic growth.

Table 3: Capital Share of Output in Several Studies

Study	Value	Study	Value
Bernanke and Gurkaynak (2002)	[0.41; 0.69]	Seminario and Beltrán (1998)	0.51
Carranza et al. (2005)	0.44 y 0.33	Valderrama et al. (2001)	0.64
Cabredo and Valdivia (1999)	0.40	Vega-Centeno (1989)	0.55
Elías (1992)	0.66	Vega-Centeno (1997)	0.65
Miller (2003)	0.51	Vera Tudela (2013)	0.33

Note: Bernanke and Gurkaynak (2002) estimate labor shares of output; the values in this table are one minus such labor shares.

Table 4: TFP Estimates for Different Parameter Values: 2003-2012

	α			d		
	0.4	0.5	0.6	5%	6%	7%
GDP growth	6.3	6.3	6.3	6.3	6.3	6.3
Capital contribution	2.4	3.0	3.6	3.0	3.1	3.2
Capital stock	2.1	2.6	3.2	2.6	2.7	2.9
Capital quality index	0.3	0.3	0.4	0.3	0.3	0.3
Capital utilization index	0.0	0.0	0.0	0.0	0.0	0.0
Labor contribution	2.1	1.7	1.4	1.7	1.7	1.7
Employment stock	1.4	1.2	0.9	1.2	1.2	1.2
Employment quality index	0.5	0.4	0.3	0.4	0.4	0.4
Employment rate	0.1	0.1	0.1	0.1	0.1	0.1
Primal TFP growth	1.8	1.6	1.3	1.6	1.4	1.3
Return to capital contribution	-0.1	-0.1	-0.1	-0.1	-0.2	-0.2
Return to labor contribution	2.0	1.7	1.3	1.7	1.7	1.7
Dual TFP growth	1.9	1.6	1.2	1.6	1.5	1.4

Notes: The estimates for different values of α consider a depreciation rate of 5%. The estimates for different values of d consider a capital share of output of 0.5.

Physical Capital Depreciation

In the baseline scenario we assume a physical capital depreciation rate of 5%. However, technological progress should accelerate the depreciation of physical capital. There are no studies on the estimation of that parameter for the Peruvian economy. In Tables 4 and 5, values of TFP growth are reported by the primal and dual methods for values of depreciation of 5%, 6% and 7%. The results show that TFP growth between 2003 and 2012 ranges between 1.3% and 1.6%, which means that these results do not depend mainly on the economic depreciation rate of the intervals studied.

5 Conclusion

This paper estimates the growth rate of TFP for the Peruvian economy using the primal and dual methods for the period 2003-2012. The calculation of TFP using the primal approach incorporates certain improvements regarding the quality and usage of the factors of production, which are relevant features between 2003 and 2012. The adjustments that were taken into consideration complement previous research on the Peruvian economy. The procedure that this paper follows allows us to identify the contribution of the quantity and quality of the factors of production to economic growth.

By controlling for the quality and usage of the factors of production, we find that TFP grew at an annual rate of 1.6%, where physical capital has made a large contribution to economic growth, followed by employment and to a lesser extent TFP. These results contradict previous research that suggests that economic growth is explained mainly by an increase in TFP, followed by physical capital and by employment.

According to the dual approach, the TFP growth rate was 1.7% between 2003 and 2012. This approach emphasizes the relationship between the TFP growth rate and the marginal productivity growth rate of the factors of production. The existence of frictions in the labor and capital markets suggests that the indicator of the TFP growth rate is slightly different from the one estimated by the primal method.

Finally, the estimations of TFP in terms of the primal and dual methods, as well as the estimation of the contributions made by the quality and usage of the factors of production, are a first approximation of the Peruvian economy. Several extensions of this research would be desirable, for example, estimating TFP using other methods or other indicators of quality and usage (hours worked, for example), the estimation of the economic depreciation rate, and TFP growth determinants that could facilitate the intervention of policy in long-run economic growth. These would be useful subjects for future research on the Peruvian economy, but are beyond the scope of this paper.

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