

# Economic Growth Channels From Human Capital: A Dynamic Panel Analysis for Brazil

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## Keywords

Human capital, economic growth,  
GMM model, dynamic panel data

## JEL Codes

E24, O47, C23, C33

## Abstract • Resumo

The purpose of this paper is to test the effect of human capital on Brazilian economic growth through the factor accumulation channel and the total factor productivity channel. We used new human capital measures, covering the period from 1996 to 2015 and employed the two-step SYS-GMM method, with standard finite sample error correction and principal components analysis for the control of the proliferation of instruments. The results show that human capital affects economic growth through both individually tested channels. Also, both basic and advanced human capital have a positive impact on growth through the total factor productivity channel.

## 1. Introduction

The theoretical models of economic growth highlighted the importance of human capital from the perspective of obtaining education (Nelson & Phelps, 1966; Lucas, 1988; Becker, Murphy, & Tamura, 1990; Mulligan & Sala-i-Martin, 1993). Barro and Lee (2013) find a positive and significant effect of workers' schooling, measured in

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average years of total schooling, on the production level of the countries. However, due to the limited availability of education measures for different countries and regions, many proxies are used in the literature to identify the effect of human capital on economic growth (P. M. Romer, 1990; Barro, 1991; Kyriacou, 1991; Benhabib & Spiegel, 1992, 1994; Barro & Lee, 1993). Some examples of these proxies are years of study in basic and/or advanced education, total expenditures with education and expenditures by education levels, enrollment rates, among others (Pelinescu, 2015; Ogundari & Awokuse, 2018; Li & Wang, 2018; Kazmi, Ali, & Ali, 2017).

Studies on the importance of the role of human for the process of economic growth in Brazil have advanced in recent years. Several researchers try to overcome the restrictions to measuring human capital by considering different proxies to evaluate the importance of human capital in growth. For instance, Bondezan and Dias (2016) proposed a method of estimating the stock of Brazilian human capital and public and private physical capital based on the estimates of Garofalo and Yamarik (2002) and Mincer (1974). Considering the number of individuals with complete elementary and secondary education as a measure for human capital, Irffi, Arruda, Bastos, and Barboza (2016) investigate whether human capital and Brazilian trade openness have an impact in economic growth in the municipalities of Ceará. The work of Guimarães, Fully, and Silveira (2017) analyzes the evolution of total productivity factors, considering the evolution of the number of graduates in higher education in Brazil from 1971 to 2011.

In addition, the literature uses several methods to identify the effect of human capital on economic performance. The empirical analysis apply from time series methods with autoregressive vectors, vector error correction (Salgueiro, Nakabashi, & De Prince, 2011; Guimarães et al., 2017; Kazmi et al., 2017), ordinary least squares (Moreira, 2014; Gama, 2014; Cunha & Nunes, 2016; Fully & Teixeira, 2016; Jameel & Naeem, 2016), panel data (Salgueiro et al., 2011; Barro & Lee, 2013; Pelinescu, 2015), spatial econometrics (Salgueiro, 2012; Firme & Simão Filho, 2014; Gama, 2014), to even dynamic panels (Cangussu, Salvato, & Nakabashi, 2010; Fraga, 2011; Castelló-Climent & Mukhopadhyay, 2013; Silva & Sumarto, 2015; Bayraktar-Sağlam, 2016; Li & Wang, 2018; Irffi et al., 2016; Bondezan & Dias, 2016; Teixeira & Queirós, 2016; Ogundari & Awokuse, 2018).

The purpose of this paper is to examine the channels by which aggregated and disaggregated human capital at the basic and advanced level affects the economic growth of the 26 Brazilian states plus the Federal District. That is, we will test the following two hypotheses: (i) whether aggregate human capital affects growth through the *factor accumulation* channel, through the *total factor productivity* channel, or through both channels simultaneously; and (ii) whether human capital disaggregated at the basic and advanced levels affect growth through the *factor accumulation* channel, through the *total factor productivity*, or through both channels simultaneously.

This study contributes to the literature of economic growth and human capital in Brazil, not only by measuring the effects of human capital through the channels of factor accumulation and productivity, but also because we consider a new measure of human capital, expressed by wages based on the education of the graduates of the different levels of education in Brazil. As far as we know, no other work has used this variable for these purposes. This measure stands out because it addresses the main

caveats of the human capital *proxies* that are often used, since it depicts the stock rather than the flows of the accumulation of human capital, and, moreover, do not disregard aspects of school dropout or failure and of the labor productivity, related to the returns of formal education, experience and training. Another important contribution of this paper lies in its econometric analysis. That is, the empirical section innovates when applying the Two-Step System GMM Method (Arellano & Bover, 1995; Blundell & Bond, 1998), with Windmeijer's (2005) correction of standard errors for finite samples, and the Principal Component Analysis to control the proliferation of instruments (Mehrhoff, 2009; Kapetanios & Marcellino, 2010; Bai & Ng, 2010).

The paper is organized as follows. Section 2 presents the theoretical framework. Section 3 discusses the identification strategy, where we present the method and describe the data. Section 4 describes the results of the estimates. Section 5 presents the robustness analysis of the results listed in section 4. Finally, section 6 concludes.

## 2. The model<sup>1</sup>

Consider the following Solow growth model augmented with human capital, similar to those proposed by Lucas (1988) and Mankiw, Romer, and Weil (1992), with aggregate production function at time  $t$  given by

$$Y_t = A_t K_t^\alpha H_t^\beta L_t^\gamma, \quad (1)$$

where  $Y$  is the output,  $A$  is the technological level,  $K$  is the physical capital,  $H$  is the human capital,  $L$  is the labor, and  $\alpha + \beta + \gamma < 1$ . Assume that labor grows at the population growth rate  $n$  and that technology grows exogenously at rate  $g$ :

$$L(t) = L(0)e^{nt}, \quad (2)$$

$$A(t) = A(0)e^{gt}. \quad (3)$$

Denoting per capita output by  $y_{it} \equiv Y_{it}/L_{it}$ , per capita physical capital by  $k_{it} \equiv K_{it}/L_{it}$ , and per capita human capital by  $h_{it} \equiv H_{it}/L_{it}$ , where  $i$  denotes the corresponding individual of interest, the production function can be rewritten in per capita terms according to

$$y_{it} = A_{it} k_{it}^\alpha h_{it}^\beta L_{it}^{\gamma+\alpha+\beta-1}. \quad (4)$$

Moreover, by taking the logarithm on both sides of equation (4), we obtain

$$\ln y_{it} = \ln A_{it} + \alpha \ln k_{it} + \beta \ln h_{it} + (\gamma + \alpha + \beta - 1) \ln L_{it}. \quad (5)$$

Considering (2) and (3), taking first differences of (5) and denoting by  $txk$  and by  $txh$  the growth rates of per capita physical and human capital respectively, the regression equation for growth accounting can be expressed as follows:

$$\Delta \ln y_{it} = g + \theta_1 txk_{it} + \theta_2 txh_{it} + \theta_3 n_{it} + \varepsilon_{it}. \quad (6)$$

That is, equation (6) describes the *factor accumulation* channel, since it treats human capital as a factor of production, so that the growth rate of the human capital stock produces effects on the growth rate of the per capita output.

<sup>1</sup>This section is based on D. Romer and Chow (1996) and Li and Wang (2018).

On the other hand, the *total factor productivity* channel derives from the approach proposed by Nelson and Phelps (1966), which maintains that treating human capital simply as an additional factor of production represents a poor specification of the relation between this variable and economic growth. According to the authors, higher levels of human capital are capable of increasing the ability of an economy to innovate and/or adapt to new technologies. In other words, higher levels of human capital positively influence the rate of technological progress.

According to the proposed model, the main source of growth is technological diffusion, which in turn is improved by education, facilitating the process of adoption and implementation of new technologies. The growth rate of technology is therefore an increasing function of per capita human capital,  $h_{it}$ , and of the gap between the technological level supported by the theory (or technological frontier),  $T_{it}$ , and the observed level,  $A_{it}$ , given by the ratio  $(T_{it} - A_{it})/A_{it}$ , i.e.:

$$\frac{\dot{A}_{it}}{A_{it}} = \Phi(h_{it}) \frac{T_{it} - A_{it}}{A_{it}}, \quad \Phi(0) = 0, \quad \Phi'(h) > 0. \quad (7)$$

Note that, from the modifications made, the rate of technological progress becomes endogenous, since it depends on the human capital stock of the economy. If we assume that the stock of human capital affects output only through the productivity term  $A(h_{it})$ , therefore not considering it as an additional production factor, equation (4) must be modified in order to reflect this new hypothesis, i.e.,

$$y_{it} = A(h_{it}) k_{it}^{\alpha} L_{it}^{\gamma+\alpha-1}, \quad (8)$$

from which we can write the equation in logs:

$$\ln y_{it} = \ln A(h_{it}) + \alpha \ln k_{it} + (\gamma + \alpha - 1) \ln L_{it}, \quad (9)$$

and derive the growth accounting regression equation that considers only the *total factor productivity* channel:<sup>2</sup>

$$\Delta \ln y_{it} = g(h_{it}) + \theta_1 \ln k_{it} + \theta_2 \ln L_{it} + \varepsilon_{it}, \quad (10)$$

Rewriting (10) in order to make the increasing relation between per capita human capital and the rate of endogenous technological progress explicit:

$$\Delta \ln y_{it} = \theta_0 + \theta_1 \ln k_{it} + \theta_2 \ln h_{it} + \theta_3 \ln L_{it} + \varepsilon_{it}. \quad (11)$$

Equation (11) shows that, through the *total factor productivity* channel, an increase in human capital stock is capable of affecting output growth, instead of only producing a level effect on output as previously described by equation (6) through the *factor accumulation* channel.

Finally, we can think of a third specification, assuming that output growth can be simultaneously affected by both the level and the growth rate of human capital. Equation (4) should be rewritten as follows:

$$y_{it} = A(h_{it}) k_{it}^{\alpha} h_{it}^{\beta} L_{it}^{\gamma+\alpha+\beta-1}. \quad (12)$$

<sup>2</sup>Similar to the estimated equation in Benhabib and Spiegel (1994).

Taking logs,

$$\ln y_{it} = \ln A(h_{it}) + \alpha \ln k_{it} + \beta \ln h_{it} + (\gamma + \alpha + \beta - 1) \ln L_{it}, \quad (13)$$

and then taking first differences, we obtain an alternative regression equation for growth accounting, which considers both the *factor accumulation* channel and the *total factor productivity* channel:

$$\Delta \ln y_{it} = \theta_0 + \theta_1 txk_{it} + \theta_2 txh_{it} + \theta_3 \ln h_{it} + \theta_4 n_{it} + \varepsilon_{it}. \quad (14)$$

Therefore, equation (14) shows how growth is affected both by the level of per capita human capital and by the growth rate of this variable, since we are now assuming that both channels—*factor accumulation* and *total factor productivity*—simultaneously affect growth.

The regression equations for growth accounting formulated are aligned to the purpose of this paper, which is to analyze the relative importance of the two channels of accumulation of human capital. It is possible, from equations (6), (11) and (14), respectively, to investigate whether human capital affects growth through (i) the *factor accumulation* channel, (ii) the *total factor productivity* channel, or (iii) both channels simultaneously.

Thus, if hypothesis (i) is true, then equation (6) is correctly specified and the estimated coefficient of the growth rate of per capita human capital should be positive and significant. On the other hand, if hypothesis (ii) is true, then (11) it is correctly specified and the estimated coefficient of the level of per capita human capital should be positive and significant. Finally, if (iii) is true, then (14) is correctly specified and the estimated coefficients of both terms that take human capital into account must be positive and significant.

In addition, it is interesting to examine whether different levels of human capital can affect growth channels differently. Disaggregating human capital into two levels, basic human capital (related to obtaining experiences/skills associated with elementary and high school), denoted by *bh*, and advanced human capital (related to obtaining experiences/skills associated with higher education), denoted by *ah*, the following joint hypotheses will be tested: (A) basic human capital affects output growth from the *factor accumulation* channel; (B) advanced human capital affects output growth from the *total factor productivity* channel, or (C) basic human capital, through the *factor accumulation* channel, and advanced human capital, through the *total factor productivity* channel, affect output growth simultaneously.

Formally, considering the additional assumptions (A), (B) or (C), the regressions (6), (11) and (14) can be rewritten, respectively, as follows:

$$\Delta \ln y_{it} = g + \theta_1 txk_{it} + \theta_2 txbh_{it} + \theta_3 n_{it} + \varepsilon_{it}, \quad (15)$$

$$\Delta \ln y_{it} = \theta_0 + \theta_1 txk_{it} + \theta_2 \ln ah_{it} + \theta_3 n_{it} + \varepsilon_{it}, \quad (16)$$

$$\Delta \ln y_{it} = \theta_0 + \theta_1 txk_{it} + \theta_2 txbh_{it} + \theta_3 \ln ah_{it} + \theta_4 n_{it} + \varepsilon_{it}. \quad (17)$$

Finally, as a measure of robustness for the theoretical channels and also as form of designing a public policy aiming to encourage some specific level of human capital, we

can interchange the human capital measures to test whether advanced human capital affects growth via the *factor accumulation* channel and whether basic human capital affects growth via the *total factor productivity* channel, either singly or simultaneously:

$$\Delta \ln y_{it} = g + \theta_1 txk_{it} + \theta_2 txah_{it} + \theta_3 n_{it} + \varepsilon_{it}, \quad (18)$$

$$\Delta \ln y_{it} = \theta_0 + \theta_1 txk_{it} + \theta_2 \ln bh_{it} + \theta_3 n_{it} + \varepsilon_{it}, \quad (19)$$

$$\Delta \ln y_{it} = \theta_0 + \theta_1 txk_{it} + \theta_2 txah_{it} + \theta_3 \ln bh_{it} + \theta_4 n_{it} + \varepsilon_{it}. \quad (20)$$

Since this paper intends to evaluate the channels by which aggregate human capital and disaggregated human capital at the basic and advanced levels affect Brazilian economic growth, in the empirical section we will test the nine regressions described by the equations (6), (11) and (14) and from (15) to (20) using a dynamic panel containing data for the federative units of Brazil, covering the period from 1996 to 2015. We will also consider other commonly used control variables in the growth literature, as it will be clear in the next session.

### 3. Identification strategy

#### 3.1 Method

For a correct identification of the human capital channels, the regression equations must also include the (log) level of output per capita at the start of the period, to account for transitional convergence. We further consider as control variables the expenditures in education by region, the effects of the macroeconomic financial crises' shocks,<sup>3</sup> and a time trend variable. Also, because Brazil is a continental country with diverse cultures and different regions, we need to control for regional fixed effects,  $\mu_i$ . Thus, we must estimate the following regressions:

$$\begin{aligned} \Delta \ln y_{it} = \alpha + (\rho - 1) \ln y_{i,t-1} + \theta_1 txk_{it} + \theta_2 txh_{it} + \theta_3 n_{it} + \text{Covariates}'_{it} \theta_4 \\ + \mu_i + t + \varepsilon_{it}, \end{aligned} \quad (21)$$

$$\begin{aligned} \Delta \ln y_{it} = \alpha + (\rho - 1) \ln y_{i,t-1} + \theta_1 txk_{it} + \theta_2 \ln h_{it} + \theta_3 n_{it} + \text{Covariates}'_{it} \theta_4 \\ + \mu_i + t + \varepsilon_{it}, \end{aligned} \quad (22)$$

$$\begin{aligned} \Delta \ln y_{it} = \alpha + (\rho - 1) \ln y_{i,t-1} + \theta_1 txk_{it} + \theta_2 txh_{it} + \theta_3 \ln h_{it} + \theta_4 n_{it} \\ + \text{Covariates}'_{it} \theta_5 + \mu_i + t + \varepsilon_{it}. \end{aligned} \quad (23)$$

<sup>3</sup>We control for the Asian Giants' crisis (1997), the Ruble crisis (1998), the Argentine debt crisis (2001–2002) and the global financial crisis (2008–2010).

Clearly these regression equations can be written equivalently as:

$$\ln y_{it} = \alpha + \rho \ln y_{i,t-1} + \theta_1 txk_{it} + \theta_2 txh_{it} + \theta_3 n_{it} + \text{Covariates}'_{it} \theta_4 + \mu_i + t + \varepsilon_{it}, \quad (24)$$

$$\ln y_{it} = \alpha + \rho \ln y_{i,t-1} + \theta_1 txk_{it} + \theta_2 \ln h_{it} + \theta_3 n_{it} + \text{Covariates}'_{it} \theta_4 + \mu_i + t + \varepsilon_{it}, \quad (25)$$

$$\ln y_{it} = \alpha + \rho \ln y_{i,t-1} + \theta_1 txk_{it} + \theta_2 txh_{it} + \theta_3 \ln h_{it} + \theta_4 n_{it} + \text{Covariates}'_{it} \theta_5 + \mu_i + t + \varepsilon_{it}. \quad (26)$$

Therefore, the equations to be estimated to identify the effects of human capital on economic growth should control for the lagged dependent variable as an explanatory variable. The panel data structure in which the lagged dependent variable is considered as an explanatory variable is known in the literature as *Dynamic Panel Data* (DPD). Growth models<sup>4</sup> are usually estimated through DPD techniques, mainly by the *System GMM Method* proposed by Arellano and Bover (1995) and Blundell and Bond (1998). In general terms, GMM models are adequate when we come across the following setting: (i) few time periods and many individuals; (ii) linear relationship between variables; (iii) the dependent variable has dynamic characteristics; (iv) explanatory variables are not strictly exogenous, and therefore, are correlated with their past and possibly current error observations; (v) individual fixed effects; (vi) heteroscedasticity and autocorrelation within individuals, but not between them (Roodman, 2009a).

Blundell and Bond (1998) argue that the *difference-GMM* estimator proposed by Arellano and Bond (1991) may present persistence in the series, and consequently, the level variables become weak instruments for the difference equation, implying bias and low precision in finite samples. To circumvent this issue, the authors impose the condition that the difference variables should not be correlated with the individual fixed effects. Therefore, more instruments can be considered, improving the efficiency of the Arellano–Bond estimator, and providing additional moment conditions for the level regression. Thus, the system-GMM is composed by the level equation, which uses the difference lags as an instrument, and by the difference equation, that uses the lagged variables as instruments.

It should be noted that both Arellano and Bond (1991) and Blundell and Bond (1998) estimators present *one-step* and *two-step* variants. For the *one-step* estimator, it is assumed that the error terms are independent and homoscedastic for each cross-section over time. For the *two-step* estimator, the residuals obtained in the first step are used to construct a consistent estimate of the variance-covariance matrix, relaxing the hypotheses of independence and homoscedasticity. The *two-step* estimator is asymptotically more efficient than *one-step* one, but in small samples the resulting standard errors can be strongly biased downwards. Windmeijer (2005) corrects this problem (of standard errors being underestimated in finite samples), which makes the *two-step* robust and more efficient. Therefore, to identify the channels through which

<sup>4</sup>See Bond, Hoeffler, and Temple (2001).



human capital affects economic growth in Brazil, we use the *two-step system-GMM method* in the analysis.

A disadvantage of the *system-GMM* estimator stems from the proliferation of instruments. The excess of instruments creates a *trade-off* between bias (*overfitting* of endogenous variables) and efficiency (additional moment conditions), generating an imprecise estimation of the moments' variance-covariance matrix and weakening the instrument's joint validity test (Bontempi & Mammi, 2012; Roodman, 2009b). The proliferation of instruments occurs in a quadratic way in the temporal dimension, so we use the principal components' extraction condition from the instrument matrix (Mehrhoff, 2009; Kapetanios & Marcellino, 2010; Bai & Ng, 2010).

According to Mehrhoff (2009), the principal component analysis' technique (*PCA*) for the *system-GMM* context is a factorization process that condenses the informational content of the available set of instruments, reducing the risk of overidentification. Moreover, the factored instruments have the advantage over other constraints' categories in that their estimates have less bias, as well as greater robustness, being a good substitute for the arbitrariness of the researcher when restricting the number of instruments. Thus, through the use of *PCA*, we minimize informational loss and obtain a statistically reasoned and data-oriented technique, which is minimally arbitrary in the delimitation of the instruments, producing a smaller set of instruments that is maximally representative (Mehrhoff, 2009; Kapetanios & Marcellino, 2010; Bai & Ng, 2010).

As for the model specification tests, we highlight the Sargan's (1958) and Hansen's (1982) tests of overidentifying restrictions and Arellano and Bond's (1991) test for first-order and second-order autocorrelation. The test of overidentifying restrictions aim to verify the validity of the instruments. The test's null hypothesis is that the instruments are uncorrelated with the error term. Therefore, the non-rejection corroborates the validity of the instruments. The Sargan's test is appropriate when using the *one-step procedure* (homoscedastic variance-covariance matrix), but when applying the *two-step procedure* (heteroscedastic variance-covariance matrix), the Hansen's test must be used.

In this work, we report the Windmeijer's corrected robust standard errors for finite samples, and so we consider Hansen's test for the validity of the instruments. Regarding the Arellano and Bond's test for first-order and second-order autocorrelation, assuming that there is no autocorrelation between the residuals in the level equation implies, by construction, that the difference equation will present autocorrelated errors. Thus, the test for first-order autocorrelation is expected to identify serial correction, while in the second order the autocorrelation is statistically zero. Therefore, for the estimator to be consistent, the test should reject the null hypothesis for first-order, AR(1), and do not reject the null hypothesis for the higher-order, AR(2).

When the sample is composed of a few groups and the time dimension is greater than 10, there is a tendency for the Hansen test to be weak, that is, to converge to the value 1 in order to accept the null hypothesis (Roodman, 2009b). According to Labra and Torrecillas (2014) and Lillo and Torrecillas (2018), in this case, we must have a number of instruments equal to or less than the number of groups of individuals. We use the same number of instruments and groups. In our research, the number of groups is defined by the Federative Units (UF) of Brazil, which are equal to 27. It is



important to note that, in the absence of the selection of the instruments by PCA, we must also consider the specification test known as *difference-Hansen*. When using the Blundell–Bond *system-GMM* (1998), there are more instruments available than when using the Arellano and Bond (1991) *difference-GMM* procedure. Then the *difference-Hansen* tests the validity of these additional instruments. Its null hypothesis is that these additional instruments are valid.

In sum, as the main goal of this research is to evaluate the channels by which the aggregate and disaggregated human capital at the basic and advanced levels affect Brazilian states' income growth, we use the *two-step system-GMM* method with Windmeijer's (2005) finite sample correction, which is asymptotically more efficient. Due to the fact that the dynamic panel is sensitive to the residuals' autocorrelation, we report the Arellano and Bond's test for first-order and second-order autocorrelation, AR(1) and AR(2), and the *Hansen* and *Diff-Hansen* tests of the validity of instruments. Also, we use the *PCA* method to control the potential proliferation of instruments.

### 3.2 Data

One of the main problems of empirical work lies in the choice of a *proxy* for human capital. Barro and Lee (1993) argue that some *proxies* for human capital stock frequently used in the literature due to easy access have deficiencies, such as enrollment rates. These are deficient because they represent the flows, not the stock of human capital. The idea is that the accumulation of this flow that will generate the stock of human capital in the future, that is, the educational process takes time. According to Barro and Lee (1993), there is a gap between flows and inventories and, even considering an appropriate gap, the initial stock estimates for the construction of a stock of human capital will still be necessary. In addition, enrollment rates do not consider school failure, mortality, migration, and especially school dropout, which are common in developing countries.

Adult literacy rates are also widely used in empirical work as *proxies* for human capital stock. Unlike enrollment rates, they represent a component of the current stock of human capital, but are an imperfect measure as well, as they do not reflect the skills that are obtained beyond the most elementary levels of schooling and disregard aspects of human capital that are important for labor productivity, such as logical and analytical reasoning and various types of technical knowledge (Barro & Lee, 1993). Sala-i-Martin and Mulligan (1995) point out that average years of schooling is also not a good *proxy* for human capital, since it assumes that: (i) workers are perfect substitutes regardless of their areas of expertise; (ii) the productivity differences between workers are proportional to the years of schooling regardless of their wage differences; (iii) the elasticity of substitution between workers of different categories is always constant, in every labor market; and (iv) one year of study manages the same increase of skill, regardless of study's quality or area characteristics.

Mulligan and Sala-i-Martin (1993) used a *proxy* for human capital based on labor income, with the aim of circumventing the aforementioned deficiencies. The intuition behind it was that the wage depended on the relative importance to the market, so that the type of education that was most useful to the market would be better paid. However, an income-based human capital *proxy* is also not a fault-free measure, since

a worker's wage does not depend solely on the skills and on the level of education, but also on the quantities of other aggregate inputs, such as physical capital and technology.

Thus, the main measure of human capital used in this study is the average wages monthly earned in the main occupation of the graduates of elementary, middle and high school, which we call “wage based on the education of graduates” and denote by *HC*. This measure considers both formal education returns and on-the-job training and experience. Data were extracted from the National Household Sample Survey (PNAD) and cover the period between 1996 and 2015. For the years 2000 and 2010, we use the averages between the previous and the subsequent years (Table 1).

The data set is grouped in three ways: basic education, for the average wages of primary and secondary school graduates (*HC\_bh*), advanced education, for the average wages of higher education graduates (*HC\_ah*) and all levels (*HC*). That is, the *proxy* is the monthly average income in *reais* received in the main occupation of the graduates of elementary, middle and high school divided by the value of the minimum wage,<sup>5</sup> which we collect from the Institute of Applied Economic Research (IPEA). Both income and minimum wages are at constant values for the year 2010, deflated by the broad consumer price index (IPCA).

We use the expenses with education and culture in each federative unit,  $\ln(Gec)$ , as a control variable. The data were also collected from IPEA and, from the year 2010 on, they were complemented by data from *Compara Brasil*, a free access portal with data on public finances of Brazil. These values were as well deflated by the IPCA for the base year of 2010.

**Table 1.** Description of the variables.

Cod	Description	Source
<i>L</i>	Economically active population	PNAD
<i>y</i>	Gross domestic product $\div L$	IBGE
<i>txk</i>	Per capita physical capital growth	IBGE
<i>HC_bh</i>	Average salaries of primary and secondary school graduates $\div L$	PNAD
<i>HC_ah</i>	Average salaries of graduates of higher education $\div L$	PNAD
<i>HC</i>	All levels aggregated $\div L$	PNAD
<i>Gec</i>	expenditure whith education and culture	IPEA
<i>Popgr</i>	Population growth	IBGE
<i>Nº Prof. Bh</i>	Number of teachers in basic education	INEP
<i>Nº Prof. Ah</i>	Number of teachers in higher education	INEP
<i>D_Crisis</i>	Crisis Dummy: • 1997, Crisis of the Asian Giants • 1998, Ruble Crisis • 2001–2002, Argentine Crisis • 2008–2009, Great Recession • 2009–2010, Debt crisis in Europe	

<sup>5</sup>The objective of dividing the monthly income by the minimum wage amount is to expunge the income variation determined by law.

The dependent variable, i.e., the natural logarithm of per capita output,  $\ln(y)$ , is represented by the level of gross domestic product (GDP) of the Brazilian states divided by the economically active population (EAP). The GDP was collected from the Brazilian Institute of Geography and Statistics (IBGE) and deflated by the implicit GDP deflator, for 2010 values; the EAP was extracted from the PNAD and supplemented for the remaining years 2000 and 2010 by the average between the previous and the subsequent years. The growth rate of per capita physical capital,  $txk$ , was obtained from the product between the share of the states in the Brazilian GDP and the gross capital formation aggregate data for Brazil, collected from IBGE and deflated by the IPCA for the base year of 2010, divided by the EAP.

Considering that the PNAD had its geographic coverage increased gradually until covering the whole Brazilian territory from the year 2004 on, during the period between 1996 to 2003, and therefore, during part of the temporal cut of this work, PNAD did not include the rural population of Rondônia, Acre, Amazonas, Roraima, Pará and Amapá. As a result, we use the population data provided by IBGE to calculate the population growth rate ( $Popgr$ ). Missing data for higher education graduates' income for the state of Amapá in 1996 and 1997 and Roraima for 1999 were estimated using time series with exponential smoothing. Finally, data for the number of elementary school teachers ( $N^{\circ} Prof. Bh$ ) and higher education teachers ( $N^{\circ} Prof. Ah$ ), extracted from the reports of the National Institute of Studies and Educational Research Anísio Teixeira (INEP), are used as additional exogenous instruments.

We use a panel for the 27 federative units, being 26 states and one federal district. Additionally, we control for the macroeconomic shocks with a dummy variable for crisis.

As for the descriptive statistics, we point out that the level of human capital proxies represents the *total factor productivity* channel, and that the growth rates (Tx) represent the *factor accumulation* channel (Table 2).

**Table 2.** Descriptive statistics.

Variable	Obs	Mean	Std. Dev	Min	Max
$\ln y$	540	3.281146	0.5004625	2.137538	4.881639
$txk$	540	-5.385681	0.5348327	-6.683965	-3.85141
$Popgr$	513	0.0159841	0.0161496	-0.0695467	0.0869195
$\ln(Gec)$	540	20.96891	0.9650627	18.89729	23.92008
$\ln(HC)$	540	-13.1603	1.221711	-15.84615	-9.536788
$Tx(HC)$	513	-0.0569024	0.1283119	-0.4337797	0.698482
$\ln(HC_{bh})$	540	-13.74001	1.211404	-16.30259	-9.896704
$Tx(HC_{ah})$	513	1.269973	3.041304	-0.9857563	17.71353
$\ln(HC_{ah})$	540	-12.53861	1.233833	-15.29634	-9.034603
$Tx(HC_{bh})$	513	1.185477	2.882731	-0.9886244	16.25195
$D_{Cris}$	540	0.35	0.4774119	0	1
$N^{\circ} Prof. Bh$	540	82,311.36	91,034.72	3654	533,040
$N^{\circ} Prof. Ah$	540	10,870.52	15,305.2	146	89,979

## 4. Results

Table 3 presents nine estimates to assess by which channels, and to what magnitude, human capital affects economic growth in Brazil. Estimates from (1) to (3) use wages based on the education of the graduates of elementary school, high school and higher education (*HC*) as a *proxy* for human capital. Equation (1) tests the contribution of the *factor accumulation* channel; equation (2) tests the *total factor productivity* channel; and equation (3) tests both channels simultaneously. Subsequently, in equations (4) to (6), the human capital is disaggregated into basic and advanced. Equation (4) tests the effect of basic human capital through the *factor accumulation* channel; equation (5) tests the effect of advanced human capital by the *total factor productivity* channel and equation (6) tests the two measures simultaneously. For the last group of analysis, from equations (7) to (9), we reverse the previous logic, so that we test the effect of advanced human capital through the *factor accumulation* channel (equation (7)), the effect of basic human capital through the *total factor productivity* channel (equation (8)) and the two channels simultaneously (equation (9)). In every regression, we use the *two-step system-GMM method* with Windmeijer's (2005) robust standard error, and PCA to control for the proliferation of the instruments (Mehrhoff, 2009; Kapetanios & Marcellino, 2010; Bai & Ng, 2010).

In general terms, to check the quality of the model's fit we have to analyze Hansen's J-statistic specification tests, Arellano–Bond test for first-order and second-order autocorrelation and the Kaiser–Lawyer–Olkin measuring of sample adequacy (KMO). The Hansen test results do not reject the null hypothesis that the instruments are valid for all the specifications used ( $>0.05$  for all estimates). As for the Arellano–Bond test for autocorrelation, the results reject the null hypothesis of the absence of first order autocorrelation ( $<0.00$  for all estimates) and do not reject the null hypothesis of the absence of second order autocorrelation ( $>0.05$  for all estimates), indicating that the instruments are valid and are not correlated with the error term for all specifications. Finally, the Kaiser–Meyer–Olkin (KMO) measure of sample adequacy for PCA shows values higher than 0.5. That is, we have confidence that the factor analysis used is adequately adjusted to the data. In short, the tests indicate good specification quality.

The estimation of the lagged level of output per capita (*transitional convergence component*) complements the correct specification of the dynamic panel data models. For all regressions, the estimated coefficients of  $\ln(y_{t-1})$  are negative and significant at the 1% level of confidence. Thus, as expected, the growth rate depends on the initial position of the economy. In other words, all things equal, poor countries should grow at a higher rate than the rich ones.

Regarding the results of the variables of interest (human capital measures), it is possible to infer that aggregate human capital was statistically significant, at the 5% confidence level, for both channels individually (estimates 1 and 2), showing greater magnitude through the *total factor productivity* channel. However, only the *total factor productivity* channel was statistically significant when we considered both channels simultaneously (estimation 3). Therefore, these first results already indicate that the *total factor productivity* channel plays an important role in explaining economic growth in Brazil. We must stress that the direct effect of human capital on economic growth through the *total factor productivity* channel is approximately 0.08%, that is, a 1%

**Table 3.** Two-step System-GMM with PCA.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Tx(HC)	0.06** (0.03)		0.01 (0.04)						
ln(HC)		0.08*** (0.03)	0.09** (0.04)						
Tx(HC_bh)				0.00 (0.00)		0.00 (0.00)			
ln(HC_ah)					0.08*** (0.03)	0.05** (0.02)			
Tx(HC_ah)							0.00 (0.00)		0.00 (0.00)
ln(HC_bh)								0.09*** (0.03)	0.10*** (0.04)
<b>Transitional Convergence</b>									
ln( $y_{t-1}$ )	-0.45*** (0.04)	-0.48*** (0.04)	-0.48*** (0.04)	-0.36*** (0.05)	-0.48*** (0.04)	-0.40*** (0.05)	-0.44*** (0.06)	-0.47*** (0.04)	-0.44*** (0.06)
<b>Covariates</b>									
txk	0.32*** (0.03)	0.29*** (0.04)	0.28*** (0.04)	0.30*** (0.02)	0.29*** (0.04)	0.27*** (0.03)	0.28*** (0.02)	0.28*** (0.04)	0.22*** (0.04)
ln(Gec)	0.03** (0.02)	0.13*** (0.04)	0.14*** (0.05)	0.02** (0.01)	0.12*** (0.04)	0.08** (0.03)	0.04** (0.02)	0.13*** (0.04)	0.15*** (0.05)
Popgr	0.53* (0.28)	0.21 (0.22)	0.20 (0.24)	0.28 (0.26)	0.23 (0.23)	0.19 (0.27)	0.53 (0.37)	0.21 (0.22)	0.12 (0.26)
D_Crisis	-0.02*** (0.00)	-0.02*** (0.00)	-0.02*** (0.00)	-0.01* (0.01)	-0.02*** (0.00)	-0.01* (0.01)	-0.01 (0.01)	-0.02*** (0.00)	-0.01 (0.01)
Trend	-0.00*** (0.00)	-0.00 (0.00)	0.00 (0.00)	-0.00*** (0.00)	0.00 (0.00)	-0.00 (0.00)	-0.00*** (0.00)	-0.00 (0.00)	0.00 (0.00)
Constant	2.54*** (0.37)	1.58*** (0.60)	1.39** (0.63)	2.51*** (0.21)	1.57** (0.63)	1.75*** (0.45)	2.22*** (0.29)	1.60*** (0.55)	0.86 (0.67)
AR(1)	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
AR(2)	[0.40]	[0.62]	[0.57]	[0.45]	[0.67]	[0.55]	[0.43]	[0.52]	[0.32]
J-Hansen	[0.12]	[0.12]	[0.09]	[0.11]	[0.12]	[0.09]	[0.14]	[0.12]	[0.10]
N° instruments	27	27	27	27	27	27	27	27	27
K-M-O	[0.850]	[0.864]	[0.850]	[0.829]	[0.864]	[0.829]	[0.855]	[0.864]	[0.855]
N	513	513	513	513	513	513	513	513	513

Notes: Dependent variable:  $\Delta \ln(y_t)$ . All estimates were made using the two-step system-GMM method. The levels of significance are represented by \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.10$ . The value in brackets represents Windmeijer's (2005) robust standard error.

increase in the human capital measure generates a direct increase of 0.08% of GDP, corroborating with the results for states and municipalities of Brazil (Salgueiro, 2012; Fraga, 2011; Salgueiro et al., 2011; Firme & Simão Filho, 2014; Irffi et al., 2016).

Deepening the analysis, we propose the use of measures of human capital denominated “wages based on the disaggregated education of the graduates”, that is to say, basic education, for the average wages of the graduating students of primary and secondary school ( $HC\_bh$ ) and advanced education, for the average of wages of the graduating students of higher education ( $HC\_ah$ ). The first variable is a suitable *proxy* for measuring the *factor accumulation* channel, since the basic human capital *proxy* is related to average labor productivity and the second, in turn, for measuring the *total factor productivity* channel, since the advanced human capital *proxy* is related to labor intensive human capital, which is specific and linked to the development of technology. Then, considering these disaggregated measures, the results show that the *total factor productivity* channel affects Brazilian growth at the 1% of significance level. This corroborates our earlier results. In addition, it should be noted that the direct effect of a 1% increase in the level of advanced human capital, through the *total factor productivity*, is also an increase of approximately 0.08% in GDP (estimation 5). Also, once again only the *total factor productivity* channel was statistically significant when we considered both channels simultaneously (estimation 6).

Finally, we propose the use of basic human capital and advanced human capital *proxies* in reverse. The idea is to test both the robustness of the *total factor productivity* channel and to analyze the relative importance of basic human capital. Then, the *total factor productivity* channel remains robust (regressions 8 and 9), that is, it is significant to at the 5% confidence level, presenting the same signal and slightly higher magnitude than previously found.

With respect to the covariates, in all specifications the growth rate of the stock of physical capital was positive and statistically significant at the 1% significance level, as predicted by the theoretical model. In terms of the magnitude of the coefficients, the relative importance of physical capital for Brazilian economic growth becomes clear. The results agree with ones of previous works (Cangussu et al., 2010; Salgueiro et al., 2011; Gama, 2014; Bondezan & Dias, 2016). The expenses with education and culture variable,  $\ln(Gec)$ , was statistically significant and positive for all specifications. This result shows that regional investments in education and culture also have an effect on economic growth. The population growth variable did not present statistical significance, except in the estimation (1). The variable for the controlling for macroeconomic shocks due to crises had a negative coefficient, as expected, and was statistically significant at the 10% confidence level, except for estimates (7) and (9). Finally, the trend variable had a coefficient close to zero in all the estimates, being significant to at the 1% confidence level in estimates (1), (4), and (7).

In sum, the results indicate that total factor productivity is the most important channel for the growth process of the Brazilian states, and that education and culture spending also have a positive impact on growth. Regarding the hypotheses raised in this research, we can highlight the importance of the *total factor productivity* channel as an important driving force for the economic growth of the Brazilian states.

Another important characteristic of the estimation through dynamic panel models is the possibility of estimating the long-term effects of human capital on economic growth. Thus, Table 4 presents the long-term effects.

**Table 4.** Long-term effects.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Tx(HC)	0.14*		0.03						
	(0.07)		(0.093)						
ln(HC)		0.18***	0.19***						
		(0.06)	(0.07)						
Tx(HC_bh)				0.00		0.00			
				(0.00)		(0.00)			
ln(HC_ah)					0.17***	0.13**			
					(0.06)	(0.05)			
Tx(HC_ah)							0.00		0.01
							(0.01)		(0.04)
ln(HC_bh)								0.18***	0.24***
								(0.06)	(0.08)

Notes: Dependent variable:  $\Delta \ln(y_t)$ . All estimates were made using the *two-step system-GMM method*. The levels of significance are represented by \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.10$ . The value in brackets represents Windmeijer's (2005) robust standard error.

In general terms, the long-term effects follow the same relative relationships as those previously found. That is, human capital affects economic growth through the *total factor productivity* channel, while the *factor accumulation* channel remains without statistical effect for most specifications, except for regression (1).

The long-term effect amplifies the direct effect found, insofar as the conditions of the state of the economy in the previous period are considered by the dynamic term. In this way, it can be observed that the human capital long-term coefficient for the regressions that analyze the *total factor productivity* channel are statistically significant at the 1% confidence level in equations (2), (5) and (8). In equation (2), we have that a 1% increase in the level of human capital results in a 0.18% increase in long-term economic growth for the Brazilian economy. In the fifth equation, when we deepen this analysis and consider the measure of advanced human capital the long-term effect remains at approximately 0.17%. Finally, in the analysis of channel robustness, we have that the long-term effect is approximately 0.18% at the 1% level of significance.

In sum, the results show that the *total factor productivity* channel is crucial for formulating economic policies in Brazil.

## 5. Robustness analysis

In this section we put the results to the test by considering different econometric specifications, in order to verify if the results previously found are robust. In this way, we propose three different specifications for controlling the proliferation of the number of instruments in the *two-step system-GMM*. First, we consider the limits of the lags along with the collapsed instruments (Table 5). Then, we relax the specifications,



considering only the limits of the lags (Table 6). And, finally, we consider only the collapsed instruments (Table 7).

According to Bontempi and Mammi (2012) the collapse of the instruments' method and depth truncation of the lags involve a certain degree of arbitrariness, so that there must be confidence in the restrictions imposed by the researcher. When the instrument matrix is collapsed, specific dynamics are assumed in the data; when we apply the method of depth truncation of the lags, the number of lags that must be included among the instruments are chosen, assuming that the relevant information is transmitted only by the considered lags of the endogenous variables. Therefore, in this robustness analysis we continue with the *two-step system-GMM* estimator, but we define the collapsed internal instruments and limit the number of lags of the endogenous variables in lag (2 10) by *total factor productivity* channel and in lag (2 6) by the *the factor accumulation* channel.

The results reported in tables 5, 6 and 7 corroborate the effect of human capital on Brazilian economic growth. In most of the estimates, the coefficients related to human capital remained significant, presenting magnitudes close to those found through the PCA model. The proportion of effects follows the same logic as previous results, that is, aggregate human capital (*HC*) affects Brazilian economic growth through the two individually tested channels. With regard to disaggregated human capital, the results show that advanced education's estimated coefficient was positive and statistically significant by the *total factor productivity* channel, corroborating its importance. Basic education, however, was also statistically significant only by the *total factor productivity* channel. The transitional convergence component variable is also statistically significant in all estimates for the three strategies considered.

Even though the variables of interest's coefficients have presented both direction and magnitude similar to those found previously, we must check the quality of the adjustment in the three strategies in the robustness analysis. So, first, we have to analyze Hansen's J-statistic specification tests and the Arellano–Bond first-order and second-order tests for autocorrelation. For the first strategy Table 5, the results of Hansen's test do not reject the null hypothesis that the instruments are valid for all of the specifications used (value  $>0.05$ ). As for the Arellano–Bond tests for autocorrelation, the results reject the null hypothesis of the absence of first order autocorrelation ( $<0.001$  for all estimates) and do not reject the null hypothesis of the absence of second order autocorrelation ( $>5$  for all estimates), indicating that the instruments are valid and that they are not correlated with the error term for all specifications.

Except for the PCA model, the *Difference in Hansen* test is available for all other estimates, which has as null hypothesis that the additional instruments are valid. The results show that we can accept the null hypothesis. Thus, the models in Table 5 indicate good specification quality. When analyzing the quality of the specification of the strategies of tables 6 and 7, some distrust about the validity of the instruments arises, due to proliferation of instruments. Since the Hansen tests are sensitive to the proliferation of instruments, the confidence in the quality of the estimates in tables 6 and 7 is lost. Thus, the estimates in tables 6 and 7 are not of satisfactory quality and cannot be considered.

**Table 5.** Two-Step System-GMM with laglimits and collapse.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Tx(HC)	0.06* (0.04)		0.04 (0.03)						
ln(HC)		0.05*** (0.02)	0.05*** (0.02)						
Tx(HC_bh)				0.00 (0.00)		0.00 (0.00)			
ln(HC_ah)					0.05*** (0.02)	0.02 (0.02)			
Tx(HC_ah)							0.00 (0.00)		0.00 (0.00)
ln(HC_bh)								0.06** (0.03)	0.05** (0.02)
<b>Transitional Convergence</b>									
ln( $y_{t-1}$ )	-0.29*** (0.03)	-0.36*** (0.04)	-0.36*** (0.04)	-0.27*** (0.04)	-0.36*** (0.04)	-0.32*** (0.05)	-0.31*** (0.04)	-0.36*** (0.04)	-0.37*** (0.05)
<b>Covariates</b>									
txk	0.27*** (0.04)	0.24*** (0.03)	0.25*** (0.03)	0.27*** (0.04)	0.24*** (0.03)	0.27*** (0.04)	0.29*** (0.04)	0.23*** (0.03)	0.26*** (0.04)
ln(Gec)	0.01 (0.01)	0.08*** (0.03)	0.08*** (0.02)	0.00 (0.01)	0.08*** (0.03)	0.04 (0.02)	0.01 (0.01)	0.08** (0.03)	0.08*** (0.03)
Popgr	0.39 (0.36)	0.29 (0.27)	0.36 (0.34)	0.27 (0.33)	0.30 (0.27)	0.27 (0.29)	0.41 (0.38)	0.28 (0.25)	0.34 (0.30)
D_Crisis	-0.01** (0.01)	-0.01** (0.01)	-0.01* (0.01)	-0.01 (0.01)	-0.01** (0.01)	-0.01 (0.01)	-0.01 (0.01)	-0.01** (0.00)	-0.01* (0.01)
Trend	-0.00*** (0.00)	-0.00 (0.00)	-0.00 (0.00)	-0.00*** (0.00)	-0.00 (0.00)	-0.00 (0.00)	-0.00*** (0.00)	-0.00 (0.00)	-0.00 (0.00)
Constant	2.34*** (0.38)	1.47*** (0.43)	1.61*** (0.39)	2.36*** (0.38)	1.52*** (0.41)	2.02*** (0.43)	2.42*** (0.36)	1.45*** (0.46)	1.74*** (0.44)
AR(1)	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
AR(2)	[0.48]	[0.60]	[0.49]	[0.41]	[0.64]	[0.45]	[0.55]	[0.52]	[0.47]
J-Hansen	[0.05]	[0.11]	[0.06]	[0.05]	[0.10]	[0.06]	[0.05]	[0.12]	[0.06]
Diff-Hansen	[0.43]	[0.61]	[0.37]	[0.84]	[0.66]	[0.74]	[0.69]	[0.63]	[0.83]
N° instruments	24	26	25	24	26	25	24	26	25
N	513	513	513	513	513	513	513	513	513

Notes: Dependent variable:  $\Delta \ln(y_t)$ . All estimates were made using the two-step system-GMM method. The levels of significance are represented by \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.10$ . The value in brackets represents Windmeijer's (2005) robust standard error.

**Table 6.** Two-Step System-GMM with laglimits.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Tx(HC)	0.06** (0.03)		0.05* (0.03)						
ln(HC)		0.04* (0.02)	0.03 (0.02)						
Tx(HC_bh)				0.00 (0.00)		0.00 (0.00)			
ln(HC_ah)					0.03* (0.02)	0.01 (0.01)			
Tx(HC_ah)							0.00 (0.00)		0.00 (0.00)
ln(HC_bh)								0.04** (0.02)	0.02 (0.01)
<b>Transitional Convergence</b>									
ln( $y_{t-1}$ )	-0.39*** (0.03)	-0.40*** (0.04)	-0.40*** (0.04)	0.40*** (0.04)	-0.39*** (0.04)	-0.40*** (0.04)	-0.37*** (0.03)	-0.39*** (0.04)	-0.38*** (0.03)
<b>Covariates</b>									
txk	0.34*** (0.03)	0.31*** (0.03)	0.33*** (0.03)	0.37*** (0.04)	0.31*** (0.03)	0.36*** (0.04)	0.35*** (0.03)	0.30*** (0.03)	0.34*** (0.03)
ln(Gec)	0.01* (0.01)	0.05** (0.03)	0.04 (0.03)	0.01** (0.00)	0.05* (0.03)	0.02 (0.01)	0.01* (0.00)	0.05** (0.03)	0.02 (0.02)
Popgr	0.25 (0.22)	0.19 (0.23)	0.17 (0.22)	0.20 (0.28)	0.18 (0.23)	0.13 (0.30)	0.16 (0.29)	0.19 (0.23)	0.10 (0.31)
D_Crisis	-0.02*** (0.01)	-0.02*** (0.01)	-0.02*** (0.01)	-0.02*** (0.01)	-0.02*** (0.01)	-0.02*** (0.01)	-0.02** (0.01)	-0.02*** (0.01)	-0.02*** (0.01)
Trend	-0.00*** (0.00)	-0.00* (0.00)	-0.00*** (0.00)	-0.01*** (0.00)	-0.00* (0.00)	-0.00*** (0.00)	-0.00*** (0.00)	-0.00** (0.00)	-0.00*** (0.00)
Constant	2.94*** (0.29)	2.35*** (0.38)	2.62*** (0.45)	3.18*** (0.37)	2.39*** (0.44)	3.05*** (0.40)	3.01*** (0.28)	2.37*** (0.40)	2.85*** (0.35)
AR(1)	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
AR(2)	[0.50]	[0.67]	[0.55]	[0.53]	[0.70]	[0.56]	[0.45]	[0.62]	[0.43]
J-Hansen	[1.00]	[1.00]	[1.00]	[1.00]	[1.00]	[1.00]	[1.00]	[1.00]	[1.00]
Diff-Hansen	[1.00]	[1.00]	[1.00]	[1.00]	[1.00]	[1.00]	[1.00]	[1.00]	[1.00]
N° instruments	110	76	111	110	76	111	110	76	111
N	513	513	513	513	513	513	513	513	513

Notes: Dependent variable:  $\Delta \ln(y_t)$ . All estimates were made using the two-step system-GMM method. The levels of significance are represented by \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.10$ . The value in brackets represents Windmeijer's (2005) robust standard error.

**Table 7.** Two-Step System-GMM with collapse.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Tx(HC)	0.04* (0.03)		-0.01 (0.03)						
ln(HC)		0.12*** (0.03)	0.09*** (0.03)						
Tx(HC_bh)				-0.00 (0.00)		-0.00 (0.00)			
ln(HC_ah)					0.11*** (0.03)	0.07*** (0.02)			
Tx(HC_ah)							-0.00 (0.00)		0.00 (0.00)
ln(HC_bh)								0.14*** (0.03)	0.14*** (0.04)
<b>Transitional Convergence</b>									
ln( $y_{t-1}$ )	-0.54*** (0.04)	-0.60*** (0.05)	-0.58*** (0.05)	-0.53*** (0.06)	-0.60*** (0.05)	-0.56*** (0.05)	-0.44*** (0.05)	-0.60*** (0.06)	-0.60*** (0.06)
<b>Covariates</b>									
txk	0.37*** (0.04)	0.34*** (0.03)	0.37*** (0.04)	0.41*** (0.03)	0.35*** (0.04)	0.39*** (0.04)	0.38*** (0.05)	0.31*** (0.04)	0.31*** (0.06)
ln(Gec)	0.04*** (0.01)	0.17*** (0.03)	0.14*** (0.04)	0.03*** (0.01)	0.16*** (0.03)	0.11*** (0.03)	0.04*** (0.01)	0.19*** (0.04)	0.20*** (0.06)
Popgr	0.57** (0.25)	0.15 (0.21)	0.12 (0.20)	0.56** (0.28)	0.18 (0.21)	0.22 (0.34)	0.61** (0.26)	0.14 (0.20)	0.31 (0.37)
D_Crisis	-0.02*** (0.00)	-0.03*** (0.01)	-0.03*** (0.00)	-0.03*** (0.00)	-0.03*** (0.00)	-0.03*** (0.01)	-0.03*** (0.01)	-0.02*** (0.00)	-0.02*** (0.01)
Trend	-0.00*** (0.00)	0.00 (0.00)	-0.00 (0.00)	-0.01*** (0.00)	0.00 (0.00)	-0.00 (0.00)	-0.00*** (0.00)	-0.00 (0.00)	-0.00 (0.00)
Constant	3.00*** (0.48)	1.73*** (0.49)	2.29*** (0.60)	3.50*** (0.36)	1.82*** (0.58)	2.64*** (0.44)	3.03*** (0.55)	1.46** (0.59)	1.31 (0.96)
AR(1)	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
AR(2)	[0.42]	[0.68]	[0.77]	[0.72]	[0.73]	[0.98]	[0.54]	[0.51]	[0.47]
J-Hansen	[1.00]	[0.91]	[1.00]	[1.00]	[0.91]	[1.00]	[1.00]	[0.92]	[1.00]
Diff-Hansen	[1.00]	[1.00]	[1.00]	[1.00]	[1.00]	[1.00]	[1.00]	[1.00]	[0.99]
N° instruments	64	45	65	64	45	65	64	45	65
N	513	513	513	513	513	513	513	513	513

Notes: Dependent variable:  $\Delta \ln(y_t)$ . All estimates were made using the two-step system-GMM method. The levels of significance are represented by \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.10$ . The value in brackets represents Windmeijer's (2005) robust standard error.

The results of this section are relevant because they reinforce the results previously found, since the *total factor productivity* channel was statistically significant in most specifications, even if we do not have confidence about the correct identification of the coefficient associated with human capital. That is, as the proliferation of instruments is a serious issue for the *System-GMM* estimator, we should expect that relaxing the instruments' control would cause a reduction in the quality of the estimates, especially in the models of tables 6 and 7. In addition, it should be emphasized that the model of Table 5 is very well adjusted and comparable to the model proposed by the research. However, the model with PCA is considered superior, since, in addition to greater efficiency, it represents a minimally arbitrary way of limiting the counting of the instruments, minimizing the loss of information and making it possible to maintain a set of major components with higher eigenvalues (Bai & Ng, 2010; Kapetanios & Marcellino, 2010; Mehrhoff, 2009).

## 6. Conclusion

Based on a Solow growth model augmented with human capital, similar to those proposed by Lucas (1988) and Mankiw et al. (1992) and the contributions of Nelson and Phelps (1966), the main goal of this study was to investigate through which channels human capital affected Brazil's economic growth, from 1996 to 2015. The following hypotheses were tested: human capital—both aggregated and disaggregated at basic and advanced levels—affects growth through (i) the *factor accumulation* channel; (ii) the *total factor productivity* channel; or (iii) both channels simultaneously.

This paper contributes to the national debate, as it proposes new *proxies* for human capital stocks, related to formal education returns, experience and workplace training, measures that are not affected by the main shortcomings of the ones already proposed by the literature, such as those related to school dropout and failure rates, and labor productivity aspects (Barro & Lee, 1993; Mulligan & Sala-i-Martin, 1993).

For the empirical analysis, we used the *two-step system-GMM method* (Arellano & Bover, 1995; Blundell & Bond, 1998), with Windmeijer's (2005) finite sample standard errors' correction and principal component analysis (PCA) for controlling the proliferation of instruments (Mehrhoff, 2009; Kapetanios & Marcellino, 2010; Bai & Ng, 2010). As a test of the results' robustness, we control the proliferation of the instruments through the *laglimit* and *collapse* methods.

The results showed that aggregate human capital, through both channels individually considered, affects economic growth. Regarding the measures of human capital disaggregated at basic and advanced levels, economic growth is affected only via the *total factor productivity* channel. With regard to the magnitudes of the estimated coefficients, we should emphasize those related to human capital at the basic level, which were significant and always produced a higher impact than those related to advanced human capital. In summary, the results found in this study, although using different data and methods, are close to those already known from the literature.

Based on the above results, we recommend that public policies aimed at promoting economic growth from higher levels of human capital be stimulated and, if there is a need for an allocative choice for resources involving distinct educational stages, that priority be given to those related to human capital at the basic level.

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