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Performance of Brazilian total factor productivity from 2004 to 2014: a sectoral and regional analysis

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Abstract
This paper aimed to study the behavior of Brazilian productivity between 2004 and 2014 and its impact on growth in a disaggregated analysis. To this end, performance was studied by examining the measurement of total factor productivity and was also based on sectoral and regional aggregation in an attempt to verify which sectors and regions contributed most to the low aggregate productivity in Brazil, considering the few disaggregated studies on productivity. In addition, based on the estimates, a growth decomposition was performed to verify the contribution of productivity to economic growth. Additionally, econometric methodologies were used to calculate productivity in order to verify whether the results obtained were similar, using panel estimates with pooled data, fixed effects, and a dynamic panel in level and differences. Among the results, it was verified that there was higher productivity growth in services and that there was a decrease in industry. The regions that achieved better performance were the North, Northeast, and Center-West, depending on the sector analyzed. In addition, considering all the regions, only industry contributed negatively to growth, except in the Center-West. Regarding econometrics, the pooled data model presented the best results.

Keywords: Economic growth, Total factor productivity, Growth decomposition

JEL Classification: D24, O47

1 Introduction

Productivity is a recurring theme in Brazilian economic scenarios, due to the concern about ensuring that the economy grows in a sustainable way in the long term. This is even more so when it is verified that there has been a reduction in economic growth rates,[1] such as from 2001 to 2010 when, on average, this rate was 3.48% per year, and the most recent period, from 2011 to 2014, when it reached 1.79% per year, according to IBGE (2017). Indeed, according to Feenstra et al. (2015), the total factor productivity in Brazil from 1950 to 2014, considering information from the Penn World Table (PWT), achieved an average growth rate of 3.58% per year.[2]

[1] Considering the GDP growth.

[2] In the 1950s, 1960s, 1970s, 1980s, 1990s, 2000s, and 2010s until 2014, the average growth rates of TFP were, respectively, 1.85% per year, 1.03% per year, 1.94% per year, 2.70% % per year, 0.52% per year, 0.32% per year, and 2.55% per year in average.

According to De Negri and Cavalcante (2014), investment did not have enough impact to stimulate the Brazilian economy in the long term, given its resilience. In addition, as stated by Squeff and De Negri (2014), Brazilian productive efficiency has had a poor performance since the 1980s, aside from some growth in early 2000s.[3] According to Nogueira et al. (2014), this growth was sustained by higher productivity growth in agriculture. Thus, in order for productivity to contribute to sustainable Brazilian growth in the long term, it would first have to be improved.

In Brazil, there are several studies on aggregate productivity (Barbosa-Filho et al. 2010; Bonelli and Veloso 2012; Bonelli and Bacha 2013; Ferreira and Veloso 2013). In turn, the sectoral approach is also present in the national literature (Squeff and De Negri 2014; Nogueira et al. 2014; Matteo 2015), but according to Ellery Jr. (2014), disaggregated productivity has many obstacles, such as a lack of information.

In this context, this paper seeks to contribute to the discussion on the subject by measuring total factor productivity in a disaggregated way, considering the sector (agriculture, industry, and services) and the region (North, Northeast, Southeast, South, and Center-West) jointly in the country from 2004 to 2014.[4] The analysis helps to verify which regions and sectors were responsible for contributing to the low aggregate performance. In addition, it also sought to verify the impact that the growth rate of these productivities had on economic growth through the growth decomposition, verifying whether the growth trend was the same for both. Finally, having verified productivity's behavior by sector and region, it is still worth adopting measures for comparing the results of calculating total factor productivity (TFP). Therefore, to allow a comparison of the results, productivity was also estimated by econometric methods, namely pooled panel data, fixed effects panels, a dynamic panel in level, and differences. This analysis allows for clarifying questions about whether the measure of TFP represents reality.

2 Theoretical and empirical review

In one of the earliest contributions to economic growth theory that can be highlighted, the analyses of economic growth by Abramovitz (1956), Kendrick (1956) and Denison (1962), productivity was considered predominant for explaining a significant part of growth, as Griliches (1998) pointed out. In these studies, the authors sought to study the growth rates of per capita production in the USA, as well as the behavior of growth rates of physical and labor capital. From their conclusions, they affirmed that much of the growth was due to productivity or, according to Abramovitz (1956), the measure of our ignorance. Having verified the importance of productivity for economic growth, Denison (1962) argued that one of the reasons for its acceleration rested in economies of scale, but this could not be directly influenced.

The following are the highlighted contributions of Solow (1956) and Swan (1956) who introduced productivity in an economic growth model, where it was called technical progress. The growth model was based on the analysis of a neoclassical production function, which assumed constant returns to scale and decreasing returns on inputs. To Solow (1956), technical progress was an increasing factor of scale by which production

[3] Considering total factor productivity as the measure of productivity growth.

[4] The justification for the beginning of the analysis in 2004 is the availability of data since only from this year IBGE began to include rural area of North in Pesquisa Nacional por Amostra de Domicílios, used as data source.

was multiplied. Meanwhile, in Swan (1956), technical progress was initially neutral but increased its responsibility for increases in output that were not caused by increases in capital or labor and indirectly increased production by increasing the contribution of capital.

In opposition to these models, endogenous models emerged in which technical progress would be internal to the model of economic growth. Among these studies are Romer (1986), Lucas (1988) and Romer (1990) who were also known for their attention to increasing incomes at scale and the consideration of models in imperfect equilibrium, assuming equilibrium in monopolistic competition, and the inclusion of human capital stock in the production function. Nevertheless, considering total factor productivity, technical progress, or technological change, there is also the model of Mankiw et al. (1992), which sought to defend Solow's contributions to economic growth by finding solutions to some of the criticisms pointed out in the original model. Thus, it was considered an augmented Solow model with human capital, and to the authors, that modification better fit the description of the growth of countries.

In the empirical literature, according to a few authors, there is a certain consensus on the behavior of Brazilian productivity, including De Negri and Cavalcante (2014), Squeff and De Negri (2014), Barbosa-Filho and Pessôa (2014) and Ellery Jr. (2014). According to these authors, there was productivity growth until the 1980s, when there was a decrease. In the following decade, 1990, productivity stagnated, while there was a slight increase in the early 2000s. However, after the 2008 crisis, there was a return to the low growth of Brazilian productivity.

Barbosa-Filho et al. (2010) studied Brazilian productivity growth through total factor productivity (TFP) between 1992 and 2007. In the period from 1992 to 1999, the growth rate was 1.4% per year, while in the period from 1999 to 2007, it was 0.11% per year. In its estimation, the study made use of the level of capacity utilization and human capital included in the production function.

Bonelli and Veloso (2012) studied the growth of TFP in Brazil from 1995 to 2009, concluding that, during the period from 1995 to 2003, the average growth of TFP was negative at 0.8% per year, while in the period from 2003 to 2009, it was positive at 1.7% per year. The estimation was made from a Cobb–Douglas function including the level of capacity utilization. It is possible to verify that the results found diverge from the results of Barbosa-Filho et al. (2010). Like Bonelli and Veloso (2012) and Bonelli and Bacha (2013) used the same methodology, but focused on the period from 1990 to 2011. The study concluded that, in the first 3 years of the period, productivity remained unchanged. In the period from 1993 to 1999, they found that the average growth rate of TFP was 0.24% per year, while in the period from 2000 to 2011, the growth was 1.03% per year.

Adopting a different methodology, Ferreira and Veloso (2013) estimated TFP using human capital in the production function and using data in dollars in purchasing power parity. When analyzing the period from 1993 to 2003, they indicated a productivity decrease of 1.2%. While in the period 2003–2009, growth was positive by 1.5%. Bonelli (2014), while studying the growth of Brazilian total factor productivity in the period from 2003 to 2013, found that the average growth was 1.3% per year, a value close to that obtained by Bonelli and Veloso (2012).

Due to the difficulty of obtaining disaggregated data, especially fixed capital stock, there are certain restrictions regarding the study of TFP in a disaggregated way. This is evidenced by the fact that there is no official measure of fixed capital in Brazil after 2008, according to Bondezan and Dias (2016). However, some studies have been successful in verifying the disaggregated total factor productivity, such as Tavares et al. (2001) who estimated the TFP at the state level from 1986 to 1998, which was a great step forward in verifying regional productivity inequalities.

Ferreira (2010) studied the total factor productivity in the state of Minas Gerais during the period from 1985 to 2003. Among his conclusions, he observed that productivity in the state followed a downward trend, reflecting the fall in Brazilian productivity. Recall that this fall in productivity, from the 1980s, was also verified by De Negri and Cavalcante (2014).

Much of the work that has been done to study TFP in a disaggregated way focused its analysis on the agricultural macrosector, such as Pereira (1999), Ferreira (2010), Gasques (2010) and Gonçalves e Parré (2012). According to Squeff and De Negri (2014), in comparison with other sectors, productivity in the agricultural sector was the one that grew most.

Pereira (1999) also studied the total factor productivity in Brazilian agriculture from 1970 to 1996. Pereira also confirmed the productivity growth in agriculture during this period but said that it was not homogeneous in all regions of the country and that it was concentrated in certain places: the Center-West, South, and Southeast. Araujo and Mancal (2015), who studied agriculture in the Northeast, found that, during the period from 1970 to 2006, this growth did not occur homogenously throughout the region.

Therefore, according to empirical literature that studies Brazilian aggregate productivity, the behavior trend is stagnation in growth. When considering the regional productivity, it was verified that the Southeast, South, and Center-West presented higher growth rates than the Northeast. In addition, finally, when considering sectoral productivity, agriculture is the fastest growing sector in terms of productive efficiency. Therefore, the intention of this study is to jointly analyze the behavior of TFP in the three sectors of the economy and macroregions to compare their behavior patterns in a more recent period and to verify in which sectors and regions efforts for productivity gains are more necessary in order to contribute to economic growth considering the Brazilian reality. It also seeks to compare the results obtained using a more complete methodology with empirical evidence found in the literature review.

3 Methodology

3.1 Database

The purpose of this study was to calculate Brazilian productivity and analyze its performance in the period from 2004 to 2014. The analyzed period was chosen due to databases restrictions, such as changes of methodology before 2004. The disaggregation was made considering the three macrosectors of economy, agriculture, industry, and services, in addition to being estimated in the aggregate. The disaggregation was also made for large regions, North, Northeast, Southeast, South, and Center-west.

Variables used to measure total factor productivity were obtained from different sources. The monthly income of main work, position in the occupation of main work, occupation situation, age of resident, product by the perspective of income, employee compensation, implicit GDP deflator, total occupations, person weight, and economically active population were used for estimating the function parameters. These data were obtained from the Pesquisa Nacional por Amostra de Domicílios (PNAD) and the Sistema de Contas Nacionais (SNA).

The gross value of production by activity and region and the implicit deflator provided the real production estimate. Population was used to calculate population growth rate; production, implicit deflator, and hours worked from the USA[5] were necessary to estimate the rate of technical progress or frontier of technological progress. Investment, depreciation, and residential and non-residential net capital in the USA[6] were used to calculate depreciation rate; these rates, together with gross fixed capital formation, the implicit deflator, regional production, and domestic production were fundamental to the methodology of fixed capital stock, with national production being used to calculate potential product, and, consequently, level of capacity utilization. These data were collected from Contas Regionais (IBGE), Sistema de Contas Nacionais, and the Bureau of Economic Analysis (BEA).

In relation to human capital, the variables used were monthly income of main work, employment situation, years of study, group of activities, age of resident, federation unit, and weight of person. Finally, the number of annual average hours worked was estimated considering federation units, grouping of activities at work, age of resident, occupancy situation, weight of person, and number of hours usually worked. These data were also extracted from PNAD.

3.2 Methods

This paper aims to follow some suggestions from Ellery Jr. (2014) for the methodology used to estimate total factor productivity since there are controversies about the correct estimation of parameters, the use of the production function itself, the best data to represent production, the method of estimating fixed capital stock, the inclusion of hours worked, level of capacity utilization, human capital, price deflator by implicit GDP deflator, and data by purchasing power parity, among others. In this estimation, besides traditional factors (product, capital, and labor), level of capacity utilization, human capital stock, and average number of hours worked per year are considered. To this end, we started considering the existence of an aggregate production function for the estimation of TFP, and its specification is given by a Cobb–Douglas type function. Therefore, the function presents first-degree homogeneity and marginal positive and decreasing productivity of inputs, besides presenting constant returns to scale and considering a market in competitive equilibrium, approaching the Mankiw et al. (1992) version. In this way, the aggregate production function follows the model proposed by Barbosa-Filho et al. (2010):

$$Y_{t,i,j} = A_{t,i,j}(u_{t,i,j}K_{t,i,j})^{\alpha}(H_{t,i,j}L_{t,i,j})^{1-\alpha} \quad (1)$$

[5] The growth rate of labor productivity in the USA was considered as technological frontier for Gomes et al. (2003). So, it was defined as the highest level possible to be achieved in a trajectory.

[6] The depreciation rate was calculated based on US National Accounts because of the reliability of their data, according to Gomes et al. (2003).

In which $Y_{t,i,j}$ is aggregate product, $A_{t,i,j}$ is total factor productivity, $u_{t,i,j}$ is the level of capacity utilization, $K_{t,i,j}$ is fixed capital stock, $H_{t,i,j}$ is human capital per worker, and $L_{t,i,j}$ is the number of average hours worked in the economy. By rearranging the function, we obtain the TFP or A:

$$A_{t,i,j} = \frac{Y_{t,i,j}}{(u_{t,i,j}K_{t,i,j})^{\alpha}(H_{t,i,j}L_{t,i,j})^{1-\alpha}} \tag{2}$$

where $t=1,\ldots,11$ represents years, $i=1,\ldots,3$ indicates macrosectors of the economy, $j=1,\ldots,5$ distinguishes regions and α is the elasticity of product related to capital, being equal to the share of capital income in aggregate income when it is in competitive equilibrium. Having defined the functional form to be used, it was necessary to establish what value would be adopted for α. To this end, the methodology indicated by Gomes et al. (2005) was used. First, labor income was estimated considering the ratio between compensation of employees and value added of Brazilian production for each year of the period obtained from the Sistema de Contas Nacionais (SCN). To correct the value, which was far from the one internationally found and that also takes into account income of the self-employed and employers, microdata of Pesquisa Nacional por Amostra de Domicílios (PNAD) was used and the earnings of employees, the self-employed, and employers were estimated, considering weight of people and age over 10 years. After that, the ratio between the sum of the income of the self-employed and employers, and the income of employees, was obtained. The resulting value was multiplied by employee's income given by SCN. Then, in order to obtain the average value of the workers, the corrected income of employees was divided by the number of employed workers. After that, the share of labor income was found by multiplying the average income of workers by the economically active population and the ratio of value added to the economy. Labor income of the period was gained by the average of annual incomes, and capital income was obtained by calculating labor income minus 1.

After defining the value of the parameters, it was necessary to decide on the unit of measure that would be considered to indicate aggregate production. In addition, according to Ellery Jr. (2014), since TFP was calculated by region and macrosector, being disaggregated measures, it was preferable to use the gross value of production, in order to prevent bias in the estimation. Real production was obtained using the implicit GDP deflator based on the year 2010, being the value of production of the macrosector given by the sum of activities belonging to the macrosector. Next, fixed capital stock was built, using perpetual inventory methodology, in which:

$$K_{t+1} = (1-\delta)K_t + I_t \tag{3}$$

With K_{t+1} and K_t aggregate capital stock in period $t+1$ and t, I_t being the annual gross investment, and δ the depreciation rate of annual fixed capital stock. To estimate the series, it was necessary to find an initial value for fixed capital stock and for the depreciation rate. Following Gomes et al. (2003), the initial stock was obtained by:

$$K_0 = \frac{I_0}{(1+g)(1+n)-(1-\delta)} \tag{4}$$

with K_0 being the initial capital stock, I_0 the initial investment, g the annual technical progress rate, and n the annual population growth rate. According to Gomes et al. (2003), initial investment was obtained by the average investment of the first 5 years of the period. All data were deflated by an implicit GDP deflator based on the year 2010, and activities were aggregated according to the respective macrosectors to which they belonged. The technical progress rate was considered as the annual growth rate of labor productivity in the USA.[7] Depreciation is calculated following the equation:

$$\delta = 1 - \frac{K_{t+1} - I_t}{K_t} \quad (5)$$

The depreciation used was calculated considering data from the USA, as suggested by Gomes et al. (2003), given the reliability of that data. After the estimation of national fixed capital stock, it was possible to use Garafolo and Yamarik's (2002) methodology to estimate the stocks of regions:

$$k_{t,i,j} = \left[\frac{y_{t,i,j}}{Y_{t,i}}\right] K_{t,i,j} \quad (6)$$

with $k_{t,i,j}$ being the fixed capital stock by region and $y_{t,i}$, the product by region, while $Y_{t,i}$ and $K_{t,i,j}$ are production and stock of domestic fixed capital, respectively. The calculation of the capacity utilization level is based on Feijó (2006):

$$u_{t,i,j} = \frac{Y_{t,i,j}}{Y^*_{t,i,j}} \quad (7)$$

in which $u_{t,i,j}$ is the level of capacity utilization, $Y_{t,i,j}$ is aggregate effective output, and $Y^*_{t,i,j}$ is potential output. Potential output was obtained through the use of the Hodrick–Prescott filter.[8] As potential product denotes possibilities of economic growth in the medium and long term without accelerating inflation, according to Souza Jr. (2009), there were years in which effective GDP was higher than potential, and in these years the level of capacity utilization was considered maximum, i.e., equal to 1. The measure of labor used in the estimation was based on the methodology of Barbosa-Filho, and Pessôa (2014):

$$L_{i.j} = \sum_{\substack{i=1 \\ j=1}}^{N} p_{i,j} HT_{i,j} \quad (8)$$

$L_{i,j}$ is the average amount of hours worked per week of all workers, $HT_{i,j}$ is the average amount of hours worked per worker, and $p_{i,j}$ is the weight of the person in the sample. The measurement of human capital followed the methodology of Caselli (2005),[9] being estimated through the function:

7 Considered as technological frontier for TFP according to Gomes et al. (2003).

8 The filter was made using the econometric software Eviews.

9 Another form of estimation of the measure of human capital in Brazil was made by Dias et al. (2013), considering a different level of disaggregation, by states.

$$H_{i,j} = e_{i,j}^{\varphi_{i,j}(s_{i,j})} \tag{9}$$

with $H_{i,j}$ being the stock of human capital per person, $\Phi_{i,j}$ representing returns on education, and $s_{i,j}$ being the average schooling. The estimation of returns on education followed Mincer (1974)'s wage equation,[10] in which:

$$\ln(w_{i,j}) = \beta_0 + \beta_1 s_{i,j} + \beta_2 \exp_{i,j} + \beta_3 \exp_{i,j}^2 + \varepsilon_{i,j} \tag{10}$$

ln (wi, j) is the natural logarithm of workers' income and $\exp_{i,j}$ is equal to experience. The return on education assumed the value of $\beta 1$ in the wage equation. Economically active population (PEA) was estimated considering people over 10 years of age, according to the Instituto Brasileiro de Geografia e Estatística (IBGE 2017). This age-group was also considered for the estimation of total average hours worked and human capital. In addition, for the year 2010, linear interpolation was used to obtain data. Growth decomposition, which aimed to show how much each production factor contributed to production performance, followed Barbosa-Filho et al. (2010) methodology for the model that considers TFP and is given by:

$$\begin{aligned} \frac{1}{N}\ln\left(\frac{Y_{t+N}}{Y_t}\right) = \frac{1}{N}\bigg\{ & \ln\left(\frac{A_{t+N}}{A_t}\right) + \alpha\ln\left(\frac{u_{t+N}K_{t+N}}{u_t K_t}\right) \\ & + (1-\alpha)\left[\ln\left(\frac{H_{t+N}}{H_t}\right) + \ln\left(\frac{L_{t+N}}{L_t}\right)\right]\bigg\} \end{aligned} \tag{11}$$

Thus, the equation shows how much the average annual growth rate of each factor contributed to product growth in the period.

To compare and analyze the similarities or differences between the measures, we sought to verify total factor productivity through the estimation of regression models considering panel data, following the methodological suggestions of Messa (2014). Estimates were made using pooled panel data model and fixed effect panels, in addition to estimation through a dynamic panel in levels and differences. The equation to be estimated was the same as previously used (Eq. 1); however, it was linearized to obey the assumptions of the classical linear regression model.[11]

$$\ln Y_{t,i,j} = \beta_0 + \beta_1 \ln K_{t,i,j} + \beta_2 \ln L_{t,i,j} + \varepsilon_{t,i,j} \tag{12}$$

where K is the capital adjusted by the level of capacity utilization and L is employed persons multiplied by the number of hours worked and human capital. Expected signals for parameters are positive, indicating that inputs contribute positively to the growth of production. The TFP estimation is obtained by:

$$\ln A_{t,i,j} = \beta_0 + \varepsilon_{t,i,j} \tag{13}$$

Nevertheless, Messa (2014) stated that the estimated model could imply endogeneity problems. Therefore, he suggested the estimation of total factor productivity through

[10] The calculation of wage equation was done using the software Stata.

[11] For more information, see Greene (2011).

dynamic panel models since they sought to solve problems of causality and heterogeneity, in which the regression to be estimated would be:

$$\ln Y_{t,i,j} = \beta_0 + \beta_1 \ln Y_{t-1,i,j} + \beta_2 \ln K_{t,i,j} + \beta_3 \ln L_{t,i,j} + u_{t,i,j} \tag{14}$$

In the use of dynamic panel models, some specifications must be followed. Among them, the errors could not be correlated with predetermined variables, according to Arellano and Bover (1995).

$$E(u_{t,i}|x_{i1}, \ldots, x_{iT}, \eta_i) = 0 \tag{15}$$

where u_{i1} represents the error of the model and x_{i1}, x_{iT} represents endogenous variables of the model in the initial and final periods, where η_i is a non-observed individual effect. Therefore, in the estimation of the dynamic model, two tests were performed, in which the rejection of the presence of the autocorrelation in the second difference using the Arellano–Bond test, and the validity of the instruments used by the Hansen test so that the instrumental variable was exogenous,[12] was verified. To meet these specifications, following Arellano and Bond (1991), the lags of the variables were used as instruments in the model. In relation to a dynamic model in differences, as suggested by Blundell and Bond (1998), the condition of additional moment was adopted, using the lags of the variables in level as instrumental variables.

4 Results and discussion

Using the methodology of Gomes et al. (2005), the parameter α obtained was 0.40, which was higher than that found by the authors at 0.33, but it was the same as that found by Gomes et al. (2003). As the methodology that was adopted was the same as that of Gomes et al. (2005), it was possible to verify that there was a change in the share input factors used in production. For the estimation of fixed capital stock, the values of technical progress rate, population growth rate, and depreciation rate obtained were equal to 0.94% per year, 1.03% per year, and 3.65% per year, respectively.

Based on these definitions, it was possible to calculate total factor productivity, according to the methodology of Barbosa-Filho et al. (2010). Thus, Fig. 1 shows the evolution of total factor productivity in Brazil. Figure 1a shows Brazilian total factor productivity in the period from 2004 to 2014, where it was possible to observe a growth trend up to 2008, the year of the financial crisis. After this year, a downward trend was identified with a slight recovery in the years 2013–2014. Considering the whole period, there is a trend of stagnation. During the period, average percentage variation was 0.40% per year, again characterizing low TFP growth compared to the results obtained by Bonelli (2014).[13]

The behavior of total factor productivity (TFP) in the three macrosectors of the Brazilian economy can be observed in Fig. 1b. It is interesting to note that the macrosector that had the highest percentage variation in the period was services, with average variation of 2.91% per year. The agricultural sector obtained an average variation of 1.98% per year. While these two sectors had positive percentage variation, industry had a negative

[12] The instruments used in the estimation were lags of variables production, labor, capital and average earnings, as suggested by Messa (2014).

[13] TFP in the period from 2003 to 2014 was 1.3% per year, calculated by Bonelli (2014). The difference in results is due to different methodologies used.

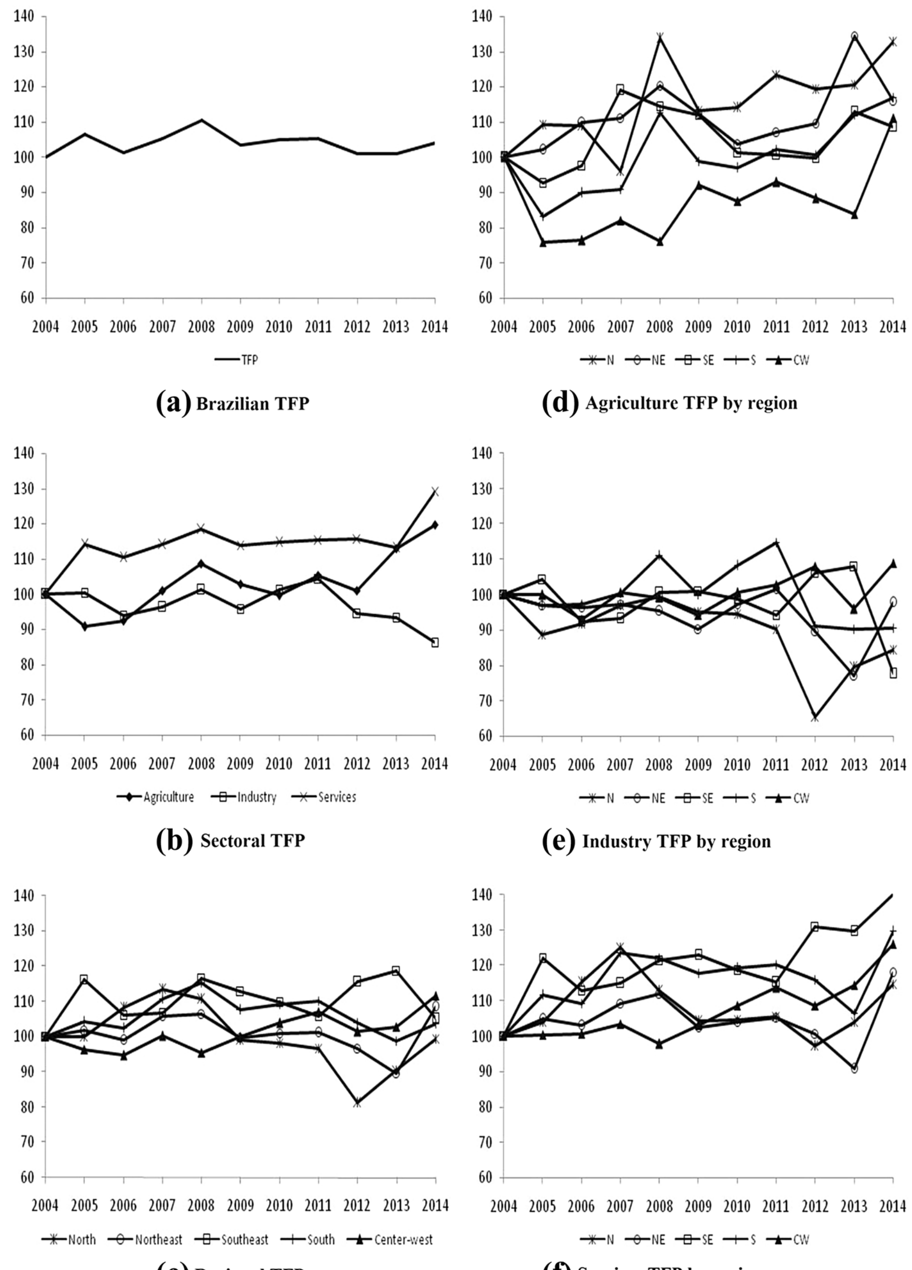

Fig. 1 Productivity index by sector and region in Brazil, 2004–2014. *Source:* Own elaboration with data of IBGE, BEA, and PNAD (2017)

average variation of 1.35% per year. The three macrosectors declined in the year after the crisis of 2008; however, services remained stagnant until the year 2012, falling in 2013, and recovering in 2014. In agriculture, a downward trend was observed until the year 2006, then recovery from 2007 until the year 2008; however, after the crisis, there was a fall until the year 2010, leading to a recovery during the following year. In contrast to services and agriculture, industry experienced periods of positive and negative variations in

TFP, and after the crisis, this sector recovered until 2010, but then, industry continued to fall from 2011 until 2014.

In turn, the evolution of total factor productivity in each region, despite being small, is positive, according to Fig. 1c. The region that had the highest average percentage variation was the Center-West, with 1.17% per year, slightly more than 1% per year. On the other hand, other regions presented a certain stagnation in TFP; the Northeast had an average variation close to 0.84% per year, the Southeast with 0.50% per year, and the South with 0.35% per year, while the North had a negative average variation of 0.05% per year. Therefore, related to TFP, the region with best performance was the Center-west.

The behavior of TFP in agriculture by region can be observed in Fig. 1d. It can be observed that all regions obtained a positive percentage variation in the period, with the largest one in the North, 3.28% per year, and the lowest one in the Southeast, 0.87% per year.

In the South, the variation was 1.69% per year, in the Northeast 1.60% per year, and in the Center-West 1.12% per year. All regions experienced a negative percentage variation after the 2008 crisis, except for the Center-west, and in the Southeast the decline began in 2007, intensifying after the 2008 crisis. On the other hand, in industry, according to Fig. 1e, none of the regions showed a tendency to grow, except for the Center-west with a positive average percentage variation in the period of 0.08% per year, but this variation indicated stagnation, falling way below 1% growth. The average percentage variation was negative at 2.24% per year in the Southeast, 1.55% per year in the North, 0.94% per year in the South, and 0.22% per year in the Northeast. The region that suffered the most from a fall in total factor productivity in industry was the Southeast, despite a slight recovery between the years 2011 and 2013, and in the year 2014 it registered a fall again.

Regarding services TFP, Fig. 1f shows a positive trend, despite a low growth rate in productivity in the period. The services sector was the one with the highest level of average percentage variation in the period, with variation of 4.01% per year in the Southeast, 2.96% per year in the South, 2.61% per year in the Center-west, 1.81% per year in the Northeast, and 1.48% per year in the North. Thus, it is possible to say that, in aggregate, since the services sector represented the largest share of GDP, and in the regions, the TFP of services in the regions was the one that most influenced the aggregate TFP of these regions, and consequently the Brazilian aggregate TFP.

Thus, in a general way, the results presented in Fig. 1 suggest modest growth of TFP in Brazil, with emphasis on the Southeast and Center-West and the services sector. In addition, in order to verify how much each factor contributed to the growth of the Brazilian economy, in the period of 2004–2014, a growth decomposition was made, according to Table 1. Initially, the contributions of each factor that integrated the production function can be observed, considering the methodology proposed by Barbosa-Filho, Veloso, and Pessôa (2010).

For the aggregate of the economy, the highest production growth occurred in the Center-west, 3.31% per year. Again, the highest rate of productivity growth occurred in the Center-west, 1.01% per year, while the only decline occurred in the North, 0.05%. Regarding the stock of fixed capital, there was positive growth for all regions, with the highest growth in the Center-west, 1.71% per year. As for services, when considered in aggregate, only the North and the Northeast had positive growth in human capital,

Table 1 Growth decomposition by sector and region in Brazil, 2004–2014. *Source:* Own elaboration based on data from IBGE, PNAD, and BEA (2017)

Sector/locality	*Y*	*A*	*uK*	*H*	*L*
Total					
Brazil	100	14.70	52.85	− 10.45	42.90
North	100	− 1.78	49.57	19.75	32.46
Northeast	100	22.23	50.67	6.24	20.86
Southeast	100	20.33	55.41	− 34.34	58.60
South	100	15.54	56.86	− 12.52	40.12
Center-west	100	29.81	50.50	− 23.83	43.52
Agriculture					
Brazil	100	229.63	107.62	− 10.35	− 226.90
North	100	68.90	53.32	10.29	− 32.50
Northeast	100	375.21	174.38	75.07	− 524.66
Southeast	100	269.56	163.95	91.03	− 424.54
South	100	1085.50	407.72	199.72	− 1592.93
Center-west	100	77.77	79.02	21.85	− 78.64
Industry					
Brazil	100	− 104.18	101.36	27.13	75.70
North	100	− 76.60	75.99	41.43	59.19
Northeast	100	− 10.26	82.42	− 45.14	72.98
Southeast	100	− 255.26	129.64	156.03	69.59
South	100	− 82.78	115.62	− 20.45	87.62
Center-west	100	22.93	64.36	− 37.66	50.38
Services					
Brazil	100	64.18	35.30	− 26.61	27.13
North	100	31.06	35.14	1.78	32.02
Northeast	100	32.86	35.97	6.96	24.21
Southeast	100	90.94	34.77	− 51.51	25.80
South	100	68.31	34.46	− 27.66	24.89
Center-west	100	55.25	35.04	− 21.39	31.10

The results are the percentage contributions of each factor input to economic growth, ratio between growth of the factor of production and production

0.60% per year and 0.21% per year, respectively. Considering the aggregate in Brazil the contribution of human capital to the growth was negative; therefore, policies to improve the quality of education in the country are recommended. When taking into account the number of hours worked in aggregate, all regions had positive growth, with the largest in the Center-west, 1.47% per year. Therefore, it was possible to highlight the performance of production and productivity in agriculture in the North, as well as the performance of the Center-west in other sectors.

In the agricultural sector, there was growth of production during the period, and the North stood out as the region where production increased the most, 3.75% per year, followed by the Center-west, 1.25% per year. In the South, agricultural production had the lowest growth in the period, 0.13% per year, which was below the Brazilian average, 0.72% per year. When analyzing the growth of total factor productivity, it was also possible to verify that there was growth during the period, and again the North stood out as the region with the highest productivity growth, 2.58% per year, representing a variation of 68.90% in relation to production growth. Productivity growth during the period in the Northeast and the South was above 1% per year, being 1.35% per year and 1.42% per year, respectively; however, when percentage variation in productivity was verified in relation to production, it was found that in the Northeast TFP varied 375.21% in relation to product, and in the South this variation was 1085, 50%. The Center-west showed the lowest productivity growth in the period, 0.76% per year, with its percentage variation in relation to product being 77.77%. Only the North was above the Brazilian average regarding TFP, with growth of 1.65% per year.

Regarding the stock of fixed capital adjusted by capacity utilization, growth was observed during the period, where once again, the North is highlighted as the region where there was the highest growth, 2.00% per year. Outside the North, only the Center-west grew above the Brazilian average, with the Center-west growth rate being 0.99% per year and the Brazilian average being 0.77% per year. In turn, as occurred with production, productivity and, fixed capital stock, the region with the highest growth for human capital was the North, 0.39% per year. In the Northeast and the Center-west, growth was 0.27% per year, and in the Southeast and the South it was 0.26% per year. However, the growth of Brazilian human capital was negative during the period, being −0.07% per year. Considering the total number of hours worked in the economy, it was verified that in all regions there was a decrease during the period. Thus, for agriculture, it was possible to conclude that in the North, the Northeast, and the South, the factor of production that grew the most and contributed to growth was total factor productivity. In the Center-West, the factor that contributed most was capital adjusted by the level of capacity utilization, and in the Southeast it was the negative contribution of hours worked in the economy.

In relation to the sector of industry, all regions had positive growth in production during the period. However, except for the Center-west, all regions had negative productivity growth, which affected the Brazilian average, with the largest drop in the Southeast, 2.31% per year, followed by the North, with 1.54% per year. Center-west growth was positive at 0.78% per year, and the Brazilian average was negative at 1.33% per year. There was also an increase in fixed capital adjusted stock in all regions, and in the Center-west there was higher growth, 2.18% per year, and the lowest in the Southeast, 1.17% per year; the Brazilian average was 1.29% per year, with the Southeast and the South growing below this average.

Considering the growth rate of human capital, except for the North and the Southeast, there was a decrease in all the regions. The biggest drop was registered in the Center-west, at 1.28% per year. Although the Brazilian average of human capital growth was positive at 0.35% per year, it was most influenced by the positive performance of the North and the Southeast. Contrary to what happened with agriculture, in industry the number of hours worked in the sector contributed positively to the growth of product, which indicated that there could be a migration of labor from agriculture to industry, suggesting the existence of structural change. As with fixed capital stock, the Center-west was the region with the highest rate of growth in number of hours worked. With respect to industry sector, it was possible to highlight that the Center-west achieved the best performance, where production, fixed capital stock, and hours worked grew the most, and it was the only region where TFP grew positively.

According to Table 1, in the service sector there was greater economic growth. In addition, within the sector, the North and the Northeast were the regions with the highest growth rate, 4.06% per year and 4.61% per year, respectively. However, when analyzing the rate of productivity growth, the Southeast performed better, followed by the South. Considering fixed capital adjusted stock, the highest growth occurred in the Northeast, 1.66% per year, while the Brazilian average was 1.28% per year. Aside from the Northeast, only the North and the Center-west had growth rates above the Brazilian average, 1.43% per year and 1.34% per year, respectively. Only the North and the Northeast had positive growth rates of human capital in the services sector, a growth of 0.07% per year and 0.32% per year, respectively. Thus, as in industry, the number of hours worked in industry increased and contributed positively to the growth of production, again giving indications of the movement of structural change. Regarding services, both the North and the Northeast had positive growth rates of factors of production; however, it was the Southeast that was most notable for higher growth in TFP.

Finally, in order to analyze Brazilian productivity considering the impacts of each factor in production Eqs. 13 and 15 are estimated, whose results are in Table 2. The panel data was balanced, that is, it has information for each year and all cross-sectional units, with 15 cross-sectional units and 11 years, considering the three sectors and five regions in estimation.

With the result of the least squares model, it was possible to verify a good fit of the model. Analyzing the parameters of explanatory variables, it was verified that variables $\ln K$ and $\ln L$ contributed positively to $\ln Y$ and were statistically significant. As the results were in logarithms in OLS, it can be said that a 1% increase in fixed capital stock would cause a 0.41% increase in production and that a 1% increase in labor would cause a 62% in production. Jointly, fixed capital stock and labor, which included employed people, human capital, and hours worked, were responsible for explaining 95% of variations in production. On the other hand, in the fixed effects panel model these variables, concomitantly, were responsible for explaining 71% of production variations. The results of OLS parameters were closer to those estimated by SCN and PNAD than the fixed effects. However, as suggested by Messa (2014), these methods could lead to problems of endogeneity; thus, it was suggested to estimate the model through the dynamic panel method in level and differences.

With a dynamic panel, the robustness of the model was verified through autocorrelation tests in first and second differences, and the results suggest that no second-order autocorrelation was found. Thus, the validity of the instruments used was also verified through the Hansen test. In addition, so that the lagged dependent variable was statistically significant for the model, the regression was also estimated with robust standard errors, as can be observed in Table 2. In a dynamic panel, which corrects any problems of endogeneity, it was verified that at level, the regression was statistically significant according to the Wald test and that the variable that most explained production behavior was the lagged production itself, at least in the short run. Considering that 11 years was analyzed in the model, a 1% variation in lagged production would cause a 0.77% change in current production. In the estimation, it was found that labor contributed more than capital to production. On the other hand, in the dynamic model in differences, the regression was also statistically valid according to the Wald test. However, the

Table 2 Estimates in the regions, 2004–2014 *Source:* own elaboration based on data from IBGE, PNAD, and BEA (2017)

Variables	Model			
	OLS	FE	Level GMM	Differences GMM
Constant	0.46	5.90***	0.24	–
ln Y_{t-1}	–	–	0.77***	0.20***
ln K	0.41***	0.70***	0.07**	0.52***
ln L	0.62***	0.09**	0.16***	0.09**
R^2	0.95	0.71	–	–
Hausman test	–	45.52	–	–
p value	–	(0.0000)	–	–
Wald test	1756.87	102.25	13,726.09	200.49
Prob > chi2	(0.0000)	(0.0000)	(0.000)	(0.000)
Hansen test	–	–	12.57	14.42
Prob > chi2	–	–	(0.322)	(0.155)
No. of instruments	–	–	15	13
AR(1)	–	–	− 2.63	− 2.59
Prob > z	–	–	(0.009)	(0.009)
AR(2)	–	–	− 0.48	− 1.55
Prob > z	–	–	(0.634)	(0.121)
Observations	165	165	120	120

The estimation of the variable labor includes the average number of hours worked and human capital besides the people employed

*** represents significance at 1%, ** significance at 5%, and * significance at 10%. In regression results the terms in parentheses represent standard errors and in tests represent significance of the tests. The lags of the variables Y, K, L, and average earnings were used as instruments

variable that most explained production was fixed capital stock, in which a variation of 1% in stock would cause a variation of 0.52% in production.

Therefore, estimates suggest different results for the parameters of capital and labor, and in the models of OLS and GMM in level the labor share obtained was higher than the share of capital. This indicates agreement with the results of previous methodologies, showing that there is more labor used in production of goods and services.[14] The OLS results were closest to those obtained previously, a result justified by the specification of each estimate.

When fixed effects of each cross-sectional unit were controlled so they would not influence the result of estimation, the use of fixed capital stock became greater than that of labor, which diverged from the considerations of Gomes et al. (2003) and Gomes et al. (2005). In addition, as Ellery Jr. (2014) stated, discrepancies in the definition of parameters used would cause discrepancies in TFP results obtained. In addition, since the dynamic model in level showed that labor share was greater than capital share, unlike the dynamic model in differences, the TFP estimated by dynamic model in level had a behavior more similar to that estimated by OLS, which was different from TFP obtained by the fixed effects model and the dynamic model in differences, showing that

[14] Remembering that the parameters of the models obtained: 0.41 of capital and 0.62 of labor for OLS, 0.70 of capital and 0.09 of labor for FE, 0.16 of labor and 0.07 of capital for GMM in level and 0.52 of capital and 0.09 of labor in GMM in differences, were different from the parameters obtained through the methodology of Gomes et al. (2005), 0.40 of capital and 0.60 of labor.

the correct definition of parameters would be very important for a precise estimation of total factor productivity. Among the models, the estimation by the dynamic panel in level also found that, in the short run, there could be little change in input appropriations for productivity to increase since the greater part of production would be explained by lagged production itself.

Thus, regarding the results obtained for the estimates of productivity growth in Brazil from 2004 to 2014, it was possible to verify that growth in the sectors followed a trend close to what Araujo and Mancal (2015) stated for agriculture in the Northeast. There was also growth of TFP in agriculture in Brazil as a whole, corroborating the conclusions of Gasques (2010). When studying the period from 1986 to 1998, Tavares et al. (2001) concluded that higher productivity was observed in Pernambuco and the states of the Southeast. On the other hand, in the present analysis considering the period from 2004 to 2014, the Center-west presented higher levels of productivity, diverging from the conclusions of Tavares et al. (2001). However, beyond this period, this may have occurred because of the different aggregation of data, in which they analyzed states' productivities whereas the present analysis studied regions.

5 Final considerations

The objective of this study was to verify how total factor productivity in Brazil between 2004 and 2014 behaved, analyzing by region and by sector, as well as performing a decomposition of the growth that allowed verification of the contribution of productivity to production. Estimates were also made for the purpose of verifying the importance of factors to production. In relation to Brazilian productivity, there was some agreement in relation to its performance in recent years being low, which occurred mainly after the year of 2008.

Regarding total factor productivity, considering aggregate productivity, the North had negative growth and the highest growth occurred in the Center-west, followed by the Northeast and the North. With the exception of industry, there was productivity growth in all other sectors. Considering agriculture, the region that obtained the greatest growth in production, as well as productivity growth, was the North. Regarding industry, the only region that had a positive growth in TFP was the Center-west, which was also the region that had the highest growth in fixed capital stock in the sector. In addition, finally, regarding services, the greatest increase in productive efficiency was obtained by the Northeast and the North, and the largest growth of fixed capital stock also occurred in the North.

When considering the econometric methodology, it was verified that the results obtained by estimating the OLS were closer to those obtained by the methodology adopted. The estimation by the dynamic level panel also resulted in a close TFP, considering that labor and capital shares were similar. However, as in the fixed effects panel and the dynamic panel in differences estimation, the share of capital was above the share or labor, resulting in the fact that the estimated TFP was far from the productivity previously estimated. Therefore, among the estimated models, OLS is closer to what is verified in theory related to the shares of labor and capital.

Therefore, considering the results of the productivity estimates, the existence of sectoral and regional heterogeneity in the country was verified, and the regions with the highest rates of productivity growth in some sectors were the Center-west, the Northeast, and the North, with a moderate role observed in the Southeast, mainly in industry, and the South. Therefore, the different regions had different and continuous behaviors over the period, which is the definition of heterogeneity. The same is true for the sectors because, while agriculture and services grew, industry fell. Therefore, if the objective is for productivity to perform better, it would be necessary to stimulate productivity in industry, given its declining behavior and stagnation, especially in the Southeast and the South, which were the regions with the lowest growth.

Authors' contributions

TAAS was responsible for the calculation of the variables used and the estimation and analysis of the results. MSC carried out the theoretical review and the comparison of the results with the literature. Both authors read and approved the final manuscript.

Authors' information

This scientific article is making a contribution regarding the study of disaggregated productivity on Brazilian regions and sectors. It happens because of the lack of studies on this area in the country due to lack of methodology and mostly because of lack of regional data. Considering that the country has a large territory, it is easy to realize that there are different performances regarding the different regions, differences that are not considered in aggregate studies. So, trying to fulfill this field, the study aimed to calculate the measures of the variables used in total factor productivity calculation in order to give a regional measure of productivity and help to understand the particularities of each region of Brazil and overcame its problems of development. So, this paper should be published in the Journal of Economic Structures, because of the contribution it is making to the theory of productivity and also growth about the country, considering its innovation on the object of study and measurement of data.

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Competing interests

The authors declare that they have no competing interests.

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