Regional Brazilian Agriculture TFP Analysis: A Stochastic Frontier Analysis Approach

Cassiano Bragagnolo

Researcher of Center for Advanced Studies on Applied Economics from "Luiz de Queiroz" College of Agriculture, University of Sao Paulo, Brazil

Humberto F. S. Spolador

Professor of Economics at "Luiz de Queiroz" College of Agriculture, University of Sao Paulo, Brazil

Geraldo Sant'Ana de Camargo Barros

Titular Professor of Economics at "Luiz de Queiroz" College of Agriculture. University of Sao Paulo, Brazil

---

Abstract

This paper estimated the total factor productivity (TFP) for the Brazilian agriculture using a translog panel data estimation. The major motivation is to investigate the evolution of the agricultural TFP over the period 1975-2006 in Brazilian states, and to analyze the effects of TFP on regional economic growth. The TFP effect was subdivided in technical progress, allocative changes, scale effects, technical inefficiency and random shocks. The conclusions suggest that over the last decades the TFP growth was not homogeneous among the states, and the technical progress was fundamental to expand the potential economic growth of Brazilian Agriculture at state level.

Keywords: : Brazilian Agriculture, Total Factor Productivity, Economic Growth

JEL Classification: Q10, Q19, O47

Resumo

Este trabalho estimou a produtividade total dos fatores (PTF) para a agricultura brasileira por meio de uma função translog com dados em painel. O principal objetivo foi investigar a evolução da PTF no período 1975-2006 nos estados brasileiros e analisar a influência da PTF sobre o crescimento da agricultura. O efeito da PTF foi subdividido em progresso técnico, eficiência alocativa, efeito escala, ineficiência técnica e choques aleatórios. As conclusões apontaram que o crescimento da PTF não foi homogêneo entre os estados e que o progresso técnico foi fundamental para expandir o potencial de crescimento da agricultura brasileira.

1. Introduction

Historically, the agricultural sector – including farming input, farming output, agro-industries, and distribution – has had a significant role in the Brazilian economy, [1] not only by keeping domestic food prices relatively low but also by attracting significant amounts of foreign currency thanks to persistent trade surpluses.

In 1994, seeking to end a period of hyperinflation, Brazil's government implemented the "*Plano Real*", a monetary plan for economic stabilization. The *Plano Real*, besides an ingenious de-indexation mechanism, used two price anchors to dampen inflation: high actual interest rates and an overvalued exchange rate. Economists informally consider that the plan used three anchors, with the third being Brazil's agricultural sector, the "green anchor". At the time, Brazilian agricultural production was growing rapidly as was international demand for agricultural products. It was thought that this rising agricultural production would keep inflation in check by keeping domestic food prices low. Despite the success of the monetary stabilization plan, overall Brazilian economic growth in the 1990s was very low.

From 1990 to 2000, Brazilian average annual GDP growth measured in the local currency (*Reais*) was 1.9% while Brazilian average annual agricultural GDP growth was 3.1%. These figures and the fact that Brazilian prices stabilized over the 1990s confirm the importance of Brazil's agricultural sector in the country's economy, both as a inflation control mechanism and as a major contributing factor to economic growth.

Figure 1 illustrates the evolution of total Brazilian GDP and Brazilian agricultural GDP from 1980 to 2010. The Figure shows that Brazilian GDP's average annual growth rate over the period was 2.8% while the country's agricultural sector's growth rate averaged 3.6%.

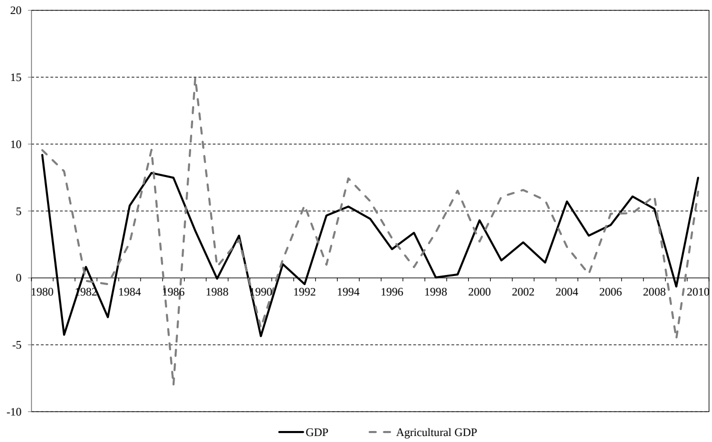
Bonelli e Fonseca (1998) estimated the Brazilian agricultural TFP over the period of 1971 and 1996, and the annual growth rate of TFP shows three years of strong reduction (1978, 1986 and 1988). Between 1979 and 1984 the growth rate of agricultural TFP was always positive at an average of 4.5-5% approximately; the exception was 1982, when the rate was near zero. After 1990, and for all the years from 1990 to 1996, the growth rate was positive, although below 5% a year. Based on the research carried out by Gasques e

⋆ Submitted in November 2010, Accepted in April 2012.

E-mail addresses: cassiano@usp.br, hspolador@usp.br, gscbarro@usp.br

[1] The agribusiness sector (that includes the agricultural and livestock activities, and factories, stocking, transportation, processing, industrialization and logistics) accounts for roughly 25% of the Brazilian GDP and approximately 40% of all Brazilian exports (Cepea: www.cepea.esalq.usp.br).

Fig. 1. The evolution of Brazilian Total GDP and Brazilian Agricultural GDP – Real percentage variation – 1980 to 2010



Source: IPEA (www.ipeadata.gov.br).

Conceição (1997), we updated the Brazilian agricultural TFP to 2005, and there have been no relevant changes in the behavior of the data.

Gasques et alii (2009) used the Tornqvist index to build a TPF historical series from 1975 to 2008. Results (Figure 2) show the strong TFP growth (244%), which allowed the agricultural growth in the period of analysis. The TFP growth, according to the authors, was a result of the implementing of a rural credit policy and of efforts of universities and the Brazilian Agricultural Research Corporation (Embrapa) to invest in the research for the development of new technologies.

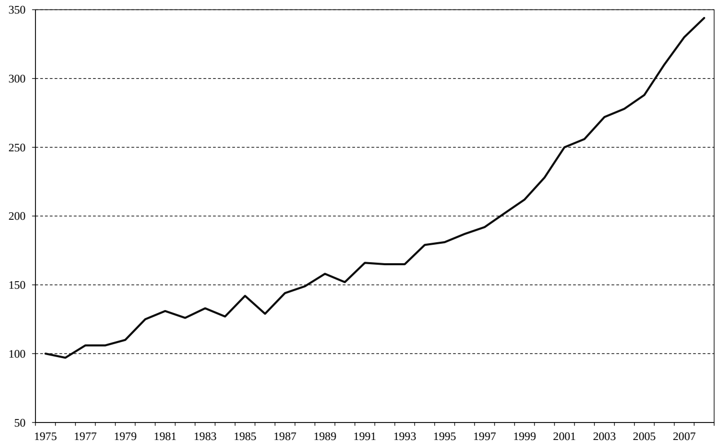
Our paper presents results from a stochastic frontier analysis of the determinants of Brazilian agricultural TFP at the individual state level. As this analysis this paper is the first to use stochastic frontier methodology to decompose components of economic growth in the Brazilian agriculture sector and is also the first to take the analysis to the state level, it adds new data and analyses to help explain Brazil's agricultural economy.

The next section, Section 2, contains a brief review of some literature relevant to the evolution of Brazilian agriculture. Section 3 presents the methodology, data and sample used in this study. Results are presented in Section 4, and our conclusions are given in Section 5.

2. Literature Review

Technological innovations throughout the 20th Century have allowed agricultural production to grow more rapidly than demand. This was first

Fig. 2. The Evolution of Brazilian Agriculture TFP – Index (1975 = 100) – 1975 to 2008



Sources: Gasques et alii (2009).

witnessed in the developed world and is now found in many developing countries (Antle 1999). Technological innovation models applied to the agricultural sector fall into four general categories: models that address the

(1) generation and dissemination of a technology,
(2) the importance of product or process innovations,
(3) the magnitude of a technology's impact of on productivity, and
(4) the compatibility of the technological package with the product or its production (Bacha 1992).

As opposed to many other economic sectors, agriculture's share in an economy trends downward over time; however, an analysis by Johnston e Mello (1961) found that there is not a dichotomy between agriculture and other economic sectors. This downward trend is a consequence of increasing agricultural productivity, which also acts to generate capital for the expansion of other sectors. According to the authors, changes in an economy caused by agriculture stem from two basic factors:

(1) the demand for food has an income elasticity less than unity; and
(2) productivity gains in the agriculture sector make it possible to expand production using less labor.

In the 1950s, the Brazilian agricultural policy has focused on expanding the agricultural frontier and, consequently, increased food production. According to Barros et alii (1977), this process was based mainly on improving the infrastructure for marketing of agricultural products, through public investments in transport and storage. The food supply was guaranteed and the main source of agricultural growth, according to the authors, was related to the substantial increase in the number of labor and the incorporation of new lands to the production process.

In the 1960s, agriculture has played the role of contributing to the stabilization process of the Brazilian economy, because of the serious problems of internal balance (inflation) and external (balance of payments). In addition, Barros (1979) stated that during the period, funds were transferred from agriculture to domestic industry. Thus, agriculture would have been primarily responsible for the growth of industry in the country.

During the 1960s there was the military regime, with changes in the Brazilian economy. The new government took the priority of agrarian reform and introduced a model that was based on the modernization of agriculture. For Barros (1982), this process of modernization of agriculture was based on four main points:

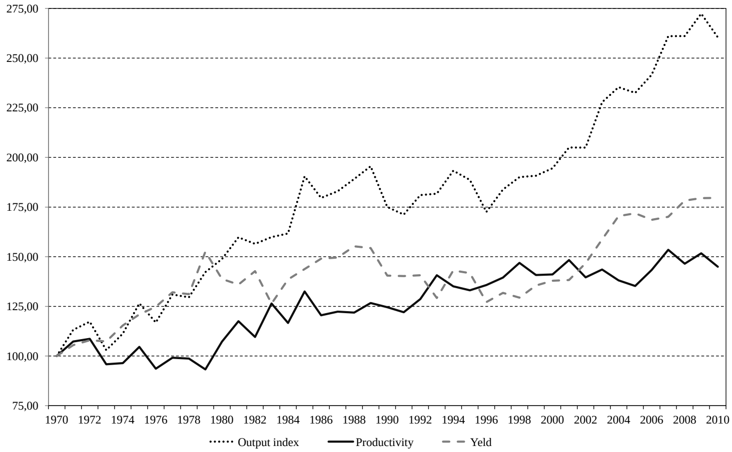
(1) openness to international trade;
(2) strong expansion of subsidized rural credit programs;
(3) increased spending on agricultural extension; and
(4) special treatment of sector inputs and factors of production (tractors, fertilizers, insecticides and herbicides).

Brazil's agriculture modernization era began in 1965 with creation of the National Rural Credit System (SNCR) and reformulation of PGPM (Oliveira e Montezano 1982). Both SNCR and the reformulated PGPM offered agricultural sector subsidies intended to expand the agricultural frontier and increase the grain production (Coelho 2001). This governmental focus on agriculture ensured fast growth in the sector through the extensive use of land and constant productivity. The government's programs and, in some cases foreign investment spurred the occupation of parts of Brazil's Central-West. Figure 3 illustrates the expansion of Brazilian territory devoted to agriculture and the associated growth in agricultural production between 1970 to 2010.

There was a change in the focus of Brazil's agricultural policies after the 1973 international oil crisis (Barros 1979). Although the post-crisis policy instruments themselves remained unchanged, the amount of subsidization increased considerably. Barros (1979) highlights six consequences of this change in agricultural policies and guidelines:

(1) long-run policies to stimulate investment in the agricultural sector, especially infrastructure investment, were marginalized;
(2) such modernization that occurred in the agriculture sector was concentrated in only a few products and regions;
(3) The agricultural sector was segmented into two sub-sectors: the internal market and the export market;
(4) an increase in Brazilian agricultural product exportation, abetted by more openness and favorable conditions in the international market;
(5) pressure to increase food production; and
(6) failure of the agricultural credit policy in terms of efficiency, equity and stability.

Fig. 3. Agricultural Productivity, Yield and Output Index (1970 = 100) - Brazil, 1970-2010



Source: IBGE, and elaboration of the authors.

Alves e Contini (1988) concluded that Brazilian agriculture sector growth in the 1980s was greatly influenced by two factors other than labor and natural resource availability:

(1) modernization, driven by technological innovation; and
(2) adaptation to the demand stimulus provided by Brazil's more industrialized economy and growing urban population.

To meet this new demand, the agricultural frontier had to expand. From the mid 70s to the mid 80s, Brazilian agricultural policy was reshaped to stimulate both frontier expansion and land productivity, which led to the liberalization of rural credit through use of a subsidized interest rate, the modernization of agricultural inputs and the agribusiness model, a reorganization of the national research and development system, and the expansion of rural support services (Alves e Contini 1988).

Gasques e Conceição (2001) analyzed the structural transformation of Brazilian agriculture over past decades and noted that the main features of this transformation follow an almost worldwide trend: a declining share of agriculture in the gross domestic product (GDP) and a decrease in the percentage of workers occupied in the rural labor force. The authors also estimated that Brazilian agricultural production growth was greatly influenced by an increase in total factor productivity between 1985 and 1995 (Gasques e Conceição 2001).

From 1976 to 1994 Brazil's agricultural total productivity index increased 91.56%, with labor productivity being the main factor driving this increase; although, increased land productivity made an important contribution (Gasques e Conceição 1997). Table 1 shows the growth rate of Brazilian agricultural GDP, TFP, labor, land, capital, and inputs between 1975 and 2008 and for sub-periods within that period. TFP growth was found to be very strong over the entire period and for the sub-periods, especially from 2000 to 2008. Between 2000 and 2008, the TFP growth rate reached 4.98% and was the most important variable explaining agricultural GDP performance, according to Gasques et alii (2009).

Table 1
Growth Rate of Brazilian Agricultural GDP, Labor, Land, Capital, Inputs and TFP – 1975 to 2008 and sub-periods

Period	1975-2008	1980-1989	1990-1999	2000-2008
Labor	-0.40	1.22	-0.49	-0.08
Land	0.12	0.46	-0.23	0.44
Capital	0.30	0.53	0.03	0.79
Inputs	0.01	1.11	-0.35	0.58
TFP	3.66	2.25	3.37	4.98
GDP Growth	3.68	3.38	3.01	5.59

Sources: Gasques et alii (2009).

In 1990, the inauguration of a new Brazilian government and domestic macroeconomic turbulence reduced investment in Brazil's agricultural sector. That year, the volume of SNCR credit fell from the previous year in real terms while the public sector fiscal imbalance, having reached a maximum point of inefficiency, was distorting and constraining development in various economic sectors. It was thought that the credit subsidies would act as a compensatory variable to counteract these macroeconomic distortions' effect on agriculture; but due to the concentrated distribution of this assistance, its benefit was minimized (Barros 1991).

Overall public expenditure on agriculture was reduced in the 1990s. Gasques e Villa Verde (2003) found that by 2000/2001, changes in agricultural policy had reduced governmental expenditures on agriculture to the lowest levels in fifteen years. Using the growth accounting method, Bonelli e Fonseca (1998) estimated the TFP of Brazilian agriculture from 1971 to 1996. Their results showed that Brazilian agricultural TFP grew 25% from 1988 to 1996. Gasques et alii (2004) found that the annual growth rate of Brazilian agricultural TFP was 4.88% per year in the 1990s and 6.04% per year at the beginning of the 2000s.

Helfand e Levine (2004) explore the determinants of the technical efficiency, and the relationship between farm size and efficiency at farm level, in the Center-West of Brazil. The authors conclude that the type of land tenure, access to institutions and markets, and modern inputs are important determinants of the differences in efficiency across farms.

O'Donnel (2010) estimated that the annual rate of technical progress in global agriculture is less than 1%. Chen e Ding (2007) investigated the sources of TFP in Chinese agriculture from 1985 to 2003 and found TFP growth was slowing for all products other than wheat. Lambert e Parker (1998) reported technical change, technical efficiency and multifactor productivity indices for a multiple-output, multiple-input production technology using Chinese provincial data for the 1979-95 period. Results showed significant variation in productivity change across years and provinces.

Some of the main studies of agricultural productivity across countries and regions include those of Hayami e Ruttan (1970, 1971), Kawagoe e Hayami (1983, 1985), Kawagoe et alii (1985), Lau e Yotopoulos (1989), Capalbo e Antle (1988), Bureau et alii (1995) e Fulginiti e Perrin (1993, 1997), Boskin e Lau (1992), Rao (1993), Battese e Rao (2001) and Battese et alii (2001), Coelli e Rao (2005), Amadi et alii (2004) and Bravo-Ortega e Lederman (2004). Bravo-Ortega and Lederman's (2004) report of the agricultural TFP growth for a selected sample of countries is the main source of data shown in Table 2.

Table 2 shows the TFP growth rate for several countries but is impaired because the periods over which growth was measured were not the same for all countries. Over the longest period, 1960 to 2000, Brazil's TFP growth rate was only surpassed by that of Australia, the United States and India. Brazil's TFP growth rate of 4.98% in the 2000-2008 period was the highest TFP growth for any country over any period, followed by Brazil's rate for the 1975-2008 period and China's rate for the 2000-2006 period.

In our work, TFP growth was divided into four components, among which are the technical progress and technical efficiency. Nishimizu e Page (1982) argued that there is an important reason for dividing the TFP growth into technical progress and change in technical efficiency. When increases in TFP are derived from technical progress, there are innovations that provide this advance, on the other hand, TFP gains related to changes in efficiency are mainly related to technological diffusion. Therefore this distinction becomes relevant to policy analysis because when there is no technical progress we have a lack of new technologies and when there is no technical efficiency expansion the problems are in the diffusion of new technologies or in the suitability of these new technologies to meet farmers' needs.

In the current decade, despite the vigorous TFP growth, the Brazilian agriculture was benefited by the increase of the global economy, especially in the emerging countries, and by the international trade following an increase of prices for commodities offset the exchange rate overvaluation, and allowed an increase of exports. Since 2004, [2] the Brazilian effective exchange rate has overvalued 27% while the CRB [3] index increased 147%, approximately.

---

[2] The period from 2004 to 2008.

[3] The CRB Index is a commodity price index. It has been calculated since 1958 was by Commodity Research Bureau.

Table 2
TFP Growth Rate of Selected Countries

Country	Period	TFP Growth	Reference	Method
Argentina	1960-2000	1,84	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Bolivia	1960-2000	1,18	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Brazil	1960-2000	1,93	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Brazil	1975-2008	3,66	Gasques et alii (2009)	Tornqvist index
Brazil	2000-2008	4,98	Gasques et alii (2009)	Tornqvist index
Chile	1960-2000	1,2	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Colombia	1960-2000	1,43	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Cuba	1960-2000	1,17	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Ecuador	1960-2000	1,28	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
El Salvador	1960-2000	0,53	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Guatemala	1960-2000	0,79	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Haiti	1960-2000	0,97	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Mexico	1960-2000	1,85	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Nicaragua	1960-2000	0,79	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Paraguay	1960-2000	0,74	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Peru	1960-2000	1,36	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Venezuela	1960-2000	1,35	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Australia	1960-2000	2,12	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Austria	1960-2000	0,69	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Canada	1960-2000	1,23	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Denmark	1960-2000	0,66	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Finland	1960-2000	0,25	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
France	1960-2000	1,77	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Germany	1960-2000	1,39	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation

Table 2
TFP Growth Rate of Selected Countries (cont.)

Country	Period	TFP Growth	Reference	Method
Greece	1960-2000	1,62	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Ireland	1960-2000	0,72	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Italy	1960-2000	1,73	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Japan	1960-2000	1,4	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Netherlands	1960-2000	1,16	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Portugal	1960-2000	1,41	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Spain	1960-2000	1,89	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
United Kingdom	1960-2000	1,67	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
United States	1975-2006	1,95	Gasques et alii (2009) *apud* USDA (2007)	-
United States	1960-2000	2,11	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
China	1960-2000	1,67	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
China	2000-2006	3,2	Gasques et alii (2009) *apud* OCDE (2009)	-
India	1960-2000	1,98	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Papua New Guinea	1960-2000	-0,36	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Sierra Leone	1960-2000	-0,18	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
South Africa	1960-2000	1,64	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation
Zambia	1960-2000	-0,26	Bravo-Ortega e Lederman (2004)	Panel data Translog estimation

Source: Gasques et alii (2009) and Bravo-Ortega e Lederman (2004).

3. Methodology

This section, which presents the stochastic frontier model, is based on the research carried out by Pires e Garcia (2004), and their references to Battese e Coelli (1992), Bauer (1990) and Kumbhakar (2000). The contribution of this paper to the Brazilian literature of agricultural economic growth is to decompose the economic growth at a state level, and not to propose a new methodology.

The technological frontier measurement proposed by Battese e Coelli (1992)

is the stochastic frontier method. Other methods based on the greatest efficiency point could have been used.[4] However, according to Coelli e Rao (2005), the stochastic frontier model has some properties that are not available in these other methods. Among the advantages of the proposed method are:
(1) the possibility of testing hypothesis about the parameters;
(2) include controls to explain the technical efficiency considering only one stage of production and
(3) consider the presence of white noise in the environment in which the production unit operates.

Then, according to Pires e Garcia (2004), we assume that the Brazilian agriculture has a stochastic frontier described by the equation (1):

$$y = f(t, x, \beta) \exp(v) \exp(-u) \tag{1}$$

where:
$y =$ the vector for the agricultural product of all Brazilian states;
$x =$ the vector for the production factor (labor, capital and land);
$\beta =$ the vector of parameters;
$v, v =$ terms that represent different error components, assuming that $v \sim N(0, \sigma^2)$ and $u \sim NT(\mu, \sigma^2)$, then, the distribution of u is normal-truncated.

About vectors v and u, Pires e Garcia (2004) explain that:

"*The first refers to the random part of the error, while the second represents technical inefficiency, i.e., the part that is a downward deviation from the production frontier (which can be inferred by the negative sign and the restriction $u \geq 0$*" (p. 4).

This two errors approach was proposed independently by Aigner e Lovell (1977) and Meeusen e Van Den Broeck (1977).

Battese e Coelli (1992) formulated a parameterization that Pires e Garcia (2004) assumed to take the technical inefficiency component as a time-variant, then:

$$u_{it} = \exp\left[-\eta(t - T)\right] u_i \qquad u_{it} \geq 0 \quad i = 1, \cdots, N \text{ e } t \in \tau(i) \tag{2}$$

where η signals the behavior of the technical inefficiency over the time, and $\tau(i)$ contains all periods in the panel. The model admits a *translog* function that has three production factors, labor (L), capital (K) and land (T), as shown in the equation (3).

$$\begin{aligned} \ln y_{it} = {} & \beta_0 + \beta_t t + \beta_K \ln K_{it} + \beta_L \ln L_{it} + \beta_T \ln T_{it} + \frac{1}{2}\beta_{KK}(\ln K_{it})^2 \\ & + \frac{1}{2}\beta_{LL}(\ln L_{it})^2 \end{aligned}$$

[4] Among these is predominant in the literature on DEA (Data Envelopment Analysis).

$$+\frac{1}{2}\beta_{TT}(\ln T_{it})^2+\frac{1}{2}\beta_{KL}(\ln K_{it})(\ln L_{it}+\frac{1}{2}\beta_{KT}(\ln K_{it})(\ln T_{it}) \quad (3)$$
$$+\frac{1}{2}\beta_{TL}(\ln T_{it})(\ln L_{it})+\beta_{Kt}[(\ln K_{it})t]+\beta_{Lt}[(\ln L_{it})t]$$
$$+\beta_{Tt}[(\ln T_{it})t]+v_{it}+u_{it}$$

The technical progress is expressed by the differentiation of equation (2):

$$\frac{\dot{y}}{y}=\frac{\partial \ln f(t,K,L,T,\beta)}{\partial t}+\varepsilon_K\frac{\dot{K}}{K}+\varepsilon_L\frac{\dot{L}}{L}+\varepsilon_T\frac{\dot{T}}{T}-\frac{\partial u}{\partial t} \quad (4)$$

Considering that RTS is the returns to scale, $RTS=\varepsilon_K+\varepsilon_L+\varepsilon_T$, and $\varepsilon_K,\varepsilon_L$ and ε_T are output elasticities, and:

$$\lambda_K=\frac{\varepsilon_K}{RTS},\lambda_K=\frac{\varepsilon_L}{RTS},\lambda_T=\frac{\varepsilon_T}{RTS} \quad (5)$$

Pires e Garcia (2004) present the Divisia index as in the equation: [5]

$$g_{TFP}=\frac{\dot{y}}{y}-S_K\frac{\dot{K}}{K}-S_L\frac{\dot{L}}{L}-S_T\frac{\dot{T}}{T} \quad (6)$$

The authors also show that, after the estimation of equation (3) and the algebraic manipulation of (4), (5) and (6), we can find the change rate in total factor productivity:

$$g_{TFP}=TP-\dot{u}+(RTS-1)\left[\lambda_K g_K+\lambda_L g_L+\lambda_T g_T\right]$$
$$+\left[(\lambda_K-S_K)g_K+(\lambda_L-S_L)g_L+(\lambda_T-S_T)g_T\right] \quad (7)$$

where:
$TP=\frac{\partial \ln f(t,K,L,T,\beta)}{\partial t}$ is the technical progress;
$\dot{u}$ is the change in the technical efficiency;
$(RTS-1)\lambda_K g_K+\lambda_L g_L+\lambda_T g_T$ is the change in the scale of production;
$(\lambda_K-S_K)g_K+(\lambda_L-S_L)g_L+(\lambda_T-S_T)g_T$ is the change in allocative efficiency.

3.1. *Data and sample*

The basic source of data in this paper is the Brazilian Rural Statistical Yearbook and the Brazilian Agricultural Census, published by the Brazilian Institute of Geographic and Statistics (IBGE – from its initials in Portuguese), of the following years: 1975, 1985, 1995 and 2006. [6] All the information (capital stock, labor, land and the respective share of each production factor in income) was obtained from the Brazilian Agricultural Census. The GDP was taken from the Brazilian Rural Statistical Yearbook. We used observation at a city level.

[5] The terms S_K and S_L are the share of capital and labor in income, respectively.
[6] The last edition of the Brazilian Rural Statistical Yearbook published.

This city-based sample allowed estimating the growth in states that had not yet existed in 1975. This approach makes it possible to calculate these states considering city by city and then analyzing the aggregated results.

The variable for capital stock used in this paper is the total number of properties of farmers (which include the rural constructions and buildings, equipment, machinery and lands). The data on labor used in this paper is the data on people employed in agriculture. The data on land used is the harvested area expressed in hectares.

To calculate the portion of product for each production factor, we used variables of investments in rural constructions and buildings, equipment, machinery for the capital stock, participation, investments in land aimed at the land participation and the salaries paid with the purpose of the labor participation in the product. All these data were not available at a city basis. For this information, we used a state-basis data for all cities located in the state.

Both capital stock and GDP were deflated by the IBGE implicit GDP deflator expressed in *Reais* (R$ – prices of 2000).The data were organized in a panel model to estimate equation (3) and results were used to decompose the local (cities) agricultural TFP, and results are exposed for each Brazilian state[7] following equation (7). All results are presented in Section 4.

4. Results and Discussion

For models estimated by maximum likelihood, Greene (2003) suggests a Likelihood Ratio Test (LR). The objective is to test the complete model represented by equation (3) and the restricted model. The null hypothesis, in the case of this paper as shown in Table 3, is that the column-model is contained in the line-model. According to Greene (2003, p. 491), if the computed value is larger than the critical value, the null hypothesis cannot be rejected.

The restricted models were defined in accordance to Jones (2000) definition: for a Cobb-Douglas function with technological variables like $Y = f(K, AL)$, the technology is "Harrod neutral"; other possibilities are $Y = f(AK, L)$ and the technology is "Solow neutral", or $Af(K, L)$, and technology is "Hicks neutral". Table 3 shows the results for the likelihood ratio tests, and the full translog model represented by equation (3) was selected as the most appropriated model.

Results on Table 4 are all statically significant at 1%, except for coefficient β_{KL}. The negative signs of coefficients β_{kt} and β_{Lt} mean that the non-neutral part of the technical progress is labor and capital saving On the other hand, the technical progress increases with land expansion ($\beta_{Tt} > 0$), which means that the technical progress is more intense in the states with large land supply.

[7] Results for the agricultural TFP at a state level is a weighted average (based on the local GDP share on the state share) of the local agricultural TFP.

Table 3
Likelihood ratio tests results

Model	Full translog	Harrod neutral	Solow neutral	Hicks neutral	Translog TP[1]	Cobb-Douglas[2]	Cobb-DouglasTP[3]
Full translog	-	280.62	827.15	1361.80	1695.08	2283.51	2386.10
		$\chi^2(1)$	$\chi^2(1)$	$\chi^2(2)$	$\chi^2(5)$	$\chi^2(10)$	$\chi^2(11)$
Harrod neutral	-	-	NC4	1081.18	1414.41	2002.89	2105.48
				$\chi^2(1)$	$\chi^2(4)$	$\chi^2(9)$	$\chi^2(10)$
Solow neutral	-	-	-	534.65	867.92	1456.36	1558.95
				$\chi^2(1)$	$\chi^2(4)$	$\chi^2(9)$	$\chi^2(10)$
Hicks neutral	-	-	-	-	332.28	921.71	1024.30
					$\chi^2(3)$	$\chi^2(8)$	$\chi^2(9)$
Translog TP[1]	-	-	-	-	-	NC4	691.02
							$\chi^2(6)$
Cobb-Douglas[2]	-	-	-	-	-	-	102.59
							$\chi^2(1)$
Cobb-Douglas TP[3]	-	-	-	-	-	-	-

[1]Translog function without technical progress;
[2]Cobb-Douglas function with technical progress;
[3]Cobb-Douglas function without technical progress;
[4]The likelihood ratio test is not applicable.
Source: The authors.

Results of the estimated model allowed decomposing agricultural TFP of the 27 Brazilian states. The general average, for the 27 states, of all factors (Table 5) is consistent with results found in other research about the Brazilian agricultural TFP, such as Gasques et alii (2009). For example, Gasques et alii (2009) estimated for the period 1975/2008 a growth of 3.66% while the average TFP growth found in our model suggests a growth of 3.1%. Another similar result concerns the growth of capital accumulation and land expansion, and reduction of labor force.

For all states (except Rio Grande do Norte) there was positive TFP growth; the states of the Northern Region (Rondônia, Acre, Amazonas, Roraima, Pará, Amapá and Tocantins) had the largest TFP growth, which is consistent with the agricultural frontier expansion in the last decades. Thirty years ago, practically there was no agricultural activity in these states, and results reflect the recent occupation of the region. The same result is estimated to technical progress and allocative efficiency.

Other states that had high economic growth were: Bahia, Minas Gerais,

Table 4
The results for the time-variant inefficiency model

Number of observations: 18,325						
Log likelihood $= -15,919.244$				Prob> $\chi^2 = 0.0000$		
$\ln y$	Coefficients	Standard errors	z	$P > \lvert z \rvert$	[95% Conf. Interval]	
β_t	1.250.237	0.045885	27.25	0.000	1.160.304	1.340.169
β_k	0.275491	0.041972	6.56	0.000	0.193228	0.357755
β_L	0.597959	0.033017	18.11	0.000	0.533247	0.662671
β_T	-0.31893	0.03744	-8.52	0.000	-0.39231	-0.245550
β_u	0.029552	0.012192	2.42	0.015	0.005655	0.053448
β_{kk}	0.020684	0.004618	4.48	0.000	0.011633	0.029734
β_{LL}	0.010366	0.003222	3.22	0.001	0.00405	0.016681
β_{TT}	0.050691	0.004473	11.33	0.000	0.041924	0.059458
β_{KL}	-0.00198	0.006004	-0.33	0.741	-0.01375	0.009783
β_{TK}	-0.0347	0.005196	-6.68	0.000	-0.04489	-0.024520
β_{TL}	0.011571	0.00695	1.67	0.096	-0.00205	0.025192
β_{kt}	-0.05913	0.003531	-16.75	0.000	-0.06605	-0.052210
β_{Lt}	-0.12301	0.004249	-28.95	0.000	-0.13134	-0.114680
β_{Tt}	0.070116	0.003976	17.64	0.000	0.062324	0.077908
β_0	1.584.759	0.309937	5.11	0.000	0.977294	2.192.223
μ	170.578	0.119855	14.23	0.000	1.470.869	1.940.691
η	-0.25224	0.012781	-19.74	0.000	-0.2773	-0.227190
$\ln \sigma^2$	-0.75538	0.017713	-42.65	0.000	-0.7901	-0.720670
$ilgt\gamma$	-0.08194	0.042326	-1.94	0.053	-0.1649	0.001020
σ^2	0.469831	0.008322	-	-	0.4538	0.486429
γ	0.479527	0.010564	-	-	0.458869	0.500255
σ_u^2	0.225297	0.008466	-	-	0.208705	0.241889
σ_v^2	0.244534	0.003104	-	-	0.238451	0.250618

Source: The authors.

Table 5. Results of agricultural TFP decomposition for the Brazilian States

State	Economic growth	Capital accumulation	Labor expansion	Land expansion	Change in TFP	Technical progress	Technical efficiency	Scale effects	Allocative efficiency	Randon shocks
Rondônia	1.2%	0.5%	-1.9%	-1.9%	8.3%	9.7%	-2.8%	-0.8%	2.1%	-3.7%
Acre	3.8%	2.8%	-1.6%	0.7%	6.4%	5.7%	-2.0%	1.0%	1.6%	-4.5%
Amazonas	6.0%	1.3%	-2.0%	3.1%	9.9%	7.1%	-1.4%	1.4%	2.8%	-6.3%
Roraima	0.5%	-0.2%	-1.0%	2.0%	10.3%	10.2%	-2.3%	0.3%	2.0%	-10.8%
Pará	3.4%	3.9%	-0.9%	0.9%	6.1%	5.8%	-2.3%	1.7%	0.8%	-6.6%
Amapá	2.2%	3.1%	-1.8%	3.4%	11.2%	6.7%	-2.0%	2.1%	4.4%	-13.6%
Tocantins	5.7%	3.4%	-1.4%	1.2%	2.9%	2.5%	-3.0%	2.2%	1.2%	-0.4%
Maranhão	1.7%	2.1%	-1.1%	-0.4%	3.3%	3.9%	-2.3%	0.8%	0.9%	-2.3%
Piauí	1.8%	1.4%	-0.5%	0.5%	1.5%	3.1%	-3.3%	1.0%	0.7%	-1.1%
Ceará	1.4%	1.1%	-0.5%	-1.2%	1.0%	2.5%	-2.8%	0.4%	0.9%	1.1%
Rio Grande do Norte	2.3%	1.1%	-1.3%	-2.0%	-0.9%	2.3%	-3.1%	0.0%	-0.1%	5.5%
Paraíba	0.2%	-0.2%	-1.5%	-1.6%	0.0%	3.2%	-3.2%	-0.7%	0.6%	3.6%
Pernambuco	0.9%	0.2%	-1.1%	-0.8%	1.2%	3.4%	-2.6%	-0.1%	0.5%	1.4%
Alagoas	0.7%	1.5%	-1.0%	-0.2%	0.4%	3.4%	-2.9%	0.5%	-0.6%	0.0%
Sergipe	1.7%	0.7%	-0.9%	0.5%	1.5%	4.0%	-3.3%	0.3%	0.5%	-0.1%
Bahia	3.1%	2.4%	-0.6%	1.4%	3.8%	4.9%	-3.0%	1.6%	0.4%	-3.9%
Minas Gerais	3.2%	1.4%	-0.7%	0.0%	2.5%	3.2%	-2.6%	0.9%	1.0%	-0.1%
Espírito Santo	3.3%	1.9%	-0.8%	0.0%	4.4%	4.6%	-2.0%	0.9%	0.9%	-2.1%
Rio de Janeiro	-0.7%	-0.7%	-1.0%	-1.8%	2.9%	5.2%	-2.5%	-0.7%	0.9%	0.0%
São Paulo	2.4%	0.4%	-1.4%	0.2%	1.6%	3.7%	-2.7%	0.1%	0.6%	1.5%
Paraná	-0.4%	0.8%	-2.1%	0.0%	2.7%	4.8%	-2.9%	-0.2%	1.0%	-1.8%
Santa Catarina	2.4%	1.5%	-1.7%	-0.8%	3.4%	4.1%	-2.4%	0.1%	1.6%	0.0%
Rio Grande do Sul	-1.3%	0.2%	-2.1%	-1.1%	3.1%	5.3%	-2.8%	-0.9%	1.5%	-1.5%
Mato Grosso do Sul	1.5%	0.5%	-1.8%	-0.3%	4.0%	5.3%	-2.8%	0.1%	1.5%	-1.0%
Mato Grosso	6.4%	1.9%	-1.8%	3.4%	7.9%	8.5%	-2.3%	1.5%	0.3%	-5.0%
Goiás	2.1%	1.0%	-1.3%	0.2%	2.8%	3.6%	-2.8%	0.5%	1.5%	-0.6%
Distrito Federal	4.9%	4.3%	2.8%	7.1%	0.8%	1.3%	-2.5%	4.3%	-2.3%	-10.2%
Average	2.4%	1.3%	-1.3%	0.2%	3.1%	4.3%	-2.7%	0.5%	1.0%	-0.8%

Source: The authors.

São Paulo and Mato Grosso. These are the states, along with Paraná and Rio Grande do Sul, which account the most for the Brazilian agricultural GDP. For the mentioned states, the contribution of technical progress was higher than the TFP growth, although the TFP growth was large and positive. Mato Grosso showed the largest growth of TFP and technical progress, and the analysis is the same for the states of the Northern Region: in the Center-Western Region, Mato Grosso concentrates the most important soybean planted area; other states like Goiás and Mato Grosso do Sul are more relevant in the livestock activity.

The technological efficiency is negative for all states, but results should be analyzed as the gap distance of each state to the technological frontier. In the period, 1975/2005, all states grew and incorporated technological progress, but the expansion of the technological frontier was larger than the expansion of technical efficiency. [8]

It is apparently contradictory that results for Paraná and Rio Grande do Sul, showed negative economic growth, on the average of the period. This result is influenced by two sub-periods (see Annex A): 1985-1995 and 1995-2006. In these sub-periods, the agricultural TFP grew 1.7% and 5.3% in Paraná respectively, and 2% and 3.8% in Rio Grande do Sul, respectively. The technical progress for Paraná and Rio Grande Sul was 4.8% and 7.1%, 5.6% and 8.1%, in the sub-periods, respectively. What had strong negative influence on the economic growth was the simultaneous reduction of capital accumulation, labor force and land expansion in the period. For the first sub-period, 1975-1985, Paraná had an economic growth of 2.8%, and Rio Grande do Sul, 2.7%.

Rio de Janeiro also had a negative economic growth, but this result was expected because the agricultural activity in the state is not significant and this state has been losing relevance in the agricultural GDP in the recent decades.

Results allowed concluding that TFP expansion based on technical progress is the major determinant of the Brazilian agricultural growth from 1975 to 2005. At a regional level, the states in the agricultural frontier of rural Brazil have grown at higher rates.

The most important states to Brazilian agricultural GDP have grown too, exception made to the negative results for economic growth of Paraná and Rio Grande do Sul. Results for these two states reflect the loss in grain harvests in the 2004/05 and 2005/06 seasons, due to adverse climatic conditions in the Southern region of Brazil. According to the Brazilian Rural Statistical Yearbook, 1995 and 2005 were to mark two adverse years to agricultural activities, when the GDP for the sector in some states decreased. As a consequence, it influenced the econometric results of this paper (especially for Paraná and Rio Grande do Sul) because 1995 and 2005 are year-basis of the

[8] In some empirical applications of the time-varying model as Battese e Tessema (1993), the inclusion of time-varying parameters in the stochastic frontier resulted in the conclusion that technical inefficiency exists. This is the case found in this paper.

panel data, since in these years editions of Brazilian Agricultural Census were published. Despite of the negative results for the economic growth in 1995 and 2005 to Paraná and Rio Grande do Sul, the econometric model was able to capture the positive growth of TFP and technical progress observed in those states. [9]

For the sub-periods, shown in Table 6, the sub-period that presented high technological progress and TFP growth was 1985-2005, when the TFP grew at 4.5% and the technological progress 7.4%. This result is consistent with the Brazilian macroeconomic analyses on the period: economic openness, monetary stabilization, interest rates decreasing after the adoption of the flexible exchange rate system in 1999 and the economic growth recovery. The international scenario had positive influence on the Brazilian agriculture performance, especially after 2003, following the growth of global economy, high levels of commodities prices and increase of trades of commodities in the international scenario.

5. Conclusion

This paper analyzed the Brazilian agricultural growth, from 1975 to 2005, estimating a stochastic frontier to decompose the Total Productivity Factor (TFP) at a state level.

Results suggest that the agricultural frontier expansion in the Northern and Center-Western regions was possible due to strong technical progress and positive TFP growth. The states that, traditionally, have a large share in the agricultural GDP, such as Minas Gerais and São Paulo, also showed high technical progress and TFP growth to ensure an economic growth of 3.2% and 2.4%, respectively, in the period.

The econometric model captured the expected reduction of labor force in agriculture in all states, and reduction of land expansion in states where agriculture has decreased its share in the state GDP and, therefore, the economic diversification (industrialization and services). On the other hand, for the states in the Northern region there was increase of land expansion, which was a result of the agricultural frontier expansion.

Finally, the period 1995-2005 witnessed the highest increase of technical progress and TFP growth. It is a result of a decade characterized by macroeconomic advances like monetary stabilization, economic openness, and recovery of economic growth. Recently, the Brazilian agriculture has been favored by the high level of commodities prices and the increase of trade of commodities in the international scenario.

[9] These results are showed in Anexx A.

Table 6. The results for the agricultural TFP decomposition by period

Year	Economic growth	Capital accumulation	Labor expansion	Land expansion	Change in TFP	Technical progress	Technical efficiency	Scale effects	Allocative efficiency	Randon shocks
1975-1985	7.1%	7.0%	0.6%	0.1%	2.5%	-0.2%	-2.1%	3.8%	1.0%	-3,00%
1985-1995	-0.8%	-1.3%	-1.3%	-1.0%	2.2%	5.7%	-2.7%	-1.2%	0.4%	0,50%
1995-2005	1.0%	-1.8%	-3.3%	1.5%	4.5%	7.4%	-3.3%	-1.1%	1.5%	0,10%
1975-2005	2.4%	1.3%	-1.3%	0.2%	3.1%	4.3%	-2.7%	0.5%	1.0%	-0,80%

Source: The authors.

References

Aigner, D. J. & Lovell, C. A. K. (1977). Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics*, 6:21–37.

Alves, E. & Contini, E. (1988). A modernização da agricultura brasileira. In Brandão, A. S. P., editor, *Os principais problemas da agricultura brasileira: Análises e sugestões*. IPEA, Rio de Janeiro.

Amadi, J., Piesse, J., & Thirtle, C. (2004). Crop level productivity in the Eastern Counties of England, 1970-97. *Journal of Agricultural Economics*, 55:367–383.

Antle, J. M. (1999). The new economics of agriculture. *American Journal of Agricultural Economics*, 81:993–1010.

Bacha, C. J. C. (1992). Alguns aspectos dos modelos de análise dos impactos de mudança tecnológica no comportamento do setor agrícola. *Revista Brasileira de Economia e Sociologia Rural*, 30:41–62.

Barros, J. R. M. (1979). Política e desenvolvimento agrícola no Brasil. In Veiga, A., editor, *Ensaios sobre política agrícola*, pages 9–35. Secretaria da Agricultura, São Paulo.

Barros, J. R. M. (1982). Política e desenvolvimento agrícola no Brasil. IPE/USP, Texto para Discussão 16/82, Instituto de Pesquisas Econômicas da Universidade de São Paulo, São Paulo.

Barros, J. R. M. (1991). A agricultura e o ajuste fiscal. *Revista Brasileira de Economia*, 45:318–328.

Barros, J. R. M., Pastore, A. C., & Rizzieri, J. A. (1977). Evolução recente da agricultura mineira. In Barros, J. R. M. & Graham, D., editors, *Estudos sobre a modernização da agricultura brasileira*. Instituto de Pesquisas Econômicas da Universidade de São Paulo, São Paulo.

Battese, G. E. & Coelli, T. J. (1992). Frontier production functions, technical efficiency and panel data: With application to paddy farms in India. *Journal of Productivity Analysis*, 3:153–169.

Battese, G. E. & Rao, D. S. P. (2001). Productivity potential and technical efficiency levels of firms in different regions using a stochastic frontier metaproduction function model. CEPA Working Paper 6/2001, Centre for Efficiency and Productivity Analysis, Armidale.

Battese, G. E., Rao, D. S. P., & Walujadi, D. (2001). Technical efficiency and productivity of garment firms in different regions in Indonesia: A stochastic frontier analysis using a time varying inefficiency model and a metaproduction function. CEPA Working Paper 7/2001, Centre for Efficiency and Productivity Analysis, Armidale.

Battese, G. E. & Tessema, G. A. (1993). Estimation of stochastic frontier production functions with time-varying parameters and technical efficiencies using panel data from Indian villages. *Agricultural Economics*, 9:313–333.

Bauer, P. W. (1990). Decomposing TFP in the presence of cost inefficiency, nonconstant returns to scale and technological progress. *Journal of Productivity Analysis*, 1:287–299.

Bonelli, R. & Fonseca, R. (1998). Ganhos de produtividade e de eficiência: Novos resultados para a economia brasileira. Texto para Discussão 557, IPEA, Rio de Janeiro.

Boskin, M. J. & Lau, L. J. (1992). Capital, technology and economic growth in technology and the wealth of nation. In Rosenberg, N., Landau, R., & Mowerry, D. C., editors, *Technology and the Wealth of Nations*, pages 15–49. Stanford University Press, Stanford.

Bravo-Ortega, C. & Lederman, D. (2004). Agricultural productivity and its determinants: Revisiting international experiences. *Estudios de Economía*, 31:133–163.

Bureau, C., Färe, R., & Grosskopf, S. A. (1995). Comparison of three nonparametric measures of productivity growth in European and United States agriculture. *Journal of Agricultural Economics*, 46:309–326.

Capalbo, S. M. & Antle, J. M. (1988). *Agricultural productivity: Measurement and explanation*. Resources for the Future, Washington: D.C. .

Chen, W. & Ding, Y. (2007). Total factor productivity in Chinese agriculture: The role of infrastructure. *Frontier of Economics in China*, 2:212–223.

Coelho, C. N. (2001). 70 anos de política agrícola no Brasil. *Revista de Política Agrícola*, 10:1–59.

Coelli, T. J. & Rao, D. S. P. (2005). Total factor productivity growth in agriculture: A Malmquist index analysis of 93 countries, 1980-2000. *Agricultural Economics*, 32:115–134.

Fulginiti, L. & Perrin, R. (1993). Prices and productivity in agriculture. *Review of Economics and Statistics*, 75:471–482.

Fulginiti, L. & Perrin, R. (1997). LDC agriculture: Nonparametric Malmquist productivity indexes. *Journal of Development Economics*, 53:373–390.

Gasques, J. G., Bastos, E. T., & Bacchi, M. R. P. (2009). Produtividade e fontes de crescimento da agricultura. Nota técnica, Ministério da Agricultura, Pecuária e Abastecimento (MAPA), Brasília.

Gasques, J. G., Bastos, E. T., Bacchi, M. R. P., & Conceição, J. C. P. R. (2004). Condicionantes da produtividade da agropecuária brasileira. Projeto BRA 97/013, Pesquisa 31, IPEA, Brasília.

Gasques, J. G. & Conceição, J. C. P. R. (1997). Crescimento e produtividade da agricultura brasileira. Texto para Discussão 502, IPEA, Brasília.

Gasques, J. G. & Conceição, J. C. P. R. (2001). Transformações estruturais da agricultura e produtividade total dos fatores. In Gasques, J. G. & Conceição, J. C. P. R., editors, *Transformações da agricultura e políticas públicas*, pages 18–92. IPEA, Brasília.

Gasques, J. G. & Villa Verde, C. M. (2003). Gastos públicos na agricultura, evolução e mudanças. Texto para Discussão 948, IPEA, Brasília.

Greene, W. (2003). *Econometric Analysis*. Prentice Hall, New Jersey, 3rd. edition.

Hayami, Y. & Ruttan, V. (1970). Agricultural productivity differences among countries. *American Economic Review*, 5:895–911.

Hayami, Y. & Ruttan, V. (1971). *Agricultural development: An international perspective*. Johns Hopkins Press, Baltimore.

Helfand, S. M. & Levine, E. S. (2004). Farm size and the determinants of productive efficiency in the Brazilian Center-West. *Agricultural Economics*, 31:241–249.

Johnston, B. & Mello, R. J. W. (1961). The role of agriculture in economic development. *American Economic Review*, 51:566–593.

Jones, C. I. (2000). *Introdução à teoria do crescimento econômico*. Campus, Rio de

Janeiro.

Kawagoe, T. & Hayami, Y. (1983). The production structure of world agriculture: An intercountry cross-section analysis. *The Developing Economies*, 21:189–206.

Kawagoe, T. & Hayami, Y. (1985). An intercountry comparison of agricultural production efficiency. *American Journal of Agricultural Economics*, 67:87–92.

Kawagoe, T., Hayami, Y., & Ruttan, V. (1985). The intercountry agricultural production function and productivity differences among countries. *Journal of Development Economics*, 19:113–132.

Kumbhakar, S. C. (2000). Estimation and decomposition of productivity change when production is not efficient. *Econometric Reviews*, 19:425–460.

Lambert, D. K. & Parker, E. (1998). Productivity in chinese provincial agriculture. *Journal of Agricultural Economics*, 49:378–392.

Lau, L. & Yotopoulos, P. (1989). The meta-production function approach to technological change in world agriculture. *Journal of Development Economics*, 31:241–269.

Meeusen, W. & Van Den Broeck, J. (1977). Efficiency estimation from Cobb-Douglas production function with composed error. *International Economic Review*, 8:435–444.

Nishimizu, M. & Page, J. M. (1982). Total factor productivity growth, technological progress and technical efficiency change: Dimensions of productivity change in Yugoslavia 1965-78. *Economic Journal*, 92:920–936.

O'Donnel, C. J. (2010). Measuring and decomposing agricultural productivity and profitability change. *Australian Journal of Agricultural and Resource Economics*, 54:527–560.

Oliveira, J. C. & Montezano, R. M. S. (1982). Os limites das fontes de financiamento da agricultura no Brasil. *Estudos Econômicos*, 12:139–159.

Pires, J. F. & Garcia, J. F. (2004). Productivity of nations: A stochastic frontier approach to TFP decomposition. Texto para Discussão 143, FGV, São Paulo.

Rao, D. S. P. (1993). Intercountry comparisons of agricultural output and productivity. FAO, Social and Economic Development Paper 112, Food and Agriculture Organization, Rome.

Annexx A

Table 7. The results for the agricultural TFP decomposition by period and State

State	Period	Economic growth	Capital accumulation	Labor expansion	Land expansion	Change in TFP	Technical progress	Technical efficiency	Scale effects	Allocative efficiency	Randon shocks
Rondônia	1975-1985	- 0.00444	- 0.00774	- 0.00714	- 0.02679	- 0.02513	0.00154	- 0.04068	- 0.00589	0.01990	0.06235
Rondônia	1985-1995	- 0.02853	0.00574	- 0.01680	- 0.01013	0.20171	0.21092	- 0.01478	- 0.00613	0.01171	- 0.20905
Rondônia	1995-2005	0.06915	0.01614	- 0.03422	- 0.02053	0.07196	0.07915	- 0.02919	- 0.01058	0.03258	0.03579
Rondônia	1975-2005	0.01206	0.00471	- 0.01939	- 0.01915	0.08285	0.09720	- 0.02822	- 0.00753	0.02140	- 0.03697
Acre	1975-1985	0.03048	0.03298	0.00961	- 0.00637	0.03412	0.01963	- 0.01708	0.02003	0.01153	- 0.03985
Acre	1985-1995	- 0.02531	0.01463	- 0.01431	- 0.00317	0.06514	0.07528	- 0.01776	0.00097	0.00666	- 0.08760
Acre	1995-2005	0.10758	0.03614	- 0.04327	0.03030	0.09127	0.07540	- 0.02399	0.00894	0.03092	- 0.00686
Acre	1975-2005	0.03758	0.02791	- 0.01599	0.00692	0.06351	0.05677	- 0.01961	0.00998	0.01637	- 0.04477
Amazonas	1975-1985	0.08891	0.06821	0.01075	0.01717	0.04265	0.02059	- 0.01238	0.03438	0.00005	- 0.04987
Amazonas	1985-1995	0.00921	- 0.01103	- 0.01460	- 0.02909	0.04249	0.04562	- 0.01362	- 0.00969	0.02018	0.02145
Amazonas	1995-2005	0.08107	- 0.01763	- 0.05590	0.10438	0.21072	0.14610	- 0.01617	0.01703	0.06377	- 0.16051
Amazonas	1975-2005	0.05973	0.01318	- 0.01992	0.03082	0.09862	0.07077	- 0.01406	0.01391	0.02800	- 0.06298
Roraima	1975-1985	- 0.01412	0.01198	- 0.02485	- 0.02194	0.18022	0.17689	- 0.01736	- 0.00695	0.02765	- 0.15953
Roraima	1985-1995	0.03935	- 0.01130	0.02464	0.07218	0.00088	0.03497	- 0.02254	0.01951	- 0.03107	- 0.04705
Roraima	1995-2005	- 0.01091	- 0.00636	- 0.02862	0.01124	0.12936	0.09537	- 0.02761	- 0.00329	0.06489	- 0.11655
Roraima	1975-2005	0.00477	- 0.00189	- 0.00961	0.02049	0.10349	0.10241	- 0.02250	0.00309	0.02049	- 0.10771
Pará	1975-1985	0.11708	0.09735	0.02472	0.01844	- 0.06705	- 0.10374	- 0.01332	0.05512	- 0.00510	0.04360
Pará	1985-1995	- 0.02512	0.00312	- 0.01599	0.00503	0.16494	0.19129	- 0.02694	- 0.00343	0.00402	- 0.18222
Pará	1995-2005	0.01019	0.01663	- 0.03511	0.00329	0.08481	0.08758	- 0.02791	0.00081	0.02433	- 0.05943
Pará	1975-2005	0.03405	0.03903	- 0.00879	0.00892	0.06090	0.05837	- 0.02272	0.01750	0.00775	- 0.06601
Amapá	1975-1985	0.09620	0.11720	0.00043	0.02940	0.05731	0.00082	- 0.01435	0.05462	0.01621	- 0.10813
Amapá	1985-1995	- 0.01662	0.00108	- 0.00973	- 0.00997	0.03333	0.05571	- 0.02348	- 0.00540	0.00649	- 0.03133
Amapá	1995-2005	- 0.01230	- 0.02613	- 0.04358	0.08133	0.24539	0.14362	- 0.02235	0.01361	0.11050	- 0.26932
Amapá	1975-2005	0.02243	0.03072	- 0.01762	0.03359	0.11201	0.06672	- 0.02006	0.02095	0.04440	- 0.13626
Tocantins	1975-1985	0.09038	0.07873	0.00833	0.00252	0.02453	- 0.00586	- 0.02359	0.04474	0.00924	- 0.02373
Tocantins	1985-1995	- 0.00159	- 0.00292	- 0.01003	- 0.02891	- 0.02609	- 0.00000	- 0.02930	- 0.01010	0.01332	0.06635
Tocantins	1995-2005	0.08319	0.02594	- 0.03977	0.06234	0.08910	0.08195	- 0.03630	0.02993	0.01351	- 0.05441
Tocantins	1975-2005	0.05733	0.03391	- 0.01382	0.01198	0.02918	0.02536	- 0.02973	0.02152	0.01202	- 0.00393

Table 7 – The results for the agricultural TFP decomposition by period and State (continued)

State	Period	Economic growth	Capital accumulation	Labor expansion	Land expansion	Change in TFP	Technical progress	Technical efficiency	Scale effects	Allocative efficiency	Randon shocks
Maranhão	1975-1985	0.03221	0.08865	0.00763	- 0.02019	0.00397	- 0.03182	- 0.01804	0.04347	0.01035	- 0.04786
Maranhão	1985-1995	- 0.01448	- 0.01132	- 0.01000	0.02402	0.04522	0.07122	- 0.02275	- 0.00368	0.00042	- 0.06239
Maranhão	1995-2005	0.03210	- 0.01339	- 0.02980	- 0.01600	0.04937	0.07795	- 0.02912	- 0.01517	0.01571	0.04192
Maranhão	1975-2005	0.01661	0.02131	- 0.01072	- 0.00406	0.03285	0.03912	- 0.02330	0.00821	0.00883	- 0.02278
Piauí	1975-1985	0.04131	0.07635	0.01925	0.02492	0.02029	- 0.00299	- 0.02477	0.04923	- 0.00118	- 0.09951
Piauí	1985-1995	- 0.00873	- 0.01554	- 0.01297	0.00319	0.00166	0.04428	- 0.03411	- 0.01089	0.00238	0.01493
Piauí	1995-2005	0.02062	- 0.01801	- 0.02224	- 0.01176	0.02237	0.05284	- 0.04112	- 0.00972	0.02037	0.05026
Piauí	1975-2005	0.01773	0.01427	- 0.00532	0.00545	0.01477	0.03138	- 0.03333	0.00954	0.00719	- 0.01144
Ceará	1975-1985	0.06664	0.07890	0.01622	- 0.01920	0.00517	- 0.02499	- 0.02238	0.04430	0.00824	- 0.01445
Ceará	1985-1995	- 0.02495	- 0.01917	- 0.00681	- 0.00580	0.01267	0.04849	- 0.02792	- 0.01208	0.00417	- 0.00583
Ceará	1995-2005	0.00056	- 0.02677	- 0.02386	- 0.01192	0.01091	0.05163	- 0.03511	- 0.02001	0.01439	0.05219
Ceará	1975-2005	0.01409	0.01099	- 0.00482	- 0.01230	0.00958	0.02504	- 0.02847	0.00407	0.00894	0.01064
R. G. do Norte	1975-1985	0.07056	0.07709	0.00916	- 0.00343	0.00051	- 0.01177	- 0.02371	0.03774	- 0.00176	- 0.01277
R. G. do Norte	1985-1995	- 0.02462	- 0.01792	- 0.01291	- 0.01765	- 0.01632	0.02664	- 0.03074	- 0.01475	0.00253	0.04017
R. G. do Norte	1995-2005	0.02253	- 0.02762	- 0.03525	- 0.03985	- 0.01222	0.05417	- 0.03895	- 0.02405	- 0.00339	0.13747
R. G. do Norte	1975-2005	0.02282	0.01052	- 0.01300	- 0.02031	- 0.00934	0.02302	- 0.03113	- 0.00035	- 0.00087	0.05496
Paraíba	1975-1985	0.04365	0.05257	- 0.00065	0.00451	0.00755	0.00873	- 0.02476	0.02543	- 0.00184	- 0.02033
Paraíba	1985-1995	- 0.02180	- 0.02217	- 0.01650	- 0.02984	- 0.01419	0.03024	- 0.03102	- 0.02062	0.00721	0.06090
Paraíba	1995-2005	- 0.01447	- 0.03652	- 0.02819	- 0.02254	0.00553	0.05813	- 0.04003	- 0.02505	0.01248	0.06725
Paraíba	1975-2005	0.00246	- 0.00204	- 0.01512	- 0.01596	- 0.00037	0.03237	- 0.03194	- 0.00674	0.00595	0.03594
Pernambuco	1975-1985	0.06110	0.06068	0.01337	- 0.00438	0.00174	- 0.00904	- 0.02034	0.03494	- 0.00383	- 0.01030
Pernambuco	1985-1995	- 0.01221	- 0.01843	- 0.01426	- 0.00625	0.00977	0.04580	- 0.02667	- 0.01345	0.00410	0.01696
Pernambuco	1995-2005	- 0.02292	- 0.03585	- 0.03316	- 0.01362	0.02566	0.06596	- 0.03245	- 0.02310	0.01525	0.03405
Pernambuco	1975-2005	0.00866	0.00213	- 0.01135	- 0.00809	0.01239	0.03424	- 0.02649	- 0.00054	0.00517	0.01357
Alagoas	1975-1985	0.08244	0.05991	0.02025	0.01623	- 0.00024	- 0.00484	- 0.02333	0.04216	- 0.01424	- 0.01370
Alagoas	1985-1995	- 0.02761	- 0.00408	- 0.02169	- 0.01116	0.00331	0.04738	- 0.02826	- 0.01193	- 0.00387	0.00601
Alagoas	1995-2005	- 0.03487	- 0.01184	- 0.02918	- 0.01021	0.00871	0.05970	- 0.03545	- 0.01460	- 0.00094	0.00766
Alagoas	1975-2005	0.00665	0.01466	- 0.01021	- 0.00171	0.00393	0.03408	- 0.02901	0.00521	- 0.00635	- 0.00001

Table 7 – The results for the agricultural TFP decomposition by period and State (continued)

State	Period	Economic growth	Capital accumulation	Labor expansion	Land expansion	Change in TFP	Technical progress	Technical efficiency	Scale effects	Allocative efficiency	Randon shocks
Sergipe	1975-1985	0.08942	0.06182	0.01047	0.00789	0.01479	0.00558	- 0.02600	0.03377	0.00145	- 0.00555
Sergipe	1985-1995	- 0.01299	- 0.01605	- 0.00376	0.00524	0.00124	0.04039	- 0.03287	- 0.00708	0.00080	0.00034
Sergipe	1995-2005	- 0.02445	- 0.02562	- 0.03350	0.00205	0.02942	0.07529	- 0.04123	- 0.01711	0.01247	0.00320
Sergipe	1975-2005	0.01732	0.00672	- 0.00893	0.00506	0.01515	0.04042	- 0.03337	0.00319	0.00490	- 0.00067
Bahia	1975-1985	0.10258	0.10293	0.02274	0.01665	0.00372	- 0.03323	- 0.02346	0.06290	- 0.00249	- 0.04346
Bahia	1985-1995	- 0.04564	- 0.01523	- 0.01495	- 0.00473	0.06223	0.10085	- 0.02977	- 0.01192	0.00308	- 0.07297
Bahia	1995-2005	0.03677	- 0.01701	- 0.02616	0.03048	0.04924	0.07802	- 0.03706	- 0.00265	0.01093	0.00021
Bahia	1975-2005	0.03123	0.02356	- 0.00612	0.01413	0.03840	0.04854	- 0.03010	0.01611	0.00384	- 0.03874
Minas Gerais	1975-1985	0.11499	0.08768	0.01448	- 0.00197	0.03261	- 0.01919	- 0.01971	0.05054	0.02097	- 0.01780
Minas Gerais	1985-1995	- 0.01401	- 0.01640	- 0.00938	- 0.00117	0.01177	0.04731	- 0.02492	- 0.01050	- 0.00012	0.00118
Minas Gerais	1995-2005	- 0.00633	- 0.02821	- 0.02516	0.00298	0.02926	0.06671	- 0.03246	- 0.01414	0.00915	0.01480
Minas Gerais	1975-2005	0.03155	0.01435	- 0.00669	- 0.00005	0.02455	0.03161	- 0.02570	0.00863	0.01000	- 0.00061
Espírito Santo	1975-1985	0.10001	0.10850	0.01182	0.00426	0.03756	- 0.02208	- 0.01650	0.06167	0.01448	- 0.06213
Espírito Santo	1985-1995	0.00206	- 0.02168	- 0.00871	- 0.01068	0.05262	0.08201	- 0.01782	- 0.01540	0.00383	- 0.00948
Espírito Santo	1995-2005	- 0.00313	- 0.03045	- 0.02670	0.00532	0.04116	0.07846	- 0.02662	- 0.02072	0.01005	0.00753
Espírito Santo	1975-2005	0.03298	0.01879	- 0.00786	- 0.00037	0.04378	0.04613	- 0.02032	0.00851	0.00945	- 0.02136
Rio de Janeiro	1975-1985	0.03814	0.02866	0.00934	- 0.01097	0.01727	0.00740	- 0.01667	0.01660	0.00994	- 0.00615
Rio de Janeiro	1985-1995	- 0.03433	- 0.02171	- 0.02094	- 0.02792	0.03620	0.07680	- 0.02811	- 0.02132	0.00883	0.00004
Rio de Janeiro	1995-2005	- 0.02519	- 0.02936	- 0.01948	- 0.01639	0.03288	0.07116	- 0.03117	- 0.01487	0.00775	0.00716
Rio de Janeiro	1975-2005	- 0.00713	- 0.00747	- 0.01036	- 0.01843	0.02878	0.05179	- 0.02531	- 0.00653	0.00884	0.00035
São Paulo	1975-1985	0.08546	0.06312	0.00046	0.00771	0.02335	0.01039	- 0.02115	0.03450	- 0.00040	- 0.00918
São Paulo	1985-1995	0.00681	- 0.01659	- 0.01323	- 0.01304	0.00040	0.03916	- 0.02713	- 0.01513	0.00350	0.04926
São Paulo	1995-2005	- 0.02128	- 0.03418	- 0.02992	0.01185	0.02543	0.06027	- 0.03294	- 0.01734	0.01545	0.00553
São Paulo	1975-2005	0.02366	0.00412	- 0.01423	0.00218	0.01639	0.03661	- 0.02707	0.00068	0.00618	0.01520
Paraná	1975-1985	0.02768	0.06039	- 0.00922	- 0.00700	0.04143	0.02396	- 0.02195	0.02556	0.01385	- 0.05791
Paraná	1985-1995	- 0.02625	- 0.01204	- 0.01748	- 0.01434	0.00667	0.04798	- 0.02913	- 0.01651	0.00432	0.01094
Paraná	1995-2005	- 0.01395	- 0.02423	- 0.03641	0.02166	0.03164	0.07147	- 0.03572	- 0.01591	0.01180	- 0.00660
Paraná	1975-2005	- 0.00417	0.00804	- 0.02104	0.00010	0.02658	0.04781	- 0.02893	- 0.00229	0.00999	- 0.01786

Table 7 – The results for the agricultural TFP decomposition by period and State (continued)

State	Period	Economic growth	Capital accumulation	Labor expansion	Land expansion	Change in TFP	Technical progress	Technical efficiency	Scale effects	Allocative efficiency	Randon shocks
Santa Catarina	1975-1985	0.06142	0.05912	0.00387	0.00036	0.03173	0.00156	- 0.01821	0.03146	0.01692	- 0.03366
Santa Catarina	1985-1995	0.00426	- 0.00160	- 0.01035	- 0.01029	0.01721	0.04276	- 0.02487	- 0.00670	0.00602	0.00929
Santa Catarina	1995-2005	0.00596	- 0.01353	- 0.04429	- 0.01303	0.05345	0.07933	- 0.02923	- 0.02311	0.02646	0.02335
Santa Catarina	1975-2005	0.02388	0.01466	- 0.01692	- 0.00765	0.03413	0.04121	- 0.02410	0.00055	0.01647	- 0.00034
Rio Grande do Sul	1975-1985	0.02745	0.04167	- 0.00384	- 0.00706	0.03571	0.02211	- 0.02080	0.01917	0.01522	- 0.03904
Rio Grande do Sul	1985-1995	- 0.02217	- 0.01241	- 0.01462	- 0.01814	0.01997	0.05579	- 0.02730	- 0.01613	0.00761	0.00303
Rio Grande do Sul	1995-2005	- 0.04371	- 0.02292	- 0.04431	- 0.00736	0.03842	0.08088	- 0.03515	- 0.02858	0.02127	- 0.00754
Rio Grande do Sul	1975-2005	- 0.01281	0.00211	- 0.02092	- 0.01085	0.03137	0.05293	- 0.02775	- 0.00851	0.01470	- 0.01452
Mato Grosso do Sul	1975-1985	0.06423	0.06875	- 0.00380	- 0.00292	0.06735	0.03253	- 0.02179	0.03499	0.02163	- 0.06516
Mato Grosso do Sul	1985-1995	0.02741	- 0.01409	- 0.00933	- 0.02072	0.00899	0.04029	- 0.02901	- 0.01222	0.00992	0.06257
Mato Grosso do Sul	1995-2005	- 0.04647	- 0.03902	- 0.04075	0.01558	0.04423	0.08500	- 0.03446	- 0.02001	0.01370	- 0.02651
Mato Grosso do Sul	1975-2005	0.01506	0.00521	- 0.01796	- 0.00269	0.04019	0.05261	- 0.02842	0.00092	0.01508	- 0.00970
Mato Grosso	1975-1985	0.03219	0.05257	- 0.00987	0.03532	0.11443	0.10600	- 0.01287	0.02994	- 0.00864	- 0.16025
Mato Grosso	1985-1995	0.05701	- 0.00164	- 0.01092	- 0.00787	0.04829	0.07266	- 0.02285	- 0.00573	0.00422	0.02915
Mato Grosso	1995-2005	0.10270	0.00572	- 0.03463	0.07426	0.07499	0.07623	- 0.03416	0.02031	0.01260	- 0.01765
Mato Grosso	1975-2005	0.06397	0.01888	- 0.01847	0.03390	0.07924	0.08496	- 0.02329	0.01484	0.00272	- 0.04958
Goiás	1975-1985	0.03129	0.05892	0.00711	- 0.01937	0.03126	- 0.00911	- 0.02076	0.03102	0.03011	- 0.04663
Goiás	1985-1995	0.01555	- 0.00849	- 0.00924	- 0.01180	0.01088	0.04294	- 0.02914	- 0.00829	0.00537	0.03420
Goiás	1995-2005	0.01570	- 0.01967	- 0.03684	0.03717	0.04078	0.07464	- 0.03498	- 0.00736	0.00848	- 0.00573
Goiás	1975-2005	0.02084	0.01025	- 0.01299	0.00200	0.02764	0.03616	- 0.02830	0.00512	0.01466	- 0.00606
Distrito Federal	1975-1985	0.08546	0.15665	0.04061	0.14997	0.04814	- 0.00006	- 0.01907	0.11682	- 0.04955	- 0.30991
Distrito Federal	1985-1995	0.10276	- 0.01380	- 0.00876	0.01932	0.05084	0.08609	- 0.02427	- 0.00959	- 0.00138	0.05516
Distrito Federal	1995-2005	- 0.04213	- 0.01531	0.05323	0.04387	- 0.07375	- 0.04565	- 0.03081	0.02201	- 0.01930	- 0.05017
Distrito Federal	1975-2005	0.04870	0.04251	0.02836	0.07105	0.00841	0.01346	- 0.02472	0.04308	- 0.02341	- 0.10164
Brasil	1975-1985	0.07090	0.06987	0.00608	0.00054	0.02486	- 0.00210	- 0.02061	0.03797	0.00959	- 0.03046
Brasil	1985-1995	- 0.00814	- 0.01272	- 0.01259	- 0.00987	0.02248	0.05696	- 0.02652	- 0.01225	0.00429	0.00456
Brasil	1995-2005	0.01030	- 0.01817	- 0.03324	0.01507	0.04518	0.07354	- 0.03307	- 0.01056	0.01528	0.00145
Brasil	1975-2005	0.02436	0.01300	- 0.01325	0.00191	0.03084	0.04280	- 0.02673	0.00505	0.00972	- 0.00815