2015

Is there a Slowdown in Agricultural Productivity Growth in South America?

Federico Trindade
University of Nebraska-Lincoln

Lilyan E. Fulginiti
University of Nebraska-Lincoln, lfulginiti1@unl.edu

AGRICULTURAL ECONOMICS

Agricultural Economics 46 (2015) supplement 69–81

Is there a slowdown in agricultural productivity growth in South America?

Federico José Trindade*, Lilyan Estela Fulginiti

Department of Agricultural Economics, University of Nebraska, Lincoln, NE 68583, USA

Abstract

This article estimates agricultural productivity growth in 10 South American countries in 1969–2009 with the objective of investigating if the slowdown being measured in other countries is present in the region. Results show that productivity growth accounts for half of the three-fold increase in agricultural output during this period and that performance is sensitive to R&D investments in the sector. The slowdown found for the 1990s to 2000s in the U.S. and some European economies does not seem to be present yet in South America. The region's total factor productivity (TFP) growth rate increased steadily from 1.07% during the 1970s to 2.29% during the 2000s. Given lags in adoption and the adaptive nature of innovations in these economies, we have yet to see the potential effects in South American agriculture of decreases in R&D in advanced economies.

JEL classifications: Q160, O430, O470, O490, R110

Keywords: Slowdown; Agricultural productivity; South America; Stochastic frontier

Introduction

Global agricultural productivity growth rates have been a popular topic of research. Several recent studies have found a decrease in global annual rates of yield growth during the last decades for high- and middle-income countries (Alston et al (2010), Fuglie (2010) and World Bank Development Report (2007)). Alston et al. (2010) has also identified a decrease in TFP growth rates in the U.S. and other advanced economies. Slower productivity growth might lead to a slower growth of global supply relative to demand of agricultural products, with important consequences on food prices and potentially on food security. If this finding extends to agriculture in developing countries the concerns are multiplied.

Productivity growth accounts for growth in output not attributable to growth in inputs. While input growth leads to increases in output, it is innovation what allows sustained increases in output. This growth is usually measured by changes in total factor productivity (TFP), where TFP is defined as the ratio of outputs to all inputs.[1]

Given the vast availability of land in South America, it is expected that this region will play a major role in increasing future food supply. For the last 35 years, agricultural production has increased steadily in most South American countries. While part of output growth has been due to input growth, one goal of this article is to determine the relative importance of TPF growth in output growth and to evaluate how consistent that growth has been. What have the growth rates in agricultural productivity in South America been and are they keeping up?

Our study presents a comparative analysis of agricultural productivity growth in South America with updated estimates from 1969 to 2009 with the objective of checking if the slowdown in TFP growth rates that seems present in advanced economies is also present in South American agriculture.[2] We use parametric and nonparametric methods in an attempt to uncover the robustness of our results to the methods employed. We examine agricultural productivity by econometrically estimating a translog production frontier for a set of 10 South American countries during the 1969–2009 period. TFP growth rates using a nonparametric and nonstochastic Malmquist index are also calculated to gain information that might be lost due to the strong specification imposed by the econometric approach. To relate the differences in efficiency to the different

*Corresponding author. Tel.: +01-402-570-3820; fax: +01-402-472-3460. *E-mail address*: ftrindade@gmail.com (F.J. Trindade).

Data Appendix Available Online

A data appendix to replicate main results is available in the online version of this article. Please note: Wiley-Blackwell is not responsible for the content or functionality of any supporting information supplied by the authors. Any queries (other than missing material) should be directed to the corresponding author for the article.

[1] In this article, TFP is synonymous to multifactor productivity (MFP). TFP growth rate is a MFP measure given by the growth rate of an output index minus the growth rate of an index of inputs. The growth rate of yields is a partial productivity measure referring to the growth of output per unit of land.

[2] A reviewer has noted that during the period of analysis most of these economies have gradually open up with expected feedback into faster agricultural productivity growth (Edwards (1993), Frankel and Romer (1999), Martin and Anderson (2006), World Bank (2012))

 DOI: 10.1111/agec.12199

environmental characteristics of each country we estimate an inefficiency effects model (Battese and Coelli, 1995).

We do not know of any other study for this region that includes recent estimates. The extension of the period of analysis is important because it allows us to look for a potential slowdown in the 21st century, in particular in the last years of the 2000s.

Literature review

During the last two decades many studies investigated agricultural productivity in South America and the rest of the world finding different results depending on the method employed and the years included in the analysis.

Looking at global agricultural production, Alston et al. (2010) find decreasing global yield growth rates for corn, wheat, rice, and soybeans when comparing the period 1960–1990 with 1990–2007; this result was observed for high-income countries but also for middle income countries. The World Bank Development Report (2007) also estimates a halving in developing countries major cereal yields growth rates from the high values observed during the 1960s and late 1970s when comparing them to the 2000s. Although the USDA (accessed on March 2015) estimates increasing TFP growth rates for world agriculture, several regions show signs of a slowdown during the last two decades. These are the U.S. and Canada, Oceania and Sub-Saharan Africa, while Latin America is stagnant. These estimates are consistent with those in Fuglie (2012). For the United States, Ball et al. (2013) find a lower TFP growth rate in 1974–2009 (1.57%) than in 1948–1974 (1.7%) and the USDA estimates a decrease in TFP growth from 1.82% in 1990–1999 to 0.85% in 2000–2009.

Focusing on South America, Fuglie (2012) estimates increasing TFP growth rates for Brazil, from 0.25% in the first decade to 4.03% in the last decade, with the exception of 1991–2000. The Andean countries[3] show a deceleration then acceleration from 1981 on. In the Southern Cone, agricultural TFP growth rate alternates between increasing and decreasing.[4] In an earlier study that uses a Malmquist index method, a nonuniform trend was found by Ludena (2010) for countries in South America when comparing TFP growth rate for 2000–2007 to that of 1990–1999 period. Argentina, Bolivia, Brazil, Ecuador, Paraguay, and Uruguay had an increase in the average TFP growth rate, while Chile, Colombia, Peru, and Venezuela had a decrease. Using an econometric approach and fitting a translog stochastic frontier production function, Bharati and Fulginiti (2007) find no sign of a slowdown in the region when analyzing data from 1972 to 2002. The region's agricultural TFP growth rate increased from 1.96% in 1972–1981 to 2.33% in 1982–1991 to 2.36% in the period 1992–2002. From their sample of 10 countries, comparing the last two periods, only Colombia, Paraguay, and Peru had an important decrease in the TFP growth rates. Finally, for a slightly different time period, Avila and Evenson (2010) using an index methodology find no sign of a slowdown for the region. Argentina, Brazil, Chile, Colombia, Ecuador, Peru, and Uruguay were found, on average, to have increasing TFP growth rates when comparing 1961–1980 to 1981–2001, Paraguay and Venezuela had decreasing rates and Bolivia showed no change.

An important problem in estimating agricultural TFP growth rates in developing countries using Fisher or Tornquist indexes is the scarcity as well as the quality of input price information. This is important because input prices are needed to obtain the cost shares used when the estimation is done by one of these index number methodologies. To circumvent this problem several authors have used alternatives. Avila and Evenson (2007) and Fuglie (2012) approached the problem of lack of information by estimating, or collecting from other studies, input shares for some large economies where data on prices were available, and then using those shares to estimate the index of smaller economies from the same region.

Distance functions, parametric or nonparametric, have been used to estimate TFP growth rates. The Malmquist index (Caves et al., 1982), when nonparametric and nonstochastic, is constructed by comparing individual country observations with the best practice frontier defined by a set of efficient countries included in the sample. Estimating a stochastic parametric frontier, Bharati and Fulgini (2007) use different institutional and economic variables to explain the differences in the efficiency performance of the countries analyzed. Among the variables considered, life expectancy, agricultural research (in amount of researchers) and trade intensity were found to be significant and positively related to increases in efficiency. Using a different parametric approach, Headey et al. (2010) perform a two steps regression to calculate the effect of different environmental variables on agricultural TFP growth rates. Between the variables that were found significant in explaining positive changes in TFP growth rate they highlight agricultural expenditures, number of agricultural scientists per thousand workers and the real rate of assistance to agriculture.

The model

In this study the focus is on a potential decrease of the rates of productivity growth in the latter years of the series as observed by other authors in other countries. The agricultural technology is approximated with a translog production function and the estimation of the agricultural productivity growth rate is obtained using an econometric maximum likelihood (ML) stochastic frontier approach (SFA).[5] A nonparametric Malmquist index is

[3] In Fuglie (2012), Andean countries are Bolivia, Colombia, Ecuador, Peru and Venezuela and Southern Cone countries are Argentina, Chile, Paraguay and Uruguay.

[4] Fuglie (2012) estimates are 0.58% (1961-1971), 2.56% (1971-1980), −0.82% (1981-1990), 1.61% (1991-2000) and 1.29% (2000-2009).

[5] Econometric estimation provides standard errors and allows tests of hypotheses but it might add specification error.

also calculated.[6] Since each method has advantages and shortcomings (see footnotes 5 and 6) we employ the two methods to check robustness of the estimation across methods. The standard neoclassical production function in logs is defined as:

$$y_{it} = f(x_{it}, t; \beta) \; i = 1, \ldots, I \quad t = 1, \ldots, T, . \tag{1}$$

where y_{it} is the logarithm of output of the ith country during the time period t, x_{it} is an Jx1 vector of the logarithm of j inputs for the ith country in time period t, β is a vector of unknown parameters, and $\varepsilon_{\mathrm{it}}$ are random variables. For the SFA, following Battese and Coelli (1995), the error term is decomposed into two random variables: $\varepsilon_{\mathrm{it}} = v_{\mathrm{it}} - u_{\mathrm{it}}$. Where v_{it} are random errors which are assumed to be iid $N(0,\sigma_v^2)$ and independently distributed from u_{it}, and where u_{it} are nonnegative random variables assumed to be iid $N(\eta, \sigma_u^2)$, where η is associated with technical inefficiency of countries over time.

The production function in (1) is used to decompose output growth into three parts: growth in the use of inputs, changes in efficiency in the use of inputs and technological change; the last two are referred to as TFP change. This is

$$\frac{dy_{it}}{dt} = \sum_{n} \frac{\partial f(x, t, \beta)}{\partial x_j} \frac{dx_{ijt}}{dt} + \frac{dTFP_{it}}{dt} \qquad i = 1, \ldots, I \quad t = 1, \ldots, T \qquad j = 1, \ldots, J \tag{2}$$

The growth in TFP can be further decomposed into:

$$\frac{dTFP_{it}}{dt} = \frac{\partial f(x, t, \beta)}{\partial t} + \frac{dTE_{it}}{dt}. \tag{3}$$

The first term on the right-hand side of (3) represents technical change (TC) or that growth due to innovations; it is the shift of the production frontier. The second term represents technical efficiency (TE) change (EC) or growth due to catching-up to the most efficient countries; it is the rate at which a country moves toward or away from the best practice frontier. The TE of the ith country in period t is the ratio of observed output for the i-th country in period t, Y_{it}, relative to its potential output when the individual country effects are zero, this is

$$TE_{it} = \frac{Y_{it}}{\exp\left[f(x_{it}, \beta) + v_{it}\right]}. \tag{4}$$

[6] This index is nonparametric, nonstochastic and constructed based on observations on two consecutive time periods so it is very sensitive to extreme values. Although it is free of specification error it needs to assume a constant returns to scale technology to reflect productivity change as pointed out by Balk (1993), Grifell-Tatjé and Lovell (1995) and O'Donnell (2012). Under CRS with a single output and multiple inputs, the Malmquist productivity index matches the Hicks Moorsteen (HM) index (Bjurek et al, 1998) and only when these two indexes are indistinguishable, the Malmquist productivity index can be interpreted as a TFP index (Bjurek, 1996 and Kerstens and Van de Woestyne, 2014). It gives us a check for the general trend of the econometrically estimated TFP growth rates.

The measure in (4) takes values from zero to one, where a value of one indicates that the country is fully efficient.

TE is captured by Eq. (1) when a frontier approach is used. Given the definition of u_{it}, the mean of the TE component η is defined as

$$\eta_{it} = z_{it}\delta, \tag{5}$$

where z_{it} is a (1xp) vector of explanatory variables that are associated with the efficiency of the countries over time (institutional, environmental and quality variables) and δ is a (px1) vector of unknown parameters to be estimated. The random variable u_{it} is obtained by truncation of the normal distribution with mean η and variance σ_u^2; this error term is associated with technical inefficiency of production. In this model u_{it} will account for differences across countries that cause departures from the maximum potential output, also referred to as the catch-up growth component.

The output-based Malmquist index estimation follows Färe et al. (1994a); this index at time t is defined in term of the distance function

$$D_O^t(x^t, y^t \,|\, C, S) = \inf\left\{\theta : \left(x^t, \frac{1}{\theta} y^t\right) \epsilon\; S^t\right\}. \tag{6}$$

where D_O^t is the output distance function in period t, and θ is the ratio of the current output basket to the maximum achievable multiple of that basket given the current level of inputs. In Färe et al. (1994b) the output-based Malmquist productivity index is

$$m^{t+1} = \frac{D^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D^t\left(x^t, y^t\right)} \left[\frac{D^t\left(x^{t+1}, y^{t+1}\right)}{D^{t+1}\left(x^{t+1}, y^{t+1}\right)} \frac{D^t\left(x^t, y^t\right)}{D^{t+1}\left(x^t, y^t\right)}\right]^{\frac{1}{2}}. \tag{7}$$

The first term on the right-hand side is the change in efficiency between years t and $t{+}1$ and the term in brackets is technical change between those years. Values greater than one in any of them reflect gains and smaller than one reflect losses. A Malmquist index value greater than one indicates increases in productivity. Coelli's DEAP program (version 2.1) was used to estimate the Malmquist indexes.

Data

The countries included in the analysis are Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, and Venezuela. In 2009, according to FAO data, these countries represented more than 99% of South America's agricultural output and population, with Argentina and Brazil accounting for 77% of the output.

Data on output and conventional[7] agricultural inputs (land, labor, livestock, and machinery) were obtained from the FAOSTAT website.[8] Fertilizer input data was obtained from Fuglie (2010) as he used a mix of FAO data and International Fertilizer Association data that is assumed to be more accurate and recent. Agricultural output is agricultural gross production in international dollars. It is an index, base 2004–2006, developed by FAO that uses a common set of commodity prices as weights. Following Fuglie (2010), to minimize the effect of short run shocks that are not accounted for by the variables considered (like weather or other sudden disturbances) we smooth the output series for each country using the Hodrick-Prescott filter, where the smoothing parameter λ was set equal to 6.25 as suggested by Ravn and Uhlig (2002).

Land is agricultural land used on permanent crops, annual crops and pastures in thousands of hectares. The countries with bigger increases in the use of land were Paraguay (+85%), Ecuador (+57%), and Brazil (+37%). Labor is measured in economically active persons (in thousands) in agriculture. There was big variability in the evolution of labor in the region; while Bolivia (+138%), Paraguay (+112%), and Peru (+94%) had big increases in the amount of labor employed, Brazil (−24%), Uruguay (−10%), and Venezuela (−7%) had decreases in labor usage. Livestock is number of animals in farms expressed in cattle equivalent converted using Hayami and Ruttan (1985) weights.[9] Following the evolution of this variable, we can differentiate two groups: countries with a modest (lower than +50%) increase in the amount used (Colombia, Chile, Peru, Uruguay, and Argentina) and countries with big increases (higher than +100%) in the amount of livestock used (Brazil, Paraguay, Venezuela, Bolivia, and Ecuador). Machinery is the number of agricultural tractors used; for this item, when possible, FAO data were updated using estimates from the respective national institutes of statistics (ANFAVEA 2011 and INDEC 2011). This variable also had important increases; we can highlight Brazil (+450%), Paraguay (+450%), and Ecuador (+400%). Fertilizer is total fertilizer consumed in metric tons of N, P_2O_2, and K_2O. This variable is very volatile. Fertilizer use increased 83 times in Paraguay and 16 times in Brazil and Argentina. The smallest increases in fertilizer use are in Uruguay that doubles its consumption, while Peru and Chile quadruple it.

Table 1 has summary statistics of the output and inputs by country. Figure 1 depicts the cumulative frequency distribution (cdf) of the growth rates of output and inputs. This graph also highlights the big changes in fertilizer input during the 1969–2009 period; an important observation given that most of these countries used very little at the start of the period of analysis. The median growth rate is about 3% but 20% of the observations show decreases of about 10% or higher and 20% show increases of 20% or higher. 80% of the growth rates for the rest of the inputs and for output are between −3% and 3%. The fact that the output cdf lies mostly to the right of the inputs means that output growth rates were generally higher than inputs growth rates (with the exception of fertilizer). Median growth rates for output and fertilizer are around 3%, for livestock around 2%, for machinery around 1%, and for land and labor around 0%.

In terms of scale of production, Brazil greatly dominates. It accounts for about 50% of the total output of the region, uses 44% of land, and is relatively fertilizer, machinery, and labor intensive. Argentina contributes 20% of the region's output and it is relatively land and machinery intensive. The next biggest contributor is Colombia with close to 8% of production and a labor intensive system. Figure 2 shows the average output and input allocations across countries.

In addition to traditional input variables, environmental, institutional, and socioeconomic variables are also considered. These variables are treated differently than inputs and are associated to the mean of the one-sided error term, hypothesizing that they might help to understand the catch-up process of countries relative to the best performers. The variables included are:

-Gross Domestic Product per capita (US$, 2000 = 100): is a proxy for overall economic development that includes aspects such as better financial instruments and better infrastructure for transportation.

-Openness (percentage): this variable is defined as the sum of exports and imports divided by real GDP (US$, 2005=100) and is obtained from the Penn World Tables. This variable reflects differences in trade environment across countries.

-Health (years): this variable is proxied by life expectancy in each country and is obtained from the United Nations Development Program (UNDP) website and the World Bank Development Indicators. This variable tries to control for differences in health population characteristics across countries.

-Education (percentage): this variable is represented by the total public expenditure (current and capital) on education expressed as a percentage of the Gross Domestic Product (GDP) in a given year. It was obtained from the World Bank Development Indicators. Since the data have some missing values, these values were linearly interpolated when possible or extrapolated using 5 years moving averages when interpolation was not possible.

-Irrigation ratio (percentage): this variable is the percentage of agricultural land that was equipped to provide water (via irrigation) to crops. It was obtained from FAOSTAT/AQUASTAT website.

-Number of persons employed full time in agricultural research (FTEs): this variable is considered to account for public investment in agricultural R&D. This item was estimated from data obtained from different specialized institutions. The estimation of these variables was made with the following procedure: from 1972 to 1992 data from the International Service for National Agricultural Research (ISNAR) and the respective institutes from each country (obtained from Cremers and Roseboom, 1997) was used. For some countries during the

[7] Following Hayami and Ruttan (1985) and other researchers.

[8] We note that FAO data is not corrected for quality changes but no alternatives are available for this set of countries. Our results are then subject to the quality of the data.

[9] Conversion ratios to beef cattle units are: 1.25 for horses, 0.25 for pigs, 0.13 for small ruminants, 12.50 per 1,000 heads of poultry, and 1.38 for camels.

Table 1
Summary statistics output and inputs. Region: South America—Period: 1969 to 2009

Output—Thousands of constant 2004–2006 Int'l Dollars—Source: FAO

Country	Mean	Max	Min	SD
Argentina	26,409,035	41,018,090	17,607,523	6,857,556
Bolivia	1,788,513	3,281,880	840,790	691,426
Brazil	67,970,692	136,391,172	29,434,361	30,376,773
Chile	4,644,448	8,088,545	2,474,154	1,856,847
Colombia	9,185,106	13,642,292	4,930,400	2,593,829
Ecuador	3,838,590	7,241,063	2,229,424	1,593,923
Paraguay	2,368,815	4,561,145	1,023,921	975,914
Peru	4,311,696	8,426,306	2,736,002	1,666,462
Uruguay	2,416,401	3,776,850	1,866,199	554,146
Venezuela	4,213,579	6,324,550	2,209,913	1,268,731
Region	12,714,687	136,391,172	840,790	22,074,840

Fertilizer - Metric Tonns - Source: Fuglie (2010)

Country	Mean	Max	Min	SD
Argentina	454,764	1,346,000	66,900	441,903
Bolivia	8,337	24,621	1,545	5,396
Brazil	4,706,091	10,654,800	630,400	2,822,905
Chile	309,263	557,500	102,100	158,168
Colombia	464,272	807,045	144,400	186,461
Ecuador	118,930	297,789	18,400	77,783
Paraguay	59,998	264,279	1,000	86,116
Peru	174,942	328,830	75,400	82,034
Uruguay	86,315	153,500	40,000	31,866
Venezuela	271,422	666,500	47,000	138,883
Region	665,434	10,654,800	1,000	1,633,900

Livestock - Thousand of cattle equivalents - Source: FAO

Country	Mean	Max	Min	SD
Argentina	63,518,622	71,495,126	56,873,650	3,370,212
Bolivia	10,666,550	15,477,500	6,859,389	2,181,506
Brazil	172,646,819	244,506,141	95,388,025	44,071,246
Chile	5,900,083	7,039,268	4,823,191	671,707
Colombia	29,574,951	34,185,096	22,435,083	2,745,069
Ecuador	6,337,631	8,432,054	3,770,163	1,594,689
Paraguay	8,796,651	12,652,013	5,060,745	2,254,800
Peru	13,545,654	16,947,738	12,007,697	1,452,847
Uruguay	13,497,605	14,863,030	11,729,825	793,638
Venezuela	16,359,130	23,792,355	9,951,994	4,221,207
Region	34,084,370	244,506,141	3,770,163	51,045,388

Machinery—No. of tractors—Source: FAO—National Institutes

Country	Mean	Max	Min	SD
Argentina	225,258	267,782	166,700	36,794
Bolivia	4,700	6,000	2,100	1,264
Brazil	625,955	867,815	155,400	228,031
Chile	41,963	54,555	33,950	8,560
Colombia	25,658	34,232	21,000	4,707
Ecuador	9,615	14,700	2,900	4,253
Paraguay	14,223	25,823	4,700	7,194
Peru	12,413	13,191	10,431	787
Uruguay	33,633	36,465	29,450	2,136
Venezuela	41,124	49,000	17,700	10,015
Region	103,454	867,815	2,100	198,956

Land—Thousand hectares—Source: FAO

Country	Mean	Max	Min	SD
Argentina	129,849	141,000	127,380	3,614
Bolivia	34,846	37,111	30,261	2,119
Brazil	238,649	264,700	193,778	22,351
Chile	15,919	17,200	14,848	630
Colombia	44,418	45,668	41,607	1,271
Ecuador	6,999	8,129	4,795	1,092
Paraguay	16,247	20,900	11,317	3,250
Peru	19,927	21,966	17,819	1,453
Uruguay	14,917	15,081	14,591	127
Venezuela	21,190	22,010	19,840	602
Region	54,296	264,700	4,795	70,576

Labor—Thousands workers—Source: FAO

Country	Mean	Max	Min	SD
Argentina	1,417	1,462	1,309	43
Bolivia	1,253	1,932	812	331
Brazil	14,409	16,342	11,336	1,423
Chile	868	982	683	110
Colombia	3,375	3,587	2,760	238
Ecuador	1,096	1,239	922	111
Paraguay	592	820	387	131
Peru	2,736	3,671	1,892	593
Uruguay	195	209	184	5
Venezuela	795	867	718	38
Region	2,673	16,342	184	4,057

1994 to 2006 period, this series was extended following the trend observed in the Agricultural Science & Technology Indicators (ASTI) data from the International Food Policy Research Institute (IFPRI). For countries with no information in ASTI, the trend in the World Bank's evolution of researchers per million people was used. For countries where none of the other data sources were available, an estimated trend was obtained from a mix of expenditure in research as percentage of GDP and the evolution of GDP (World Bank, 2013). Finally for those years where there were no data available from any source, the last estimated value was used.[10] Table 2 has summary statistics of these variables.

[10] This accounts for 15.8% of the total number of observations for this variable.

Estimation and Results

A translog production function is estimated using a ML frontier approach. Imposing symmetry, the function estimated is (8):

$$y_{it} = a_0 + \sum_{j=1}^{5} b_j x_{ijt} + \frac{1}{2}\sum_{j=1}^{5} c_{jj} x_{jj}^2 + \sum_{j=1}^{5}\sum_{k>j}^{5} c_{jk} x_{ijt} x_{ikt} + b_t t + \frac{1}{2} b_{tt} t^2 + \sum_{j=1}^{5} b_{jt} x_{ijt} t + \varepsilon_{it}. \quad (8)$$

where y_{it} is the logarithm of agricultural output for country i during year t; x's are logarithms of the inputs; t is time, a proxy

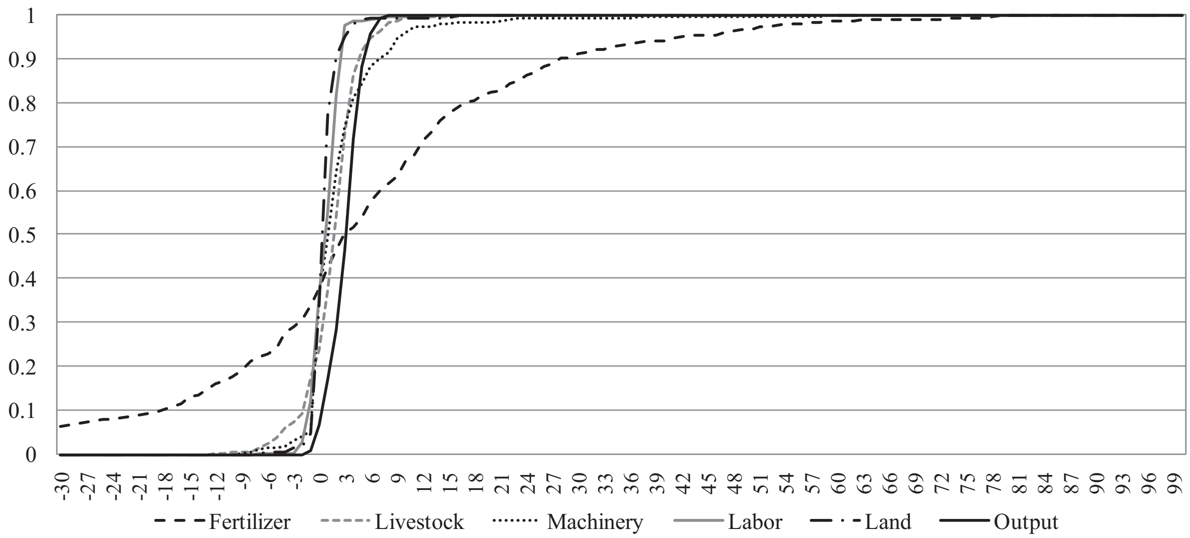

Fig. 1. Cumulative frequency growth rate (%) of output and inputs in agricultural production. South America—Period: 1969 to 2009.

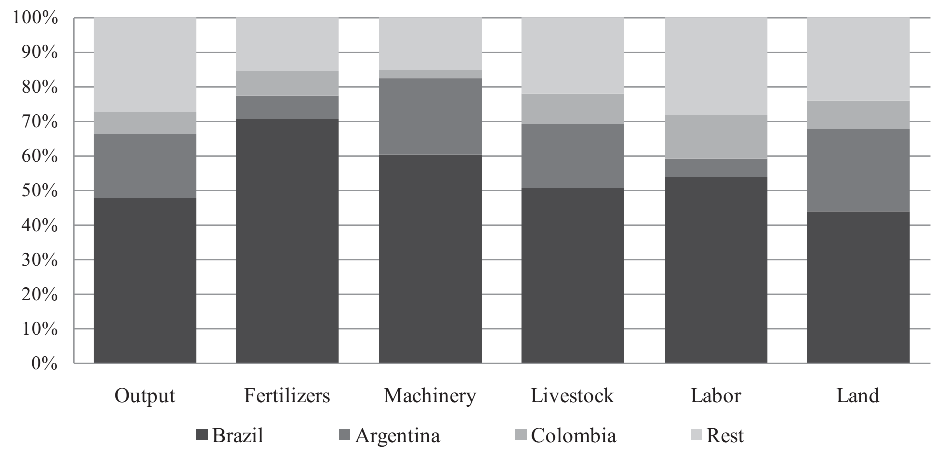

Fig. 2. Average output and input shares by country in agricultural production. South America—Period: 1969 to 2009

for technical change; a, b and c are parameters to be estimated, and ε_{it} is an error term. As stated previously, for the case of the stochastic frontier method the error is decomposed into two random variables: $\varepsilon_{\text{it}} = v_{\text{it}}$ - u_{it}.

The first derivative of (8) with respect to t corresponds to the rate of technical change, TC:

$$TC_{it} = b_t + b_{tt}t + \sum_{j=1}^{5} b_{jt}x_{ijt}t. \tag{9}$$

Coelli and Henningsen's (2013) Frontier Package for R was used to simultaneously estimate the 28 parameters of Eq. (8), the six specific parameters of Eq. (5) and the ratio of the variance of u to the total variance of $\varepsilon{:}\gamma = \frac{\sigma_u^2}{\sigma_u^2+\sigma_v^2}$. This last ratio reflects the proportion of the error term which is due to inefficiency effects. Thirty one out of 35 parameters are significantly different from zero at the 99% confidence level and 1 parameter at 95% confidence level. Parameter estimates are in the Appendix.

A Wald test was conducted to compare the translog specification versus a simpler Cobb-Douglas specification. The result of restricting all the second order coefficients of the translog form gave a Chi-square test statistic of 914.81 with a p-value of 2.2e^{-16}, rejecting the nested Cobb-Douglas specification as a better specification. According to Henningsen (2014) the estimate of gamma in the MLE translog frontier estimation, cannot be interpreted as the actual proportion of the total variance that is due to inefficiency because the estimated σ_u^2 is not equal to the variance of the inefficiency term u. We re-estimate the translog frontier's gamma parameter following his suggested procedure. The estimated value of gamma is .437; this indicates that inefficiency (or the estimated variance of the one-sided error term) explains around 44% of the total variance. A likelihood ratio test was performed to test if the OLS (no inefficiency, no one-sided error) specification was preferred to the SFA specification;

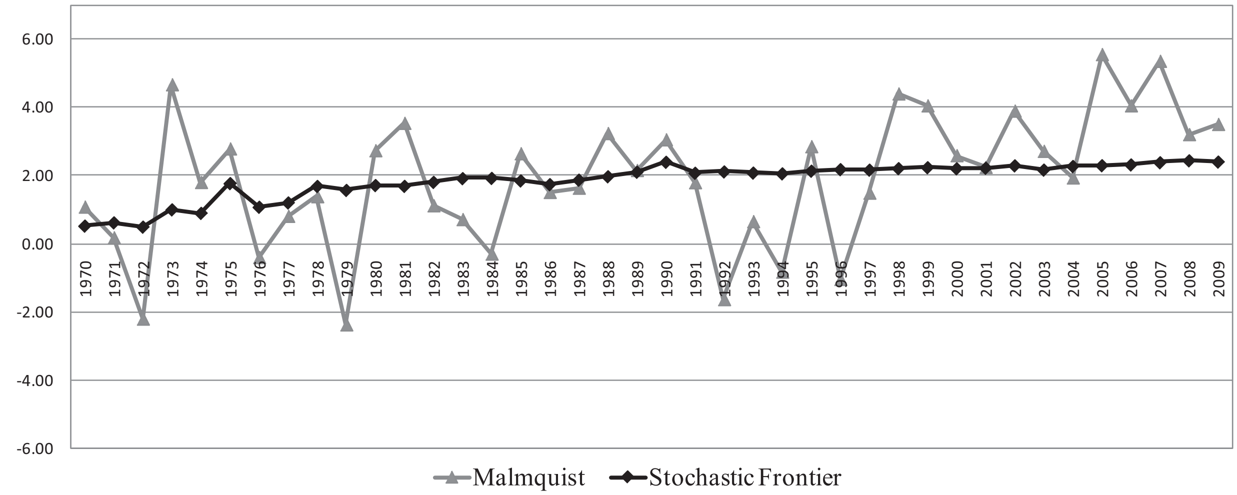

Fig. 3. TFP growth rate agricultural production. South America—Period: 1969 to 2009.

the OLS model was rejected in favor of the SFA model, i.e., the one-sided error term captures a significant portion of the total variance or there is significant variance due to technical inefficiency.[11]

Of particular interest are the parameter values of the variables used to estimate the mean of the one sided-error term, Eq. (5), as they help understand differential performance across countries.

The coefficients of life expectancy, irrigation, FTE, and the ratio education/GDP are negative and significant at the 99% confidence level implying that countries with greater values of these variables tend to be more efficient. The Openness variable coefficient estimate is counter-intuitive, as it indicates that the more open the economy is the more the average inefficiency.[12] GDP per capita was found to be not significant in explaining differences in performance across countries. The positive and significant coefficient estimated for FTE's is important as it indicates that the more agricultural R&D the better the economy performs.[13] This is consistent with our intuition and with previous results in Bharati and Fulginiti (2007) and Headey et al. (2010).

Agricultural Productivity Growth

Average agricultural output growth for the region was 3.22% per year. We estimate that TFP's contribution to this growth was 1.84% per year. Estimates are similar to the 1.7% increase found by Ludena (2010) for the period 1961–2007 for land abundant countries (excludes Ecuador) and to the 1.95%[14] increase found by Fuglie (2012) for the period 1971–2009, but lower than the 2.24% increase found by Bharati and Fulginiti (2007) for the period 1972–2002. Comparing to advanced economies, our estimated growth rate is equal to the one in Fuglie (2012) for USA/Canada (1.84%) for the period 1971–2009, it is slightly higher than the 1.58% estimated by the USDA (2015) for the United States during the same period and the 1.77% estimated by Fulginiti (2010) also for the United States (1950-1993), but lower than Headey's (2010) estimate of 2.4% for the same country during 1970–2001.

Figure 3 represents the weighted average TFP growth rates, using output as weights,[15] estimated by the two different approaches. TFP growth rates follow a positive trend during this period.

The Malmquist index is more volatile than the econometric approach because it is nonstochastic and it only uses information of two consecutive periods per year; hence if there is a slowdown in productivity growth with respect to the previous year, it will produce, by construction, a negative value. Although very different by construction, the estimated trend in growth rates during the period of analysis is similar across these methods.

Table 3 disaggregates the frontier TFP growth rate estimation by decades. For all the decades the average TFP growth rate is positive and increasing with respect to previous decades. We observe that the productivity growth rate rose steadily from 1.07% during the 1970s to 2.29% during the 2000s. There is no evidence of a productivity slowdown for the region.

[11] Average production elasticities for the stochastic frontier model are: 0.04 for fertilizer, 0.14 for labor, 0.10 for land, 0.55 for livestock, and 0.11 for machinery, indicating a scale elasticity of 0.94, not notably different from the unitary scale elasticity assumed in the Malmquist estimation. The technology even if monotone at the average is not at each data point. Violations are: fertilizer 26%, machinery 38%, livestock 11%, labor 26%, and land 48% for the frontier model. Bharati and Fulginiti (2007) find the following production elasticities for this region: 0.15 for land, 0.06 for tractors 0.3 for labor, 0.02 for fertilizer, and 0.24 for livestock.

[12] A reviewer indicated that this might be due to the cost of adjustment as a result of opening the economy.

[13] Parameters estimated are robust to the exclusion of this variable.

[14] We aggregate Fuglie's (2012) estimates from Table 16.4 using our average output shares to obtain a value for South America.

[15] The average output weights are: Brazil 52%, Argentina 22%, Colombia 7%, Chile 4%, Ecuador, Peru, and Venezuela 3%, Paraguay and Uruguay 2%, and Bolivia 1%.

Table 2
Summary statistics for variables associated with technical inefficiency of production. Region: South America - Period: 1969 to 2009

GDP per capita − US Dollars, 2000 = 100 − Source: World Bank Database

Country	Mean	Max	Min	SD
Argentina	7,223	9,936	5,582	948
Bolivia	997	1,203	832	98
Brazil	3,373	4,479	1,874	572
Chile	3,536	6,240	1,890	1,407
Colombia	2,253	3,153	1,428	449
Ecuador	1,315	1,711	889	176
Paraguay	1,270	1,518	759	220
Peru	2,150	2,962	1,628	289
Uruguay	5,714	8,425	4,246	1,143
Venezuela	5,406	6,548	3,966	639
Region	3,324	9,936	759	2,166

Openness − Percentage, US Dollars, US Dollars, 2005 = 100 − Source: Penn world tables

Country	Mean	Max	Min	SD
Argentina	27	49	13	12
Bolivia	50	69	34	9
Brazil	15	28	9	6
Chile	49	82	25	17
Colombia	29	44	20	7
Ecuador	49	67	35	9
Paraguay	84	167	43	37
Peru	32	48	22	7
Uruguay	40	65	22	13
Venezuela	51	62	37	7
Region	42	167	9	23

Life expectancy—Years—Source: World Bank Database

Country	Mean	Max	Min	SD
Argentina	71	75	66	3
Bolivia	57	66	45	7
Brazil	66	73	58	4
Chile	72	79	62	5
Colombia	68	73	61	4
Ecuador	68	75	57	6
Paraguay	68	72	65	2
Peru	64	74	53	6
Uruguay	72	76	69	2
Venezuela	70	74	63	3
Region	68	79	45	6

Education—Education as % of GDP—Source: World Bank Database

Country	Mean	Max	Min	SD
Argentina	2.81	6.03	1.05	1.44
Bolivia	5.50	8.08	4.66	0.77
Brazil	4.66	5.82	3.78	0.40
Chile	3.50	5.20	2.36	0.66
Colombia	3.16	4.84	1.73	0.85
Ecuador	4.28	10.21	0.98	2.13
Paraguay	3.17	3.48	2.50	0.26
Peru	2.82	5.30	1.15	1.33
Uruguay	2.43	3.10	1.99	0.28
Venezuela	4.15	5.21	2.53	0.53
Region	3.65	10.21	0.98	1.39

Irrigation—% of agricultural land irrigated—Source: AQUASTAT (FAO)

Country	Mean	Max	Min	SD
Argentina	1.15	1.22	0.97	0.06
Bolivia	0.37	0.47	0.26	0.05
Brazil	0.98	1.70	0.39	0.38
Chile	9.87	12.62	7.24	2.12
Colombia	1.40	2.16	0.57	0.60
Ecuador	10.46	12.74	9.47	0.93
Paraguay	0.39	0.46	0.32	0.04
Peru	5.87	6.26	5.42	0.29
Uruguay	0.86	1.49	0.28	0.41
Venezuela	2.12	2.72	1.36	0.49
Region	3.35	12.74	0.26	3.82

FTE—Personnel employed full time in agricultural research—Source: several

Country	Mean	Max	Min	SD
Argentina	1,043	1,723	820	207
Bolivia	190	427	48	120
Brazil	1,796	2,585	1,037	460
Chile	209	289	150	45
Colombia	478	688	321	83
Ecuador	191	298	115	45
Paraguay	75	115	24	31
Peru	206	273	143	43
Uruguay	79	119	64	10
Venezuela	579	1,690	285	356
Region	485	2,585	24	558

All the countries show a positive rate of TFP growth in the four decades with the sole exception of Bolivia in the 1970s (−0.84%). During the last decade analyzed, TFP grew, in most countries, at more than 2% a year. Chile (3.23%) followed by Brazil (2.54%), Ecuador (2.55%), and Venezuela (2.28%) have the fastest growth rates; Bolivia (0.78%) and Colombia (0.74%) the slowest.

Ludena's (2010) Malmquist index estimate for the period 2001–2007 (2.00%) is lower than our estimate (2.27%) for the same years and Fuglie's (2012) Tornqvist-Theil index estimate for the period 2001–2009 (2.96%) is higher than our estimate (2.31%) for the same period.

Comparing the estimated growth in the last decade across regions we found a similar growth rate (2.24%) to that in Fuglie (2012) for the United States and Canada (2.24%) and a higher estimate than the USDA's productivity accounts for the United States (0.85%)

Table 3 also shows that the TFP growth rate is mainly driven by a technological change component that has been steadily increasing since the 1970s. This positive and

Table 3
Maximum likelihood estimates of technical change, efficiency change and total factor productivity change (yearly averages). South America—period: 1969 to 2009

	TC				EC				TFP			
Country	1969-1979	1980-1989	1990-1999	2000-2009	1969-1979	1980-1989	1990-1999	2000-2009	1969-1979	1980-1989	1990-1999	2000-2009
Argentina	1.23	1.79	2.10	2.13	0.08	−0.04	0.07	0.01	1.31	1.74	2.17	2.14
Bolivia	−0.95	−0.15	0.35	0.61	0.11	1.48	1.21	0.17	−0.84	1.33	1.57	0.78
Brazil	1.02	2.09	2.41	2.52	0.02	0.03	0.00	0.02	1.04	2.11	2.41	2.54
Chile	1.87	2.24	2.70	3.25	0.12	0.02	0.03	−0.01	1.98	2.26	2.73	3.23
Colombia	0.05	0.65	0.58	0.72	0.44	0.47	0.01	0.02	0.49	1.12	0.60	0.74
Ecuador	0.71	1.24	1.89	2.38	0.12	0.21	−0.16	0.17	0.83	1.45	1.73	2.55
Paraguay	0.66	1.24	1.78	1.93	0.59	0.22	−0.98	0.45	1.25	1.47	0.80	2.38
Peru	0.29	0.78	1.17	1.34	0.78	0.20	1.55	0.05	1.07	0.97	2.72	1.39
Uruguay	1.05	1.53	1.81	2.20	−0.27	0.19	0.18	0.06	0.79	1.72	1.99	2.26
Venezuela	0.99	1.49	1.99	2.26	0.14	−0.05	0.08	0.02	1.13	1.45	2.06	2.28
Weighted Average	0.87	1.77	2.10	2.26	0.12	0.08	0.06	0.03	1.07	1.85	2.16	2.29

increasing trend applies for every country in the region with the exception of Colombia during the 1990s. Countries such as Chile, Brazil, and Argentina, have higher technological change presumably due to a faster adoption of new technologies. These countries have a production profile similar to that of temperate advanced countries and have been able to adapt technology faster. We also observe that the EC component has steadily decreased its contribution showing an initially fast catching up of the more inefficient countries with respect to those that are on the frontier. Once on the frontier, performance can only be enhanced by innovations that expand the frontier.

Half of the countries have a steady increase in the TFP growth rate. Brazil's rate increased from 1.15% during the 1970s to 2.61% during the 2000s. This estimate is lower than that found by Gasques et al. (2008) using a Tornquist index, than Ludena's (2010) Malmquist index for the period 2000–2007 (2.80%) and than Fuglie's (2012) Tornquist index (4.03%) for the 2001–2009 period but higher than the 2.55% estimated for 1985–2006 by Rada and Valdes (2012) using a SFA. We do observe slower growth in the second economy of the region, Argentina; the rate of growth during the 2000s is similar to that of the previous decade. Argentina's TFP growth rate for the 1990s is lower than that found by Bharati and Fulginiti (2007) using an econometric frontier for the period 1992–2002 (2.31%) but much higher than that found by Ludena (2010) for 1991–2000 (0.8%). We estimate faster rates for this country for the 2001–2009 period (2.13%) consistent with Ludena's 3.8% estimate but contrary to Fuglie's (2012) estimated slowdown (1.45% in 1991–2000 and 1.22% in 2001–2009). For most of the remaining countries, Chile, Colombia, Ecuador, Paraguay, Uruguay and Venezuela there is an increase in TFP growth rate in the 2000s with respect to the 1990s.

In Table 4 TFP growth estimates per country are presented. Averaging growth rates could be misleading, in particular for the Malmquist index as this index is built from comparison of two consecutive periods only and is very sensitive to outliers with the average affected by these extremes making direct comparisons of the average rates across methods suspect. Still we present them in this table for the sake of transparency.

The SFA shows that the TFP growth is driven mainly by technical change (1.73% average per year versus only .07% efficiency change).[16] Chile shows the highest average TFP growth rate, followed by Brazil and Argentina. This result, in part, was also found by Bharati and Fulginiti (2007) where technical change (1.97%) was found to be the main driver of TFP change (2.24%). In their study though the countries with the higher average TFP growth rate were Brazil (2.62%), followed by Venezuela (2.39%) and then Chile (2.16%) and Argentina (2.15%). Among the ten countries analyzed, Bolivia and Peru have the most impressive catching-up performance; for Bolivia this has been the most important force driving its TFP growth rate (it had a negative TC of −.034%). Consistent with Bharati and Fulginiti (1997), these bigger gainers in efficiency caught up fast to a frontier determined by Brazil (32 years) and Argentina (9 years). Argentina's innovations were responsible for displacing the frontier during the late 1970s and late 1990s while Brazil's performance dominated during the remaining years. Most countries improved their efficiency by the late 2000s with the sole exception of Paraguay.

The Malmquist index estimates for some countries show negative average values that should be understood having in mind the sensitivity of this method to consecutive years with sharp changes. These issues that stem from methodological differences between the parametric and non-parametric approaches are also found in Fulginiti and Perrin (1997), Fulginiti et al. (2004), Headey et al. (2010), and Tong et al. (2012).

Figure 4 shows the cdf of TFP growth rates estimated with the stochastic frontier method for the average of the region and for the individual countries. The median for the region is about 2%; with a minimum of 0.4% and a maximum of 2.6%. There is more variability in the lower half of the TFP growth rates' distribution. With respect to individual countries, consistent

[16] A reviewer pointed out that high technological change with low efficiency might be associated with the introduction and adaptation to new technologies (learning by doing).

Table 4
Average TFP growth rates (%) in agriculture South America—Period: 1969–2009

	Stochastic Frontier			Malmquist			
Country	TC	EC	TFP	TC	EC	TFP	Output
Argentina	1.812	0.028	1.840	−0.945	0.000	−0.945	2.146
Bolivia	−0.034	0.742	0.707	2.223	0.000	2.223	3.472
Brazil	2.011	0.014	2.025	2.195	0.998	3.193	3.910
Chile	2.514	0.037	2.551	1.885	0.000	1.885	2.993
Colombia	0.500	0.236	0.736	1.045	1.167	2.128	2.567
Ecuador	1.554	0.085	1.639	0.102	0.000	0.103	2.987
Paraguay	1.403	0.070	1.473	0.240	−0.855	−0.658	3.818
Peru	0.894	0.644	1.538	−0.080	1.903	1.363	2.878
Uruguay	1.647	0.042	1.690	1.360	0.055	1.313	1.789
Venezuela	1.684	0.047	1.731	1.915	0.120	2.023	2.668
Weighted Average	1.729	0.072	1.844	1.283	0.631	1.914	3.225

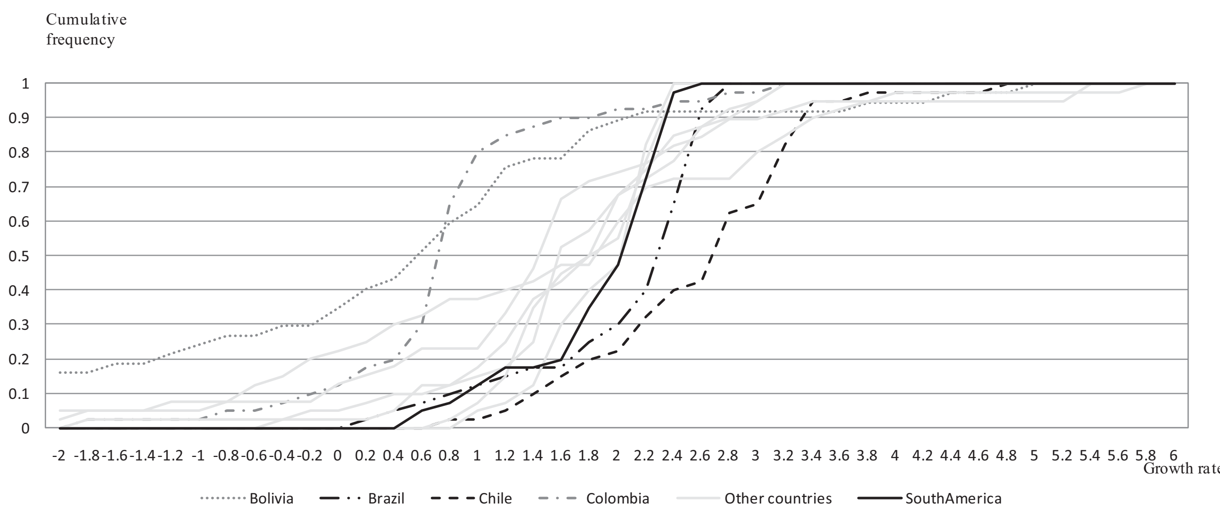

Fig. 4. Cumulative frequency distribution TFP growth rate in agricultural production. South America—Period: 1969 to 2009.

with our previous analysis, the countries that have more than 90% of their TFP growth rates below the region's average are Bolivia and Colombia. In Bolivia, in 24 out of 41 years, the TFP growth rates are lower than 1%, with negative rates in more than half of these years. Colombia does not have as many negative growth rates but in 32 years the TFP growth rates are smaller than 1.5%. On the other extreme we find Brazil and Chile with growth rates higher than the region's average. Chile has been consistently above the average showing the highest growth rates for most of the period and a median of 2.6%. Brazil's TFP growth rates are higher than the South American average in most years and its median rate is 2.3%.

Figure 5 shows TFP indexes for every country since 1969. Note the strong agricultural productivity performance of Chile and Brazil while Bolivia and Colombia seem to fall behind the rest of the countries in the region.

Table 5 shows the average annual growth rate of output, the imputed change in output that would have been possible from the observed input changes, and the Solow residual (TFP change plus unexplained residual) for all countries during the period of analysis. Approximately half of the average output growth for the region can be attributed to input growth and half to productivity change.

Table 5
Growth Decomposition of TFP rates in agriculture South America—Period: 1970–2009 (%)

South America—Period: 1970–2009 (%)			
Country	Output Growth	Inputs	Solow residual*
Argentina	2.15	0.73	1.42
Bolivia	3.47	4.94	−1.46
Brazil	3.91	2.09	1.82
Chile	2.99	0.76	2.24
Colombia	2.57	2.09	0.47
Ecuador	2.99	2.11	0.88
Paraguay	3.82	2.91	0.91
Peru	2.88	1.47	1.41
Uruguay	1.79	0.45	1.34
Venezuela	2.67	1.85	0.81
Weighted average	3.22	1.67	1.55

*Solow residual is TFP change as in Eq. (3) plus unexplained residual.

Performance by country during the last decade of analysis, 2000–2009, is shown in Table 6. During this decade, Chile's TFP growth rates are the highest, above 3%. TFP growth rates for Argentina, Brazil, Ecuador, and Venezuela are between 2%

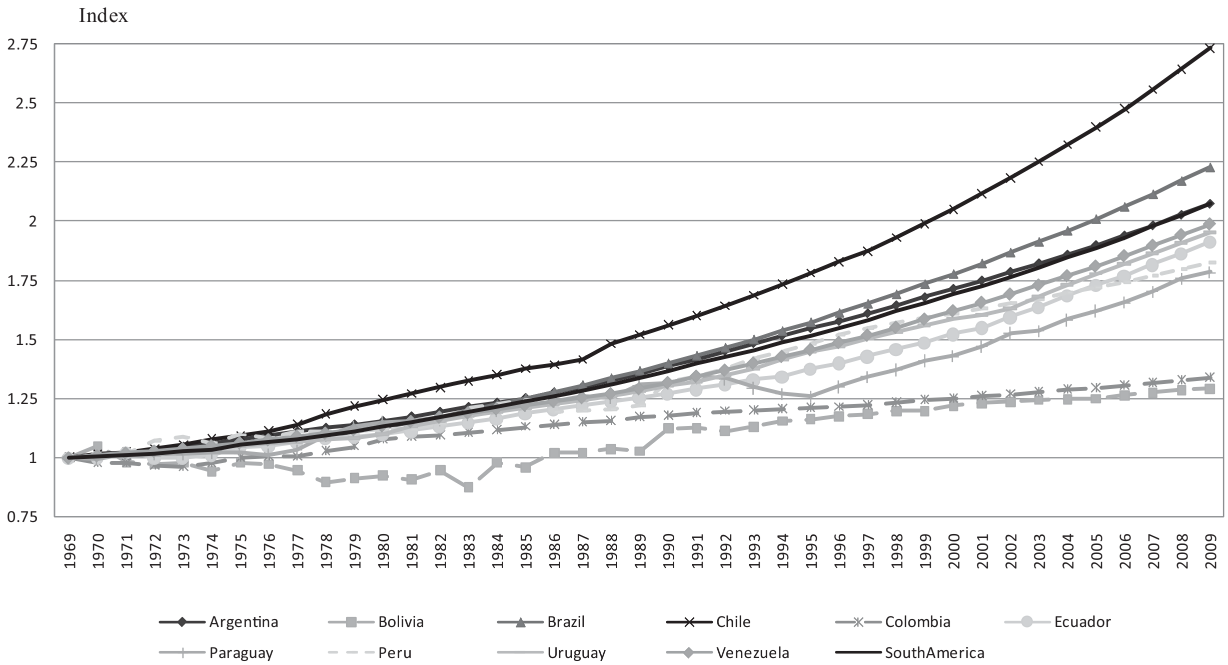

Fig. 5. Stochastic frontier TFP index (1969 = 1). South America—Period: 1969 to 2009.

Table 6
TFP growth rates in agriculture by year (%). South America—Period: 2000–2009

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Argentina	2.12	2.06	2.09	2.03	2.01	2.19	2.12	2.20	2.26	2.30
Bolivia	1.90	0.88	0.53	0.62	0.30	0.10	1.13	0.86	1.03	0.42
Brazil	2.47	2.51	2.53	2.42	2.46	2.53	2.57	2.60	2.65	2.65
Chile	3.15	3.17	3.13	3.17	3.21	3.18	3.26	3.30	3.39	3.38
Colombia	0.52	0.75	0.74	0.66	0.78	0.66	0.72	0.84	0.93	0.77
Ecuador	2.38	1.75	2.91	2.50	3.08	2.59	2.36	2.64	2.69	2.55
Paraguay	1.33	2.93	3.75	0.62	3.06	2.38	2.18	2.87	3.16	1.51
Peru	1.23	1.35	1.24	1.10	1.54	1.30	1.44	1.54	1.54	1.58
Uruguay	1.83	1.03	1.70	2.87	3.11	2.63	2.37	2.39	2.31	2.42
Venezuela	2.23	2.19	2.10	2.25	2.27	2.30	2.42	2.36	2.36	2.34
Weighted average	2.20	2.22	2.29	2.16	2.27	2.29	2.31	2.38	2.44	2.40

and 3%. The rest of countries, except Colombia and Bolivia, show TFP growth rates in the 1%–2% range. Colombia's productivity was one of the lowest (second after Bolivia) but the most improved. The slight decrease in the region's TFP growth rate in 2009 is mainly due to a decrease in the TFP growth rates of Paraguay, Colombia and Bolivia. We do not find evidence of an overall slowdown for the region during the years 2000–2009.

Conclusions

The objective of the present study is to estimate agricultural productivity growth during the 1969–2009 period with particular attention to a potential slowdown in the last decade of analysis. Studies have found a slowdown in agricultural productivity growth in OECD economies that started in the late 1990s and is likely related to decreases in R&D investment funding. With this purpose in mind we estimated agricultural TFP growth rates in South American countries. Different institutional, economic and sociological environmental features of each country were also considered in the econometric estimation and used to shed light on the differences in performance between the countries in the sample.

Results show that productivity growth is strongly associated to output growth contributing to half of this growth. While output growth in the region during 1969–2009 is 3.22%, productivity growth is 1.84%, increasing from 1.07% to 2.29% by the end of the period. The best performer is Chile (2.55%) followed by Brazil (2.03%). The worst performer is Bolivia (0.71%). This increase on TFP growth in the region is mostly related to innovations. We also find that spending on education and R&D in agriculture as well as irrigation and differences in life expectancy are important in understanding differential performance across the countries of this region. Estimates for the last decade of the analysis, 2000–2009, show no evidence of a slowdown in agricultural productivity growth in South America.

Although this analysis shows no evidence, so far, of a slowdown in agricultural productivity in South American agriculture, we end with a note of caution. During 2000–2009 agricultural production increased by 3.91% yearly and productivity growth rates went from 2.16% during the 1990s to 2.29% in the 2000s. This is not surprising because the region has benefited from innovations in advanced economies in addition to those resulting from their own R&D investments. Given the lags in adoption and the time needed for adaptation of new technologies imported from advanced economies, we do not expect an immediate impact in productivity growth in South America of decreases in R&D investments in basic research in advanced economies. Given the responsiveness of South American agriculture to R&D investments, we remain attentive to the potential consequences of decreases in R&D funding for agriculture in advanced economies as well as in their own domestic investments.

Acknowledgments

Support is acknowledged from the Agricultural Research Division's Strategic Investments: Enhancing Interdisciplinary Teams Program "Forty-First Parallel Agro-Ecosystem Sustainability and Productivity," University of Nebraska, and from USDA, NIFA NEB-24-164 and NEB-24-172.

Appendix

Agricultural productivity in South America - 1969 to 2009 Maximum Likelihood Parameter Estimates. Stochastic Frontier Analisys

Coefficients:	Estimate	Std. Error	t value	Pr (>|t|)
(Intercept)	47.9760	2.9528	16.2475	<2.2e-16
X1	−1.0316	0.2883	-3.5788	0.0003
X2	6.7701	0.3530	19.1766	<2.2e-16
X3	−5.9218	0.6119	-9.6785	< 2.2e-16
X4	1.6052	0.5872	2.7338	0.0063
X5	-4.8808	0.7214	-6.7662	0.0000
X1sq	0.0358	0.0067	5.3132	0.0000
X2sq	0.1848	0.0191	9.6827	< 2.2e-16
X3sq	0.3595	0.0427	8.4242	< 2.2e-16
X4sq	0.1050	0.0158	6.6589	0.0000
X5sq	0.3695	0.0477	7.7491	0.0000
X1X2	-0.1467	0.0226	-6.5008	0.0000
X1X3	0.0937	0.0337	2.7790	0.0055
X1X4	-0.0726	0.0173	-4.1967	0.0000
X1X5	0.0737	0.0320	2.3022	0.0213
X2X3	-0.6919	0.0516	-13.4187	< 2.2e-16
X2X4	0.2349	0.0340	6.9166	0.0000
X2X5	0.0814	0.0528	1.5410	0.1233
X3X4	0.0856	0.0670	1.2783	0.2011
X3X5	0.0034	0.0983	0.0343	0.9727
X4X5	-0.5880	0.0544	-10.8152	< 2.2e-16

Coefficients:	Estimate	Std. Error	t value	Pr (>|t|)
T	0.0610	0.0157	3.8742	0.0001
Tsq	0.0002	0.0000	5.8283	0.0000
TX1	-0.0030	0.0008	-3.8051	0.0001
TX2	0.0127	0.0011	11.5285	< 2.2e-16
TX3	-0.0059	0.0015	-4.0287	0.0001
TX4	0.0036	0.0009	3.8427	0.0001
TX5	-0.0078	0.0018	-4.2786	0.0000
Z_Intercept	1.8444	0.2773	6.6519	0.0000
Z_GDPcapita	0.0000	0.0000	-1.7748	0.0759
Z_Openness	0.0012	0.0004	3.2520	0.0011
Z_Lifeexp	-0.0221	0.0034	-6.4371	0.0000
Z_FTE	-1.6367	0.5283	-3.0979	0.0019
Z_Irrigation	-0.0003	0.0001	-2.6376	0.0083
Z_educgdp	-0.0828	0.0159	-5.2160	0.0000
sigmaSq	0.0044	0.0007	6.1942	0.0000
gamma	0.6808	0.0749	9.0906	< 2.2e-16

X1: log of fertilizer, x2: log of machinery, X3: log of livestock, X4: log of labor, X5: log of land, T: time trend.

References

Agricultural Science and Technology Indicators (ASTI). Accessed May 2012, available at http://www.asti.cgiar.org/.

Alston, J.M., Babcock, B.A., Pardey, P.G., 2010. The Shifting Patterns of Agricultural Production and Productivity Worldwide. The Midwest Agribusiness Trade Research and Information Center Iowa State University, Ames, Iowa.

AQUASTAT, 2013. Accessed Nov 2013, available at www.fao.org/nr/water/aquastat/data/query/index.html?lang=en.

Associação Nacional dos Fabricantes de Veículos Automotores (ANFAVEA). 2011. Brazilian Automotive Industry Yearbook. Brazil. Available at http://www.anfavea.com.br/anuario.html.

Avila, F., Evenson, R., 2010. Total factor productivity growth in agriculture In Evenson, R.E., Pingali, P. (Eds.), The role of technology capital, in Handbook of Agricultural Economics, Vol. IV, Chapter 72. Elsevier, Amsterdam, pp. 3769–3822.

Balk, B. M., 1993. Malmquist productivity indexes and Fisher ideal indexes: Comment. Econ. J. 103, 680–682.

Ball, E., Schimmelpfennig, D., Wang, S. L., 2013. Is US agricultural productivity growth slowing? Appl. Econ. Persp. Policy 35(3), 435–450.

Battese, G.E., Coelli, T.J., 1995. A model for technical inefficiency effects in a Stochastic frontier production function for panel data. Empirical Econ. 20(2), 325–332.

Bharati, P., Fulginiti, L., 2007. Institutions and agricultural productivity in Mercosur. In Teixeira, E.C., Braga, M.J. (Eds.), Institutions and Economic Development. Viçosa, Brazil.

Bjurek, H., 1996. The Malmquist total factor productivity index. Scand. J. Econ. 98(2), 303–313.

Bjurek, H., Førsund, F., Hjalmarsson, L., 1998. Malmquist productivity indices: An empirical investigation. In Färe, R., Grosskopf, S., Russell, R. (Eds.), Index Numbers: Essays Honour of Sten Malmquist. Kluwer, Boston, 217–239.

Caves, D.W., Christensen, L.R., Diewert, W.E., 1982. The economic theory of index numbers and the measurement of input, output, and productivity. Econometrica 50(6), 1393–1414.

Coelli, T.J., 1996. A Guide to DEAP version 2.1: A Data Envelopment Analysis (Computer) Program. Working paper, Centre for Efficiency and Productivity Analysis (CEPA), Department of Econometrics, University of New England, Armidale, Australia, No. 8/96.

Coelli, T., Henningsen, A., 2013. Frontier: Stochastic Frontier Analysis. R package version 1.1-0.available at http://CRAN.R-Project.org/package=frontier.

Cremers, M., Roseboom, J., 1997. Agricultural Research in Government Agencies in Latin America: A Preliminary Assessment of Investment Trends. International Service for National Agricultural Research (ISNAR), Discussion Papers 97-7.

Edwards, S., 1993. Openness, trade liberalization, and growth in developing countries. J. Econ. Lit. XXXI, 1358–1393.

Frankel, J.A., Romer, D., 1999. Does trade cause growth?. Am. Econ. Rev. 89(3), 379–399.

FAOSTAT, 2013. Accessed Nov 2013, available at http://faostat.fao.org/site/339/default.aspx.

Färe, R., Grosskopf, S., Lovell, K., 1994*a*. Production Frontiers. Cambridge University Press, Cambridge.

Färe, R., Grosskopf, S., Norris, M., Zhang, Z., 1994*b*. Productivity growth, technical progress, and efficiency change in industrialized countries. Am. Econ. Rev. 84(1), 66–83.

Fuglie, K.O., 2010. Total factor productivity in the global agricultural economy: Evidence from FAO data. The Shifting Patterns of Agricultural Production and Productivity Worldwide. Chapter 4. The Midwest Agribusiness Trade Research and Information Center Iowa State University, Ames, Iowa.

Fuglie, K.O., 2012. Productivity growth and technology capital in the global agricultural economy. In Fuglie, K.O., Wang, S.L., Eldon, B.V. (Eds.), Productivity Growth in Agriculture: An International Perspective. CABI, Wallingford (UK) and Cambridge, MA (USA). pp. 335–368.

Fulginiti, L., 2010. Estimating Griliches' k-shifts, Am. J. Agric. Econ. 92(1), 86–101.

Fulginiti, L., Perrin, R.K., B., Yu, 2004. Institutions and agricultural productivity in Sub-Saharan Africa. Agricultural Economics, Vol. 31, Blackwell, pp. 169–180.

Fulginiti, L., Perrin, R.K., 1997. LDC agriculture: Non parametric Malmquist productivity indexes. J. Dev. Econ. 58, 373–390.

Grifell-Tatjé, E., Lovell, C.K., 1995. A note on the Malmquist productivity index. Econ. Lett. 47(2), 169–175.

Gasques, J.G., Bastos, E.T., Bacchi, M., 2008. Produtividade e Crescimento da Agricultura Brasileira. Assessoria de Gestão Estratégica, Brasilia.

Hayami, Y., Ruttan, V.W., 1985. Agricultural development: An international perspective. Baltimore: Johns Hopkins University Press.

Headey, D., Alauddin, M., Rao, D.S. 2010. Explaining agricultural productivity growth: An international perspective. Agric. Econ.41(1), 1–14.

Henningsen, A. 2014. Introduction to econometric production analysis with R (Draft Version). Department of Food and Resource Economics, University of Copenhagen, August 31, 2014.

Instituto Nacional de Estadísticas y Censos (INDEC). 2011. Informe de coyuntura de la Industria de Maquinaria Agrícola - Cuarto Trimestre Año 2010. Instituto Nacional de Estadísticas y Censos, Argentina.

Kerstens, K., Van de Woestyne, I., 2014. Comparing Malmquist and Hicks–Moorsteen productivity indices: Exploring the impact of unbalanced vs. balanced panel data. Eur. J. Oper. Res. 233(3), 749–758.

Ludena, C.E., 2010. Agricultural productivity growth, efficiency change and technical progress in Latin America and the Caribbean. Inter-American Development Bank, 2010.

Martin, W., Anderson, K., 2006. The Doha agenda negotiations on agriculture: What could they deliver?. Am. J. Agric. Econ. 88(5), 1211–1218.

O'Donnell, C.J., 2012. An aggregate quantity framework for measuring and decomposing productivity change. J. Product. Anal. 38, 255–272.

Penn World Tables Version 7.1. 2012. Heston, A., Summers, R., Atem, B. Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania, Nov 2012.

Rada, N., Valdes, C., 2012. Policy, Technology, and Efficiency of Brazilian Agriculture. United State Department of Agriculture (USDA)—Economic Research Service (ERS)—Economic Research Report No. 137.

Ravn, M., Uhlig, H., 2002. On adjusting the Hodrick–Prescott filter for the frequency of observations. Rev Econ Stat. 84(2), 371–375.

Tong, H., Fulginiti, L.E., Sesmero, J.P., 2012. Agricultural productivity in China: National and regional growth patterns, 1993–2005. In Fuglie, K.O., Wang, S.L., Eldon, B.V. (Eds.), 2012. Productivity Growth in Agriculture: An International Perspective. CABI, Wallingford (UK) and Cambridge, MA (USA). pp. 163–181.

United Nations, 2013. United Nations Development Program web-site. Accessed Nov 2013, available at http://hdr.undp.org/hdr2006/statistics/

United States Department of Agriculture (USDA), Economic Research Service (ERS), 2015, Agricultural Productivity in the U.S. Accessed Mar 2015, available at http://www.ers.usda.gov/data-products/agricultural-productivity-in-the-us.aspx

United States Department of Agriculture (USDA), Economic Research Service (ERS), 2015, International Agricultural Productivity. Accessed Mar 2015, available at http://www.ers.usda.gov/data-products/international-agricultural-productivity.aspx.

World Bank, 2007. World Bank Development Report 2008. Washington DC.

World Bank, 2012. Sustainable Agricultural Productivity Growth and Bridging the Gap for Small-Family Farms. Available at http://documents.worldbank.org/curated/en/2012/06/16432393/sustainable-agricultural-productivity-growth-bridging-gap-small-family-farms#.

World Bank, 2013. World Development Indicators on line. Accessed Nov 2013, available at http://web.worldbank.org/WBSITE/EXTERNAL/DATASTATISTICS/.