IDB

IDB WORKING PAPER SERIES No. IDB-WP-186

Agricultural Productivity Growth, Efficiency Change and Technical Progress in Latin America and the Caribbean

Carlos E. Ludena

May 2010

Inter-American Development Bank
Department of Research and Chief Economist

Agricultural Productivity Growth, Efficiency Change and Technical Progress in Latin America and the Caribbean

Carlos E. Ludena

Inter-American Development Bank

Inter-American Development Bank

2010

Cataloging-in-Publication data provided by the
Inter-American Development Bank
Felipe Herrera Library

Ludena, Carlos E.
Agricultural productivity growth, efficiency change and technical progress in Latin America and the Caribbean / Carlos E. Ludena.
p. cm. (IDB working paper series ; 186)
Includes bibliographical references.
1. Agricultural productivity—Latin America. 2. Agricultural productivity—Caribbean Area. 3. Agriculture—Economic aspects—Caribbean Area. 4. Agriculture—Economic aspects—Latin America. I. Inter-American Development Bank. Research Dept. II. Title. III. Series.

HD1790.5 L83 2010

Abstract[1]

This paper analyzes total factor productivity growth in agriculture in Latin America and the Caribbean between 1961 and 2007 employing the Malmquist Index, a non-parametric methodology that uses data envelopment analysis (DEA) methods. The results show that among developing regions, Latin America and the Caribbean shows the highest agricultural productivity growth. The highest growth within the region has occurred in the last two decades, especially due to improvements in efficiency and the introduction of new technologies. Within the region, land-abundant countries consistently outperform land-constrained countries. Within agriculture, crops and non-ruminant sectors have displayed the strongest growth between 1961 and 2001, and ruminant production performed the worst. Additional analysis of the cases of Brazil and Cuba illustrates potential effects of policies and external shocks on agricultural productivity; policies that do not discriminate against agricultural sectors and that remove price and production distortions may help improve productivity growth.

JEL Classification: O13, O47, O54
Keywords: Total factor productivity, Agriculture, Crops, Livestock, Latin America and the Caribbean, Malmquist Index

[1] The author would like to thank Carmen Fernandes for her invaluable help in constructing the data on fertilizers and livestock, and the comments of an anonymous reviewer.

1. Introduction

Productivity growth in agriculture has captured the interest of economists for a long time. As agriculture develops, it releases resources to other sectors of the economy. This has been the base of successful industrialization in now developed economies such as the Unites States, Japan or countries in the European Union. Thus, agricultural development becomes an important precondition of structural transformation towards industrial development, as it precedes and promotes industrialization (Adelman and Morris, 1988).

Agricultural productivity plays a key role in the process of industrialization and development. Krueger, Valdes and Schiff (1991) and Stern (1989) show that countries with high levels of productivity growth and only modest discrimination against their agricultural sectors were successful industrializers. Meanwhile, countries with low levels of productivity growth and a strong bias against agriculture through trade and pricing policies were unsuccessful industrializers.

In Latin America and the Caribbean, most of the analysis of total factor productivity (TFP) growth in agriculture in the last 20 years has been in the context of worldwide multicountry studies (Fulginiti and Perrin, 1993, 1997, 1998; Arnade, 1998; Trueblood and Coggins, 2003; Nin, Arndt and Preckel, 2003; Coelli and Rao, 2005; Weibe et al., 2000; Bravo-Ortega and Lederman, 2004; and Ludena et al., 2007). These studies offer a broad view of agricultural productivity growth and present results for certain Latin American countries.

At the country level, there have been several studies that analyze agricultural productivity using total factor productivity with focus on particular countries. The countries analyzed in these studies include Argentina (Lema and Brescia, 2001; Lema and Parellada, 2000; Lema and Battaglia, 1998), Brazil (Rada, Buccola and Fuglie, 2009; Gasques, Bastos and Bacchi, 2008; Pereira et al., 2002; Gasques and Conceição, 2001; Gasques and Conceição, 1997; and Avila and Evenson, 1995), Chile (Olavarría, Barvo-Ureta and Cocchi, 2004), Colombia (Romano, 1993), Mexico (Fernández-Cornejo and Shumway, 1997), and Uruguay (Arancet and Calvete, 2003). Other studies have focused on group of countries such as the Andean region (Pfeiffer, 2003; Ludena et al., 2005) and South American countries (Bharati and Fulginiti, 2007).

However, none of these studies offer a complete comparative analysis of agricultural productivity growth among countries within Latin America and the Caribbean. With the exception of Avila and Evenson (2005), there is no updated comparative study in the literature that analyzes TFP growth in agriculture in the region. Additionally, for most of the multicountry studies cited, the time period analyzed is usually from the 1960s up to the year 2000,[2] which misses significant developments that have taken place in the agricultural sector over the past decade.

This study tries to fill this gap in the literature in various ways. First, it shows how agricultural productivity has evolved during the last 47 years in Latin America and the Caribbean and how it compares to other regions around the world. Second, it provides additional information of sectoral agricultural productivity in crops and livestock (ruminants and non-ruminants). Finally, it offers the most updated country analysis for the region, as it covers 24 countries in South and Central America and the Caribbean.

The remainder of this paper is organized as follows. In Section 2 we describe the Malmquist Index method used in the study and the data used. In Section 3 we present and discuss our results on agricultural productivity for the 1961-2007 period. In Section 4 we discuss sectoral results for crops and livestock, while in Section 5 we showcase Brazil and Cuba as examples on how agricultural productivity is influenced by changes in economic policy and by external shocks. The final section presents some concluding comments.

2. Methodology: A Malmquist Index Approach

To estimate total factor productivity in agriculture we use the Mamquist Index (Färe et al., 1994), a non-parametric methodology that uses data envelopment analysis (DEA) methods to construct a piece-wise linear production frontier for each country and year in the sample. This methodology has been used extensively for measuring agricultural productivity, as it offers some advantages (Coelli et al., 2005). This approach: i) does not require price information, ii) does not assume that all countries are efficient, iii) does not assume a behavioral objective function such as cost minimization or revenue/profit maximization, and iv) allows for TFP decomposition into technical change, efficiency change and scale change.

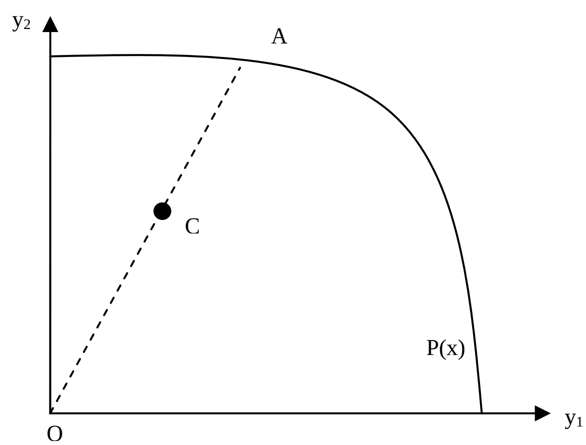
The Malmquist index is based on the idea of a function that measures the distance from a given input/output vector to the technically efficient frontier along a particular direction defined by the relative levels of the alternate outputs. Shephard's output distance function is defined as

[2] Most of these studies use FAO data, which until very recently, only offered input and output data up to the year 2003. In this study we use the most up-to-date data released by FAO in June 2009, which includes output data until 2007.

the reciprocal of the maximum proportional expansion of an output vector *y* given input *x*, seeking to increase all outputs simultaneously.

Figure 1 shows the output possibility set for period *t*. The production possibility frontier given outputs y_1 and y_2 represents efficient combinations of these outputs. There are efficient and inefficient production units in this output possibility set. Points A and C represent an efficient and an inefficient production unit, respectively, along the same ray through the origin at time *t*. The maximum proportional expansion of *y* with respect to the frontier for production unit C is denoted by the ratio OA/OC, while how far C is from the frontier is denoted by the distance from the production point to the frontier denoted by $D_0(x,y)$ = OC/OA.

Figure 1. Output Possibility Set and Distance Functions



Färe et al. (1994) show that the distance function can be computed as the solution to a linear programming problem, with the model exhibiting constant returns to scale:

$$\left[D_0\left(\boldsymbol{x}^{k^*}, \boldsymbol{y}^{k^*}\right)\right]^{-1} = \max_{z^k, \theta^{k^*}} \theta^{k^*} \qquad (1)$$

subject to

$$\sum_{k=1}^{N} z^k y_j^k \geq y_j^{k^*} \theta^{k^*} \qquad j = 1, \dots, J$$

$$\sum_{k=1}^{N} z^k x_h^k \geq x_h^{k^*} \qquad h = 1, \dots, H$$

$$z^k \geq 0 \qquad k = 1, \dots, N$$

where k is the set of countries (k^* is a particular country whose efficiency is being measured), j is the set of outputs, h is the set of inputs, z^k is the weight of the k^{th} country data and θ is the efficiency index, which is equal to one if country k^* is efficient in producing the output vector.

The Malmquist Index between period t and t+1 is defined as the geometric mean of two Malmquist Indices:

$$M_0 = [M_0^t \times M_0^{t+1}]^{1/2} = \left[\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)} \times \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^t, y^t)}\right]^{1/2} \quad (2)$$

The first term refers to the Malmquist index that measures TFP change between two data points with reference technology at time t and the second term measures the distance with reference technology at time t+1. Values of this index larger than one indicate increase in productivity.

As shown by Färe et al. (1994) the Malmquist index can be decomposed into an efficiency component and a technical change component.

$$M_0 = \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^t, y^t)} \times \left[\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})} \times \frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)}\right]^{1/2} \quad (3)$$

The first term is the efficiency change component or "catching-up," which measures the change from observed output toward frontier output (i.e., maximum potential production) between period t and t+1. The second term is the technical change component or "innovation," which captures the shift in technology (the world frontier) at each country's observed input mix between period t and period t+1. Once a country reaches the frontier, further growth is limited by the rate of innovation, or movement of the frontier itself.

To estimate productivity growth within agriculture for crops and livestock, Nin, Arndt, Hertel and Preckel (2003) modify the specification in (1) to estimate a directional Malmquist Index. This directional index takes advantage of information on input allocations by introducing specific input constraints for allocated inputs (Chung, Färe and Grosskopf, 1997). The output-specific directional Malmquist is then defined as:

$$M_0 = \left[\frac{D_0^t(x^{t+1}, y^{t+1}, y_{-i}^{t+1}; y_i^{t+1}, \mathbf{0})}{D_0^t(x^t, y^t, y_{-i}^t; y_i^t, \mathbf{0})} \times \frac{D_0^{t+1}(x^{t+1}, y^{t+1}, y_{-i}^{t+1}; y_i^{t+1}, \mathbf{0})}{D_0^{t+1}(x^t, y^t, y_{-i}^t; y_i^t, \mathbf{0})}\right]^{1/2} \qquad (4)$$

The output-specific Malmquist Index in (4) indicates that TFP growth is being measured for output y^t_i holding all other outputs y^t_{-i} constant. As with the Malmquist Index, this measure can also be decomposed in both efficiency and technical change components. This directional Malmquist Index is used to estimate the results of TFP growth in crops and livestock.

The Malmquist index is estimated with the General Algebraic Modeling System (GAMS), which is a high-level software used for mathematical programming and optimization (Brooke et al., 1992). The distance measures used to estimate the Malmquist Index are calculated by solving four linear programming problems of the type shown in equation (1).[3] For country *i*, a series of four linear programming problems are solved, one for each of the distance of country *i* at time *t* and time *t*+1 with respect to the frontier at time *t* and time *t*+1. The distance of each country *i* to the frontier is estimated as a byproduct of the frontier estimation method. Each linear programming problem corresponds to the solution of one distance function between period *t* and period *t*+1. The first problem evaluates the distance to the frontier at time *t* with respect to the technology and time *t*; the second evaluates the distance at time *t*+1 with technology at time *t*+1; the third evaluates the distance at time *t* with respect to the technology at time *t*+1; and the fourth evaluates the distance to the frontier at time *t*+1 with respect to the technology at time *t*.

Finally, we use a cumulative frontier approach as in Nin, Arndt and Preckel (2003). This broader technology definition eliminates the possibility of technical regress, but allows negative productivity growth through the efficiency change component of the productivity index.[4]

2.1 Limitations

As described by Coelli el at. (2005), non-parametric methods such as DEA have some drawbacks. DEA assumes that data is free of noise and error, as it assumes an exact relationship between inputs and outputs. Other parametric methods such as the stochastic frontier approach allow for such error measures in the data. Also, DEA does not allow for traditional hypothesis testing of the significance of the variables in the model. The assumption of constant returns to

[3] For the directional Malmquist Index, we use the modified optimization problem in (1).
[4] Using this definition of technology, Nin, Arndt and Preckel (2003) reserve findings by Arnade (1998) and Fulginiti and Perrin (1997, 1998) on technical regress for almost all 20 countries in their sample.

scale implies that the underlying technology is the same across all countries and regions is clearly another limitation. A problem with the non-parametric approach is that the hypothesis underlying the technology cannot be tested formally.[5]

Regarding the directional Malmquist Index, there are two limitations as pointed out by Nin, Arndt, Hertel and Preckel (2003). First, there might be cases where the distance function takes on the value of -1, in which case the Malmquist Index is not well defined. Second, there might be a reallocation factor bias in the measure, where there is movement of unallocated inputs from one activity to the other rather than technical growth.

2.2 Data on Outputs and Inputs

Data for inputs and outputs were collected from FAOSTAT for a 47-year period from 1961 to 2007. The data included 120 countries considering two outputs (crops and livestock), and five inputs (animal stock, land, fertilizer, tractors, and labor).[6] The description of these data follows in the next paragraphs.

Output for crops and livestock is the value of production expressed in millions of 1999-2001 international dollars. Labor is the total economically active population in agriculture, in thousands of people. This measure of agricultural labor input, also used in other cross-country studies, is an uncorrected measure that does not account for hours worked or labor quality (education, age, experience, etc.). Tractors are the total number of agricultural tractors in use without any allowance for horsepower differences. Fertilizer is defined as the quantity of nitrogen, phosphorus, and potassium in metric tons of plant nutrient consumed in agriculture.

Land consists of arable land and permanent crops and is expressed in thousands of hectares. As defined by FAOSTAT arable land includes “land under temporary crops, temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years). Permanent crops include land cultivated with crops that occupy the land for long periods and need not be replanted after each harvest, such as cocoa, coffee and rubber; this category includes land under flowering shrubs, fruit trees, nut trees and vines, but

[5] In the parametric stochastic literature this has been dealt with the use of meta-frontiers (see Battese, Prasada Rao and O’Donnell, 2004, O’Donnell, Prasada Rao and Battese, 2008, and Moreira and Bravo-Ureta, 2010).

[6] We considered including weather variables that could account for some of the variability in productivity. However, we have not been successful in gathering climate variability time series data at the country level that could account for variations around the mean or another measure of climate “volatility.”

excludes land under trees grown for wood or timber." Excluded from this definition are permanent pastures. Finally, we do not make adjustments for input "quality" changes.[7]

Animal stock is the number of cattle, buffalos, camels, sheep, goat, pigs, chicken, turkeys, ducks and geese expressed in livestock unit (LU) equivalents. Given the variability of body sizes of the main animal species across geographical regions, animal units are standardized for comparisons across the world as in Ludena et al. (2007). Carcass weight statistics from 2000 are used to generate conversion factors for several regions around the globe, and used to convert stock quantities into livestock units using OECD cattle as the base unit of measure. This animal stock variable improves the measures used by Ludena et al. (2007) as it incorporates buffalos and camels, important species in Asia and Africa. In the definition of livestock sectors, ruminants include bovine cattle, buffalos, camels, sheep, goat and horses, and non-ruminants include pigs, chicken, turkeys, ducks and geese.

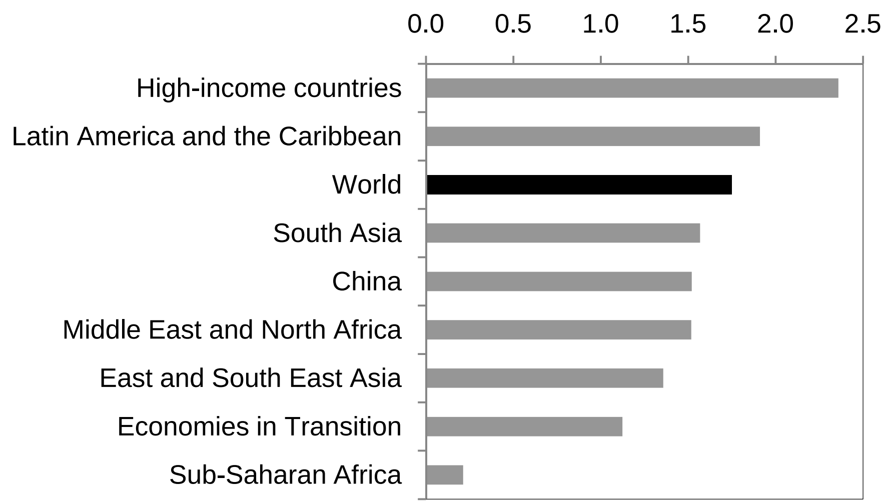
We adjusted some of the data to cover the whole period 1961-2007. For tractors and labor, times series only covered the period 1961-2006. We estimated the 2007 values on the average growth of the previous two years. For fertilizers, FAO has data on total consumption from 1961-2002. For the period 2002-2007, FAO changed methodology and revised its dissemination formats. After reviewing the new data, we found some consistency problems which led us to estimate consumption data for the period 2002-2007 based on growth rates from statistics of the International Fertilizer Industry Association (IFA).

3. Productivity Growth in Agriculture Worldwide and in Latin America

Figure 2 shows that world agricultural productivity has grown between 1961 and 2007 at an average annual rate of 1.7 percent. Productivity in high-income countries grew faster than any other group of countries at an annual rate of 2.4 percent. Relative to other regions, Latin America and the Caribbean has experienced the highest growth rate in agricultural productivity among developing regions (1.9 percent), higher than Asian countries and Economies in Transition. As shown by Ludena et al. (2007), most of the growth in agriculture comes from the livestock sector, especially non-ruminants (pigs and poultry), as production technology in these sectors is more transferable from developed to developing countries.

[7] Wiebe et al. (2000) quantify the importance of accounting for land quality in agricultural productivity.

Figure 2. Annual Percentage Total Factor Productivity Growth in Agriculture (Weighted Average), 1961–2007

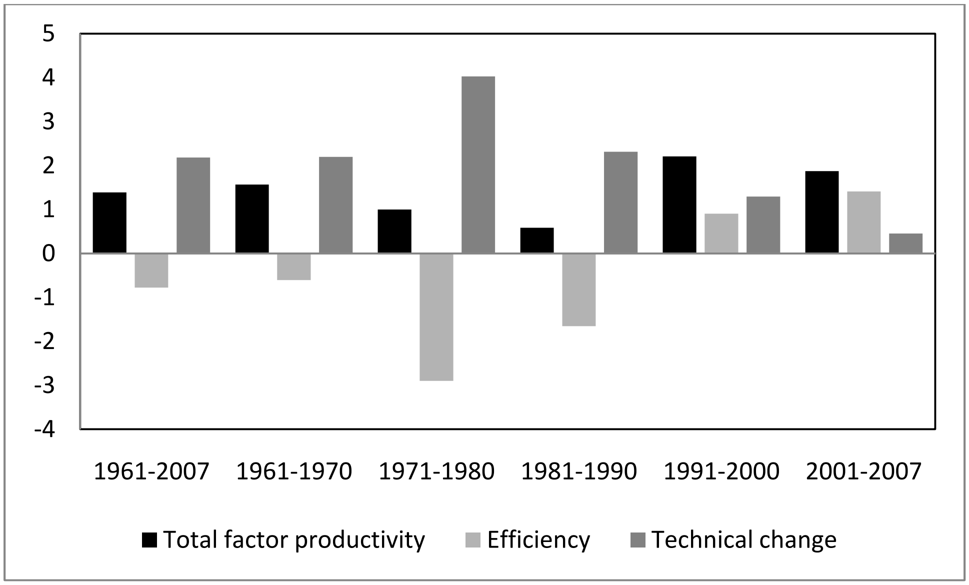


Source: Author's estimations.

As we take a closer look at Latin America and the Caribbean, Figure 3 shows that agricultural productivity has grown at an average rate of 1.4 percent per year.[8] Of this growth, all is due to growth in technical change (2.2 percent). In contrast, efficiency changes—that is, whether the existing technology is used more efficiently irrespective of whether that technology is itself improving—have been negative over the period (-0.8 percent). That is, on average, total factor growth in Latin America has been driven by technological change rather than changes in efficiency.

[8] This is a regional simple average and not a weighted average as in Figure 2.

Figure 3. Annual Percentage Growth in TFP, Technical Change, and Efficiency in Agriculture in Latin America and the Caribbean, 1961–2007



Source: Author's estimations.

However, as we analyze decade by decade, we observe that agricultural productivity has grown at a faster rate in the last two decades at a combined rate of over 2 percent per year, posting the fastest growth during the 1990s. Most of this growth in these last two decades is due to growth in efficiency, which had been negative during the 1960s through the 1980s but turned positive in the 1990s. This increase in efficiency is remarkable, which when compared to decline in efficiency in developed countries during the 2000s (not shown here), may denote convergence with developed economies' levels of agricultural production.

Latin America's gains in agricultural productivity are associated mostly with introduction of cost saving technologies. These technologies include genetically modified crops, or GMCs, (see Falck-Zepeda et al., 2009), zero tillage (Trigo et al., 2009), or the use of global positioning systems (GPS) for fertilization and harvesting. These new technologies were for the most part developed in high-income countries, but with important spillover effects in developing economies. In Latin America, Argentina and Brazil are countries where these types of technologies have become most widely used.

Taking a look at each individual country, we observe that productivity growth has been very heterogeneous among them (Figure 4). However, certain patterns are evident: those countries with higher land availability have performed better than those with land limitations.

Land-abundant countries (defined as those with 10 or more hectares per laborer)[9] have grown at an annual average rate of 1.7 percent between 1961 and 2007, and five of them (Argentina, Chile, Colombia, Mexico and Venezuela) have grown at rates equal to or higher than 2 percent. Countries with land constraints experienced lower average productivity growth rates. Those so called continental land-constrained countries grew at an average rate of 1.5 percent, while island countries in the Caribbean grew at a much slower rate of 0.5 percent. This suggests the importance of resource availability in agricultural productivity, in this case land, for these countries in Latin America.[10,11]

The lower growth of land-constrained countries has important implications for food security and poverty reduction. Most of these countries are already net food importers, and any reduction in productivity in agriculture may exacerbate problems in achieving food security. This may also affect poverty reduction in rural areas and the competitiveness of agricultural products from these countries in world markets.

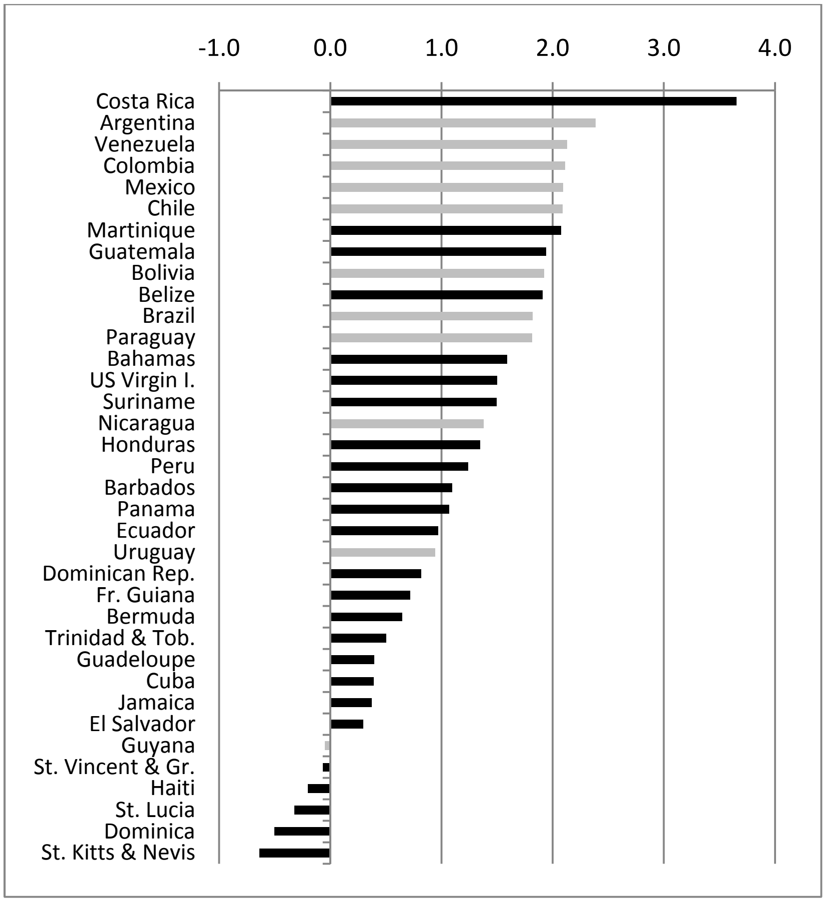
---

[9] The selection of 10 Ha. per laborer is an arbitrary measure for classification on these countries. As a reference, the country classified as land abundant with the lowest value of hectares per laborer is Colombia with 11 Has. per laborer, followed by Mexico (12), Nicaragua (13) up to Argentina (92). Panama, with 8.8 Has. per laborer is the country with the highest value of those classified as land constrained, followed by Costa Rica (8.5) and Cuba (8.0).

[10] Productivity growth rates as well as cumulative productivity indices do not tell us anything about productivity levels, which may be different from one country to the next and unrelated to those productivity growth rates. For example, countries with a lower production base and productivity levels can have higher productivity growth rates.

[11] Appendix Table 1 compares the estimates in this paper with previous studies. The table should be used only as reference, as the studies include different time periods, set of countries (peer selection is important), and input/output data.

Figure 4. Percentage Productivity Growth in Agriculture by Country in Latin America and the Caribbean, 1961–2007



Note: Countries in gray are land-abundant countries (more than 10 hectares per laborer). Countries in black are land-constrained countries.
Source: Author's estimations.

As we analyze country productivity growth decade by decade, there is also not a specific pattern among countries (Table 1). Some countries like Argentina, Bolivia and Venezuela showed strong productivity growth during the 46-year period. For Brazil and Chile, which also had strong growth, the 1960s proved to be a difficult period, with productivity growth rates below their own annual average for the whole period. Other countries showed the same pattern as Latin America as a whole, with slow growth during the 1970s and 1980s, and higher productivity growth rates during the 1990s and 2000s. Countries that followed this pattern include El Salvador, Panama and Peru. Appendix Figure 1 shows the evolution of productivity growth, efficiency change and technical change for selected countries.

Table 1. Agricultural Percentage Productivity Growth in Latin America and the Caribbean, 1961-2007

Country	1961-2007	1961-1970	1971-1980	1981-1990	1991-2000	2001-2007
Land- abundant countries (Ha/EAP < 10)						
Argentina	2.4	3.7	3.4	0.9	0.8	3.8
Bolivia	1.9	1.0	1.9	1.3	2.4	3.9
Brazil	1.8	-0.6	1.5	3.4	2.4	2.8
Chile	2.1	0.9	1.0	2.1	4.0	2.8
Colombia	2.1	2.0	2.8	2.4	2.5	0.2
Guyana	-0.1	-0.5	0.7	-2.4	6.0	-6.1
Mexico	2.1	2.7	1.4	0.5	3.3	2.9
Nicaragua	1.4	4.7	0.0	-2.2	4.5	-0.7
Paraguay	1.8	0.3	0.5	3.7	-0.5	7.4
Uruguay	0.9	-0.9	3.1	-0.7	-0.3	5.3
Venezuela	2.1	2.8	1.4	1.4	4.4	-0.1
Average	1.7	1.5	1.6	0.9	2.7	2.0
Land-constrained countries (Ha/EAP < 10)						
Continental countries						
Belize	1.9	3.7	2.7	-2.3	6.6	-2.7
Costa Rica	3.7	5.2	0.7	4.5	4.6	3.0
Ecuador	1.0	0.6	-0.5	0.9	0.9	4.4
El Salvador	0.3	1.8	-0.3	-1.4	0.5	1.2
French Guiana	0.7	5.8	-6.6	5.7	1.6	-4.3
Guatemala	1.9	2.3	2.1	1.2	2.0	2.2
Honduras	1.3	1.6	1.1	0.5	0.6	4.1
Panama	1.1	2.6	0.2	-0.3	0.6	3.1
Peru	1.2	0.8	-2.0	-0.3	5.2	3.7
Suriname	1.5	5.3	6.1	-2.3	-2.4	1.0
Average	1.5	3.0	0.4	0.6	2.0	1.6
Island Countries						
Bahamas	1.6	2.6	3.4	-2.4	1.8	3.6
Barbados	0.5	2.2	-0.9	-1.4	0.0	4.6
Bermuda	0.6	3.1	-2.9	3.0	-0.8	1.3
Cuba	0.4	-4.2	2.2	0.7	3.2	0.0
Dominica	-0.5	0.9	-2.8	1.8	-2.7	1.0
Dominican Republic	0.8	-0.2	1.3	0.1	1.5	1.7
Guadeloupe	0.4	1.9	-3.9	3.6	2.4	-3.3
Haiti	-0.2	-0.2	2.0	-0.2	-2.5	0.1
Jamaica	0.4	2.1	-1.6	0.7	0.4	0.2
Martinique	2.1	1.3	1.3	3.1	1.0	4.8
St. Kitts and Nevis	-0.6	-2.9	2.6	-2.6	-0.6	1.2
St. Lucia	-0.3	1.4	-2.9	3.0	-6.1	6.0
St. Vincent and Gr.	-0.1	-1.5	-0.3	3.5	-1.4	-0.8
Trinidad and Tobago	0.5	-1.0	-1.5	0.0	4.1	1.3
US Virgin Islands	1.5	3.4	-2.3	-0.1	3.7	3.9
Average	0.5	0.6	-0.4	0.9	0.3	1.7

Note: EAP = economically active population in agriculture.
Source: Author’s estimations.

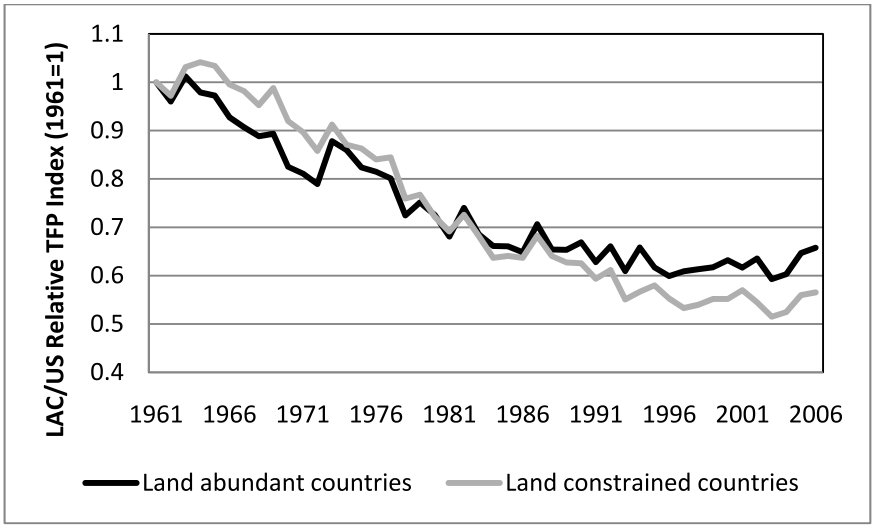
Despite the relatively good performance of agriculture relative to other sectors in Latin America and to other developing economies, there are important reasons not to be complacent. Convergence in agricultural productivity is important as outlined by Ludena et al. (2007). What matters for convergence to the frontier is the extent to which agricultural productivity grows in Latin America relative to frontier countries such as the United States and other developed economies. So is it important to compare agricultural productivity growth in Latin America with that of developed economies?

Figure 5 shows the relative average cumulative productivity index for land-abundant and land-constrained countries in the region with respect to the cumulative productivity index in the United States. That is, how productivity in Latin America and the Caribbean has evolved over the period relative to the United States. We should be careful in interpreting this graph, as we assume in this case that Latin America has the same level as the United States in 1961. Alauddin, Headey and Prasado Rao (2005) mention Brazil's TFP level in 1970 was half that of the United States, while Argentina's was 31 percent greater than the US level in 1970. This demonstrates the greater variation of initial productivity levels within Latin American and Caribbean countries.

The graph shows that the relative cumulative productivity index for both groups of countries in Latin America consistently declined from the 1960s throughout the 1980s. That is, during the first three decades of the period analyzed the productivity gap widened between Latin America and the United States. However, this relative decline was reduced during the 1990s and seemed to have leveled off at around 60 percent of United States' cumulative TFP index. This denotes convergence in relative productivity levels with the United States due to the rise of efficiency observed throughout the last two decades.

Comparing the two groups of Latin American countries relative to the United States, the relative productivity of land-abundant countries is around 66 percent by the end of the period. For land-constrained countries the relative productivity level is around 57 percent. The gap between these two groups of countries has widened during that time, mainly due to the high productivity growth rate of land-abundant countries, especially during the 1990s. However, it should be noted that much of the gap between these two groups of countries is due to island countries in the Caribbean, whose relative productivity to the United States was only 47 percent.

Figure 5. Latin America and Caribbean Cumulative Productivity Index Relative to the United States (1960 = 1)



Source: Author's estimations.

3.1 Sectoral Productivity Growth in Agriculture: Crops and Livestock

In this section we examine productivity growth at the sectoral level, i.e., separately for crops and livestock. Understanding the behavior of each sector within agriculture would allow us to identify which sectors within agriculture are lagging behind and may become roadblocks to agricultural development. This would allow the development of policies aimed at improving productivity growth at the sectoral level, which may be different from those policies aimed at the agricultural sector as a whole.

To analyze sectoral productivity growth, we base our analysis on unpublished data from Ludena (2005). Using a directional Malmquist Index (Nin, Arnd, Hertel and Preckel, 2003), Ludena (2005) estimated agricultural productivity growth in crops and livestock, the latter split into two major sectors that includes ruminants (bovine cattle and milk production) and non-ruminants (pigs and poultry). Ludena (2005) covered 116 countries around the world, including most Latin American and Caribbean countries from 1961 to 2001.[12]

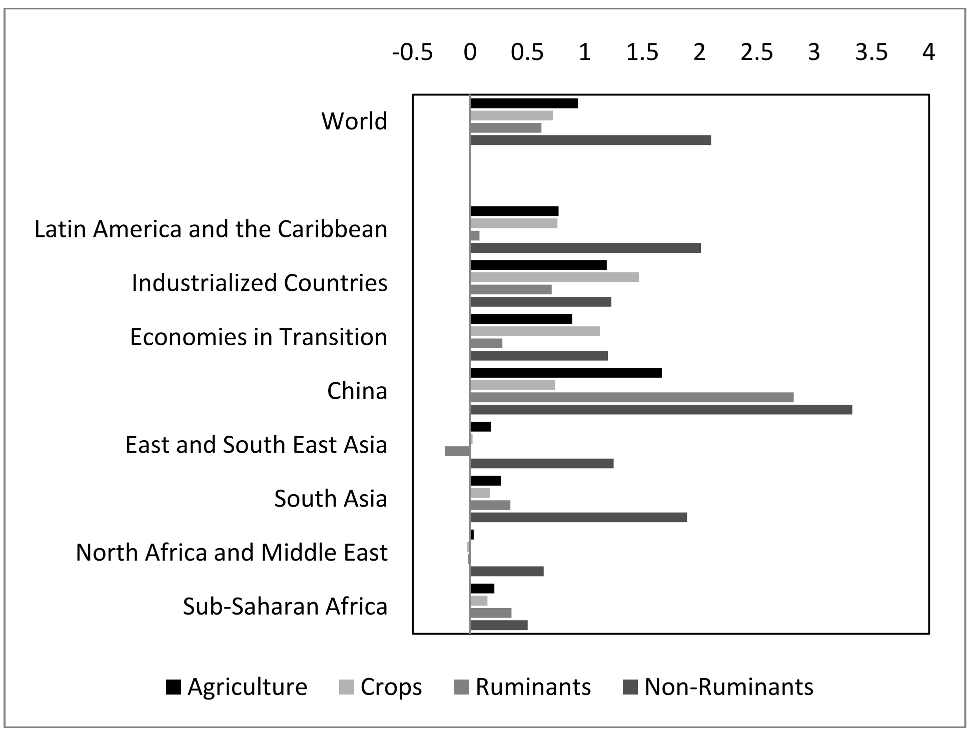
Figure 6 shows the results for Latin America and the Caribbean as it compares to other regions. The results of this analysis show that for almost all regions crops and non-ruminants have the largest growth rate, and ruminants show the weakest growth rate. Crops grew at an

[12] We were not able to analyze the 1961-2007 period, as some of the data used in Ludena (2005) are not available up to 2007. This includes data from FAO Food Balance Sheets, which contains information to estimate the feed input variable used in livestock productivity measures.

average rate of 0.7 percent, while within livestock, non-ruminants was the sub-sector with the largest average productivity. The world average annual growth rate for non-ruminants was 2.1 percent, while ruminant productivity grew at 0.6 percent. For ruminants, most regions show low growth rates (less than 1 percent), with some regions, such as East and South East Asia, showing negative productivity growth rates.

For Latin America, we observe the same pattern. Crops grew at an average annual rate of 0.8 percent and non-ruminants at 2.0 percent. Ruminants showed the weakest growth at 0.1 percent. Relative to other regions, Latin America's productivity in crops grew at a rate higher than the world average and other developing regions, but below industrialized economies, economies in transition and China. For non-ruminants, Latin America grew, with the exception of China, at the highest rate around the world. However, for ruminants Latin America shows one of the weakest performances among all regions.

Figure 6. Annual Percentage Productivity Growth Rate in Crops and Livestock, 1961-2001

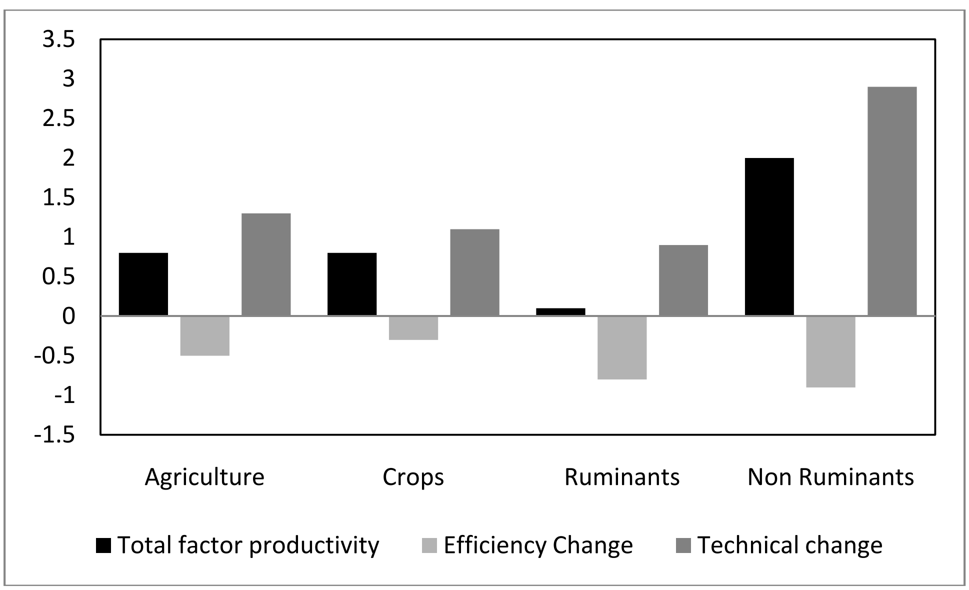


Source: Author's estimations based on unpublished data from Ludena (2005).

The high growth of non-ruminant production (pigs and poultry) is consistent with the fact that technologies from developed countries are more transferable than those for ruminant production. This has enabled increased efficiency in production systems with the use of these new technologies. Another factor that has also helped is the increased use of processed feed, which has lowered costs in livestock production, as feed makes up a large share of total costs in ruminant and non-ruminant production.

Figure 7 shows the decomposition of productivity for each agricultural sector over the 1961-2001 period. Similar to the results in Figure 3, most of the growth for all agricultural sectors (crops, ruminants and non-ruminants) comes from technological change. In other words, the outward shift of the production possibility frontier for the region, caused from technology spillovers from developed countries. As for changes in efficiency, we observe that these have been negative over the entire period. It is worth noting that there is efficiency growth in livestock during the 1990s; however, that growth is not enough to compensate for efficiency losses between the 1960s and 1980s.

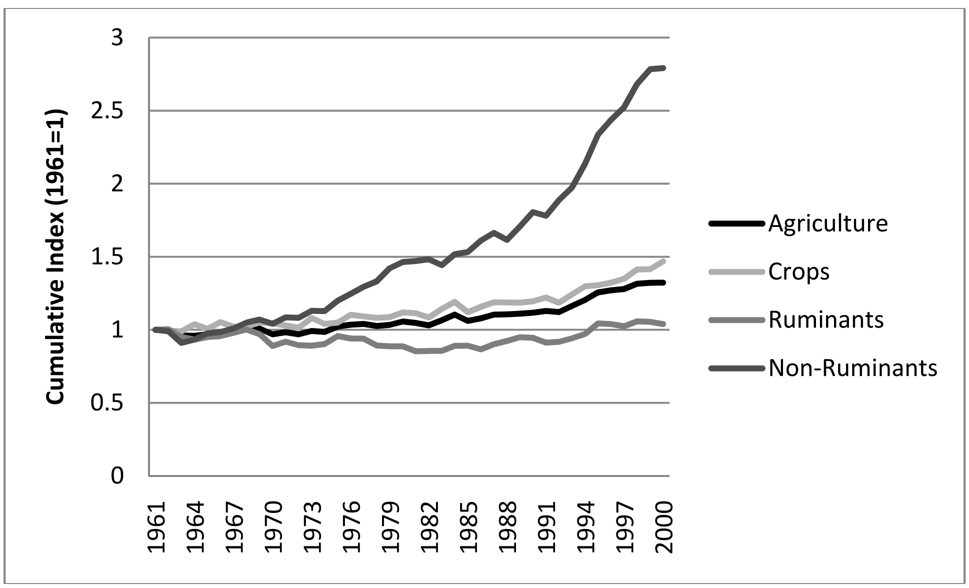
Figure 7. Percentage Productivity Growth by Agricultural Sector in Latin America and the Caribbean, 1961-2001



Source: Author's estimations based on unpublished data from Ludena (2005).

Finally, Figure 8 shows the cumulative productivity for all agriculture and separately for each of the three sectors. This graph clearly shows stagnation in productivity during the 1960s and 1970s, and growth during the 1980s and 1990s. As we compare the sectors, non-ruminants outperformed crops and ruminants. However, ruminants seems to be the sector that is dragging down overall agricultural productivity in Latin America. This is important, as specific policies for beef and milk production could be developed in the region to improve technology transfer and the efficiency of production systems. Appendix Table 2 and Appendix Table 3 contain more detailed country-level data on crop and livestock productivity growth decade by decade from 1961 to 2001. We do not discuss them here and leave them for the reader's reference.

Figure 8. Cumulative Productivity Growth in Agriculture and Sectors in Latin America and the Caribbean (1961 = 1)



Source: Author's estimations based on unpublished data from Ludena (2005).

4. Total Factor Productivity: Policy Reforms and External Shocks

Up to this point this paper has presented how productivity growth has changed due to improvements in technology and efficiency. However, there has not been a discussion on the possible effects of policies or external shocks that may have led to these productivity changes. To better illustrate this, we discuss the cases of Brazil and Cuba, and how productivity is influenced by changes in policy towards agriculture, macroeconomic shocks, and political events. These reason to choose these two countries is that they showcase very clearly how the estimated total factor productivity measures are able to pick up productivity variations due to changes in policy and other external shocks. This is by no means an exhaustive analysis, as we acknowledge that a second-stage analysis should be used to establish the effects of policy reforms and external shocks on agricultural productivity.

4.1 Changes in Economic Policy towards Agriculture: The Case of Brazil

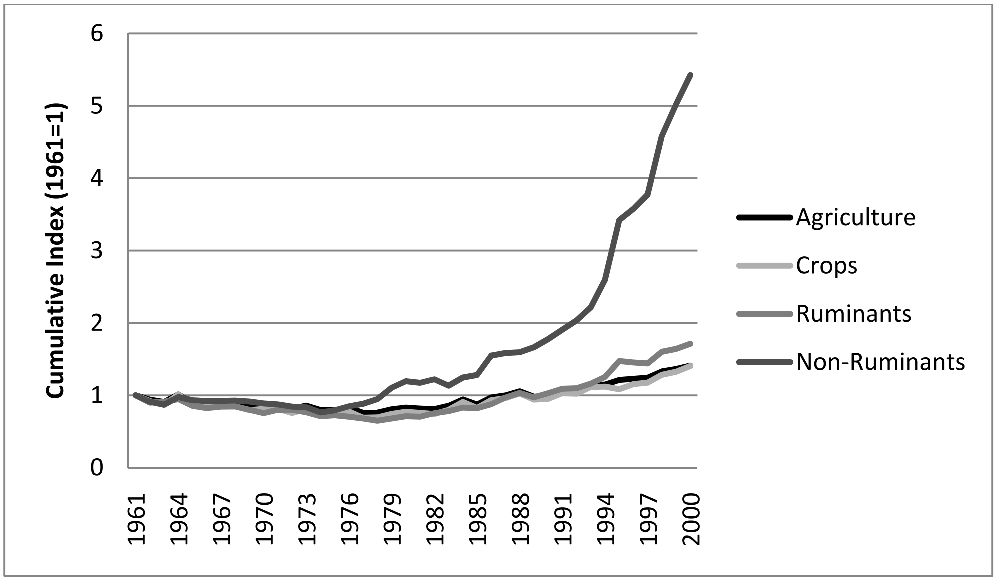
From 1943 until the mid-1980s, the minimum price program (MPP) was the cornerstone of Brazil's agricultural policy (OECD, 1997). The program was intended to reduce price risks, hence providing incentives for higher investment and production in agriculture. However, the program became the foundation of a "cheap food policy" for over 40 commodities which consisted of controlling agricultural prices and protecting consumers through price freezes and price fixing, controlling marketing margins and allowing subsidized imports to compete with domestic production. During this period, productivity growth declined in Brazilian agriculture, both for crops and livestock. Between 1961 and 1985 agricultural productivity declined on average 0.6 percent per year (Table 2). Crop productivity decreased 0.9 annually, and ruminant productivity (beef and milk) declined 1.0 percent per year. The exception was the pig and poultry sector, which increased its productivity on average 1 percent per year during the period (Figure 9).

Table 2. Percentage Productivity Growth in Agriculture and its Sectors in Brazil and Cuba, 1961-2001

Country	Period	Agriculture	Crops	Ruminants	Non-Ruminants
Brazil	1961-1985	-0.6	-0.9	-1.0	1.0
	1986-2000	3.3	3.6	5.0	10.1
Cuba	1961-1988	0.4	-4.9	-1.0	1.9
	1989-1992	-20.9	-16.9	-22.4	-23.3
	1993-2000	6.9	2.9	5.3	9.8

Source: Author's estimations based on unpublished data from Ludena (2005).

Figure 9. Cumulative Productivity Growth Index of Agriculture and its Sectors in Brazil, 1961-2001 (1961=1)



Source: Author's estimations based on unpublished data from Ludena (2005).

In 1985 policies towards the agricultural sector began to change with trade liberalization and the reduction of state intervention, with deregulation and the elimination of direct price controls on agricultural commodities. These changes led to reduced production costs and an increase in productivity growth in crops and livestock. Since 1986, Brazil's agricultural productivity has grown at an average annual rate of 3.3 percent, with livestock productivity being the driving force in this increase. Poultry and pork productivity grew at 10 percent, and beef and milk productivity grew at 5 percent per year. For crops, productivity grew at a rate of 3.6 percent. This growth in crop productivity might have not been uniform across regions within Brazil. For maize and wheat, Magalhaes and Diao (2009) show convergence in productivity among regions in Brazil, as yields in less productive regions grew faster than in more productive regions.

One reason for increased poultry and pork productivity is that production of these sectors has been expanding beyond traditional regions and towards the Brazilian corn/soybean belt and the states in these regions have given incentives to these industries. This shift has translated into feed cost savings which have compensated for additional transportation costs incurred by these industries. With these gains in the last 20 years, Brazilian agricultural productivity has grown by

41 percent between 1961 and 2001. Non-ruminant productivity has grown almost 5 times (442 percent), and ruminant has risen by 71 percent.

The case of Brazil shows the negative effects that disincentives, like price fixing and policies that favor urban consumers, can have on agricultural innovation and production. Changes in these policies towards market and trade liberalization have allowed the agricultural sector in Brazil to become more innovative, acquire new technologies (e.g., better crop varieties that are disease, pest or drought resistant) or increased feed efficiency in livestock, thus fostering cost reductions and productivity growth. As discussed by Helfand and Castro de Rezende (2004), policy reforms transformed agriculture into Brazil's most dynamic sector during the 1990s.

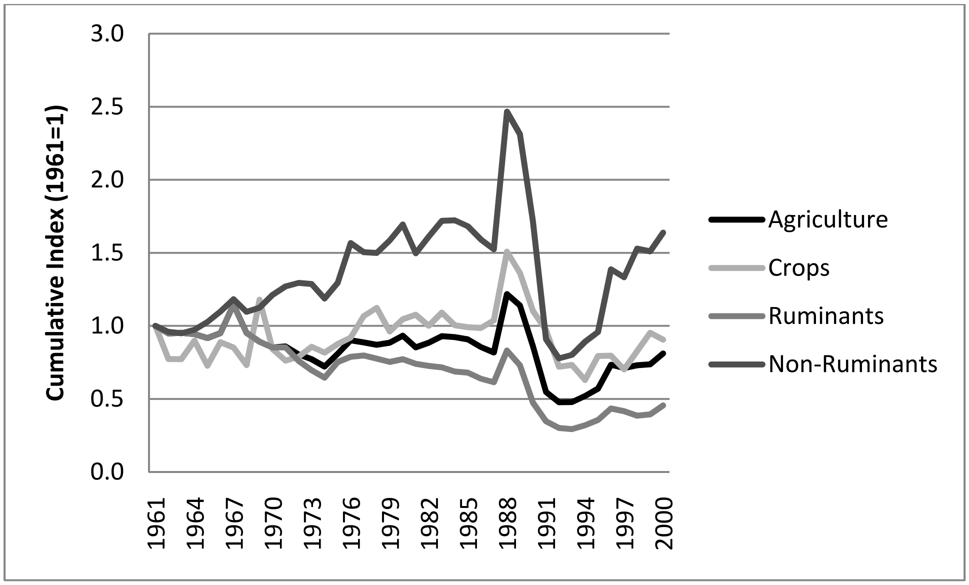
4.2 External Shocks and Agricultural Policy: The Case of Cuba

Cuban agriculture in the 1960s followed the Soviet model of monoculture, with high mechanization and heavy use of fertilizers. Large state farms were created, which covered 70 percent of all agricultural land, leaving the rest to small farmers and cooperatives, with farms no larger than 70 hectares per farmer. Cuba at that time used as many tractors and fertilizer per hectare as the United States, trading sugar at preferential terms with the Soviet Union in exchange for oil, chemicals and machinery. During that time (1950s-1980s), Cuban agricultural productivity declined, indicating excessive input usage.[13] Crop and ruminant productivity decreased during this period (1 and 32 percent, respectively), while non-ruminant productivity increased by 68 percent (Table 2).

In 1989 the Soviet Union collapsed, which meant that $6 billion dollars in subsidies to the island vanished almost overnight. According to Zepeda (2003), GDP shrank by 25 percent between 1989 and 1991, oil imports fell by 50 percent, availability of fertilizers and pesticides decreased by 70 percent, and other imports fell by 30 percent. These reductions in the availability of inputs adversely affected Cuban agriculture and led to a 52 percent decrease in agricultural productivity between 1989 and 1992. All sectors suffered declines in productivity, especially ruminant production (Figure 10).

[13] Similar productivity declines are observed during the "Green Revolution" in India, where high-yield wheat varieties required more intensive use of fertilizer and other inputs.

Figure 10. Cumulative Productivity Growth Index of Agriculture and its sectors in Cuba, 1961-2001 (1961=1)



Source: Author's estimations based on unpublished data from Ludena (2005).

Facing this crisis, in 1993 the Cuban government embarked on a series of reforms. The government gave land to farmers and cooperatives and created the UBPC (Basic Unit of Cooperative Production) as the fundamental unit of production, where farmers were allowed to sell excess production in farmer's markets. By the year 2000, the share of arable land under these units was 42 percent, while the share of state-owned land decreased from 75 to 33 percent. With these reforms, Cuba's agricultural productivity grew by an average rate of 7 percent per year. The largest increase in productivity was observed in non-ruminants (10 percent) and ruminant production (5 percent).

Non-ruminant production reached pre-1988 productivity levels in the year 2000. This was driven primarily by the pork industry, which accounts for most of the meat in farmers' markets, as cuts in feed imports promoted alternative feed sources. Urban agriculture, through production in small plots within cities, and a more efficient use of inputs (feed) for pork, also experienced productivity gains. Additionally, the State established a contract system with farmers, where the government assigned animal feed per ton of pork production. However, for poultry it was a different story. Reduced feed imports decreased poultry production, with many poultry production units remaining idle because of the lack of feed.

Ruminant productivity did not fully recover from the 1989 crisis. Due to oil shortages, the government turned to animal traction as a substitute for tractors. By the year 2000, there were a total of 400,000 oxen in use, more than double the 1990 levels, with the number of tractors decreasing by 40 percent between 1990 and 2000 (Rios and Cardenas, 2003). Sale of beef was prohibited, and anyone caught slaughtering cattle illegally could be sent to prison (Zepeda, 2003). As a result of these reforms, beef availability in Cuba decreased.

The Cuban case illustrates how external shocks can affect productivity growth in agriculture. However, it also shows how policy reforms, in this case changing the land tenure system and allowing farmers to sell excess production, can have significant positive effects on productivity growth.

5. Conclusions and Policy Implications

This paper has analyzed agricultural productivity growth, technical change and efficiency change in Latin America and the Caribbean. We have analyzed the agricultural sector as a whole, as well as sectors within agriculture including crops, ruminants and non-ruminants. We have also analyzed the cases of Brazil and Cuba, and how changes in productivity relate to policy reforms and external shocks to agriculture.

The results show that overall, Latin America and the Caribbean has performed well among other developing regions. In fact, the region shows the strongest growth of all developing countries. It is also important to note that there has been a recovery of efficiency in the last two decades, which has closed the widening gap between Latin America and developed economies such as the United States.

As we look into particular countries within Latin America, the results are very heterogeneous; but, on average, land-abundant countries had a higher productivity growth rate than land constrained countries. This highlights the importance of access to land in agricultural productivity.

Within agriculture, non-ruminant livestock and crops have been the sectors with the highest productivity levels, which is consistent with the relative ease of technology transfer for these activities from developed economies to developing countries. Such technologies include genetically modified crops that reduce costs of pesticides. Improved crop productivity may lower feed prices, which constitutes a large share of the costs in livestock production. However, ruminant production has lagged behind, with almost no growth in the whole period analyzed.

These findings have important implications for sectoral policies within agriculture and suggest the need for stronger technology transfer and investment in agricultural research and development (R&D) in ruminant production. However, this may prove difficult, given the overall low levels of investment in R&D in the region. As discussed by Stads and Beintema (2009), the region invested the equivalent of only 1.14 percent of agricultural output on R&D in 2006 (around 3 billion dollars). Of this amount, 70 percent was invested by three countries, namely Argentina, Brazil and Mexico (all land-abundant countries).

Stads and Beintema (2009) mention that the higher share of R&D invested by high-income countries has widened the gap with middle and low-income countries. This has important implications for agricultural productivity, food security and poverty reduction in these middle and low-income countries, because countries with lower R&D investment are at the same time those that are land constrained and net food importers. Lower levels of investment on R&D in these countries may hinder the ability to generate and transfer new technologies and improve efficiency in the agricultural sector. As productivity is compromised, food security and reduction of rural poverty may also be affected.

Finally, governments in the region should implement economy-wide and sectoral policies that promote agricultural productivity growth. These policies should be included within an agricultural development framework that helps increase efficiency, transfer technology, implement best agricultural practices and provides access to credit, market opportunities and inputs such as fertilizer and other chemicals.

References

Adelman, I., and C. Morris. 1988. *Comparative Patterns of Economic Development, 1850–1914*. Baltimore, United States: John Hopkins University Press

Alauddin, M., D. Headey and D.S. Prasada Rao. 2005. “Explaining Agricultural Productivity Levels and Growth: An International Perspective.” Centre for Efficiency and Productivity Analysis Working Paper 02/2005. Brisbane, Australia: University of Queensland, School of Economics.

Arancet, C. and S. Calvete. 2003. “Evolución, Determinantes y Contribución de la Productividad Total de Factores al Crecimiento del Producto Agropecuario Uruguayo.” Montevideo, Uruguay: Universidad del la República, Facultad de Ciencias Económicas y de Administración. Trabajo de Investigación Monográfico para la obtención del Título de Licenciado en Economía.

Arnade, C. 1998. “Using a Programming Approach to Measure International Agricultural Efficiency and Productivity.” *Journal of Agricultural Economics* 49: 67-84.

Avila, A.F.D., and R.E. Evenson. 1995. “Total Factor Productivity Growth in Brazilian Agriculture and the Role of Agricultural Research.” *Anais do XXXIII Congresso Brasileiro de Economia e Sociologia Rural*. Volume 1: 631-657.

----. 2005. “Total Factor Productivity Growth in Agriculture: The Role of Technological Capital.” In: B.L. Gardner and G.C. Rausser, editors. *Handbook of Agricultural Economics.* Volume 3B. Amsterdam, The Netherlands: Elsevier.

Battese, G.E., D.S. Prasada Rao and C.J. O’Donnell. 2004. “A Metafrontier Production Function for Estimation of Technical Efficiencies and Technology Gaps for Firms Operating under Different Technologies.” *Journal of Productivity Analysis* 21(1): 91-103.

Bharati, P., and Fulginiti, L. 2007. “Institutions and Agricultural Productivity in Mercosur.” In: E.C. Teixeira and M.J. Braga, editors. *Institutions and Economic Development*. Vicosa, Brazil: Os Editores.

Bravo-Ortega, C., and D. Lederman. 2004. “Agricultural Productivity and Its Determinants: Revisiting International Experiences.” *Estudios de Economía* 31(2): 133-163.

Brooke, A. et al. 1992. *GAMS: A User’s Guide*. Washington, DC, United States: GAMS Development Corporation.

Chung, Y.H., R. Färe, and S. Grosskopf. 1997. "Productivity and Undesirable Outputs: A Directional Distance Function Approach." *Journal of Environmental Management* 51: 229-40.

Coelli, T.J. and D.S. Prasada Rao. 2005. "Total Factor Productivity Growth in Agriculture: A Malmquist Index Analysis of 93 Countries, 1980-2000." *Agricultural Economics* 32(s1): 115-134.

Coelli, T.J. et al. 2005. *An Introduction to Efficiency and Productivity Analysis*. New York, United States: Springer.

Falck-Zepeda, J. et al. 2009. "La Biotecnología Agropecuaria en América Latina: Una Visión Cuantitativa." IFPRI Documento de Discusión 00860SP. Washington, DC, United States: International Food Policy Research Institute.

FAOSTAT. 2009. http://faostat.fao.org/site/339/default.aspx. Accessed July, 2009.

Färe, R. et al. 1994. "Productivity Growth, Technical Progress and Efficiency Change in Industrialized Countries." *American Economic Review* 84(1): 66-83.

Fernández-Cornejo, J., and C.R. Shumway. 1997. "Research and Productivity in Mexican Agriculture." *American Journal of Agricultural Economics*, 79(3) 738-753

Fulginiti, L. and R.K. Perrin. 1993. "Prices and Productivity in Agriculture." *Review of Economics and Statistics* 75(3): 471-482.

----. 1997. "LDC Agriculture: Non Parametric Malmquist Productivity Indexes." *Journal of Development Economics* 58: 373-390.

----. 1998. "Agricultural Productivity in Developing Countries. *Agricultural Economics* 19(1-2) 45-51.

Gasques, J.G., and J.C. Conceição. 1997. "Crescimento e Produtividade da Agricultura Brasileira." Texto para Discussão 502. Brasilia, Brazil: Instituto de Pesquisa Econômica Aplicada.

----. 2001. "Transformações Estruturais da Agricultura e Produtividade Total dos Fatores." In: J.G. Gasques and J.C. Conceição, editors. *Transformações da Agricultura e Políticas Públicas.* Brasilia, Brazil: Instituto de Pesquisa Econômica Aplicada.

Gasques, J.G., E.T. Bastos and M.R.P. Bacchi. 2008. "Productividade e Fontes de Crescimiento da Agricultura Brasileira." In: J. de Negri and L. Kubota, editors. *Políticas de Incentivo á*

Inovação Tecnológica. Brasilia, Brazil: Instituto de Pesquisa Econômica Aplicada. Available at: http://www.ipea.gov.br/sites/000/2/livros/inovacaotecnologica/capitulo11.pdf

Helfand, S.M., and G.C. de Rezende. 2004. "The Impact of Sector-Specific and Economy-Wide Policy Reforms on the Agricultural Sector in Brazil: 1980-98." *Contemporary Economic Policy* 22(2): 194-212.

Krueger, A., A. Valdes and M. Schiff, editors. 1991. *Political Economy of Agricultural Pricing Policy: Latin America*. Baltimore, United States: Johns Hopkins University Press.

Lema, D., and S. Battaglia. 1998. "Crecimiento y Productividad en la Agricultura Argentina 1970-1997: Inspiración o Transpiración." Reunión Anual de la Asociación Argentina de Economía Agraria, La Plata, October.

Lema, D., and V. Brescia. 2001. "Medicion del Cambio Tecnológico la Productividad y la Eficiencia en el Sector Agropecuario." Presentation at "La Modelización en el Sector Agropecuario" Buenos Aires, Argentina, June19-20.

Lema, D. and G. Parellada. 2000. *Productivity and Competitive Advantage of the Argentinean Agriculture*. Buenos Aires, Argentina: Instituto Nacional de Tecnología Agropecuaria, Instituto de Economía y Sociología.

Ludena, C.E. 2005. "Productivity Growth in Crops and Livestock and Implications to World Food Trade." West Lafayette, United States: Purdue University. Doctoral dissertation.

Ludena, C.E. et al. 2005. "Cambios Tecnológicos y Productividad en el Sector Agropecuario: Un Análisis de la Comunidad Andina." *Cuestiones Económicas* 21(1): 61-84.

Ludena, C.E. et al. 2007. "Productivity Growth and Convergence in Crop, Ruminant and Non-Ruminant Production: Measurement and Forecasts." *Agricultural Economics* 37: 1-17.

Magalhaes, E., and X. Diao. 2009. "Productivity Convergence in Brazil: The Case of Grain Production." IFPRI Discussion Paper 00857. Washington, DC, United States: International Food Policy Research Institute.

Moreira, V.H., and B.E. Bravo-Ureta. 2010. "Technical Efficiency and Metatechnology Ratios for Dairy Farms in Three Southern Cone Countries: A Stochastic Meta-Frontier Model." *Journal of Productivity Analysis* 33(1): 33-45.

Nin, A, C. Arndt and P.V. Preckel. 2003. "Is Agricultural Productivity in Developing Countries Really Shrinking? New Evidence Using a Modified Nonparametric Approach." *Journal of Development Economics* 71(2): 395-415.

Nin, A., C. Arndt, T.W. Hertel, and P.V. Preckel et al. 2003. "Bridging the Gap between Partial and Total Factor Productivity Measures using Directional Distance Functions." *American Journal of Agricultural Economics* 85(4): 928-942.

O'Donnell, C.J., D.S. Prasada Rao and G.E. Battese. 2008. "Metafrontier Frameworks for the Study of Firm-level efficiencies and technology ratios. *Empirical Economics* 34(2): 231-255.

Organisation for Economoic Co-operation and Development (OECD). 1997. "Brazilian Agriculture: Recent Policy Changes and Trade Prospects." Working Paper 55. Paris, France: OECD.

Olavarría, J.A., B.E. Bravo-Ureta and H. Cocchi. 2004. "Productividad Total de los Factores en la Agricultura Chilena: 1961-1996." *Economía Agraria y Recursos Naturales* 4(8): 121-132.

Pereira, M.F. et al. 2002. "Productivity Growth and Technological Progress in the Brazilian Agricultural Sector." *Pesquisa Operacional* 22(2): 133-146.

Pfeiffer, L.M. 2003. "Agricultural Productivity Growth in the Andean Community." *American Journal of Agricultural Economics* 85(5): 1335–1341.

Rada, N.E., S.T. Buccola and K.O. Fuglie. 2009. "Brazil's Rising Agricultural Productivity and World Competitiveness." Agricultural and Applied Economics Association 2009 AAEA and ACCI Joint Annual Meeting, Milwaukee, United States, July 26-29.

Ríos, A., and J. Cárdenas. 2003. "Animal Traction in Cuba: An Historical Perspective." Havana, Cuba: Instituto de Investigaciones de Mecanización Agropecuaria (IIMA). Available at: http://www.recta.org/pdf/iimahistory-en-22april03.pdf

Romano, L.O. 1993. "Productividad Agropecuaria: Evolución, Estado Actual y Tendencias Futuras." *Boletín Técnico*: 7-27. Bogota, Colombia: Instituto Colombiano Agropecuario, División Planeación Estratégica.

Stads, G-J., and N.M Beintema. 2009. "Public Agricultural Research in Latin America and the Caribbean: Investment and Capacity Trends." Agricultural Science and Technology Indicators (ASTI) Synthesis Report. Washington, DC, United States: International Food Policy Research Institute. Available at: http://www.asti.cgiar.org/pdf/LAC_Syn_Report.pdf.

Stern, N. 1989. "The Economics of Development: A Survey." *Economic Journal* 99(397): 597-685.

Trigo, E. et al. 2009. "The Case of Zero-Tillage Technology in Argentina." IFPRI Discussion Paper 00915. Washington, DC, United States: International Food Policy Research Institute.

Trueblood, M.A. and J. Coggins. 2003. "Intercountry Agricultural Efficiency and Productivity: A Malmquist Index Approach." Washington, DC, United States: World Bank. Mimeographed document.

Weibe, K. et al. 2000. "Resource Quality and Agricultural Production: A Multicountry Comparison." Washington, DC, United States: US Department of Agriculture, Economic Research Service. Mimeographed document.

Zepeda, L. 2003. "Cuban Agriculture: A Green and Red Revolution." *Choices* 4th Quarter. Available at: http://www.choicesmagazine.org/2003-4/2003-4-01.htm.

Appendix

Appendix Table 1. Percentage Productivity Growth in Agriculture in Latin America and the Caribbean, Study Compilation

Author(s)	This Study	Coelli and Rao	Nin et al.	Nin, Arndt and Preckel	Trueblood and Coggins	Fulginiti and Perrin	Arnade	Bravo-Ortega and Lederman	Avila and Evenson	Bharati and Fulginiti	Pfeiffer
Date of study	2010	2003	2003	2003	2003	1998	1998	2004	2004	2007	2003
Number of countries	120	93	115	20	115	18	70	77	82	10	5
Time period	1961-2007	1980-2000	1965-94	1961-94	1961-91	1961-85	1961-93	1960-2000	1961-2001	1972-2001	1972-2000
Estimation method	DEA	DEA	DEA	DEA	DEA	DEA	DEA	Translog	OLS	Translog	DEA/Translog
Argentina [1]	2.4	-2.7		2.5	-2.6	-4.8	-1.9	1.8	2.1	3.5	
Bahamas	1.6										
Barbados	0.5										
Belize	1.9										
Bermuda	0.6										
Bolivia	1.9	1.1	0.9		0.4		4.7	1.2	2.3		1.8/1.2
Brazil [2]	1.8	2.0	-0.5	-0.3	-0.6	-0.5	-2.1	1.9	1.9	5.0	
Chile [3]	2.1	1.1	0.9	0.6	1.4	1.1	1.3	1.2	1.4		
Colombia	2.1	1.4		1.5	1.6	0.0	1.8	1.4	1.6		1.9/1.4
Costa Rica	3.7	2.8	1.8		2.7		3.3		1.5		
Cuba	0.4	2.5			-1.2			1.2			
Dominica	-0.5										
Dominican Rep.	0.8	1.0		0.9	-0.4	1.0	-1.2		1.4		
Ecuador	1.0	0.3			-0.6		-1.0	1.3	1.1		0.0/2.1
El Salvador	0.3	0.8	-0.2		0.3		-0.8	0.5	1.1		
French Guiana	0.7										
Guatemala	1.9	0.5	0.3		0.9		-0.5	0.8	0.7		
Guadeloupe	0.4										
Guyana	-0.1										
Haiti	-0.2	-4.3			-0.8			1.0	1.6		
Honduras	1.3	0.3	-0.5		-1.3		-0.4	0.8	1.6		
Jamaica	0.4				0.4				1.2		
Martinique	2.1										
Mexico [4]	2.1	1.5	0.9		0.5		1.2	1.9	1.9		
Nicaragua	1.4	1.8			-3.6		-2.0	0.8	1.6		
Panama	1.1		-0.1		0.4				1.0		
Paraguay	1.8	-1.6		-2.0	-1.1		0.2	0.7	1.2	-0.4	
Peru	1.2	1.5	0.7		-0.1		0.6	1.4	1.2		1.4/1.9
St. Kitts and Nevis	-0.6										
St. Lucia	-0.3										
St. Vincent & Gr.	-0.1										
Suriname	1.5				1.7						
Trinidad & Tob.	0.5				-1.0						
Uruguay	0.9	0.0		1.5	-0.1		-1.3		0.5	2.2	
US Virgin Islands	1.5										
Venezuela	2.1	0.6	0.6		0.7		0.2	1.4	2.0		1.5/1.1

[1] 1.9 (1970-97), Lema and Brescia (2001); [2] 2.0 (1985-1995) Rada et al., 2009; 2.5 (1975-2005) Gasques et al., 2008; 4.8 (1970-96), Pereira et al., 2002; 2.3 (1970-95) Gasques and Conceição, 2001; 3.9 (1976-94) Gasques and Conceição, 1997; [3] 2.8 (1961-1996), Olavarría et al., 2004; [4] 2.8 (1960-90), Fernandez-Cornejo and Shumway, 1997.

Appendix Table 2. Percentage Productivity Growth in Crops in Latin America and the Caribbean, 1961-2000

Country / Region	1961-2000	1961-1970	1971-1980	1981-1990	1991-2000
Latin America & Caribbean	0.7	0.1	-0.1	0.6	2.3
South America	0.9	-0.2	-0.7	1.6	2.7
Caribbean	-2.2	-6.4	0.4	-0.3	-2.4
Argentina	n.d.	n.d.	n.d.	2.1	3.7
Belize	3.1	0.6	3.4	1.2	7.2
Bolivia	0.6	-3.5	-0.5	2.1	4.6
Brazil	0.7	-1.7	-1.5	2.2	3.7
Chile	3.0	4.0	1.8	3.2	3.1
Colombia	1.5	0.8	2.6	1.6	1.2
Costa Rica	2.7	4.2	0.0	3.7	3.1
Cuba	-0.4	-3.8	2.5	1.3	-1.6
Dominican Republic	0.7	2.5	0.4	-0.6	0.6
Ecuador	0.2	0.7	-1.1	0.4	0.9
El Salvador	-0.2	1.3	0.1	-1.3	-1.0
Guatemala	1.3	1.8	1.7	0.7	1.2
Guyana	3.6	3.2	4.5	0.9	5.9
Haiti	n.d.	n.d.	n.d.	-0.2	-2.7
Honduras	-1.2	-2.8	-0.1	-0.8	-1.2
Jamaica	0.7	2.6	-1.7	-0.1	2.2
Mexico	0.5	1.8	0.5	-2.3	2.0
Nicaragua	2.2	8.9	-0.0	-2.6	3.0
Panama	-1.6	-2.1	-1.7	-1.2	-1.5
Paraguay	2.1	0.3	5.4	1.6	1.3
Peru	0.7	-0.8	-1.8	0.8	4.7
Puerto Rico	n.d.	n.d.	n.d.	n.d.	n.d.
Suriname	0.1	-1.4	4.9	2.2	-5.0
Trinidad and Tobago	n.d.	n.d.	n.d.	n.d.	-1.6
Uruguay	n.d.	n.d.	4.9	0.7	2.8
Venezuela	1.2	0.8	-0.2	2.0	2.1

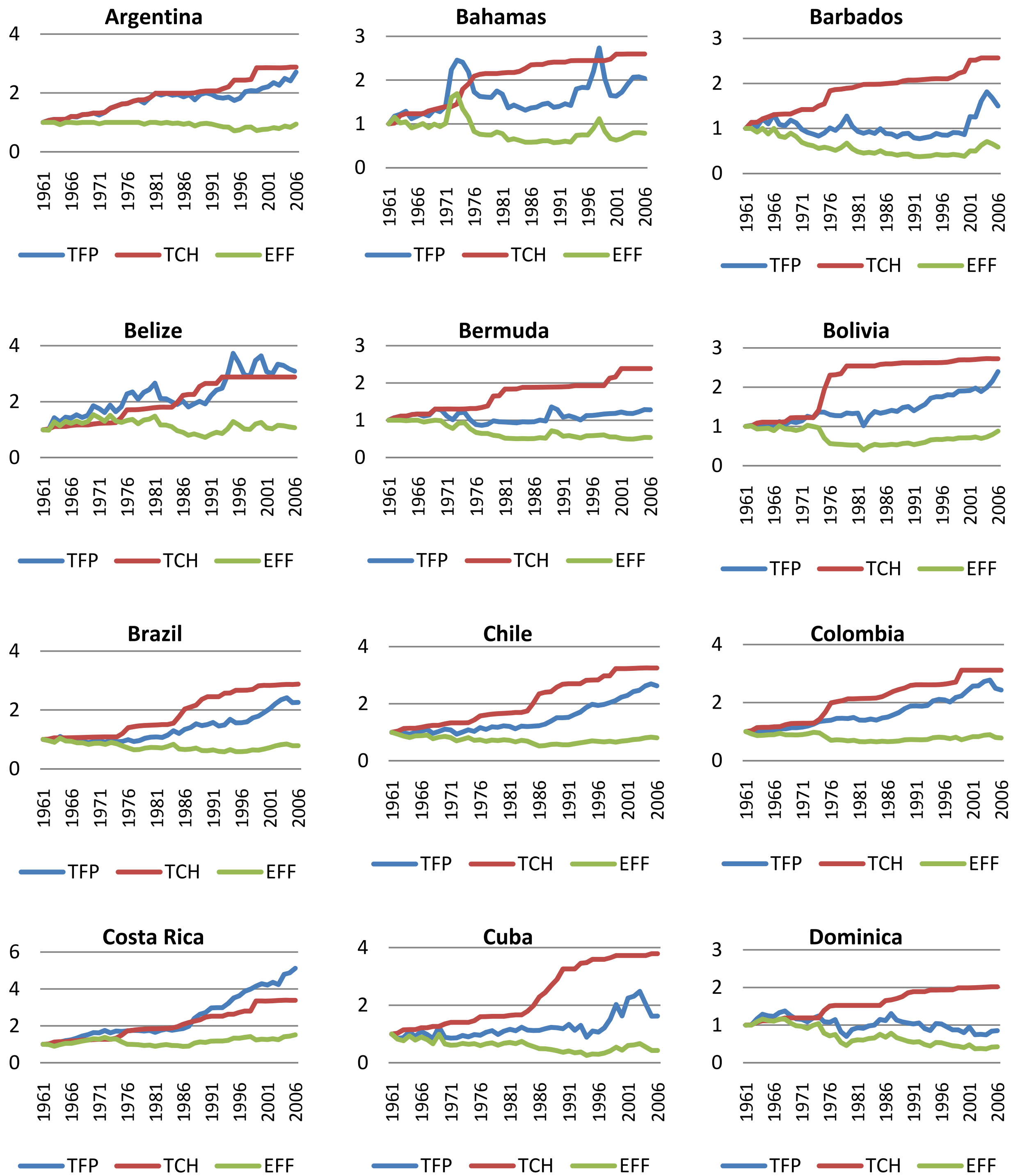
n.d. = No data available.
Source: Author's estimations based on unpublished data from Ludena (2005).

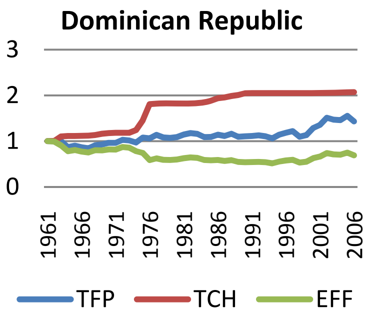
Appendix Table 3.
Percentage Productivity Growth in Livestock
in Latin America and the Caribbean, 1961-2000

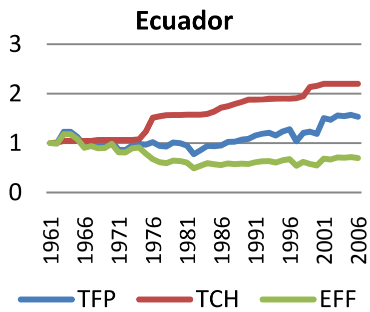
Country / Region	1961-2000	1961-1970	1971-1980	1981-1990	1991-2000
Latin America & Caribbean	0.8	-0.8	1.2	1.9	1.0
South America	0.5	-1.4	0.8	1.9	0.6
Caribbean	1.2	0.7	1.8	0.4	1.8
Argentina	n.d.	n.d.	n.d.	n.d.	n.d.
Belize	n.d.	-0.4	n.d.	n.d.	n.d.
Bolivia	0.8	-3.0	1.4	1.5	3.6
Brazil	1.0	-3.3	0.9	2.9	3.8
Chile	1.8	2.1	0.4	3.0	1.6
Colombia	2.0	-0.8	1.0	3.3	4.8
Costa Rica	n.d.	1.5	1.5	11.9	n.d.
Cuba	1.0	2.5	2.1	-1.1	0.3
Dominican Republic	n.d.	n.d.	n.d.	n.d.	6.2
Ecuador	n.d.	n.d.	-3.3	3.0	0.7
El Salvador	1.8	1.1	2.7	1.7	1.8
Guatemala	0.8	1.1	-1.6	1.7	2.0
Guyana	n.d.	n.d.	n.d.	n.d.	n.d.
Haiti	n.d.	n.d.	n.d.	n.d.	-2.9
Honduras	-0.4	-0.8	2.4	-1.9	-1.4
Jamaica	n.d.	n.d.	-0.1	-1.9	7.3
Mexico	2.2	-0.2	3.5	1.7	4.0
Nicaragua	n.d.	n.d.	n.d.	3.3	10.1
Panama	0.8	-3.3	1.4	4.7	0.6
Paraguay	n.d.	0.3	n.d.	n.d.	13.0
Peru	n.d.	2.0	1.8	n.d.	n.d.
Puerto Rico	n.d.	n.d.	n.d.	9.4	n.d.
Suriname	n.d.	-1.3	n.d.	n.d.	-21.1
Trinidad and Tobago	n.d.	n.d.	n.d.	n.d.	-0.2
Uruguay	1.7	2.0	2.8	1.2	0.8
Venezuela	2.3	2.82	2.22	0.2	4.0

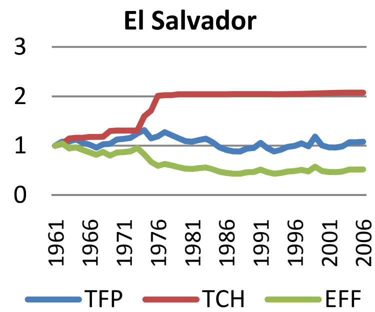
n.d. = No data available.
Source: Author’s estimations based on unpublished data from Ludena (2005).

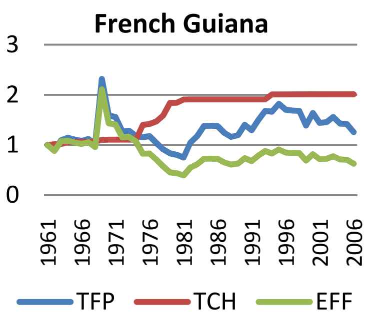
Appendix Figure 1.
Cumulative Total Factor Productivity, Technical Change and Efficiency Change in Latin American and Caribbean Countries, 1961-2007 (1961=1)

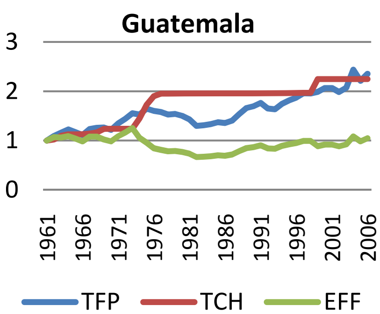


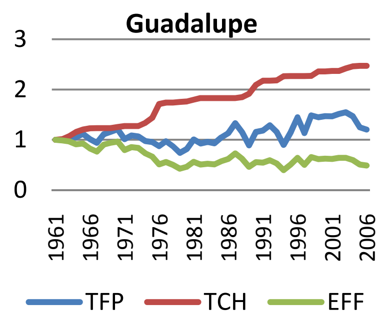

Dominican Republic
3
2
1
0
1961 1966 1971 1976 1981 1986 1991 1996 2001 2006
TFP TCH EFF

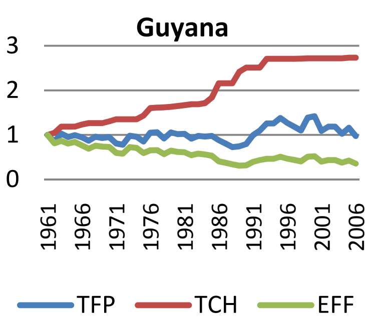

Ecuador
3
2
1
0
1961 1966 1971 1976 1981 1986 1991 1996 2001 2006
TFP TCH EFF

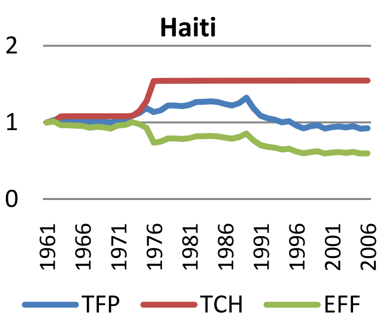

El Salvador
3
2
1
0
1961 1966 1971 1976 1981 1986 1991 1996 2001 2006
TFP TCH EFF

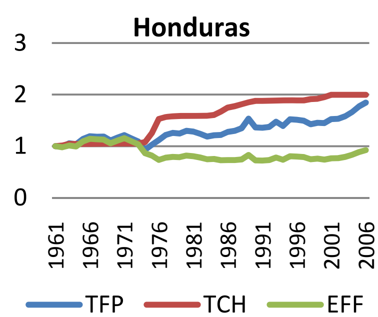

French Guiana
3
2
1
0
1961 1966 1971 1976 1981 1986 1991 1996 2001 2006
TFP TCH EFF

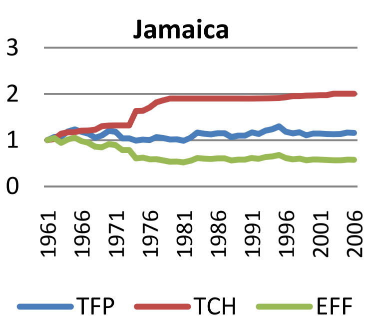

Guatemala
3
2
1
0
1961 1966 1971 1976 1981 1986 1991 1996 2001 2006
TFP TCH EFF

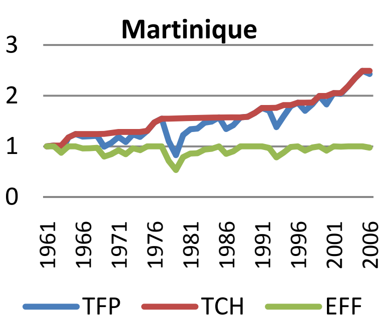

Guadalupe
3
2
1
0
1961 1966 1971 1976 1981 1986 1991 1996 2001 2006
TFP TCH EFF

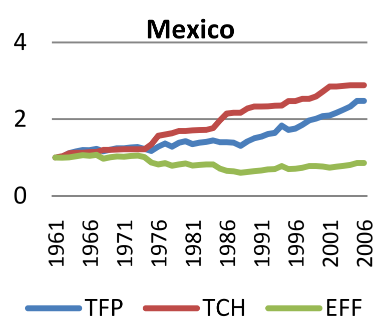

Guyana
3
2
1
0
1961 1966 1971 1976 1981 1986 1991 1996 2001 2006
TFP TCH EFF

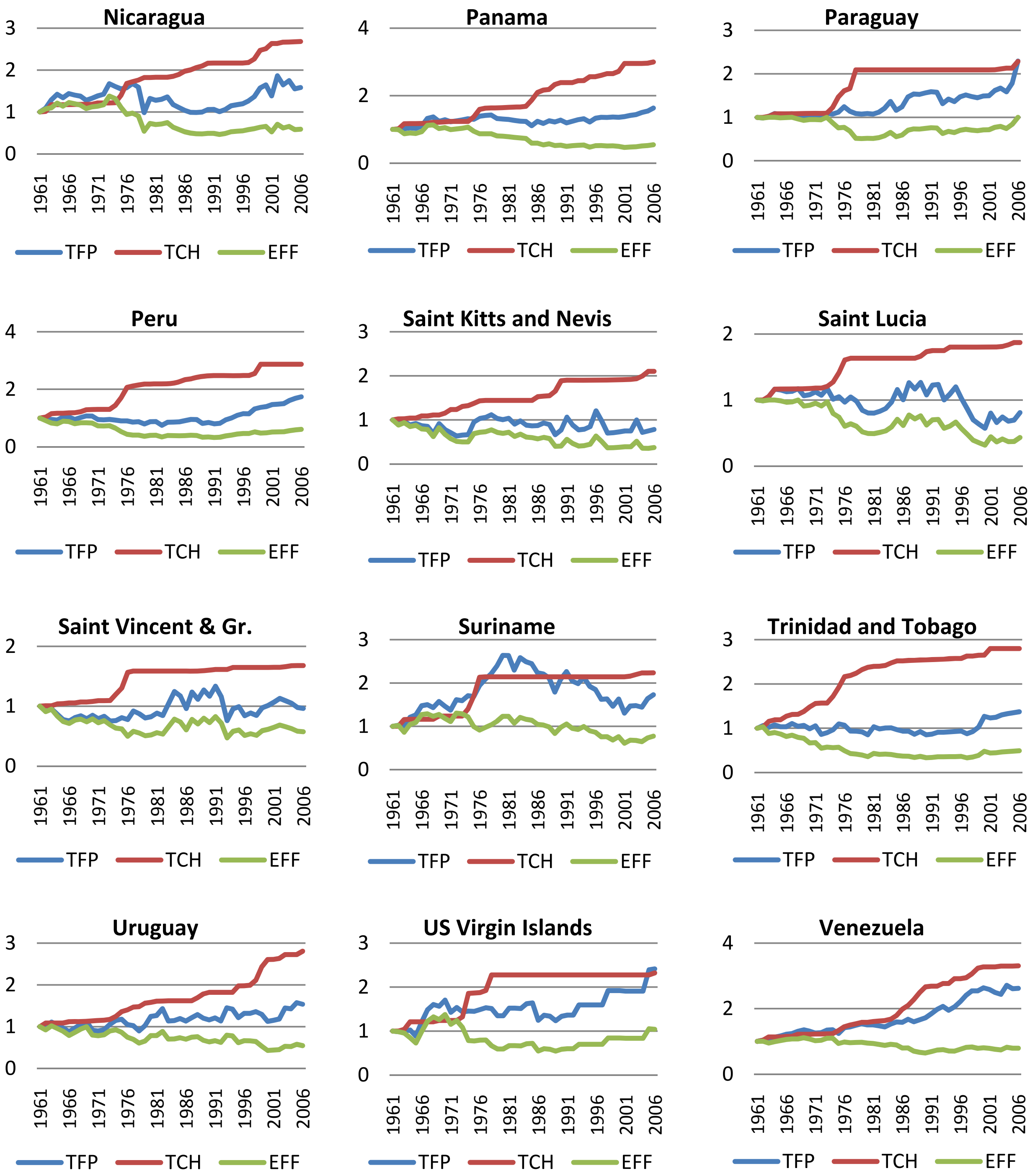

Haiti
2
1
0
1961 1966 1971 1976 1981 1986 1991 1996 2001 2006
TFP TCH EFF


Honduras
3
2
1
0
1961 1966 1971 1976 1981 1986 1991 1996 2001 2006
TFP TCH EFF


Jamaica
3
2
1
0
1961 1966 1971 1976 1981 1986 1991 1996 2001 2006
TFP TCH EFF


Martinique
3
2
1
0
1961 1966 1971 1976 1981 1986 1991 1996 2001 2006
TFP TCH EFF


Mexico
4
2
0
1961 1966 1971 1976 1981 1986 1991 1996 2001 2006
TFP TCH EFF



Note: TFP = Total factor productivity; TCH = Technical change; EFF = Efficiency change
Source: Author's estimations.