國立臺灣大學生物資源暨農學院農業經濟研究所

碩士論文

Department of Agricultural Economics

College of Bio-resources and Agriculture

National Taiwan University

Master Thesis

中美洲農業部門效率與生產力變動之研究

A Study of Efficiency and Productivity Changes for Agricultural Sector in Central America

勞亦理

Eliseo Arauz Quiroz

指導教授：黃芳玫 博士

Advisor: Fung-Mey Huang, Ph.D.

中華民國 106 年 7 月

July, 2017

doi: 10.6342/NTU201700916

doi: 10.6342/NTU201700916

Abstract

The purpose of this study is to identify the main sources of agricultural growth for Central America (C.A.) between 1979 and 2014 using data for six countries of the region. Two analytical methods are used. The first method is data envelope analysis (DEA), which is a non-parametric estimation. The second one applies a parametric function by using stochastic frontier analysis (SFA) which also includes "exogenous variables". The results from DEA indicate that agricultural growth in countries of C.A. is driven by technical change (TC) rather than efficiency change (EC). The results from SFA suggest that just upper-middle income (UM) economies are driven by TC (or frontier shift) while lower-middle income (LM) economies in C.A. are mostly driven by EC (or catch-up). The empirical results from the exogenous variables also suggest that the more the use of irrigation, human capital, and specialization of crops, the more efficient a country's agricultural sector becomes.

Keywords: Agriculture, Efficiency, Productivity, DEA, SFA, Central America

doi: 10.6342/NTU201700916

Dedication

I would like to dedicate this thesis to my family, my friends, and all those who have believed in me. Also to the memory of those who are no longer in this world, but in my memory and my heart forever.

doi: 10.6342/NTU201700916

Acknowledgement

I would like to give thanks to my advisor: Professor Fung Mey-Huang (Ph.D.), who contributed and helped me during the process of writing this thesis. Thanks to all my professors and staff of the Department of Agricultural Economics at NTU for their guidance, knowledge, and hospitality.

Special thanks to my family and lovely mother: Linda Quiroz, for her continuous support.

Furthermore, to my friends, classmates, and colleges for their academic support during the course of living, studying, and writing this thesis.

doi: 10.6342/NTU201700916

Table of Contents

doi: 10.6342/NTU201700916

doi: 10.6342/NTU201700916

List of Figures

doi: 10.6342/NTU201700916

List of Tables

doi: 10.6342/NTU201700916

doi: 10.6342/NTU201700916

Chapter 1 Introduction

1.1 Introduction and motivation

Technical change (TC) and efficiency change (EC) are two important sources of agricultural productivity growth. Because the rapid growth of world population leads to an increasing demand of food, many countries have set their goal to increase the agricultural sector's productivity. To improve agricultural productivity, new varieties of seed, advanced equipment, and new methods of production have been implemented, which have improved the agricultural capability of some countries to face food insecurity and increase competitiveness among regions. However, the improvements of agricultural productivity deal with the effects of environmental and social conflicts which could hinder the best performance of the sector in Central America (C.A.).

In order to identify the main sources of agricultural growth in C.A. and understand the region's agricultural evolutions, we analyze the total factor productivity and their two driving engines: efficiency change and technical change from 1979 to 2014. This analysis may grant an opportunity to introduce appropriate national agricultural policies according to the heterogeneity of the region. Two approaches are used: the data envelope analysis (DEA) and the stochastic frontier analysis (SFA).

This study contributes to the existing literature on different fronts. First, we focus on the analysis of agricultural productivity growth in C.A. Previous studies examined only selected countries in this region which limit the capacity for analysis and the comparability across countries. Second, this study extends the previous analysis by using data in more recent years. Much of the existing literature analyzed the agricultural productivity growth in

doi: 10.6342/NTU201700916

C.A with very short periods of time. To understand the development of productivity in current periods and to contrast this development of productivity with some recent economic and social phenomena is important. Third, we have classified the countries according to their income level and identified possible associations between the driven factors of productivity and the level of income of the countries. In studies of productivity in Latin America, there is no evidence that shows advantages of rich countries in the absorption of technology, or evidence suggesting that poor countries compensate for the lack of technology by implementing more efficient production mechanisms. Fourth, it incorporates the effect of exogenous variables in the analysis. The incorporation of exogenous variables in the model allows us to analyze the efficiency of productivity taking into account the environmental, social, economic or infrastructure differences among the countries of the region. Finally, two different approaches are used to analyze the growth pattern of the region. In most studies the researchers decide to use a single method of productivity analysis, especially to avoid confusion in the results, however, this study allows to evaluate the productivity in the region from 2 different approaches, taking into account the advantages of one study over another.

According to the World Bank (WB), there are 5% of the population in C.A. living with less than $1.90 per day, and 13% living with less than $3.10 per day in 2014. Because the agriculture sector represents an opportunity of subsistence for the rural area and poor population, improving agricultural productivity is a potential solution to increase their welfare. In 2014, the agricultural share of GDP in C.A was around 11%, but the proportion varied substantially between countries with low-middle income (LM) and countries with

doi: 10.6342/NTU201700916

upper-middle income (UM) countries.[1] The agricultural share of GDP in the LM income countries is usually higher than the proportion of the UM income countries.

A closer diagnostic reveals that agricultural production for the region has grown considerably since 1979, without any substantial change concerning its agricultural structure, which is mostly concentrated in the production of a few crops, including: sugar cane, banana, maize, plantain, coffee, and cotton.

The results of this study suggest that countries in C.A. might still improve their efficiency. In addition, the region experimented a persistent growth in agricultural productivity, which is mainly driven in middle-upper incomes economies by TC. Interestingly, the agricultural growth of countries with middle-lower income is driven by EC instead of TC.

The remainder of this thesis is organized as follows. In chapter 2, I will briefly introduce the essential aspects of the economy of C.A. in general focusing on agriculture of this region, and the theory used in the analysis of productivity. Following the theoretical chapters, the data and methodology will be described. The last two chapters contain the results and conclusion, followed by suggestions for further investigation.

[1] According with the World Bank classification in 2014 the low-middle income countries are those with a Gross National Income (GNI) per capita between $1,046 and $4,125; the upper middle income are those with a GNI between $4,126 and $12,735.

doi: 10.6342/NTU201700916

1.2 Objectives of this study

The objectives of this study are to analyze the productivity growth of the agricultural sector, to identify the driving factors of agricultural productivity growth, and to examine the effect of socioeconomic variables on agricultural productivity growth.

doi: 10.6342/NTU201700916

Chapter 2. Overview of Central America Agriculture

2.1 Economies

Central America (C.A.) is a region in the middle of the American continent with a land area of approximately 507,966 square kilometers. The region consists of seven countries: Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica, Panamá and Belize. In this study Belize is excluded due to the unavailability of information. C.A. is considered an important platform for commerce; bordered by Mexico to the north, and Colombia to the southeast, and between the Caribbean Sea and the Pacific Ocean, this region have a highly coveted strategic (Figure 2.1).

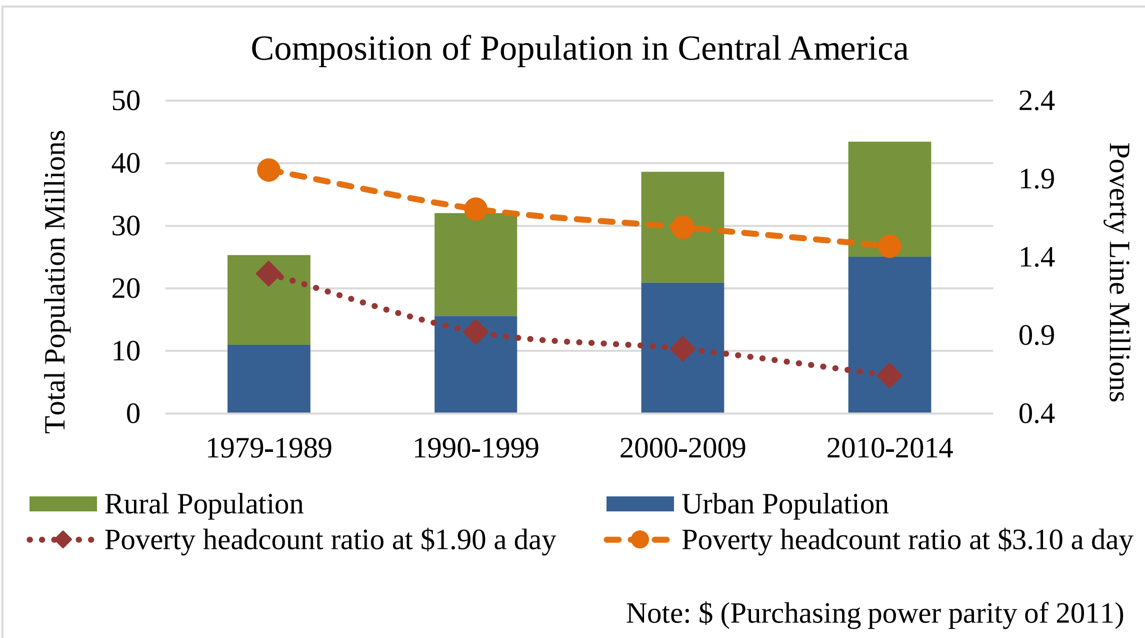
Source: Geology.com

Figure 2.1 Map of Central America

doi: 10.6342/NTU201700916

The total population of the six countries analyzed in this study in 2014, according to the World Bank, was 44,723,934 persons. Among those, 44% are considered rural population and the remaining are urban population.

In terms of population growth, C.A experienced a nearly 2% growth in its population, increasing from 22.37 million people in 1979 to 44.72 million people in 2014. (See Figure 2.2).



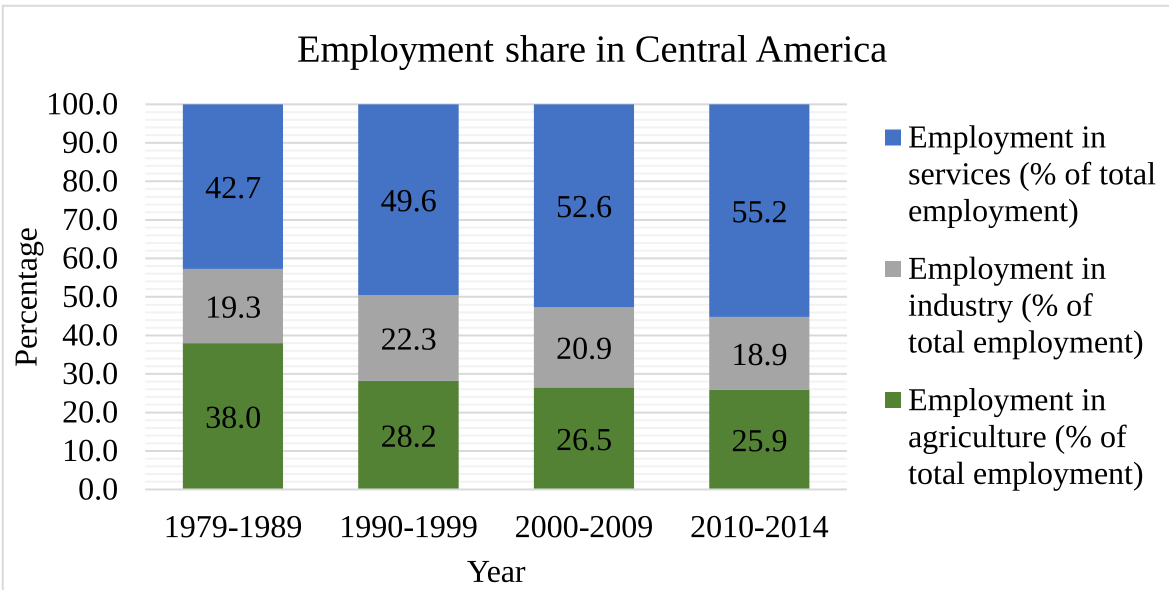
Source: World Bank

Figure.2.2 Composition of population and poverty line in Central America.

In spite of the increase in population, the average percentage of employment in agriculture decreased (Figure 2.3). The share of the total employment in agriculture between 1979 and 2014 was around 30%. In 2014, the percent of the population engaged in agricultural activities was below 25%, with significant differences among countries. It is worthwhile mentioning that, Honduras had the highest participation rate of people working

doi: 10.6342/NTU201700916

in agriculture (37%) while Costa Rica had the lowest participation rate (14%). According to estimates of the FAO (2014), almost half of the rural population of Latin America (L.A.) is poor and one-third live in extreme poverty.

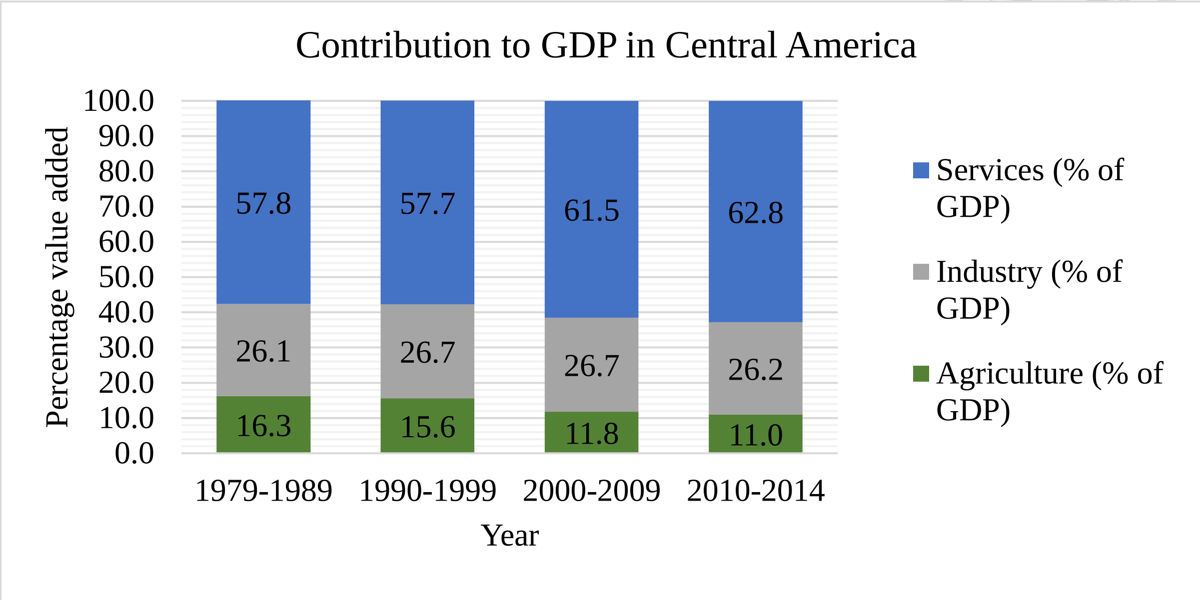


Source: World Bank

Figure 2.3 Employment share in Central America.

Because farming is an important way of subsistence for the families living in rural areas, increasing productivity for agricultural sector means, at the micro scale, improving the life of families in poverty and, at the macro scale, increasing the comparative advantage and opportunities to compete with industrialized and advanced economies. Therefore, this study is important from a political perspective as the government desires to improve the welfare of farmers and to increase the competitiveness of the agricultural sector.

doi: 10.6342/NTU201700916



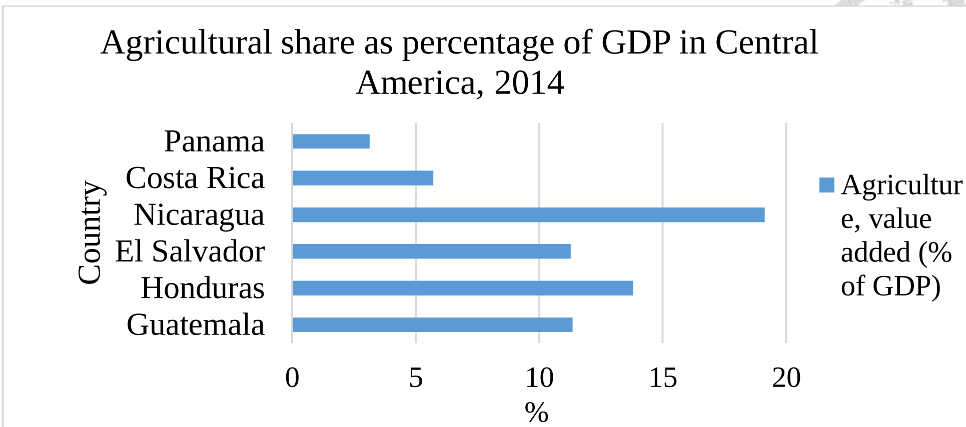
Source: World Bank

Figure.2.4 Sector value added (%GDP)

Since 1980, the agricultural sector in C.A. has shown dramatic changes in terms of Gross Domestic Product (GDP)'s contribution. According to the data released by the World Bank (WB, 2014), the average share of agricultural value added on GDP in Central America decreased from 16% in 1980's to 11% in 2014 (Figure 2.4).

It is notable that the agricultural sector's share of GDP varies between countries considerably. In Panamá, for instance, the value was below 4% while in Nicaragua the value was around 19% (Figure 2.5).

doi: 10.6342/NTU201700916



Source: Food Agricultural Organization

Figure 2.5 Agricultural share as percentage of GDP

Panamá's economy is mainly based in the service sector. According to the International Labor Organization (ILO, 2014), the percentage of labor working in service represents around 65% of the employment; while the employment in agriculture represents around 16.7% in 2014. Nicaragua has the highest percentage of the population engaged in agriculture. According to the ILO, the labor in agriculture represented around 32.2% of total employment in the region.

The Economic Commission for Latin America and the Caribbean (ECLAC) appointed significant advances in the labor sector in C.A. these countries however, also show that structural weaknesses persist, especially due to the large informality of the labor market.

doi: 10.6342/NTU201700916

Chapter 3. Literature Review

Improving productivity of agriculture can increase agricultural production and minimize the cost incurred by farms. Bravo-Ortega, C. (2004) determined several elements that may improve efficiency and productivity in agriculture. In addition to this study, Adelman et al. (1988) identified different patterns in agriculture among regions. This result suggests that some elements mentioned by Bravo-Ortega may have different effects across countries and regions. In 1970 Hayami. et al. (1970) studied the difference in productivity among countries; however, this study was not focused on Latin America and did not take account of the singularities among regions.

To investigate in detail the sources of growth in L.A., Dias, A. et al. (2010) identified some specific characteristics of the agricultural sector. Ludena, C. et al. (2010) extended this study and applied a different measure as suggested by Fulginiti, L. (1998) using two important components including efficiency change and technical change for productivity growth.

Based on the finding of previous researchers, improving the productivity of agriculture may have several positive effects on economies. Although the results extend previous information about productivity analysis, little of them account for the possible implication of inclusion of environmental variables for productivity change in C.A. This knowledge void warrants further investigation and exploration.

There are few studies considering the countries in C.A. for agricultural productivity. The results from Coelli (2005) on agricultural productivity for 93 countries (including five countries from C.A), shows that the main source of growth was TC and there is no evidence

doi: 10.6342/NTU201700916

that suggests technological regression on agriculture. These findings can also be applied to C.A with an exception for Nicaragua, where the growth was driven mainly by EC. Ebata (2014) conducted an analysis of 14 countries of C.A. and the Caribbean and found that TC was the most important source of growth in agriculture. For those countries in C.A., the growth in agriculture was driven by TC as well with exceptions in some periods.

A recent study by Ludena (2010) about agricultural productivity growth in Latin America and the Caribbean (LAC) from 1967 to 2010, shows that the highest growth within the region occurred during the 1990's and 2000's, as result of increases in efficiency and the adoption of new technologies. This result is supported by Diaz, A. (2010) who found that the performance of total factor productivity (TFP) for Latin America was better in the last decade of his study (1990-2000).

To the best of our knowledge, the previous studies found that Costa Rica has the highest TFP growth of the region, and Panamá has the lowest one. Overall, these studies highlight patterns of growth for the agricultural sector and provide important insights concerning the main sources of growth.

doi: 10.6342/NTU201700916

Chapter 4. Data and Methodology

Normally productivity in economic is a ratio of outputs to inputs. Sometimes this ratio involves a basic quotient of a single dependent and an independent variables, however, in most cases, constructing a productivity measure requires the aggregation of multiple inputs. In such cases, the aggregation of all the factor of production may provide a better diagnosis of the reality than when we just partially analyze the productivity.

In this analysis, we measure the TFP in C.A. by using two alternative methods to estimate frontiers: data envelope analysis (DEA) and stochastic frontier analysis (SFA). DEA is considered a non-parametric approach that among its advantages has the fact of not requiring information about prices. In this approach the TE is not measured according to the average performance of the companies or countries but in relation to the maximum performance done. Because we also have a particular interest to analyze the efficiency based on the average performance we use SFA which is a parametric method that in this study also includes exogenous variables that could affect the efficiency of a country.

For missing values, we regress the variables on time by using different functional forms (i.e., linear, quadratic and cubic) and select the model with the best R-square to obtain the predicted values. We replace the missing values with its predicted one.[2]

[2] Percentage of predicted values :
Employment: 44%, Machinery: 28 %, Fertilizer: 0.01%, Land: 0%, and Primary Crops: 0%.

doi: 10.6342/NTU201700916

4.1 Data Envelope Analysis (DEA)

First, we analyze the efficiency by using the non-parametric frontier Malmquist index which is an alternative to the SFA approach. This method uses a linear programming to construct an envelope frontier which considers all the countries in the sample and considers that any possible deviation from frontier is as a result of inefficiency.

DEA is based on the Farrel (1957) theory of efficiency measurement method and was introduced by Charnes et al. (1978). This method can be either input or output oriented. In the case of input-oriented, the frontier is defined by reducing inputs while holding output quantity constant. The output-oriented method, conversely, seeks to increase output bundle with inputs level held constant.

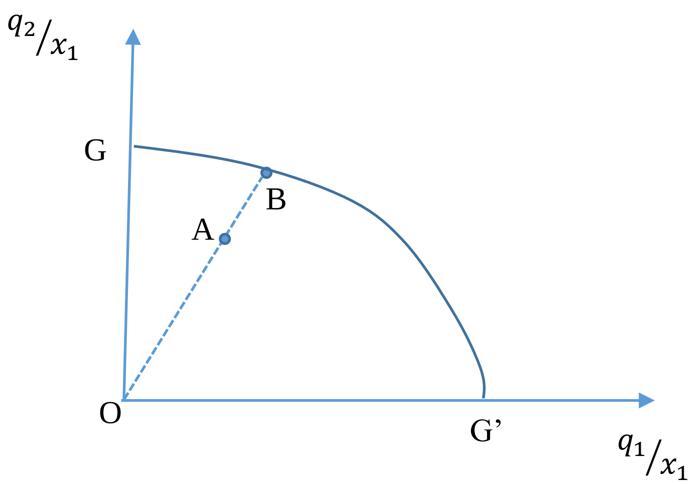
In this analysis, we use a variable return to scale (VRS) output-oriented DEA involving 6 countries and 216 observations over a 36-years period with one dependent variable and four independent variables.

In our case, the output orientation is considered more in agriculture farms and countries that do not have particular orders to fill output quantities, and also because farmers have more control over inputs than over output.

We can illustrate the output-oriented measures by using a case where one input (x) and two output ($q_1$and q_2) are used (Figure 4.1). The measure of technical efficiency (TE) is represented in by OA/OB, which is the difference between the observed point of production and the point on the production possibility frontier (PPF) which is defined by GG'. Normally researchers consider more appropriate to use the assumption of constant return to scale (CRS)

doi: 10.6342/NTU201700916

especially when financial constraint, imperfect competition, etc., may not affect the countries. However, as Coelli et al. (2005) mention, this seems less realistic. Therefore, we use VRS instead of CRS. Note that A is operating in the area bounded by the PPF, at this area any country operation is consider inefficient.



Source: Coelli et al. (2005)

Figure 4.1 Technical Efficiency from an Output Orientation.

By using linear programming for each country, we can calculate the output-oriented DEA.

$$max_{\emptyset\lambda}\emptyset$$

$$\text{st} \quad -\emptyset q_i + Q\lambda \geq 0$$

$$-\emptyset q_i + Q\lambda \geq 0$$

$$x_i + X\lambda \geq 0$$

$$I1'\lambda = 1$$

$$\lambda \geq 0 \qquad (1)$$

doi: 10.6342/NTU201700916

where $1 \leq \emptyset < \infty$, and $\emptyset - 1$ is the proportional increase in output that an i-th country, can achieve by held input constant. $\emptyset$ is a scalar, and λ is a $I \times 1$ vector of constants. The resulted TE, which is defined by $1/\emptyset$, is the score reported by DEAP Version 2.1.[3]

The main purpose of this stage is to measure the changes of TFP and decompose it into TC and EC. This study use Färe et al. (1994) output-based Malmquist productivity change index).

4.1.1 Malmquist productivity equation

The Malmquist productivity equation is the following

$$m_o(q_s, q_t, x_s, x_t) = [m_o^s(q_s, q_t, x_s, x_t) * m_o^t(q_s, q_t, x_s, x_t)]^{\frac{1}{2}}$$
$$= \left[\left(\frac{d_o^s(x_t, q_t)}{d_o^s(x_s, q_s)}\right) * \left(\frac{d_o^t(x_t, q_t)}{d_o^t(x_s, q_s)}\right)\right]^{\frac{1}{2}} \quad (2)$$

This equation compares two points at time s and t and can be decomposed as EC and TC. The first distance function with technology in period t, $d_o^s(x_t, q_t)$, is defined as the references; it measures the maximal proportional change in output required to make (x_t, q_t) achievable in relation with technology in period t. The second distance function in the denominator $d_o^s(x_s, q_s)$ measures the reciprocal proportional expansion of output vector q_s given the input vector x_s.

---

[3] Data Envelopment Analysis (Computer) Program.

doi: 10.6342/NTU201700916

Similar analysis for the second term in the bracket can be applied when we use technology in period s as the reference

4.1.2 Decomposition of the Malmquist index

Färe, et al. (1992a, 1992b) rearranged the Malmquist productivity index as follows:

$$Total\ Factor\ Productivity\ Change$$
$$= \frac{d_o^t(x_t,q_t)}{d_o^s(x_s,q_s)}\left[\left(\frac{d_o^s(x_t,q_t)}{d_o^t(x_t,q_t)}\right) * \left(\frac{d_o^s(x_s,q_s)}{d_o^t(x_s,q_s)}\right)\right]^{\frac{1}{2}} \quad (3)$$

Where,

The first expression illustrates the efficiency corresponding to the countries with best practices in the sample. Therefore, the performance captured by this component can be interpreted as the catching up effect.

$$Efficiency\ Change$$
$$= \frac{d_o^t(x_t,q_t)}{d_o^s(x_s,q_s)} = \frac{q_t/q_c}{q_s/q_a} \quad (4)$$

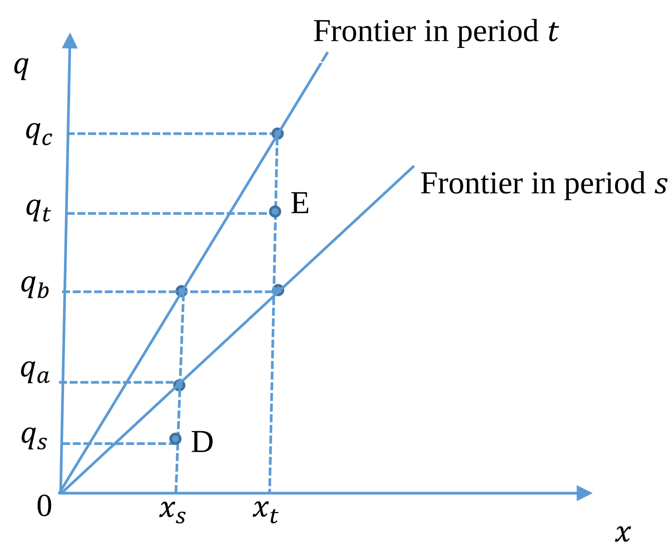
The second expression inside the brackets can be interpreted as TC, and this measures the shift of the frontier over the period of study. Fare et al. (1994), considers any improvement of this component as innovation by the country.

$$Technical\ Change$$
$$= \left[\frac{d_o^s(x_t,q_t)}{d_o^t(x_t,q_t)} * \frac{d_o^s(x_s,q_s)}{d_o^t(x_s,q_s)}\right]^{\frac{1}{2}} = \left[\frac{q_t/q_c}{q_s/q_a} \times \frac{q_t/q_c}{q_s/q_a}\right]^{\frac{1}{2}} \quad (5)$$

doi: 10.6342/NTU201700916

To confirm a positive or negative productivity change will depend on the value of the TFP for any country. A TFP greater than one implies that a country has a positive change in productivity, while a TFP value lower than 1 implies a negative change. However, if the country exhibits the same productivity in respect the previous period, then the TFP is equal to 1, implying that the country TFP has not changed.

The previous decomposition is illustrated in Figure 4.2 by considering a case of constant return to scale, where one input and one output are used.



Source: Coelli et al. (2005)

Figure 4.2 Malmquist Productivity Indices.

In Figure 4.2 a country operates at two different points (D and E) in time (s and t). In both cases, the production is consider inefficient because the country is not operating in the frontier but below the technology for the corresponding period.

doi: 10.6342/NTU201700916

In addition to this method, we use the SFA approach including exogenous variables to verify if the results are similar or differ significantly with the inclusion of exogenous variables and the application of a different approach. It's important to mention that we do not pretend to compare the results of both method; if that were the case, we would have to regress the efficiency score of DEA upon the exogenous variables that we want to analyze, which is also known as second stage analysis of DEA or exclude from the SFA model the exogenous variables, so the results can be as comparable as possible.

4.2 Stochastic Frontier Analysis (SFA)

The stochastic frontier model (SFM) was proposed by Aigener et al. (1977), and by Meeusen and Vanden Broeck (1977) simultaneously. This method is regularly used for the purpose of efficiency analysis, especially because it takes into account possible noise in the information and measurement errors ($v_{it} - u_{it}$).

In general, this method uses two approaches: Ordinary Least Square (OLS) and Maximum Likelihood method (ML). The first approach assumes that all the countries are efficient because the error term(ε_{it}) doesn't consider technical inefficiency (TI), which is given by a non-negative random term denoted as u_{it}.

The second approach, unlike the first, consider technical inefficiency because the error term has two separate components ($\varepsilon_{it} = v_{it} - u_{it}$).

The component u_{it} represents the unobserved variables such as climate, quality of land, or other exogenous elements not defined in the production function (these variables are

doi: 10.6342/NTU201700916

associated with technical inefficiency). This component is non-negative and assumed normally distributed with distribution pattern truncated normal, half-normal, or exponential (half normal for this study). The component v_{it} represents the random shock variable which have mean value (μ_i) equal to 0, variance constant or N (0, σ_v^2), and normally distributed, where u_{it} and v_{it} are distributed independent of each other.

Although it is true that this method has more advantages compared to DEA, it requires specifying a functional form that involves the use of econometric techniques, especially with the most functional forms.[4]

For this analysis, we use the translog functional form, a widely used functional form in the study of agricultural productivity which is more flexible than the linear and Cobb-Douglas functions.

4.2.1 Stochastic Frontier Model

The functional form of a translog production model when the ML method is utilized in SFA can be expressed as:

$$\ln(Y_{it}) = \beta_0 + \sum_{i=1}^{n} \beta_1 lnX_{it} + \frac{1}{2}\sum_{i=1}^{n} \beta_{ii} lnX_{it}^2 + \sum_{i=1}^{n}\sum_{j\neq i=1}^{n} \beta_{ij} lnX_i lnX_j + v_{it} - u_{it}$$

(6)

where Y_{it} denotes output

X_{it} = inputs variables

[4] Second-order flexible forms.

doi: 10.6342/NTU201700916

$\beta_0, \beta_i, \beta_{ii}$= the unknown parameters to be estimated. v_{it}= ramdom variables associated with disturbance in production; u_{it}=country specific/social economic characteristics. Where the technical inefficiency effects can be specified and defined as:

$$u_{it} = d_0 + d_1 z_{it} + d_2 z_{it} + \cdots \quad (7)$$

where the z's are social-economic variables which explain inefficiency

and it= i-th country in the t-th period.

The ML method is similar to the OLS method, with the difference that OLS assumes that all the countries are efficient, and then the random error of the OLS (ε_i) is equal to the random variables of the ML, that is $\varepsilon_{it} = v_{it}$.

In the ML method, the error term has two components. According to Coelli et al. (1998), the first component v_{it} is assumed to be iid N(0,σ_v^2) random error and independent of the second term (u_{it}). The second term is considered as a non-negative random variable and assumed to be distributed iid N($\eta_{it,}\sigma_u^2$) and truncated at zero. Kumbhakar and Lovell (2003) also incorporate a composed error structure with a two-sided symmetric term and a one-sided component. When the assumptions concerning to the distribution of error term are valid, the ML irrespective to the type of model estimated has many desired large sample (i.e asymptotic) properties, which is also the reason why ML is more popular in the analysis of productivity.

doi: 10.6342/NTU201700916

Because technological advances often affect the economic relationship among variables, especially with production functions, this model includes a time variable or time trend (t_i) that accounts for non-neutral technical change, and a time square term to allow for a non-monotonic technical change; this is

$$\ln(Y_{it}) = \beta_0 + \beta_t t + \frac{1}{2}\beta_{tt} t^2 + \sum_{i=1}^{n} \beta_{ti} t \, lnX_{it} + \sum_{i=1}^{n} \beta_i lnX_{it} + \frac{1}{2}\sum_{i=1}^{n} \beta_{ii} lnX_{it}^2 + \sum_{i=1}^{n}\sum_{j=1}^{n} \beta_{ij} lnX_i lnX_j + v_{it} - u_{it} \quad (8)$$

where t is a time trend representing technical change;

β: the unknown parameters to be estimated;

v_{it} : the random error, assumed to be i.i.d and have N(0, σ_v^2) distribution, independent of the $u_{it}s$.

And u_{it} the technical inefficiency effect.

The EC and TC of each country can be predicted using previous approaches. In this parametric case, the EC in equation (4) of DEA analysis can be compared directly with equation (9).

$$TE_{it} = E(\exp(-u_{it})/e_{it}) \quad (9)$$

Where $e_{it} = v_{it} - u_{it}$ can be used to calculate the component of efficiency change. By observing that $d_o^t(x_{it}, q_{it})$=TE_{it} and $d_o^s(x_{is}, q_{is})$=TE_{is} we calculate the efficiency change by dividing the *TE* in period *t* by the *TE* in period *s*.

We can also define the TE as the ratio resulting between observed production and the production output from the frontier production function.

doi: 10.6342/NTU201700916

$$TE_{it} = \frac{Y_{it}}{\exp(X'_{it}\beta + v_{it})} = \frac{\exp(X'_{it}\beta + v_{it} + u_{it})}{\exp(X'_{it}\beta + v_{it})} = \exp(-u_{it}) \qquad (9a)$$

In the same way, we can estimate TC using the parameter of our ML model. The TC index between periods for each of the countries can be calculated using the following equation:

$$Technical\ Change = \exp\left(\frac{1}{2}\left[\frac{\partial lnq_{is}}{\partial s} + \frac{\partial lnq_{it}}{\partial t}\right]\right) \qquad (10)$$

This is, TC is equal to the exponential of the arithmetic mean of the log derivatives of the production function with respect to time using the data for each country in period *s* and *t*.

Considering equation (7), the derivative of output respect time can be rewritten as:

$$Technical\ Change = exp\left\{\frac{1}{2}[(\sum_{i=1}^{n}\beta_t lnX_{it} + \beta_{tt} * t + \beta_t)period\ s + (\sum_{i=1}^{n}\beta_t lnX_{it} + \beta_{tt} * t + \beta_t)period\ t]\right\} \qquad (10a)$$

in the i-th country($i = 1,2,3,..,6$) in the t-th period ($t = 1,2,3,..,36$)

doi: 10.6342/NTU201700916

4.2.2 Empirical Stochastic Frontier Model

The functional form of translog production model in SFA used in this study is defined as follows:

$\ln(Y_{it}) = \beta_0 + \beta_1 \ln(Labor_{it}) + \beta_2 \ln(Machinary_{it}) + \beta_3 \ln(Area_{it}) + \beta_4 \ln(Fertilizer_{it}) + \beta_5 (Time_{it}) + \frac{1}{2}[\beta_{11} \ln(Labor_{it}^2) + \beta_{22} \ln(Machinary_{it}^2) + \beta_{33} \ln(Area_{it}^2) + \beta_{44} \ln(Fertilizer_{it}^2) + \beta_{55} (Time_{it}^2)] + \beta_{12} \ln(Labor_{it})* \ln(Machinary_{it}) + \beta_{13} \ln(Labor_{it})* \ln(Area_{it}) + \beta_{14} \ln(Labor_{it})* \ln(Fertilizer_{it}) + \beta_{15} \ln(Labor_{it})* Time_{it} + \beta_{23} \ln(Machinary_{it})* \ln(Area_{it}) + \beta_{24} \ln(Machinary_{it})* \ln(Fertilizer) + \beta_{25} \ln(Machinary_{it})* Time + \beta_{34} \ln(Area_{it})* \ln(Fertilizer_{it}) + \beta_{35} \ln(Area_{it})* Time_{it} + \beta_{45} \ln(Fertilizer_{it})* Time_{it} + v_{it} - u_{it}$, $i = 1,2,3,..,6$, $t = 1,2,3,..,36$ (11)

where $\ln(Y_{it})$ denotes the log of primary crops (1000 mt)[5] in country i in year t.

$\beta_0, \beta_i, \beta_{ii}$: the unknown parameter to be estimated.

The inputs include in the model, namely,

$\ln(Labour)$: log of total employment in agriculture (1000 persons).

$\ln(Machinary)$: log of total machinery used in agriculture (1000 units).

$\ln(Land)$: log of total land for agriculture (1000 ha)[6] .

$\ln(Fertilizer)$: log of total fertilizer used in agriculture (1000 mt) .

v_{it}= random variables associated with disturbance in production, and u_{it}=country specific/social economic characteristics.

u_{it} can be specified and defined as:

$$u_{it} = \delta_0 + \delta_1 co2_{it} + \delta_2 hc_{it} + \delta_3 irr_{it} + \delta_4 rp_{it} + \delta le_{it} + \delta_6 hhi_{it} \quad (12)$$

[5] mt stands for metric tons.
[6] ha stands for hectares.

doi: 10.6342/NTU201700916

where

$co2_{it}$= represent the emission of Co2 in agriculture in country i in year t.

hc_{it}= human capital index in country i in year t.

irr_{it}= irrigation area in country i in year t.

rp_{it}= rural population in country i in year t.

le_{it}= life expectancy in country i in year t.

hhi_{it}= Herfindahl-Hirschman index (HHI) in country i in year t.

4.2.3 Elasticities

Based on the coefficient estimates of MLE, the estimated frontier elasticity of each input can be calculated by using equation (13).

The elasticity is expressed as:

$$\varepsilon = \frac{\partial \ln f(x,t)}{\partial \ln x_m} = \hat{\beta}_m + \sum_{n \neq m} \hat{\beta}_{mn} \ln x_n + \hat{\beta}_{mn} \ln x_m + \hat{\beta}_{tm} t \qquad (13)$$

4.3 Data Sources and Variables

To investigate the total factor productivity and its two driving engines: efficiency change and technical change from 1979 to 2014 in Central America, this study uses data from a variety of sources: The Food and Agricultural Organization (FAO), International Labor Organization (ILO), International Fertilizer Association (IFA), the United Nations Economic Commission for Latin America and the Caribbean (ECLAC), World Bank (WB), Penn World Table (PWT), country reports, and author estimations.

doi: 10.6342/NTU201700916

Country Coverage

This study intends to focus on a homogeneous set of countries located in C.A. These countries are somewhat similar in geographic, climatic, and political characteristics. The countries included in this study are: Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica, and Panamá. Belize was omitted from this study due to the limitation of information.

Time Period

This study exam the TFP for the period 1979-2014. Since information about agriculture prior to 1979 is insufficient in C.A.

4.3.1 Output

Primary Crops

Primary crops are according to (FAO, 2014):

> "The crops that come from the land without having any indirect processing, cleaning or quality change. These variables are divided into temporary crop which are both sown and harvested during the same agricultural year (sometimes more than once), and permanent crops which are sown or planted once and not replanted after each annual harvest". (See list of primary crops in table B in appendix)

doi: 10.6342/NTU201700916

Table 4.1 Summary of Primary Crops, 1979-2014.

Country	Tons of Primary Crops	*Weight	Mean	Std. Dev.	Min	Max
Guatemala	20003690.6	40%	20003.4	8975.2	7658.4	39039.4
Honduras	7209948.9	15%	7542.5	2395.0	4985.1	12229.1
El Salvador	5962254	12%	5962.3	1374.9	3690.3	8920.8
Nicaragua	5107003.6	10%	5108.7	1723.5	3145.6	9571.7
Costa Rica	8161927.3	16%	8161.9	2648.0	4574.5	12424.8
Panamá	3366367.1	7%	3366.4	332.8	2805.1	4290.9

Source: Food and Agriculture Organization

*Note: weight= production of primary crops in each country/ total primary crops.

4.3.2 Inputs

This analysis included four inputs: labor, machinery, land, and fertilizer. Details information of these inputs is presented in the following.

Land

The variable land is measured as agricultural area. This variable account for arable land, permanents crops, and pastures. However, in this study, the land under permanent meadow and pasture which is land used permanently for a period of five years or more, is not included.

According to the Food and Agriculture Organization Statistic (FAOSTAT, 2014) the definition of arable land and permanent crops are as the following:

> "Arable land is defined as the land under temporary crops (multiple-cropped areas are counted only once) which is all land used for crops, not abandoned land resulting from shifting cultivation, and with a less than one-year growing cycle and which must be newly sown or planted for further production after the harvest.

doi: 10.6342/NTU201700916

Arable land consists of land temporarily fallow (less than five years), temporary meadows for mowing or pasture, and land under market and kitchen gardens".[7]

"Permanent crops is defined as the land cultivated with long-term crops which do not have to be replanted for several years (such as coffee), land under trees and shrubs producing flowers (such as roses), and nurseries (except those for forest trees, which should be classified under "forest")."

Table 4.2 Summary of Land Use for Agriculture, 1979-2014.

Country	*Weight	Mean	Std. Dev.	Min	Max
Guatemala	27%	1975.4	224.2	1726	2564
Honduras	23%	1674.9	201.7	1427	2015
El Salvador	11%	851.4	71.0	727	974
Nicaragua	24%	1755.3	338.8	1240	2320
Costa Rica	7%	512.0	17.7	490	547
Panamá	9%	665.4	60.5	552	757.4

Source: Food and Agriculture Organization

*Note: weight=land used in agriculture in each country/ total land used agricultural.

Machinery

According to (FAO, 2014) variable Machinery refers to:

"Number of agricultural tractors in use, which commonly refers to wheel and crawler or track-laying type tractors (excluding garden tractors) employed in agriculture."

[7] Data for "arable land" are not meant to indicate the amount of land that is potentially cultivable.

doi: 10.6342/NTU201700916

Table 4.3 Summary of Machinery used for Agriculture, 1979-2014.

Country	*Weight	Mean	Sts. Dev.	Min	Max
Guatemala	15%	4.26	0.145794	3.95	4.54
Honduras	16%	4.77	0.724735	3.2	5.46
El Salvador	12%	3.61	0.4214016	3.25	5
Nicaragua	10%	2.99	0.6571603	2.1	4.29
Costa Rica	23%	6.77	0.4555585	5.9	7.22
Panamá	24%	6.97	1.695099	5.05	9.89

Source: Food and Agriculture Organization

*Note: weight=machinery used in agriculture in each country/ total machinery used agricultural

Labor

According to International Labor Organization (ILO, 2014) this variable considers the number of labor specifically working in agriculture. The indicator provides information on persons in working age (15-64) who, during a specified short period, were classified in the following categories: a) paid employment, and b) self-employment.

The economic activity is classified according to the main activity of the establishment in which a person worked during a specific period. It does not depend on the specific duties or functions implied by the job but rather depends on the characteristics of the economic unit in which this person works.

Table 4.4 Summary of Labor in Agriculture, 1979-2014.

Country	*Weight	Mean	Sts. Dev.	Min	Max
Guatemala	37%	1241.9	457.4	84.2	2113.6
Honduras	20%	689.9	290.8	2.8	1043.8
El Salvador	13%	431.8	166.5	4.7	638.3
Nicaragua	17%	577.1	205.7	334.8	1058
Costa Rica	7%	247.4	23.0	172.8	285.1
Panamá	6%	191.5	33.3	154.9	270.2

Source: International Labor Organization

*Note: weight=agricultural labor in each country/ total agricultural labor

doi: 10.6342/NTU201700916

Fertilizer

According to International Fertilizer Organization (IFO), this variable considers the amount of fertilizer used in agriculture by considering the three most important plants nutrients. These nutrients are nitrogen (N), phosphate (P205), and potash (K20). In C.A. the use of fertilizer is increasing, especially in the last decade. The use of fertilizer is not limited to these three components alone, but these are the most commonly used.

Table 4.5 Summary of Fertilizer in Agriculture, 1979-2014.

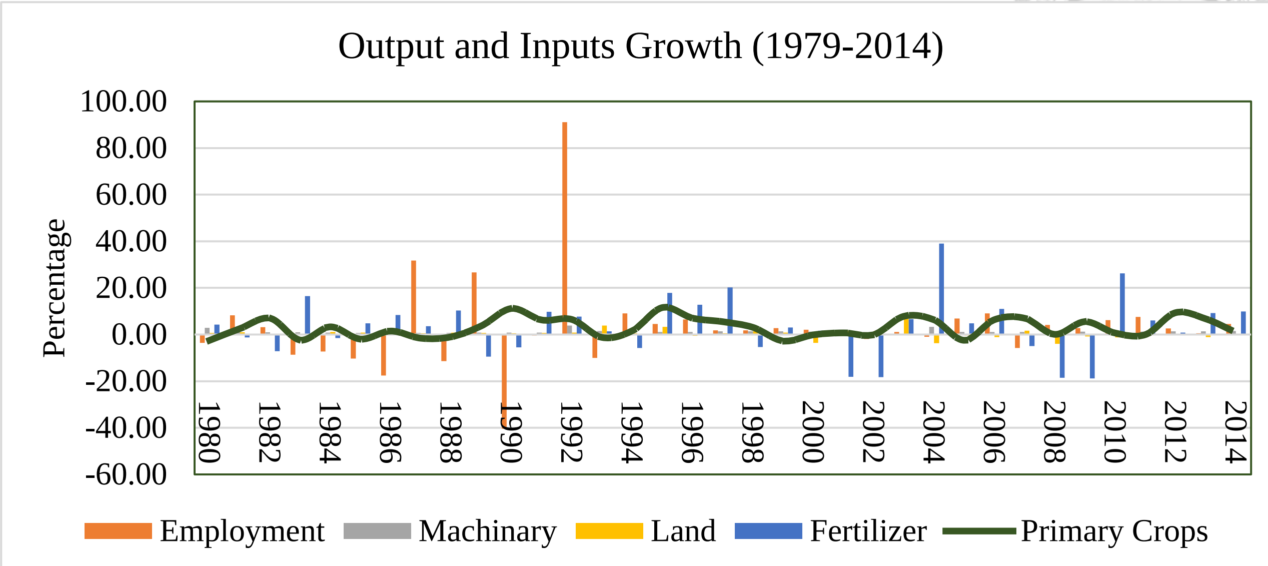
Country	*Weight	Mean	Sts. Dev.	Min	Max
Guatemala	31%	169.2	62.3	68.1	319.5
Honduras	18%	97.9	77.4	15	291.8
El Salvador	13%	72.0	12.1	53.1	97
Nicaragua	8%	43.1	15.8	17.7	76.6
Costa Rica	23%	126.4	36.2	69.9	199
Panamá	6%	33.2	8.0	23.1	60.1

Source: International Fertilizer Organization

*Note: weight=fertilizer used in agriculture in each country/ total fertilizer used in agricultural.

In Figure 4.3 the output and input growth rate are presented. In general, the decade of 1980 was characterized by slow growth and a lot of ups and downs. In addition, we have included in appendix a graph for each input and output growth over the whole period.

doi: 10.6342/NTU201700916



Source: prepared by author

Figure 4.3 Output and Input growth (1979-2014)

In the case of the production of primary products, it shows a steady growth over the years. However, we can identify the slow growth of this variable during the first years of the study and between 1998 and 2002. This stagnation is explained by the sudden arrival of the hurricane Mitch in 1998 which was one of the worst storms in the last decades and severely destroyed much of the productive infrastructure of the region.

In terms of employment, abrupt changes were experienced in the results of the war in C.A. However, a steady employment growth can be seen after 1990, although some countries such as Panama experienced a slowdown in agricultural employment.

In the case of machinery and fertilizer, both variables presented steady growth, although the fertilizer presented two important breaks in 2002 and 2009. The sudden growth during these two years is attributed to efforts of some governments for compensating the

doi: 10.6342/NTU201700916

effects of climate change that were reflected in the greater prolongation and impact of *el niño* and *la niña* phenomena in the region.

Finally in the case of land for agriculture. This variable maintained a steady tendency to growth, however after 2003 this tendency start to decrease. The decreasing use of land for agriculture might be attributed to the expansion of the urban area but also to the abandonment of agricultural activities.

To extend the analysis, we have included in appendix Table C. containing the growth rates of productivity ratios for each of the factors of production used in this study. Taking into account the identity about partial productivities of Hayami and Ruttan (1985)[8], and productivity ratios of machinery and fertilizer.

4.3.3 Exogenous Variables

In this study, we have included 6 exogenous variables that reflect differences in the quality of the inputs used in the production model but also variables outside the production that could explain qualitative differences among the countries of the region. The exogenous variables used in this study reflect variances in the quality of inputs used, infrastructure, environmental quality and social development of countries.

[8] $PrimaryCrops/Labour = (Area/Labour)(PrimaryCrops/Land)$

doi: 10.6342/NTU201700916

Carbon Dioxide (CO2)

According to FAO (2014), Carbon Dioxide (CO2) is defined as follows:

"Total emissions produced in the different agricultural emissions sub-domains, such as manure management, manure applied to soils or left on pastures, enteric fermentation, rice cultivation, synthetic fertilizers, cultivation of organic soils, crop residues, burning of crop residues, burning of savanna, and energy use. Carbon Dioxide provides a picture of agricultural contribution to the total amount of greenhouse gas (GHG) emissions. GHG emissions from agriculture consist of two non-CO2 gases, namely methane (CH4) and nitrous oxide (N2O), produced by crop and livestock production and by management activities". The unit of measure of this variable is gigagrams.

Table 4.6 Summary of Co2 in agriculture, 1979-2014.

Country	*Weight	Mean	Std. Dev.	Min	Max
Guatemala	22%	5877.8	1358.1	3711.98	8457.79
Honduras	19%	4876.4	597.7	3814.34	5954.95
El Salvador	10%	2724.3	258.2	2166.48	3294.49
Nicaragua	23%	5974.4	1186.4	3967.14	7759.27
Costa Rica	14%	3789.4	634.5	2765.79	4750.31
Panamá	12%	3029.0	249.6	2685.42	3585.04

Source: Food and Agriculture Organization

*Note: weight= emission of Co2 in agriculture in each country/ total Co2 emissions

Human Capital (HC)

We use the human capital index of Penn World Tables (PWT), which follow a standard approach in the literature, based on the construction of average years of schooling

doi: 10.6342/NTU201700916

from Barro and Lee (2013), and an assumed rate of return to education based on the estimations of Mincer equation around the world (Psacharopoulos, 1994).

Table 4.7 Summary of Human Capital, 1979-2014.

Country	Rank	Mean	Std. Dev.	Min	Max
Guatemala	6	1.58	0.1	1.34	1.85
Honduras	3	1.86	0.2	1.60	2.22
El Salvador	5	1.77	0.2	1.41	2.14
Nicaragua	4	1.84	0.2	1.52	2.18
Costa Rica	2	2.33	0.2	1.92	2.60
Panamá	1	2.49	0.2	2.08	2.81

Source: Penn World Table

Irrigation (IRR)

This variable is defined as the area equipped with irrigation infrastructure to provide water to the crops. This variable includes areas equipped for partial and full spate irrigation areas,control irrigation, and equipped wetland. The unit of measure is 1000 ha (FAO, 2014).

Table 4.8 Summary of Area equipped for irrigation, 1979-2014.

Country	Rank	Mean	Std. Dev.	Min	Max
Guatemala	1	192.8	100.7	84.0	338.0
Honduras	4	76.4	9.0	66.0	90.0
El Salvador	5	42.3	3.5	36.0	45.2
Nicaragua	2	100.7	53.9	60.0	199.0
Costa Rica	3	89.1	14.8	56.0	103.0
Panamá	6	32.0	2.3	28.0	35.0

Source: Food and Agriculture Organization

Rural Population (RP)

According to the World Bank (WB), the rural population refers to people living in rural areas. It is calculated as the difference between total population and urban population.

doi: 10.6342/NTU201700916

Table 4.9 Summary of Rural Population, 1979-2014.

Country	Mean	Std. Dev.	Min	Max	Rural Population	*Rural Population Share
Guatemala	56.1	5.8	48.20	65.69	6081414.73	37%
Honduras	53.4	5.4	46.10	62.27	3150716.34	19%
El Salvador	50.0	5.8	41.02	59.05	2439878.17	15%
Nicaragua	46.1	6.8	37.21	56.09	2130258.64	13%
Costa Rica	42.6	7.4	30.61	53.66	1462073.62	9%
Panamá	39.3	8.3	24.09	51.12	1010115.06	7%

Source: World Bank

*Note: rural population share=rural population in each country/ total rural population

Life Expectancy (LE)

Life expectancy at birth according to the World Bank (2014) refers to:

"Number of years that a newborn infant would live considering that the patterns of mortality throughout its lifetime were to remain the same".

Table 4.10 Summary of Life expectancy, 1979-2014.

Country	Rank	Mean	Std. Dev.	Min	Max
Guatemala	6	65.2	4.9	56.8	71.7
Honduras	3	68.1	4.2	58.8	73.1
El Salvador	5	66.0	5.3	56.4	72.8
Nicaragua	4	67.2	5.4	58.1	74.8
Costa Rica	1	76.5	2.1	71.5	79.4
Panamá	2	74.2	2.2	69.9	77.6

Source: World Bank

doi: 10.6342/NTU201700916

Herfindahl-Hirschman Index (HHI)

The index is named after economists Orris C. Herfindahl and Albert O. Hirschman and is usually used to measure the market concentration. In this study, we use this index to measure the concentration of primary crops in CA.

$$HHI = \sum_{i=1}^{N} s_i^2$$

Where s_i refers to the share of primary crop of country i and N is the total number of countries.

- An HHI below 100 indicates a very high diversification in production of primary crops.
- An HHI below 1,500 indicates a balanced diversification in production of primary crops.
- An HHI between 1,500 to 2,500 indicates a moderate concentration in production of primary crops.
- An HHI above 2,500 indicates a high concentration in production of primary crops.

We assumed with this approximation that countries with a higher concentration of products tend to be more specialized in the production of this one, thus increasing the efficiency of production.

Table 4.11 Summary of Herfindahl-Hirschman index, 1979-2014.

Country	Rank	Mean	Std. Dev.	Min	Max
Guatemala	2	5239.2	547.4	4207.9	6435.5
Honduras	5	3339.3	337.9	2800.2	3831.3
El Salvador	1	5368.3	706.7	3968.4	6549.2
Nicaragua	3	4892.6	366.0	4200.0	5551.7
Costa Rica	6	2757.0	537.3	2067.0	3799.8
Panamá	4	3637.6	482.7	2886.4	4536.8

Source: calculated by the author.

doi: 10.6342/NTU201700916

Chapter 5. Results and Discussion

This chapter presents the results of the DEA, and the SFA used to calculate the production frontier and the TFP components.

5.1 Data Envelopment Analysis (DEA)

5.1.1 TFP and its components

By using the Malmquist productivity index from Data Envelopment Analysis in C.A. Table 5.1 shows, the average annual TFP change, and its components. Although the EC is negative across the entire period, the TFP shows a positive growth mainly driven by TC.

Table 5.1 Annual mean of TFP change and its components, 1980-2014 (DEA).

Year*	Efficiency Change	Technical Change	TFP Change	Year*	Efficiency Change	Technical Change	TFP Change
1980	0.951	0.945	0.900	**1998**	0.981	1.047	1.027
1981	1.010	1.003	1.014	**1999**	1.032	0.957	0.988
1982	0.994	1.076	1.069	**2000**	0.993	1.023	1.016
1983	1.032	0.957	0.988	**2001**	1.033	1.096	1.132
1984	0.992	0.996	0.988	**2002**	1.120	1.031	1.154
1985	0.962	1.482	1.426	**2003**	0.923	1.019	0.941
1986	0.996	0.946	0.942	**2004**	0.984	0.972	0.956
1987	1.021	0.860	0.878	**2005**	0.991	1.025	1.016
1988	0.934	0.921	0.861	**2006**	1.057	0.932	0.985
1989	1.075	0.980	1.053	**2007**	0.891	1.137	1.013
1990	0.846	1.489	1.260	**2008**	1.083	0.990	1.071
1991	1.132	0.870	0.985	**2009**	0.938	1.128	1.059
1992	1.039	0.770	0.799	**2010**	1.053	0.823	0.866
1993	1.012	0.969	0.981	**2011**	1.058	0.991	1.049
1994	0.992	1.135	1.126	**2012**	0.958	1.040	0.996
1995	0.899	1.009	0.906	**2013**	0.965	1.022	0.986
1996	1.013	0.978	0.991	**2014**	1.032	0.964	0.995
1997	0.937	1.035	0.970	**Mean**	**0.9961**	**1.0092**	**1.0053**

*Note: the year 1980 refers to the change between 1979 and 1980, and so on.

doi: 10.6342/NTU201700916

The results in Table 5.2 show the average EC, TC, and TFP change for each country of C.A between 1979 and 2014. In terms of individual countries, Costa Rica has the highest TFP change, which is consistent with the result of (Coelli, J. and Rao, D. 2005). Panamá has the lowest total productivity. Costa Rica shows a 1.6% average growth in TFP which is entirely due to TC.[9]

Table 5.2 Summary description of TFP change and its components, 1979-2014 (DEA)

Country	Description	Efficiency Change	Technical Change	TFP Change
Guatemala	*Mean*	1.0000	1.0097	1.0097
	Max	1.0000	1.9430	1.9430
	Min	1.0000	0.4270	0.4270
	Std. Deviation	0.0000	0.2058	0.2058
Honduras	*Mean*	0.9883	1.0187	1.0066
	Max	2.2080	10.2290	10.2290
	Min	0.6120	0.3980	0.3980
	Std. Deviation	0.2549	1.5776	1.5980
El Salvador	*Mean*	1.0000	1.0114	1.0114
	Max	1.3560	1.7550	1.4490
	Min	0.7090	0.6030	0.6030
	Std. Deviation	0.1425	0.2002	0.1681
Nicaragua	*Average*	0.9986	1.0092	1.0076
	Max	1.5360	1.3250	1.4040
	Min	0.6670	0.6880	0.7050
	Std. Deviation	0.1773	0.1599	0.1872
Costa Rica	*Mean*	1.0000	1.0159	1.0159
	Max	1.0000	1.1970	1.1970
	Min	1.0000	0.8920	0.8920
	Std. Deviation	0.0000	0.0698	0.0698
Panamá	*Mean*	0.9898	0.9906	0.9806
	Max	1.4430	1.4060	1.3940
	Min	0.6280	0.8100	0.6360
	Std. Deviation	0.1666	0.1130	0.1500
CA	*Mean*	***0.9961***	***1.0092***	***1.0053***
	Max	2.2080	10.2290	10.2290
	Min	0.6120	0.3980	0.3980
	Std. Deviation	0.1534	0.6575	0.6672

[9] (1.0159-1)*100=1.59~1.60%

doi: 10.6342/NTU201700916

Panama, meanwhile, is the only country that shows a negative change of TFP (-1.95% average), which is due to the negative growth of EC (-1.02%) and the negative growth of TC (-0.94%). These results revealed that efficiency level in C.A. was less than the optimal level. The TFP growth in the region was around 0.53%. The main source of this growth was TC at 0.92%.

Analysis by period in Table 5.3 reveals that the overall TFP for the region was driven mostly by TC rather than EC.

Table 5.3 TFP change and its components by period.

Year	Efficiency Change	Technical Change	TFP Change
Period 1980-1989	0.996	1.006	1.002
Period 1990-1999	0.985	1.012	0.997
Period 2000-2009	0.999	1.033	1.032
Period 2010-2014	1.012	0.965	0.976
Period 1990-2014	0.996	1.011	1.007
Period 1980-2014	0.996	1.009	1.005

Because the decade of 1980's was particularly unstable in the region due to political and civil war, we generated the results of TFP considering only the years after 1989 (Table 5.4).

The results show that TC remains the primary source of TFP for the region despite the years with more instability were omitted. In the case of EC, the results indicate a decline of 0.43%, which was consistent with the analysis including the decade of the 1980's.

doi: 10.6342/NTU201700916

Table 5.4 Summary description of TFP change and its components, 1990-2014 (DEA)

Country	Description	Efficiency Change	Technical Change	TFP Change
Guatemala	*Mean*	1.0000	1.0075	1.0075
	Max	1.0000	1.9430	1.9430
	Min	1.0000	0.4270	0.4270
	Std. Deviation	0.0000	0.2388	0.2388
Honduras	*Mean*	0.9837	0.9965	0.9800
	Max	2.2080	1.6020	2.3180
	Min	0.6120	0.5530	0.5270
	Std. Deviation	0.3032	0.1912	0.3706
El Salvador	*Mean*	1.0000	1.0190	1.0190
	Max	1.3560	1.7550	1.2610
	Min	0.7090	0.6030	0.6660
	Std. Deviation	0.1568	0.1971	0.1403
Nicaragua	*Mean*	1.0073	1.0089	1.0162
	Max	1.4340	1.3250	1.3760
	Min	0.7020	0.6880	0.7050
	Std. Deviation	0.1495	0.1813	0.1902
Costa Rica	*Mean*	1.0000	1.0252	1.0252
	Max	1.0000	1.1970	1.1970
	Min	1.0000	0.8920	0.8920
	Std. Deviation	0.0000	0.0770	0.0770
Panamá	*Mean*	0.9858	1.0069	0.9928
	Max	1.4430	1.4060	1.3940
	Min	0.6280	0.8370	0.6360
	Std. Deviation	0.1981	0.1150	0.1635
Central America	*Mean*	***0.9961***	***1.0106***	***1.0067***
	Max	2.2080	1.9430	2.3180
	Min	0.6120	0.4270	0.4270
	Std. Deviation	0.1695	0.1726	0.2137

doi: 10.6342/NTU201700916

Table 5.5 Summary description of technical efficiency, 1979-2014 (DEA)

	Technical Efficiency	**Guatemala**	**Honduras**	**El Salvador**	**Nicaragua**	**Costa Rica**	**Panamá**	**Central America**
DEA	***Mean***	1.00	0.78	0.86	0.92	1.00	0.91	0.91
	Min	1.00	0.40	0.68	0.52	1.00	0.53	0.40
	Max	1.00	1.00	1.00	1.00	1.00	1.00	1.00

In addition to the previous results, Table 5.5 shows the value of technical efficiency (TE) reached by each country. Along the overall period, the TE was 0.912, with a minimum value of 0.396 and a maximum value of 1 represented by the countries on the frontier. A lower value of efficiency means that countries are less efficient and higher values means that countries are more efficient or closer to the frontier. The mean value of 0.912 indicates that countries can reduce the use or consumption of all inputs by 0.88% without reducing their primary crops.

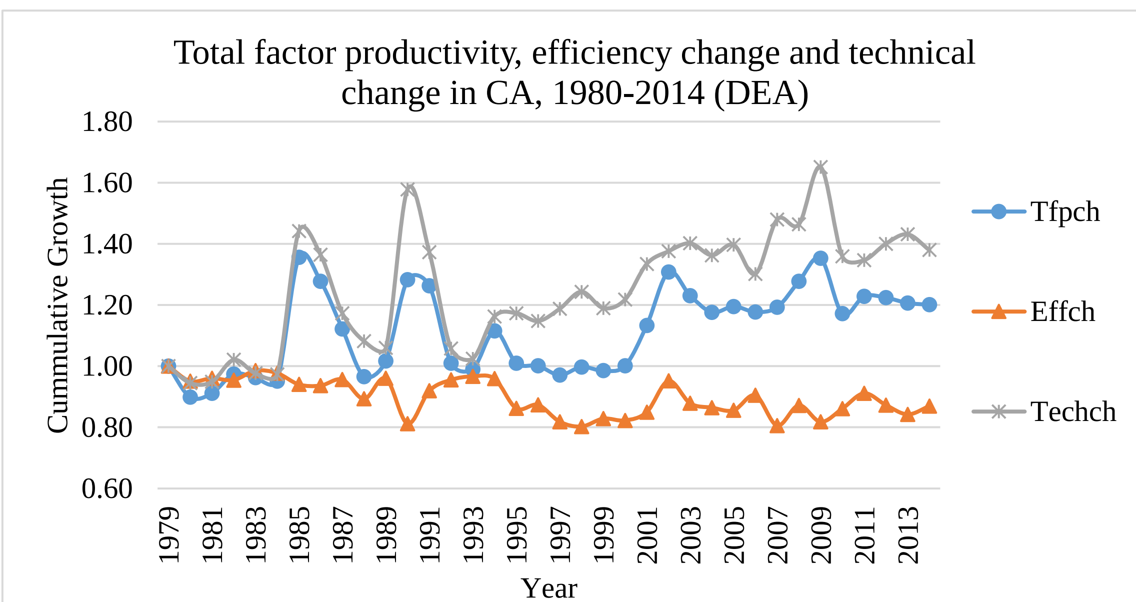


Figure 5.1 Cumulative TFP and its components (DEA)

doi: 10.6342/NTU201700916

In Figure 5.1 it is easy to identify that TC (or frontier shift) is the major source of TFP growth for C.A. The cumulative TFP at the end of the period were 1.20, while EC and TC were 0.87 and 1.38 respectively. A detailed observation shows that efficiency change (or catch –up) was also an important source of TFP growth for several years. In addition, in Table 5.6 we analyze the TFP and its components to find if there were any associate tendency among decades. With respect to productivity and efficiency, no association among countries or decades was found. However, from the analysis of EC, we can see that the frontier is defined for Guatemala and Costa Rica throughout the period. Although the average EC for El Salvador is almost 1, this country not always considered to be on the production frontier.

Table 5.6 Summary description of TFP change and its components by decade, 1980-2014

Description/Country		**Guatemala**	**Honduras**	**El Salvador**	**Nicaragua**	**Costa Rica**	**Panamá**
Efficiency Change	Decade 1980	1.00	1.00	1.00	0.98	1.00	1.00
	Decade 1990	1.00	0.91	0.98	1.02	1.00	1.00
	Decade 2000	1.00	1.05	1.00	0.99	1.00	0.95
	2010-2014	1.00	1.00	1.04	1.01	1.00	1.02
	Average	***1.000***	***0.988***	***1.000***	***0.999***	***1.000***	***0.990***
Technical Change	Decade 1980	1.02	1.08	0.99	1.01	0.99	0.95
	Decade 1990	1.00	0.98	1.03	1.01	1.04	1.01
	Decade 2000	1.03	1.04	1.03	1.04	1.02	1.03
	2010-2014	0.98	0.94	0.97	0.94	1.01	0.95
	Average	***1.010***	***1.019***	***1.011***	***1.009***	***1.016***	***0.991***
TFP Change	Decade 1980	1.02	1.08	0.99	0.99	0.99	0.95
	Decade 1990	1.00	0.90	1.01	1.03	1.04	1.01
	Decade 2000	1.03	1.09	1.03	1.03	1.02	0.98
	2010-2014	0.98	0.94	1.02	0.95	1.01	0.97
	Average	***1.010***	***1.007***	***1.011***	***1.008***	***1.016***	***0.980***

The years after 1990 are considered the years of relative stabilization and commercial opening.

doi: 10.6342/NTU201700916

5.1.2 Country Analysis of TFP change and its components

In this subsection, we investigate the TFP, TC, and EC for each individual country in C.A by using DEA.

Guatemala's TFP change and components

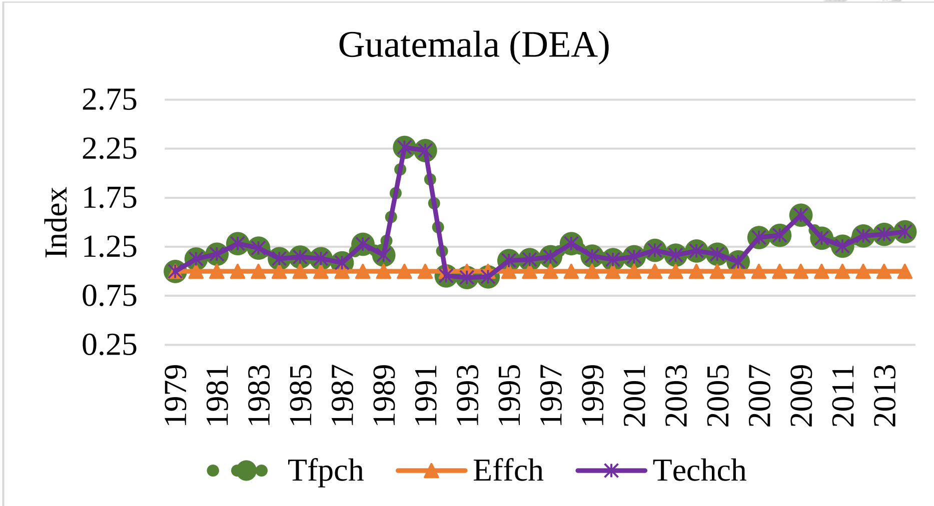
Guatemala is considered one of the countries which was located in the production frontier along the period of study. This implies that the value of the EC is equal to 1 and so that the change of TFP is due to TC. This country, like other countries in C.A., experienced important economic and social changes as a result of internal conflicts between the government and insurgent groups. The most vulnerable groups were the indigenous people, who were predominantly working or living in the agricultural sector. Normally speaking, it was the 1980's that countries in C.A. experienced abrupt changes in TFP explained by the massive change in the level of employment, especially in the agricultural sector. According to data of the International Labor Organization (ILO, 2014), employment in agriculture in Guatemala in the decade of 1980's represented almost 50% of the total force. The lower level of employment registered at the beginning of 1990 with 89,000 people employed in the agricultural sector (16 times less than the previously higher level of labor in agriculture). The stabilization of labor started after 1994, which coincides with the introduction of the framework agreement for the resumption of negotiation.[10]

The cumulative TFP for Guatemala was 1.019, which reflects a positive accumulation of the indicator along the entire period of study.

---

[10] GUATEMALA. " The process of negotiation for the search for peace "

doi: 10.6342/NTU201700916



Source: prepared by the author.

Figure 5.2 Guatemala cumulative TFP change and its components (DEA)

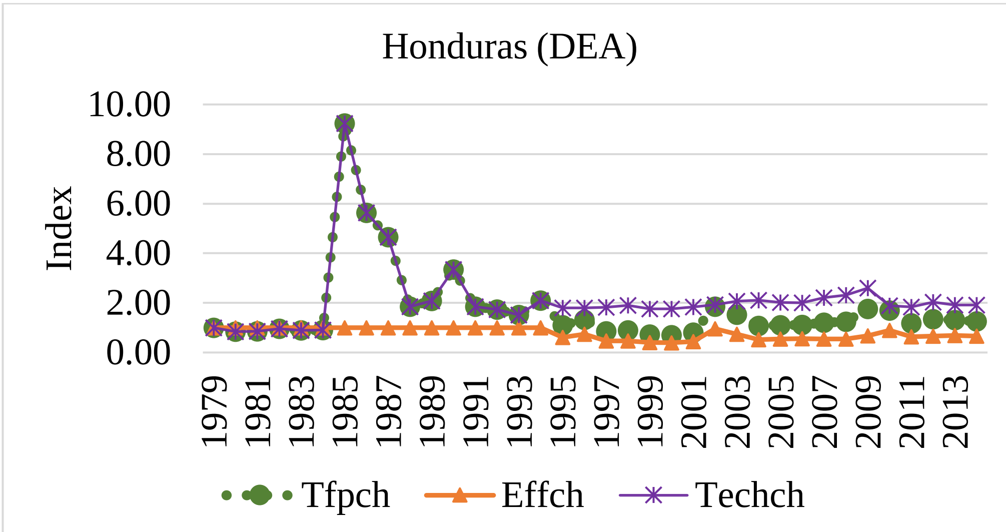
Honduras's TFP change and its components

Although Honduras did not experience war during the 1980s, it had suffered the collateral effects of severe political and social crises of its neighboring countries' that triggered death, severe violations of human rights, and massive migration of million of people. Honduras has borders with Guatemala, El Salvador, and Nicaragua.

Prior to the 1980's the government of Honduras rarely address the problem of employment, which results in a very high unemployment in 1980's. In the agricultural sector, the impact was even higher and so rural farmers flocked to the cities looking for better opportunities. Between 1983 and 1985, Honduras received foreign aid of $200 million to generate employment and compensate for the impact of the region-wide recession.

doi: 10.6342/NTU201700916

The cumulative TFP change for Honduras was 1.26, however, when we consider the cumulative growth of the region since the 1990's, the TFP change was 0.629, a result that clearly reflects the influence of the TFP of the 80's in the final result.



Source: prepared by the author.

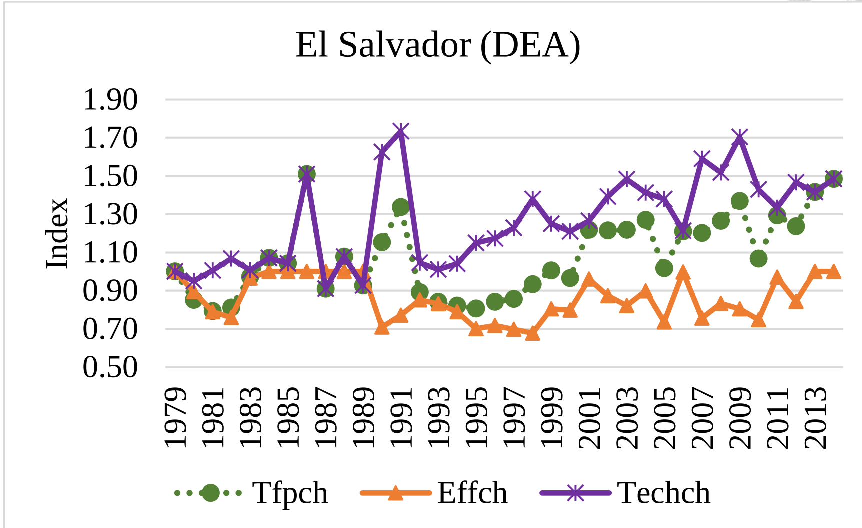
Figure 5.3 Honduras cumulative TFP change and its components (DEA)

El Salvador'S TFP change and its components

Before the 1991 peace agreement, El Salvador experienced two significant breakpoints in its development. In 1981, the so-called "final offensive" was initiated by insurgent or guerrilla groups, whose objective was to provoke the collapse of the government and to destroy the national army which had control over the majority of the urban zone. In 1989, the so-called "anti-offensive" was carried out with a direct attack on the capital, but again, the results were not decisive in overthrowing the government.

El Salvador experienced the second highest cumulative agricultural productivity growth in the region with 1.49, only behind Costa Rica (1.74). The average TFP was 1.0114, and the primary source was TC.

doi: 10.6342/NTU201700916

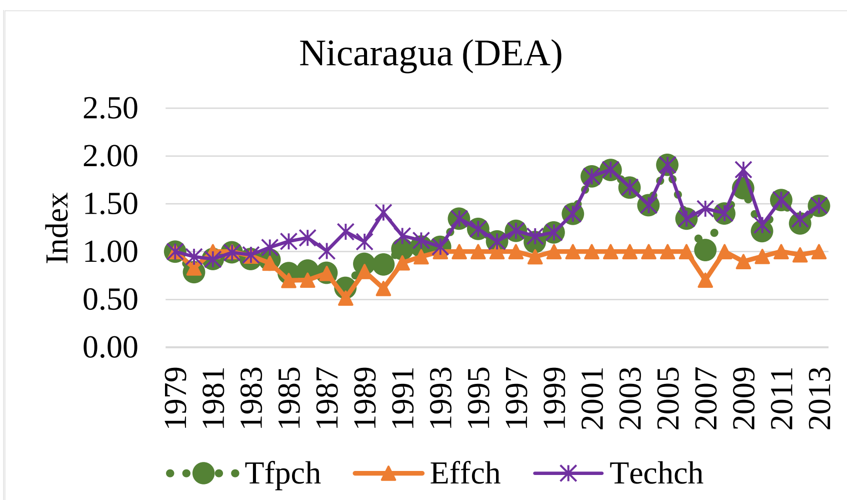


Source: prepared by the author.

Figure 5.4 El Salvador cumulative TFP change and its components (DEA)

Nicaragua's TFP change and its components

In Nicaragua, the average TFP represented 1.0076, mostly driven by TC, which also compensated for the relatively low-efficiency change.



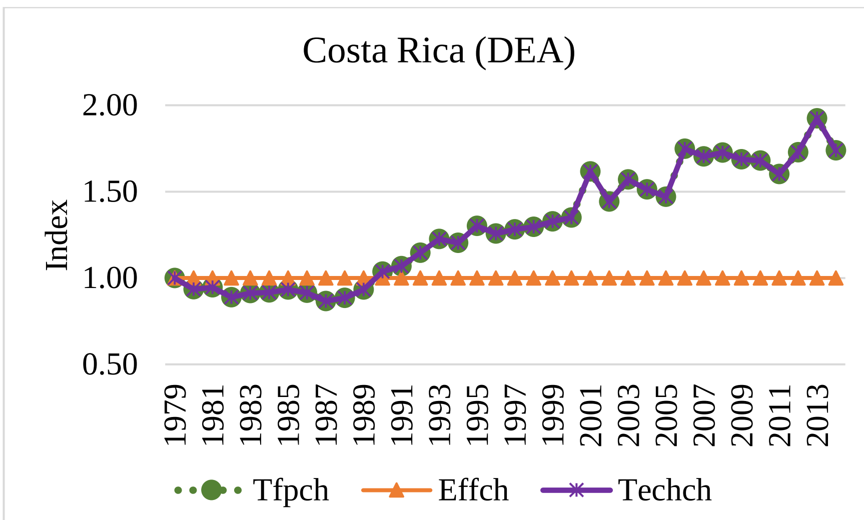
Source: prepared by the author.

Figure 5.5 Nicaragua cumulative TFP change and its components (DEA)

doi: 10.6342/NTU201700916

Costa Rica's TFP change and its components

Costa Rica has been the lucky exception confront of the chaotic politics and conflictive situation of C.A. The employment of agricultural sector in the 1980's represented 29% on average, but nowadays represents less than 14% of the total labor force (World Bank, 2014). This country has the highest average TFP change (1.016) and cumulative change of the region with 1.739 as result not only of the social and economic stability of the country but also of the use of new technology and innovation.



Source: prepared by the author.

Figure 5.6 Costa Rica cumulative TFP change and its components (DEA)

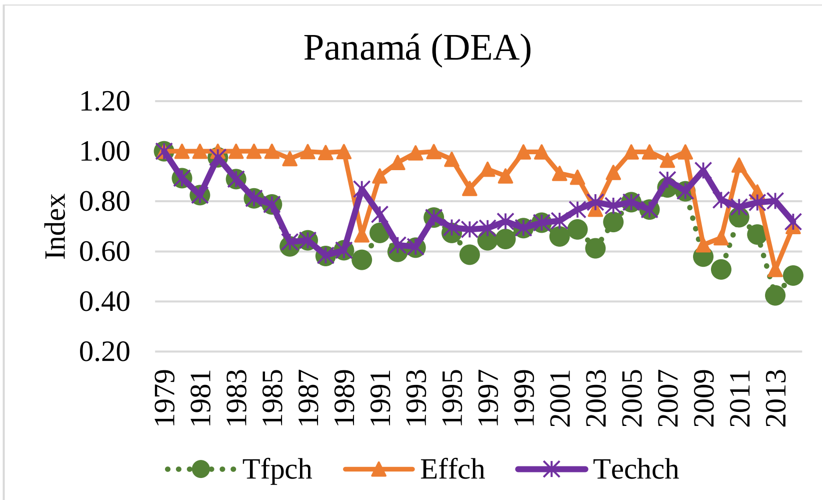
Panamá's TFP change and its components

Panama and Costa Rica did not play an important role in the 1980's and were not directly affected by the conflictive events of C.A. In this period, the labor population was mostly concentrated in the service area (54%). In relation to the other countries, this sector currently represents 65% of employment, while rural employment represents 17%. The main

doi: 10.6342/NTU201700916

reason of the low and decreasing employment rate in agriculture is because the Panama Canal has strengthened its strategic position in business, reason why the employment in the service sector is more attractive.

The average TFP growth for this country was the only one in the region which was negative (0.981), and the cumulative TFP for this region was 0.72. The deterioration of agriculture productivity for this sector was due technical and efficiency decrease.



Source: prepared by the author.

Figure 5.7 Panamá cumulative TFP change and its components (DEA)

In the previous discussion, we focused the analysis based on the Malmquist index method. After identifying the sources of productivity growth for the six countries of C.A., we introduce the results of the stochastic frontier method by incorporating six efficiency variables.

doi: 10.6342/NTU201700916

5.2 Stochastic Frontier Analysis (SFA)

5.2.1 Parametric model

By using the stochastic translog production model defined in equations (6) and (8) and the exogenous model in equation (7), we estimated the maximum likelihood (ML) for the translog production frontier including technical change.

The results are shown in Table 5.7, where model 1 is the result of the translog production model including technical change and including exogenous factors.

The tests for the maximum likelihood estimates of the stochastic production frontier model, including efficiency variables, are reported in section 5.2.3. The adjusted R-squared obtained from the estimation of the Ordinary Least Square (OLS), indicates that model 1 explain around 89.9% of the variance.

doi: 10.6342/NTU201700916

Table 5.7 Maximum-likelihood estimates of the translog production frontier model.

Production Function		*Model 1*		
Name of Variables	Parameter	Coefficient	*t* -ratio	
Sthocastic Frontier				
Constant	β_0	-288.256	-91.73	***
(Ln) Labour	β_1	-4.059	-1.96	*
(Ln) Machinery	β_2	42.167	10.89	***
(Ln) Land	β_3	23.907	11.26	***
(Ln) Fertilizer	β_4	-3.671	-1.54	
Time	β_5	0.169	0.81	
(Ln)Labour * (Ln)Labour	β_{11}	0.165	3.94	***
(Ln)Machinery *(Ln)Machinery	β_{22}	-4.034	-9.71	***
(Ln)Land *(Ln)Land	β_{33}	-0.895	-3.30	***
(Ln)Fertilizer * (Ln)Fertilizer	β_{44}	0.268	3.09	***
Time * Time	β_{55}	-0.006	-5.63	***
(Ln)Labour * (Ln)Machinery	β_{12}	0.377	1.64	
(Ln)Labour * (Ln)Land	β_{13}	0.018	0.12	
(Ln)Labour * (Ln)Fertilizer	β_{14}	-0.124	-1.80	*
(Ln)Labour * Time	β_{15}	0.021	2.43	***
(Ln)Machinery * (Ln)Land	β_{23}	-1.291	-4.87	***
(Ln)Machinery * (Ln)Fertilizer	β_{24}	0.206	1.60	
(Ln)Machinery * Time	β_{25}	0.121	6.23	***
(Ln)Land * (Ln)Fertilizer	β_{34}	0.088	0.60	
(Ln)Land * Time	β_{35}	-0.086	-6.24	***
(Ln)Fertilizer * Time	β_{45}	-0.014	-2.22	**
Inefficiency Model				
Constant	δ_0	7.662	2.70	***
Co2	δ_1	0.000	1.82	**
Human capital	δ_2	-4.431	-2.69	***
Irrigation	δ_3	-0.007	-2.68	***
Rural population	δ_4	-0.044	-2.43	***
Life expectancy	δ_5	0.066	2.17	**
HHI	δ_6	-0.001	-2.69	***
Variance parameter				
Sigma-squared	σ_u^2	0.219	2.32	**
Gamma	γ	0.933	25.15	***
Log-likelihood		71.830		

Note: (***) indicate statistical significance at 1% while (**) indicate significance at 5% level and (*) indicate significance at 10%.

doi: 10.6342/NTU201700916

From the results of the MLE including time component we obtained 15 out of 21 coefficients significantly different from zero. The large amount of significant coefficients indicates the importance of interaction and non-linearities among the variables used, which is consistent with the rejection of the Cobb-Douglas functional form as a suitable representation of agriculture in C.A.

5.2.2 Elasticity Estimation

Using the parameters obtained from the MLE, the estimated frontier elasticity of each input used was calculated by using equation (13). The elasticities for the translog models are estimated at the means of the input variables.

Table 5.8a and 5.8b present the estimate elasticities in different periods for the translog model 1, in which technical change is presented (including time variable). The partial elasticities for particular inputs in some cases differ considerably among models.

The elasticities at means by period of the stochastic frontier model for labor, machinery, land, fertilizer and return to scale are presented in Table 5.8a and Table 5.8b.

Table 5.8a Summary elasticities of inputs by country, 1979-2014

	Elasticities with respect to					
Model	Labor	Machinery	Land	Fertilizer	Time	Return to Scale
***Model 1* (Technical Change; Inefficiency)**						
Guatemala	0.471	-0.310	0.249	0.392	-0.003	**0.798**
Honduras	0.472	-0.364	0.227	0.424	-0.001	**0.758**
El Salvador	0.498	-0.374	0.209	0.410	0.002	**0.745**
Nicaragua	0.513	-0.383	0.200	0.405	0.006	**0.740**
Costa Rica	0.520	-0.429	0.179	0.408	0.007	**0.684**
Panama	0.516	-0.505	0.162	0.410	0.007	**0.590**
All	0.498	-0.394	0.204	0.408	0.003	**0.719**

doi: 10.6342/NTU201700916

Table 5.8b Summary elasticities of inputs by country, 1990-2014

Model	Labor	Machinery	Land	Fertilizer	Time	Return to Scale
	Elasticities with respect to					
***Model 1* (Technical Change; Inefficiency)**						
Guatemala	0.589	0.538	-0.041	0.277	-0.016	**1.346**
Honduras	0.572	0.402	-0.077	0.320	-0.017	**1.200**
El Salvador	0.604	0.394	-0.098	0.295	-0.012	**1.184**
Nicaragua	0.605	0.339	-0.114	0.303	-0.011	**1.121**
Costa Rica	0.616	0.279	-0.141	0.297	-0.010	**1.041**
Panama	0.615	0.238	-0.155	0.309	-0.010	**0.998**
All	0.600	0.365	-0.104	0.300	-0.013	**1.148**

Table 5.9 Summary elasticities of inputs by period

Model	Labor	Machinery	Land	Fertilizer	Time	Return to Scale
	Elasticities with respect to					
***Model 1* (Technical Change; Inefficiency)**						
Period 1979-1989	0.2665	-2.1194	0.9055	0.6534	0.0379	-0.2561
Period 1990-2014	0.6001	0.3648	-0.1043	0.3003	-0.0126	1.1484
Period 1990-1999	0.3451	0.6630	0.8036	0.3431	-0.0197	2.1350
Period 2000-2014	0.7702	0.1661	-0.7096	0.2717	-0.0078	0.4906
Period 1979-2014	0.4982	-0.3942	0.2042	0.4082	0.0029	0.7192

In C.A. the elasticity of output with respect to labor is the highest among all the input elasticities, this elasticity shows that labor is the input with the greatest influence on production, followed by fertilizer. The elasticity of return to scales (0.72) implies decreasing return to scale (DRS), which suggests that the agricultural sector in this region is engaged in production of non-optimal scale. When we exclude the 80's which is a turbulent decade in C.A., the elasticity shows increasing returns to scale (IRS). However, in the last years of the study, the elasticity shows DRS.

doi: 10.6342/NTU201700916

5.2.3 Hypothesis Test

On the model defined by equation (8) and (7), some restrictions were imposed. In order to check whether or not those restrictions were valid, the log-likelihood ratio test (LR) was conducted.

- The first null hypothesis test if inefficiency effects are not significant for the model. When this restriction was imposed, the value of the log-likelihood function (LLF) was 61.65. The result of the LR test was 20.95, which is larger than the critical value of 12.59 at 5% level of significance. We reject the null hypothesis which assumes the inefficiency variables do not have influence in the model.

- The second null hypothesis considers the Cobb-Douglas (CD) production function as an adequate representation of agricultural production in C.A. This is rejected, indicating that the functional form used is adequate.

- The third null hypothesis test the absence of technical change over time and whether or not the coefficients of the time-related variables in the translog function are equal to zero. The result supports the rejection of the null hypothesis, indicating that TC exists in the agricultural sector of C.A.

doi: 10.6342/NTU201700916

Table. 5.10 Test of Hypothesis for parameters of the Stochastic Frontier, and inefficiency model for the agricultural sector in Central America.

Null Hypothesis	Log-likelihood	Test statistic	Critical Value $\chi^2_{0.95}$	Decision
Unrestricted model	**72.123**			
H_0: δ_h= 0, h= 1,2,3,4,5,6.	61.648	20.950	12.59	H_0 Rejected
H_0: Cobb Douglas; β_{ij}= 0, i,j= 1,2,3,4,5.	-13.043	170.332	25.00	H_0 Rejected
H_0: β_5= β_{i5}= 0, i= 1,2,3,4,5.	40.806	62.634	12.59	H_0 Rejected

5.2.4 TFP and its component

The results of TFP and its components for SFA are presented as follows.

From Table 5.11, we can see that the average TFP growth for C.A. is 1.0043 and that the major source of this growth is EC with 1.0055. However, in terms of individual country performance only in Guatemala, Honduras, Nicaragua, and El Salvador was EC the major source of growth, while the main source of agricultural productivity in the other countries (Costa Rica and Panamá) was TC.

doi: 10.6342/NTU201700916

Table 5.11 Summary description of TFP change and its components, 1979-2014 (SFA)

Country	Description	Efficiency Change	Technical Change	TFP Change
Guatemala	***Mean***	***1.0135***	***0.9888***	***1.0022***
	Max	1.1576	1.0090	1.1345
	Min	0.9384	0.9205	0.9277
	Std. Deviation	0.0509	0.0157	0.0493
Honduras	***Mean***	***1.0103***	***0.9794***	***0.9895***
	Max	1.2323	1.0127	1.2433
	Min	0.8137	0.8530	0.7754
	Std. Deviation	0.1041	0.0393	0.1109
El Salvador	***Mean***	***1.0043***	***1.0038***	***1.0081***
	Max	1.1629	1.0218	1.1856
	Min	0.8515	0.9372	0.8622
	Std. Deviation	0.0711	0.0238	0.0712
Nicaragua	***Mean***	***1.0005***	***0.9751***	***0.9756***
	Max	1.3192	1.0015	1.2841
	Min	0.7721	0.9648	0.7498
	Std. Deviation	0.1010	0.0095	0.0984
Costa Rica	***Mean***	***1.0023***	***1.0328***	***1.0351***
	Max	1.1617	1.0383	1.2062
	Min	0.8729	1.0202	0.9026
	Std. Deviation	0.0616	0.0048	0.0643
Panamá	***Mean***	***1.0022***	***1.0142***	***1.0164***
	Max	1.1205	1.0268	1.1320
	Min	0.8979	1.0081	0.9069
	Std. Deviation	0.0565	0.0055	0.0574
Central America	*Mean*	***1.0055***	***0.9988***	***1.0043***
	Max	1.3192	1.0383	1.2841
	Min	0.7721	0.8530	0.7498
	Std. Deviation	0.0763	0.0285	0.0795

Analysis by period in Table 5.12 reveals that before 2010 the overall TFP for the region was driven mostly by EC rather than TC. However, the effect of TC after 2010 seems to get more important, although this is pushed in some countries more than others.

doi: 10.6342/NTU201700916

Table 5.12 TFP change and its components by period.

Year	Efficiency Change	Technical Change	TFP Change
Period 1980-1989	0.9966	0.9876	0.9842
Period 1990-1999	1.0106	0.9961	1.0067
Period 2000-2009	1.0133	1.0053	1.0186
Period 2010-2014	0.9999	1.0153	1.0151
Period 1990-2014	1.0091	1.0033	1.0124
Period 1980-2014	1.0055	0.9988	1.0043

Table 5.13 Summary description of technical efficiency, 1979-2014 (SFA)

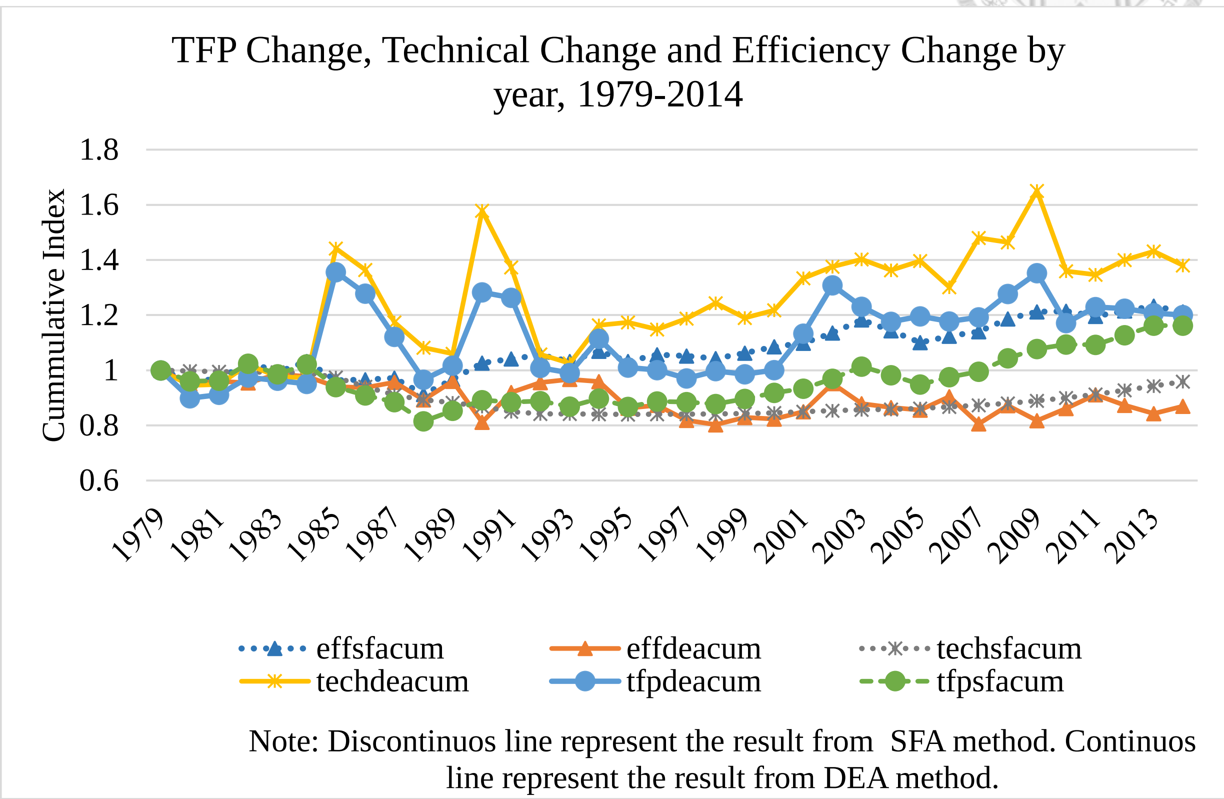
Technical Efficiency		**Guatemala**	**Honduras**	**El Salvador**	**Nicaragua**	**Costa Rica**	**Panamá**	**Central America**
SFA	***Mean***	0.91	0.71	0.88	0.87	0.82	0.85	0.84
	Min	0.61	0.52	0.62	0.60	0.73	0.66	0.52
	Max	0.99	0.97	0.98	0.98	0.92	0.96	0.99

In addition, a detailed analysis of technical efficiency in Table 5.13 shows that along the overall period the mean efficiency was 0.839, with a minimum value of 0.522 and a maximum value of 0.987 which represents the countries on the frontier. The lower value of efficiency means that countries are less efficient and higher values means that countries are more efficient or closer to the frontier. The mean value of 0.839 indicates that countries can reduce the use or consumption of all inputs by 6.1% without reducing their output.

Figure 5.8. shows the cumulative growth of the region at the end of the period. The results from SFA indicate a cumulative 1.21, 0.96, and 1.16 for EC, TC, and TFP change respectively. The TFP change in this approach is less compared to the previous approach, and the main source of agricultural growth was due to efficiency changes. Likewise, under

doi: 10.6342/NTU201700916

this approach, the average efficiency change turned out to be positive and the technical change negative.



Source: prepared by the author.

Figure 5.8 Cumulative DEA & SFA TFP change and its components, 1979-2014.

The differences between the results obtained in SFA compared with DEA are not unexpected, considering that both methods involve different calculation which affects the final result (See Table A in appendix). It is important to appoint that we must be careful when we compare the results since they only show the dispersion of efficiency within each sample.

doi: 10.6342/NTU201700916

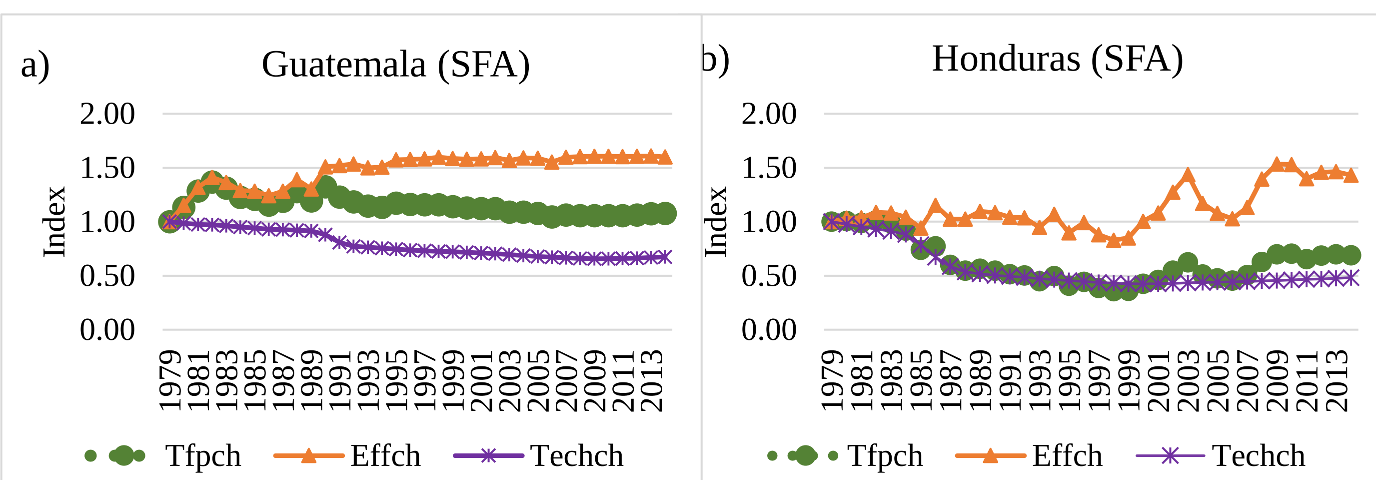
5.2.5 Country Analysis of TFP and its components

The following includes analysis of TFP, TC, and EC by income using the SFA approach.

The results of SFA show a similar pattern among the low-middle income (LM) and the upper-middle income (UM) countries of C.A. Agricultural growth in LM countries when we account for exogenous effects is mostly driven by EC, which support the conclusion of Henderson and Russell (2005) that when we account for environmental, social or economic differences, for instance, human capital, then the primary driving force may be EC. Also, the results reveal possible problems in the process of diffusion and adoption of modern technologies as is suggested by Araujo et.al (2014).

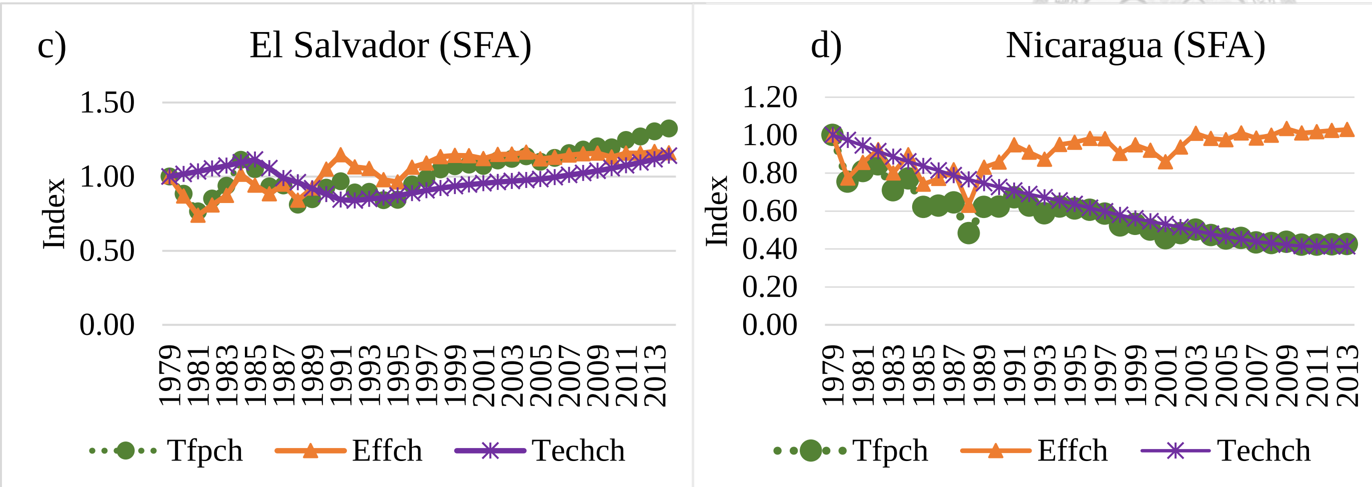
In terms of EC, the highest cumulative EC was in Guatemala with 1.60 and was followed by Honduras with 1.43. In terms of TC, most of these countries present a deterioration, with a very low improvement after 2005. The highest deterioration of TC was Nicaragua with around 0.414 at the end of 2014, and the best was El Salvador with around 1.14.

Lower-middle Income Countries



doi: 10.6342/NTU201700916

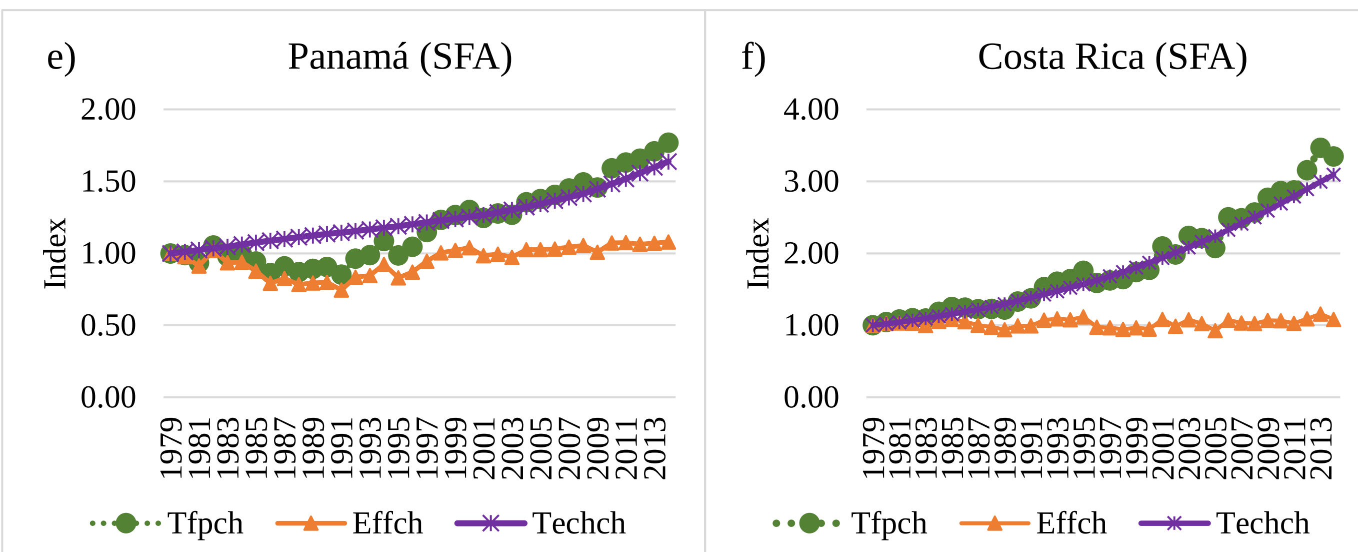
.



Source: prepared by the author.

Figure 5.9 Low-middle income economies TFP change, TC and EF

Upper-middle Income Countries



Source: prepared by the author.

Figure 5.10 Upper-Middle Income Economies TFP change, TC, and EF.

doi: 10.6342/NTU201700916

The results for UM countries show a significant TFP growth in agriculture. The best performance was in Costa Rica with a cumulative 3.35 at the end of 2014. In the case of Panamá, the cumulative TFP growth was 1.77. In both cases, the agricultural growth was due to the noticeable increase in TC and the slightly but positive contribution of EC over the entire period.

5.2.6 Efficiency Effect

The stochastic frontier model includes six exogenous variables, all of them significantly different from zero. The expectation is that the sign of the coefficient would be negative since more of each input reduces inefficiency. In the case of Co2, we expect that more of this input will worsen efficiency. In the case of rural population, we expect that more population in rural areas will increase productivity since less migration toward cities is an indicator of stability in rural areas where most agricultural activity is concentrated.

The results indicate that the 6 inputs used, satisfy the expectation of negative signs. Co2 and life expectancy both had a positive sign. However the Co2 result was not statistically significant, and the life expectancy result was significant at 10 percent. These results suggest that increments in the general welfare of a country may not necessarily indicate that the agricultural sector is becoming more productive.

The Herfindahl-Hirschman index usually used to analyze the concentration of market was used in this study to determine the concentration of primary crops. The sign

doi: 10.6342/NTU201700916

was negative as expected, since more concentration of primary crops may indicate specialization of the market.

In the case of human capital, irrigation and rural population the sign of the coefficients were as expected. More education and human capital had a significant and considerable effect in enhancing efficiency.

From the inefficiency model, we obtained 5 significant coefficients at 5% level with the exception of Co2 and irrigation. The negative sign of the coefficients implies a reduction of inefficiency as we increase the use of these inputs.

The significance of the effect is found using the parameter gamma which indicates how much variation of the composite error term corresponded to the inefficiency component ($\gamma = 0.9329$). This results was significant at 5%.

doi: 10.6342/NTU201700916

Chapter 6. Conclusion

6.1 Study Approach

This study focuses on identifying the sources of agricultural productivity growth and analyzing the agriculture growth for six countries in C.A. Country-level data on agricultural production are used from 1979 to 2014. The first approach used the method of data envelopment analysis (DEA) considering primary crops as output and four inputs; labor, land, machinery, and fertilizer.

The second approach used the method of stochastic frontier analysis (SFA), with one output, four inputs, and six exogenous variables: Co2 in agriculture (Co2) , human capital (HC), irrigation area (IRR), rural population (RP), life expectancy (LE), and an index of crop concentration (HHI).

6.2 The Results

This thesis provide important information about trends in agricultural productivity in Central America. In the first stage of analysis, DEA results showed an annual growth in TFP of 0.53% with EC (or catch-up) contributing negatively around 0.4% and TC (or frontier shift) contributing a positive 0.9% growth. The results of cumulative change with DEA indicates that on average the region at the end of 2014 had an EC, TC, and TFP growth accumulation of -13%, 38%, and 20% respectively.

Turning to the country-by-country results, the best TFP performance was shown by Costa Rica with an average growth of 1.6% followed by El Salvador with 1.14% growth. The

doi: 10.6342/NTU201700916

worst performance was shown by Panamá with a 1.94% regress. In the case of Guatemala, Honduras, and Nicaragua growth was 0.97%, 0.66%, and 0.76% respectively.

The second stage analysis by using the translog production model with exogenous effects shows an improvement of 0.43% per annum in TFP's performance for C.A. with EC contributing a positive 0.55% and TC contributing a negative 0.12%. The results of the parametric model show a cumulative EC, TC, and TFP of 1.212, 0.959, and 1.162, respectively. The estimate of the cumulative TFP in the parametric frontier is lower than that from the VRS DEA. In addition, the efficiency change contribution is positive compared to the non-parametric model.

In terms of considering the results for individual countries, the best TFP performance was shown by Costa Rica with a growth of 3.51% and was followed by Panamá with 1.64% growth. The two countries with the worst performance were Nicaragua with a deterioration of 2.44% and Honduras with a regress of 1.054%. Guatemala and El Salvador obtained a result of 0.22% and 0.81% average growth respectively.

In both, the DEA and SFA method, the results show that C.A. is not reaching the production frontier, this finding implies that countries in the region are not making an efficient use of the inputs, therefore with the adequate policies they could possibly continue reducing the use of all inputs without reducing the quantities of primary crops in order to become more efficient. Despite the advantages that DEA may have, under this method, we must assume that there is no inefficiency reason why in this study we prefer the approach of SFA since it allows us to approach the analysis from a point of view that capture the

doi: 10.6342/NTU201700916

differences between countries and addresses the heterogeneity of the region by including exogenous variables.

Compared to other factors in the production function, labor and fertilizer are more important for increasing the agricultural production. The negative sign of the machinery elasticities during the 80's may indicate an inadequate utilization or sub-utilization of machinery. However, these results require special attention and should be interpreted carefully.

The results suggest that the upper-middle income countries are more likely to adopt technologies compared to those countries with low-middle income.

6.2.1 Exogenous variables

In the second stage analysis, six social, environmental, economic and infrastructure variables were analyzed. The results show human capital as an important factor for reducing inefficiency in the region. Also, the negative sign of the parameters of the exogenous variables indicates that more irrigation, more concentration of population in rural areas, and higher specialization in the production of crops positively affect the efficiency of agriculture. The positive sign of Co2 may be related to farming practices, such as burning fields or burning of wasted crops which can decrease the quality of soils. Life expectancy is commonly associated with health care and economic welfare, for this results, the positive sign of this variable may indicate that as the general welfare of a country develops, attention to activities in the agricultural sector diminishes.

doi: 10.6342/NTU201700916

6.3 Policy implication

There are important variables that have not been included in this study due to unavailability, limitation of data, or weak results. Data such as climate, infrastructure, domestic research, and development and investment in agriculture would provide more information regarding the TFP growth and its sources in Central America.

In light of the results discussed in the previous chapter, the following implications are offered:

Decreasing TC in LM economies is the major concern and obstacle to ensuring food security and becoming more competitive internationally. The decrease in agricultural labor might be a risk for LM countries with limited technology. Hence, it is important that governments make efforts to increase access to technology and innovation.

For those countries in C.A., their inability to reach the optimum TE, far away to be something negative, represents an opportunity to still improving the productivity.

To capitalize these opportunities and to reduce the risk of decreasing growth in agricultural productivity, some changes can be done:

- Investment in irrigation can increase the efficiency of the agricultural sector in C.A. More irrigation use can compensate possible collateral effects of climate change in the region.
- Investment in education can increase efficiency, innovation, and risk management; farmers with higher education could more easily to adopt new practices, technologies, and address possible risks in the production process.

doi: 10.6342/NTU201700916

- Investment in infrastructure is vital to the delivery of services that may reduce the food waste and encourage investment in technology.
- Specializing in crop production increase efficiency. Specialization can increase the ability of farmers to improve the agricultural process and reduce the use of inputs. Therefore Central American countries can improve its absolute advantages.
- In order to encourage farmers to use fertilizers and to increase agricultural production, the government could provide a subsidy on fertilizer.
- In order to increase production and to make farmers remain in the agricultural sector, the government could design some agricultural policies, such as price support, retirement schemes, and subsidies.

6.4 Further research

It's appropriate given the particular circumstances of C.A that further analysis should include political components, land concentration, and structural changes. Also, the inclusion of price information can provide a clear representation of the productivity change for each country over the last years. Analysis of climate was tried in this study using the international disaster database of the Centre for Research on the Epidemiology of Disasters (CRED) as a reference, and information about infrastructure using the information about fixed telephone subscription provided by the World Bank as a reference. However, the results were not conclusive or significant.

doi: 10.6342/NTU201700916

References

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

Aigner, D., Lovell, C., and Schmidt, P., (1977). Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics*, 6,21-37.

Araujo, J., Feitosa, D., and Bittencourt, A. (2014). Latin America: Total factor productivity and its components. *CEPAL Review* 114.

Barro, R. and Lee, J. (2013). A New Data Set of Educational Attainment in the World, 1950-2010. *Journal of Development Economics*, vol 104, pp.184-198.

Battese, G. and Broca, S. (1997). Functional Forms of Stochastic Frontier Production Functions and Models for Technical Inefficiency Effects: A Comparative Study for Wheat Farmers in Pakistan, *Journal of Productivity Analysis*, 8, 395–414.

Battese, G. and Coelli, T. (1995). A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data. *Empirical Economics*, 20, 325-332.

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

Charnes, A., Cooper, W., and Rhodes, E. (1978). Measuring the efficiency of decision making units, *European Journal of Operational Research*, 2, 429-444.

Coelli, T. (1996). *A guide to DEAP version 2.1: a data envelopment analysis (Computer) Program*. Armidale, Australia: Working Paper, Center for Efficiency and Productivity Analysis (CEPA), Department of Econometric, University of New England.

Coelli, T. (1996). *A guide to FRONTIER Version 4.1: A computer program for stochastic frontier production and cost function estimation.* Armidale, Australia: Working Paper, Center for Efficiency and Productivity Analysis (CEPA), Department of Econometric, University of New England.

Coelli, T. and Rao, D. (2005). Total factor productivity growth in agriculture: a Malmquist index analysis of 93 countries, 1980-2000. *Agricultural Economics*, 32:s1, 115-34.

Coelli, T., Rao, D., O'donell, C., and Battese G. (2005). *An Introduction to Efficiency and Productivity Analysis* (2^{nd}*ed*.). New York, United States: Springer.

Comisión para America Latina y el Caribe. (2015). *Coyuntura laboral en América Latina y el Caribe. Protección social universal en mercados laborales con informalidad*. Boletín CEPAL-OIT. No.6

doi: 10.6342/NTU201700916

Craig, B., Pardey, P., and Roseboom, J. (1997). International productivity patterns: accounting for input quality, infrastructure, and research. *American Journal of Agricultural Economics*, 79, 1064-1077.

Dias, A., Romano, L., and Garagorry, F. (2010). Agricultural Productivity in Latin America and the Caribbean and Sources of Growth. *Handbook of Agricultural Economics*, Burlington: Academic Press, pp 3713-3768. ISBN: 978-0-444-51874-3.

Ebata, A. (2011). *Agricultural productivity growth in Central America and the Caribbean.* Thesis dissertation. University of Nebraska.

Economic Commission for Latin America. (2005). *Poverty, hunger and food security in Central America and Panama.* Social Development Division. Santiago de Chile. ISBN: 92-1-121521-8.

Färe, R., Grosskopf, S., Lindgren, B., and Roos, P. (1992a). Productivity changes in Swedish pharamacies 1980–1989: A non-parametric Malmquist approach, *Journal of Productivity Analysis*, 3, 85-101.

Färe,R., Grosskopf, S., and Lovell, C. (1992b). Indirect Productivity Measurement, *Journal of Productivity Analysis* 2, 283-298.

Färe, R., Grosskopf, S., Norris, M., and Zhang, Z. (1994). Productivity Growth, Technical Progress, and Efficiency Change in Industrialized Countries. *The American Economic Review*, 84, 66-83.

Farrell, M. (1957). The measurement of productive efficiency, *Journal of the Royal Statistical Society*, 120, 253-290.

Fulginiti, L. and Perrin, R. (1997). Productivity in LDC Agriculture: Nonparametric Malmquist Measures. *Journal of Development Economics*, 53, 373-390.

Fulginiti, L. and Perrin, R. (1998). Agricultural productivity in developing countries. *Journal of Agricultural Economics*, 19, 45-51.

Hayami, Y. and Ruttan, V. (1970). Agricultural Productivity Differences among Countries. *American Economics Review* 60, No. 5:895-911.

Hayami, Y. and Ruttan, V. (1985). *Agricultural Development: An International Perspective (2nd ed.).* Baltimore, United States: John Hopkins University Press.

Henderson, J., and Russell, R. (2005). Human capital and convergence: A production frontier approach. *International Economic Review*, 46, 1167-1205.

Hutchinson, D. and Langham, R. (1999). Productivity Growth in the Caribbean: A Measure of Key Components. Presented at the Annual meeting of the American Agricultural Economics Association. Nashville, Tennessee 21532. August 8-11 1999.

doi: 10.6342/NTU201700916

Kawagoe, T. and Hayami, Y. (1985). An intercountry comparison of agricultural production efficiency. *American Journal of Agricultural Economics*, 67, No. 1:87-92.

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

Kumbhakar, S. and Lovell, C. (2003). *Stochastic Frontier Analysis*. Cambridge, United Kingdom: Cambridge University Press.

Ludena, C. (2010). *Agricultural Productivity Growth, Efficiency Change and Technical Progress in Latin America and the Caribbean*. Inter-American Development Bank (IDB), Working Paper Series No. IDB-WP- 186.

Meeusen, W. and van Den Broeck, J. (1977). Efficiency estimation from Cobb-Douglas production functions with composed error. *International Economic Review*, 18,435-444.

Psacharopoulos, G. (1994). Returns to investment in education: A global update, *World Development*, Elsevier, vol. 22(9), 1325-1343.

Qalawi, U. Rabbaie, A., and Baniata, A. (2011). Estimating Production Efficiency: The Case of Middle-Eastern Countries. *European Journal of Economics, Finance and Administrative Sciences*, ISSN 1450-2275 Issue 38.

Zofio, J. (2007). Malmquist productivity index decompositions: a unifying framework, *Applied Economics*, 39:18, 2371-2387

doi: 10.6342/NTU201700916

Appendix

Table A. Differences between SFA and DEA.

Approach	Stochastic Frontier Analysis (SFA)	Data Envelopment Analysis (DEA)
Consistency	Both methods are efficiency frontier analysis and determine the frontier and inefficiency base in that frontier.	
Characteristic	Parametric Method	Non-Parametric Method
Efficiency Measurement	Technical Efficiency, Allocative Efficiency, Technical Change, Scale Effects and Total Factor Productivity Change.	Technical Efficiency, Allocative Efficiency, Technical Change, Scale Effects and Total Factor Productivity Change.
Strengths	1. It doesn't assume that all firms are efficient in advance. 2. Make accommodation for statistical noise and measures error. 3. It doesn't need price information 4. It's possible to hypothesis test 5. To estimate best technical efficiencies of firms, rather than average technical efficiencies of the firm.	1. It doesn't assume that all firms are efficient in advance. 2. It could handle with efficiency measurement of multiple inputs and outputs. 3. It doesn't need price information 4. Doesn't need functional form
Weakness	1. Need to assume a functional form and distributional form in advance. 2. Need enough samples to avoid lack of degree of freedom. 3. The assumed distributional type is sensitive to assessing efficiency scores.	1. Doesn't make accommodation for statistical noise such as measure error. 2. No possible to hypothesis test. 3. Outliers can affect the efficiency measurements.
Element	Multi Outputs and Inputs	Single Input (Output) and multi-output(input)
Algorithm	Regression (typically using maximum likelihood estimation)	Linear programming
Consideration of noise	Explicitly accommodate noise (stochastic model)	Noise is included in the efficiency score rather than accounted directly (deterministic model)
Functional form	Functional form specified)e.g., linear, semi-log, double-log)	Not specified (everything that might be linearized)
Factor Weight	No individual factor weight in the basic model (parametric)	Individual factor weight for each unit (non-parametric)

doi: 10.6342/NTU201700916

Source: Based upon Batesse, Rao, Coelli, and O'Donnel (2005)

Table B. List of Primary Crops in C.A.

Table B. List of Primary Crops in C.A.

Agave fibres nes	Fruit, tropical fresh nes	Pigeon peas
Anise, badian, fennel, coriander	Garlic	Pineapples
Apples	Ginger	Plantains
Artichokes	Grapefruit (inc. pomelos)	Potatoes
Asparagus	Grapes	Pulses, nes
Average	Groundnuts, with shell	Pumpkins squash, and gourds
Avocados	Jute	Rice, paddy
Bananas	Leeks, other alliaceous vegetables	Roots and tubers, nes
Barley	Lemons and limes	Rubber, natural
Bastfibres, other	Lettuce and chicory	Seed cotton
Beans, dry	Maize	Sesame seed
Beans, green	Maize, green	Sorghum
Berries nes	Mangoes, mangosteens, guavas	Soybeans
Broad beans, horse beans, dry	Manila fibre (abaca)	Spices, nes
Cabbages and other brassicas	Melons, other (inc.cantaloupes)	Spinach
Carrots and turnips	Nutmeg, mace, and cardamoms	Strawberries
Cashew nuts, with shell	Nuts, nes	Sugar cane
Cassava	Oil, palm fruit	Sweet potatoes
Castor oil seed	Oilseeds nes	Taro (cocoyam)
Cauliflowers and broccoli	Okra	Tangerines
Chillies and peppers, green	Olives	Tea
Cocoa, beans	Onions, dry	Tobacco, unmanufactured
Coconuts	Onions, shallots, green	Tomatoes
Coffee, green	Oranges	Vegetables, fresh nes
Cucumbers and gherkins	Papayas	Vegetables, leguminous nes
Eggplants (aubergines)	Peaches and nectarines	Watermelons
Fruit, citrus nes	Peas, green	Wheat
Fruit, fresh nes	Pepper (piper spp.)	Yams
		Yautia (cocoyam)

Note: Tangerines include mandarins, clementines, satsumas

doi: 10.6342/NTU201700916

Source: Food Agricultural Organization

Table C. Growth rates of productivity ratios.

	Growth rates of productivity ratios (%), by periods.						
Period/Ratio	**Y/L**	**Y/A**	**A/L**	**Y/F**	**Y/M**	**F/A**	**M/A**
1980-1989	1.9	0.2	1.8	-1.2	-0.1	2.1	0.3
1990-2014	2.8	3.6	-0.9	1.9	2.5	3.5	1.1
1990-1999	5.8	3.7	1.9	-0.1	3.3	4.4	0.3
2000-2014	0.8	3.6	-2.7	3.2	2.0	2.9	1.6
1980-2014	2.5	2.6	-0.1	1.0	1.8	3.1	0.9

Note:

Y: Tons of primary crops.
L: Workers in agriculture.
A: Hectares of agricultural land.
M: Units of tractors.
F: Tons of fertilizer.

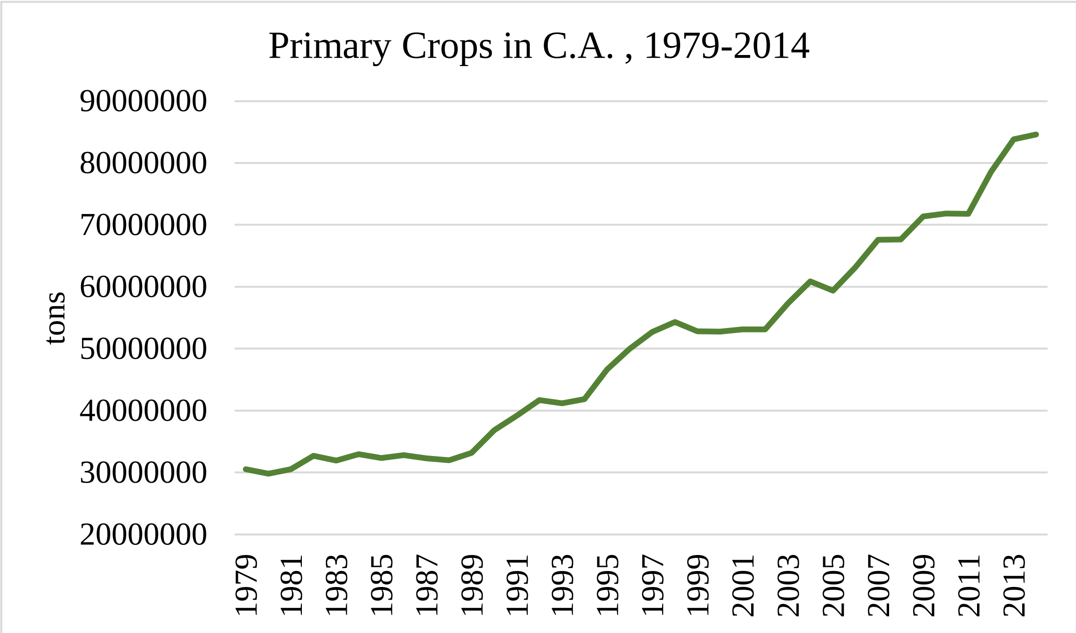


Figure A. Tons of primary crops in C.A, 1979-2014

doi: 10.6342/NTU201700916

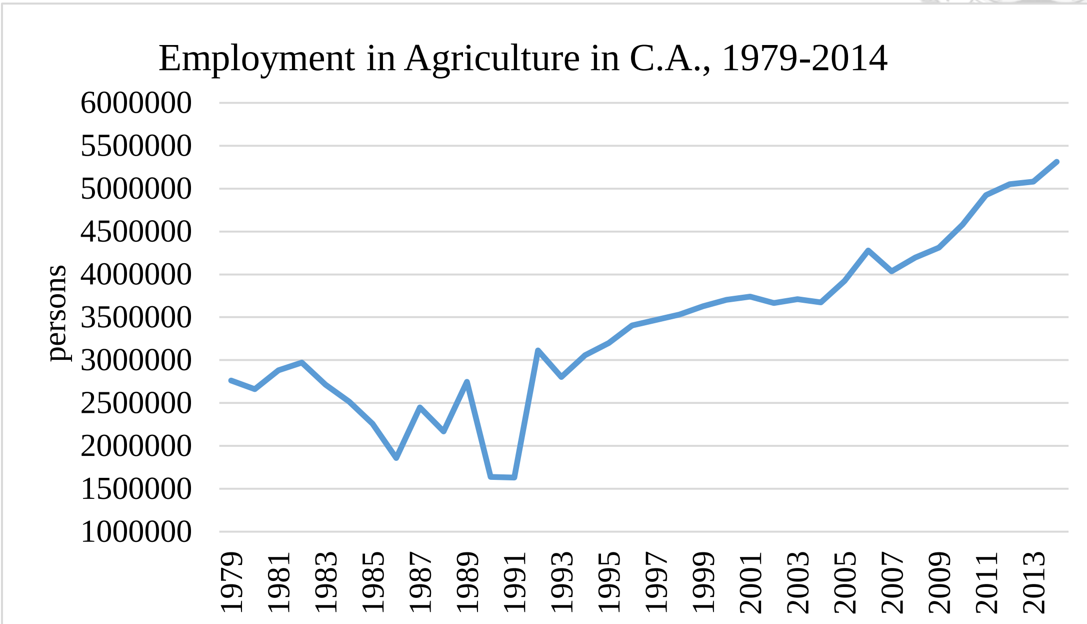
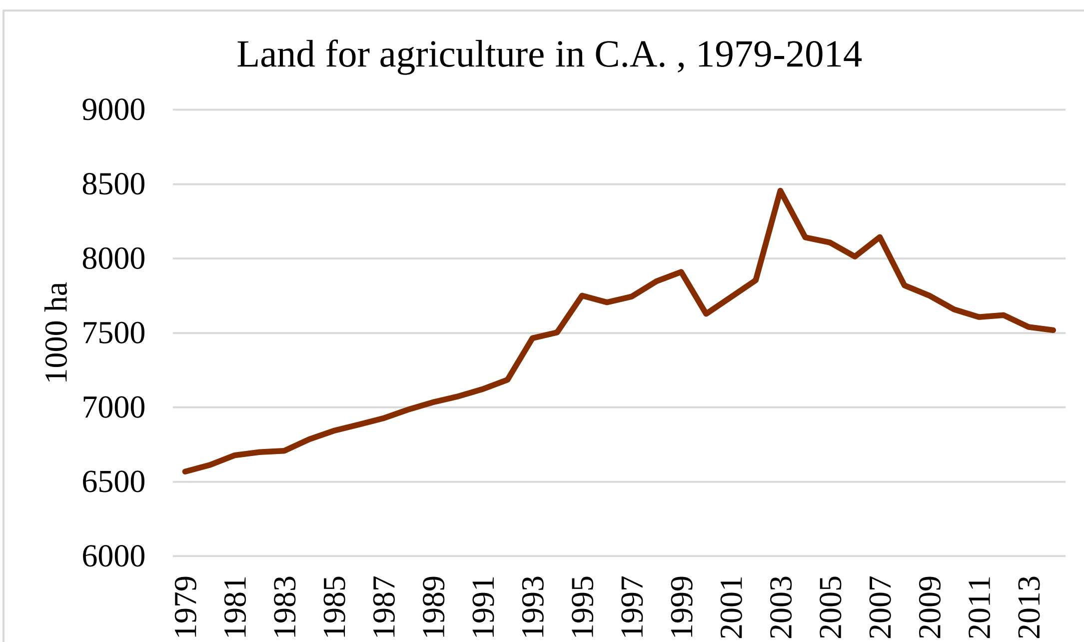


Figure B. Total employment in agriculture in C.A, 1979-2014



doi: 10.6342/NTU201700916

Figure C. Total land for agriculture in C.A, 1979-2014

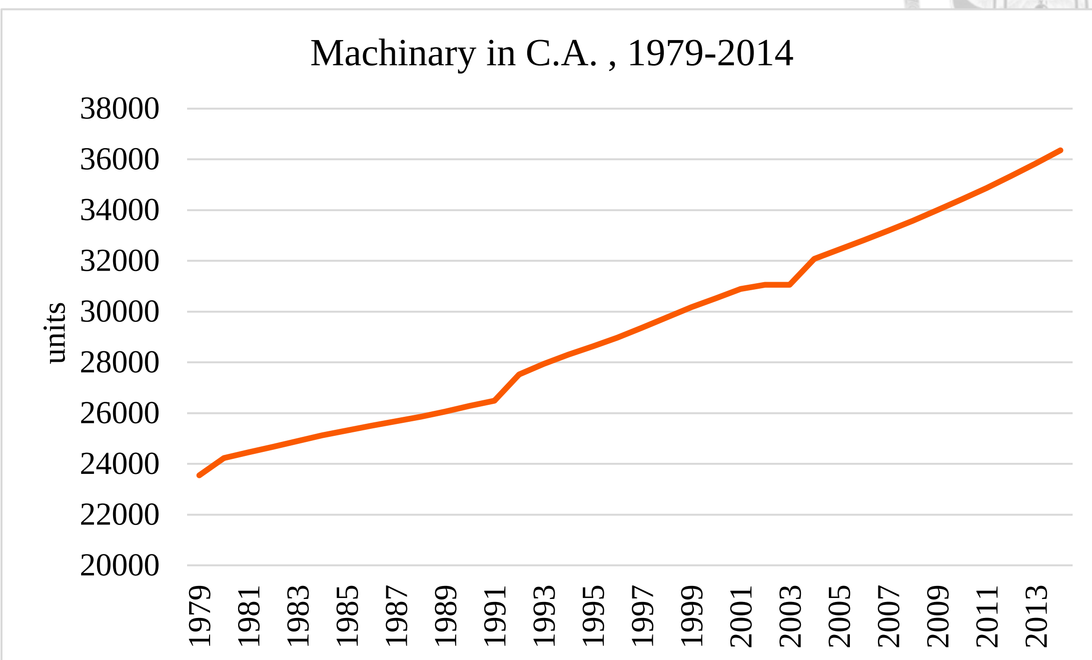
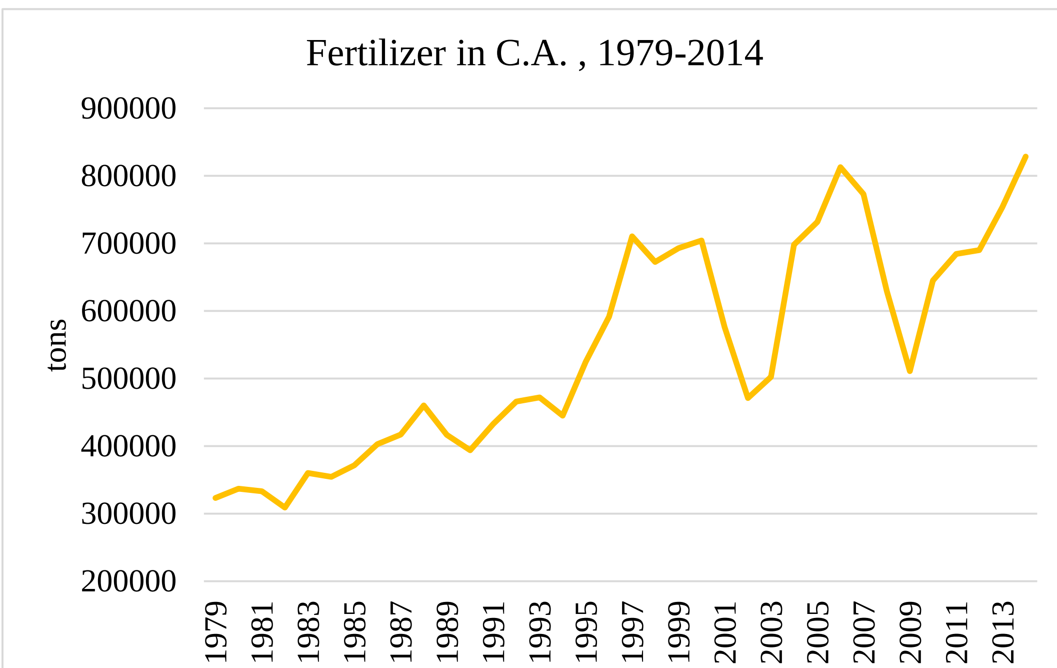


Figure D. Total machinery used in agriculture in C.A, 1979-2014



doi: 10.6342/NTU201700916

Figure E. Total fertilizer used in Agriculture in C.A, 1979-2014

doi: 10.6342/NTU201700916