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A DEA-BASED EVALUATION OF LATIN AMERICA AND THE CARIBBEAN
AGRICULTURAL ENVIRONMENTAL PERFORMANCE UNDER THE
ASSUMPTION OF NATURAL AND MANAGERIAL EFFICIENCY

*EVALUACIÓN DEL DESEMPEÑO MEDIOAMBIENTAL DEL SECTOR AGRÍCOLA DE
AMÉRICA LATINA Y EL CARIBE BAJO EL SUPUESTO DE EFICIENCIA NATURAL
Y GERENCIAL, UTILIZANDO DEA*

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ABSTRACT

This study uses the Data Envelopment Analysis to measure the agricultural environmental performance under the assumption of natural and managerial disposability, but also evaluates the Returns to Scale and Damages to Scale in Latin America and the Caribbean during 2012. Seven agricultural variables are analyzed: animal feed, fertilizers, capital stock, labor, land, value of the gross agricultural production and agricultural emissions (CO₂eq). The results found that the Bahamas, Brazil, Chile, Costa Rica and Mexico attained the maximum efficiency level in all efficiency measurements. These countries present the best performances compared with the other countries evaluated.

Keywords: Agricultural; Environmental; Efficiency; DEA.

RESUMEN

Este estudio utiliza el Análisis de Envolventes de Datos para medir el desempeño medioambiental agrícola de América Latina y el Caribe; con suposición de *natural* y *managerial disposability*, y rendimientos a escala y daños a escala; durante 2012. Se utilizan siete variables: alimentación animal, fertilizantes, reserva de capital, mano de obra, tierra, valor de la producción agrícola y emisiones agrícolas (CO₂eq). Los resultados muestran que las Bahamas, Brasil, Chile, Costa Rica y México alcanzaron el máximo nivel de eficiencia en todas las mediciones de eficiencia. Estos países presentan el mejor desempeño en comparación con el resto de países evaluados.

Palabras clave: Agricultura; Medioambiente; Eficiencia; DEA.

Clasificación JEL: C6, Q5, R5.



1. INTRODUCTION

Climate change is a global issue that threatens the Latin America and the Caribbean (LAC) countries to a greater or lesser intensity and causes negative social, environmental and economic consequences (CAF, 2013). This phenomenon is brought about by global warming, due to the increase in greenhouse gas (GHG) emissions (Sánchez and Reyes, 2015). The new regulations present the need to adapt and mitigate climate change, as a major international challenge to reduce GHG emissions (Vergara *et al.*, 2013; Espinosa and Mezouar, 2016).

Most LACs have signed and ratified the Paris agreement on climate change (COP 21) and they are among the most ambitious seeking to increasingly reduce GHG emissions to create a green economy (UNFCCC, 2016). However, LACs have been implementing the UN Framework Convention on Climate Change (UNFCCC) guidelines for a number of years with different sectoral initiatives for climate change mitigation and adaptation, which are essential for governments, private sectors and the general population to create sustainable development (CAF, 2013).

In LAC, one of the economic sectors most vulnerable to climate change is agriculture (CAF, 2013). So, LAC share a set of common environmental challenges to reduce their environmental footprint caused by unsustainable production practices (ECLAC, 2016; IDB, 2016). This new scenario raises the role of agriculture of the LAC countries particularly in sustainable development, to attain comprehensive cross-environmental policies to reconcile its agricultural productivity and its environmental performance (UNEP, 2010).

A number of empirical studies have analyzed the agricultural productivity in LAC in recent periods. These studies have been mainly based on variables such as labor, land, fertilizers, irrigation, capital stock, livestock, crop and value of the gross agriculture production. Likewise, they have used diverse methods, such as Data Envelopment Analysis (DEA), the Malmquist Index, the stochastic frontier, and the Cobb-Douglas and Translog functions.

Authors such as Pfeiffer (2003), who studied the agricultural productivity in the Andean Community between 1972 and 2000 must be highlighted. Also, Bharati and Fulginiti (2007) studied the agricultural productivity growth in ten Mercosur countries between 1972 and 2002. A feature of both studies is that they concluded that technical progress was the main contributor to agricultural

productivity growth. They also concluded that farmers benefited from research and the introduction of new technological innovation, especially in countries such as Brazil, but the gap between countries in the use of better agricultural practices was widening.

On the other hand, Hutchinson (2007) found that in many Caribbean countries the level of total agricultural productivity fell between 1961-2000, which meant that the Caribbean countries were becoming more dependent on food imports and exposed to global shocks in the food system. It is worth noting in this respect the important work by Solís *et al.* (2009) which focused on 639 farms in El Salvador and Honduras, and concluded that improvements in technical efficiency are financially beneficial to farm households while also contributing to environmental sustainability.

Analysis by Ludena (2010) has found that agricultural productivity has grown in LAC between 1961-2007. Yet, the total factor has increased mostly because of technological changes rather than changes in efficiency. Additionally, Zúniga (2011) found gains in agricultural productivity in Central America between 1994 and 2010 due to technical changes but also because of efficiency changes.

A prior significant study by Ebata (2011) analyzed the agricultural productivity in Central America and the Caribbean between 1976 and 2006. In particular, this study has included the CO₂ emissions variable in its analysis. It found that over this period agricultural productivity increased when not taking into account own environmental variables such as emissions. Conversely, a lower growth of agricultural productivity was recorded between 1992 and 2006 when CO₂ emissions are added to the analysis.

Martin-Retortillo *et al.* (2014) found that the increases in efficiency made a rather modest contribution to enhancement of the production growth in LAC countries between 1950 and 2010. Above all, the use of capital explained the production growth. Further, Nin-Pratt *et al.* (2015) highlighted that the agricultural performance in LAC between 1980 and 2012 was marked by the differences in the use of inputs per worker, the quality of natural resources and the availability and use of new technologies. In fact, they concluded that when countries increase the inputs per worker, then the productivity improves more rapidly than in the countries with a limited access to capital and land.

Trindade and Fulginiti (2015) have estimated agricultural productivity between 1969 and 2009 in South America. They concluded that the increase in agricultural productivity was brought about by new innovations in the sector. Also, they showed that spending on education and R&D in agriculture are important to understanding agricultural performance among the countries of this region.

So, in order to support the analysis, Lachaud *et al.* (2015) has analyzed agricultural productivity growth in LACs, covering the period 1961-2012. This research has included climate variables in the study for a better understanding of agricultural performance in the region. The results showed that agricul-

tural production in LACs is very sensitive to labor, animal stock, and land. In addition, an extreme temperature has a negative and significant impact on agricultural production, while rainfall has a small but positive effect. Moreover, the combined effect of all climate variables considered in the study have, on average, an increasingly negative impact.

In view of the above, Moreno-Moreno *et al.* (2017) studied the operational efficiency and environmental efficiency in the agriculture sector of eighteen LAC countries. They have proved that 6 countries fulfill the efficiency measures: Argentina, Belize, Bolivia, Brazil, Costa Rica and Mexico present the best agricultural performance. Lastly, Lachaud *et al.* (2015) and Moreno-Moreno *et al.* (2017) have concluded that new technology in agriculture will increase the ability to reduce pollution in agriculture but also achieve better agricultural performance.

Thereupon, this empirical comparison has the intention of identifying the progress of each country toward accomplishing the important challenge: to reconcile its agricultural productivity and its environmental performance. This study applies DEA for environmental assessment through the natural disposability, managerial disposability and joint performance –which is the integration of natural and managerial disposability– of the agricultural sector of 25 LACs in 2012. As well, the types of Returns to Scale (RTS) and Damages to Scale (DTS) will be provided. Therefore, animal feed, fertilizers, capital stock, labor and land are considered as input variables and value of the gross agricultural production and agricultural emissions (CO₂eq) as output variables. Based on the results, relevant knowledge will be provided to the governments so that they can work on strengthening environmental strategies, in such way as to adapt new technology to reduce pollution in order to create sustainable agriculture.

The rest of this article is organized as follows. Section 2 explains the DEA methodology based on natural disposability, managerial disposability and joint performance. Section 3 defines the descriptive statistics. Section 4 analyzes the results obtained, comparing the situation of the LACs by indicating three types of efficiency, as well as the RTS and DTS. Lastly, the conclusions are in Section 5.

2. METHODOLOGY

DEA is a mathematical technique that studies the relations between the inputs and outputs used in a production process in order to determine the levels of efficiency (Farrell, 1957). It is a nonparametric method first described by Charnes *et al.* (1978) to measure the relative efficiency of a set of Decision Making Units (DMU) and the subsequent formalization described by Banker *et al.* (1984). DEA has been applied in various fields of management science and operations research (Campos *et al.*, 2016; Expósito *et al.*, 2017 and Fernández-Serrano *et al.*, 2017).

In addition, it has been used to assess the environmental performance by several authors such as Scheel (2001); Färe *et al.* (2004); Zhou *et al.* (2008);

Sueyoshi and Goto (2012; 2014); Halkos and Tzeremes (2014); Sanz-Díaz *et al.* (2017); Vlontzos and Pardalos (2017), who emphasize the benefit of DEA as an application for environmental management, which is a problem of undoubted relevance in the policies of any state.

An important feature of DEA for environmental assessment is that it includes desirable outputs and undesirable outputs and its own production variables, which cannot be separated into an environmental analysis model of these features (Dios-Palomares *et al.*, 2014). In this way, Sueyoshi and Goto (2012) have developed a non-radial and radial model of DEA for environmental assessments. This approach classifies the outputs into desirable (good) and undesirable (bad) outputs and establishes two concepts: natural disposability and managerial disposability.

So, this study uses the DEA radial approach for the environmental assessment proposed by Sueyoshi and Goto (2014). An important feature of this approach is that it employs the DEA-RAM (Range-Adjusted Measure), first proposed by (Cooper *et al.*, 1999) to incorporate the natural disposability and managerial disposability measurements into a unified treatment.

Natural disposability: refers to a DMU seeking to achieve its efficiency by decreasing its directional vector of inputs in order to decrease the directional vector of undesirable outputs, as well as to increase the vector of desirable outputs as much as possible.

Managerial disposability: a DMU's search for reaching its efficiency by increasing the directional vector of inputs to decrease the directional vector of undesirable outputs, as well as to increase the vector of desirable outputs as much as possible.

2.1. NATURAL DISPOSABILITY

In model (1), each j -th DMU $j = 1, \dots, n$, uses inputs $X_j = (x_{1j}, \dots, x_{mj})^T$ to produce desirable outputs $G_j = (g_{1j}, \dots, g_{sj})^T$ and undesirable outputs $B_j = (b_{1j}, \dots, b_{hj})^T$. Furthermore, $d_i^x, i = 1, \dots, m$, $d_r^g, r = 1, \dots, s$ and $d_f^b, f = 1, \dots, h$ are all slack variables related to inputs, desirable outputs and undesirable outputs, respectively. $\lambda = (\lambda_1, \dots, \lambda_n)^T$ are structural or intensity variables, which are unknown and are used for connecting the input and output vectors by a convex combination. R is the range resolute through the upper and lower bounds of inputs, desirable outputs and undesirable outputs, expressed by:

$$\begin{aligned} R_i^x &= (m + s + h)^{-1} (\max\{x_{ij}|j=1, \dots, n\} - \min\{x_{ij}|j=1, \dots, n\})^{-1}, \\ R_r^g &= (m + s + h)^{-1} (\max\{g_{rj}|j=1, \dots, n\} - \min\{g_{rj}|j=1, \dots, n\})^{-1} \text{ and} \\ R_f^b &= (m + s + h)^{-1} (\max\{b_{fj}|j=1, \dots, n\} - \min\{b_{fj}|j=1, \dots, n\})^{-1}. \end{aligned} \quad (1)$$

The natural efficiency of the k th country is evaluated by the following radial model:

$$\begin{aligned}
 & \text{Max } \xi + \varepsilon \left[\sum_{i=1}^m R_i^x d_i^x + \sum_{r=1}^s R_r^g d_r^g + \sum_{f=1}^h R_f^b d_f^b \right] \\
 & \text{s. t. } \sum_{j=1}^n x_{ij} \lambda_j + d_i^x = x_{ik} \quad (i=1, \dots, m), \\
 & \quad \sum_{j=1}^n g_{rj} \lambda_j - d_r^g - \xi g_{rk} = g_{rk} \quad (r=1, \dots, s), \\
 & \quad \sum_{j=1}^n b_{fj} \lambda_j + d_f^b + \xi b_{fk} = b_{fk} \quad (f=1, \dots, h), \\
 & \quad \sum_{j=1}^n \lambda_j = 1, \\
 & \quad \lambda_j \geq 0 \quad (j=1, \dots, n), \quad d_i^x \geq 0 \quad (i=1, \dots, m), \\
 & \quad d_r^g \geq 0 \quad (r=1, \dots, s), \quad d_f^b \geq 0 \quad (f=1, \dots, h) \text{ and} \\
 & \quad \xi: \text{unrestricted}
 \end{aligned} \tag{2}$$

The natural efficiency is measured by:

$$\theta^* = 1 - \left[\xi^* + \varepsilon \left(\sum_{i=1}^m R_i^x d_i^{x*} + \sum_{r=1}^s R_r^g d_r^{g*} + \sum_{f=1}^h R_f^b d_f^{b*} \right) \right].$$

All slack variables resolved in the optimality of model (1) indicate the level of inefficiency.

The model (1) has the following dual formulation:

$$\begin{aligned}
 & \text{Min } \sum_{i=1}^m v_i x_{ik} - \sum_{r=1}^s u_r g_{rk} + \sum_{f=1}^h w_f b_{fk} + \sigma \\
 & \text{s. t. } \sum_{i=1}^m v_i x_{ij} - \sum_{r=1}^s u_r g_{rj} + \sum_{f=1}^h w_f b_{fj} + \sigma \geq 0 \quad (j=1, \dots, n), \\
 & \quad \sum_{r=1}^s u_r g_{rk} + \sum_{f=1}^h w_f b_{fk} = 1, \\
 & \quad v_i \geq \varepsilon R_i^x \quad (i=1, \dots, m), \\
 & \quad u_r \geq \varepsilon R_r^g \quad (r=1, \dots, s), \\
 & \quad w_f \geq \varepsilon R_f^b \quad (f=1, \dots, h), \\
 & \quad \sigma: \text{unrestricted}.
 \end{aligned}$$

Where $v_i, i = 1, \dots, m; u_r, r = 1, \dots, s$ and $w_f, f = 1, \dots, h$ are all positive dual variables associated with the first three constraints from the model (1). The dual variable is obtained from the fourth equation of model (1). The dual variables show the level of increase in inefficiency due to a unit increase in each production factor.

2.2. MEASUREMENT OF THE RTS BY USING SCSCS

According to Charnes *et al.* (1989) and Sueyoshi and Goto (2014), the Strong Complementary Slackness Conditions (SCSCs) have been incorporated to obtain the RTS unambiguously. Therefore, model (3) calculates the upper bound (τ^*) and lower bound (τ^{**}) of the dual variable (σ) and the influence ζ_k^g from undesirable outputs as follows: The type of RTS is determined as follows:

$$\begin{aligned}
 & \text{Max / Min } \sigma + \zeta_k^b \\
 & \text{s. t. all constraints in both (1) and (2)}
 \end{aligned} \tag{3}$$

$$\begin{aligned}
 & \zeta_k^b - \sum_{f=1}^h w_f b_{fk} = 0, \\
 & \xi + \varepsilon \left[\sum_{i=1}^m R_i^x d_i^x + \sum_{r=1}^s R_r^g d_r^g + \sum_{f=1}^h R_f^b d_f^b \right] \\
 & = \sum_{i=1}^m v_i x_{ik} - \sum_{r=1}^s u_r g_{rk} + \sum_{f=1}^h w_f b_{fk} + \sigma, \\
 & \quad \zeta_k^b \geq 0.
 \end{aligned}$$

- a) Increasing RTS $\leftrightarrow \bar{\tau} \geq \underline{\tau} > 0$: The proportion of desirable outputs is more than the increase in all factors.
- b) Constant RTS $\leftrightarrow \bar{\tau} \geq 0 \geq \underline{\tau}$: The proportion of desirable outputs is the same proportion as the increase in all factors.
- c) Decreasing RTS $\leftrightarrow 0 > \bar{\tau} \geq \underline{\tau}$: The proportion of desirable outputs is less than the increase in all factors.

2.3. MANAGERIAL DISPOSABILITY

The managerial efficiency of the k th country is evaluated by the following radial model:

$$\begin{aligned}
 & \text{Max } \xi + \varepsilon \left[\sum_{i=1}^m R_i^x d_i^x + \sum_{r=1}^s R_r^g d_r^g + \sum_{f=1}^h R_f^b d_f^b \right] \\
 & \text{s. t. } \sum_{j=1}^n x_{ij} \lambda_j - d_i^x = x_{ik} \quad (i=1, \dots, m), \\
 & \quad \sum_{j=1}^n g_{rj} \lambda_j - d_r^g - \xi g_{rk} = g_{rk} \quad (r=1, \dots, s), \\
 & \quad \sum_{j=1}^n b_{fj} \lambda_j + d_f^b + \xi b_{fk} = b_{fk} \quad (f=1, \dots, h), \\
 & \quad \sum_{j=1}^n \lambda_j = 1, \\
 & \quad \lambda_j \geq 0 \quad (j=1, \dots, n), \quad d_i^x \geq 0 \quad (i=1, \dots, m), \\
 & \quad d_r^g \geq 0 \quad (r=1, \dots, s) \text{ and } d_f^b \geq 0 \quad (f=1, \dots, h) \text{ and} \\
 & \quad \xi: \text{unrestricted.}
 \end{aligned} \tag{4}$$

The explanation of all the variables and the criterion in model (4) are the same as for the model (1), with the sole change that the model (4) considers only single-sided input deviations $-d_i^x$.

The managerial efficiency is measured by:

$$\theta^* = 1 - \left[\xi^* + \varepsilon \left(\sum_{i=1}^m R_i^x d_i^{x*} + \sum_{r=1}^s R_r^g d_r^{g*} + \sum_{f=1}^h R_f^b d_f^{b*} \right) \right].$$

All slack variables resolved in the optimality of model (4) indicate the level of inefficiency.

The dual formulation of the model (4) is as follows:

$$\begin{aligned}
 & \text{Min } -\sum_{i=1}^m v_i x_{ik} - \sum_{r=1}^s u_r g_{rk} + \sum_{f=1}^h w_f b_{fk} + \sigma \\
 & \text{s. t. } -\sum_{i=1}^m v_i x_{ij} - \sum_{r=1}^s u_r g_{rj} + \sum_{f=1}^h w_f b_{fj} + \sigma \geq 0 \quad (j=1, \dots, n), \\
 & \quad \sum_{r=1}^s u_r g_{rk} + \sum_{f=1}^h w_f b_{fk} = 1 \\
 & \quad v_i \geq \varepsilon R_i^x \quad (i=1, \dots, m), \\
 & \quad u_r \geq \varepsilon R_r^g \quad (r=1, \dots, s), \\
 & \quad w_f \geq \varepsilon R_f^b \quad (f=1, \dots, h), \\
 & \quad \sigma: \text{unrestricted.}
 \end{aligned} \tag{5}$$

Where $v_p, p=1, \dots, m$; $u_r, r=1, \dots, s$ and $w_f, f=1, \dots, h$ are all dual variables associated with the first three constraints from the model (4). The dual variable σ is obtained from the fourth equation of model (4). The dual variables show the level of increase in inefficiency due to a unit increase in each production factor.

2.4. MEASUREMENT OF THE DTS BY USING SCSCS

According to Charnes *et al.* (1989) and Sueyoshi and Goto (2014), the Strong Complementary Slackness Conditions (SCSCs) have been incorporated to obtain the DTS unambiguously. Therefore, model (6) can get the upper bound (π^*) and lower bound ($\underline{\pi}^*$) of the dual variable (σ) and the influence ζ_k^g from desirable outputs as follows:

$$\begin{aligned}
 & \text{Max / Min } \sigma - \zeta_k^g \\
 & \text{s. t. all constraints in both (4) and (5)} \\
 & \zeta_k^g - \sum_{r=1}^s u_r g_{rk} = 0, \\
 & \xi + \varepsilon [\sum_{i=1}^m R_i^x d_i^x + \sum_{r=1}^s R_r^g d_r^g + \sum_{f=1}^h R_f^b d_f^b] \\
 & = - \sum_{i=1}^m v_i x_{ik} - \sum_{r=1}^s u_r g_{rk} + \sum_{f=1}^h w_f b_{fk} + \sigma, \\
 & \zeta_k^g \geq 0.
 \end{aligned} \tag{6}$$

The type of DTS is determined as follows:

- a) Increasing DTS $\leftrightarrow \bar{\pi} \geq \underline{\pi}^* > 0$: The proportion of undesirable outputs is more than the increase in all factors.
- b) Constant DTS $\leftrightarrow \bar{\pi} \geq 0 \geq \underline{\pi}^*$: The proportion of undesirable outputs is the same proportion as the increase in all factors.
- c) Decreasing DTS $\leftrightarrow 0 > \bar{\pi} \geq \underline{\pi}^*$: The proportion of undesirable outputs is less than the increase in all factors.

2.5. JOINT PERFORMANCE: INTEGRATION OF NATURAL AND MANAGERIAL DISPOSABILITY.

The joint performance of the k th country is evaluated by the following radial model:

$$\begin{aligned}
 & \text{Max } \xi + \varepsilon [\sum_{i=1}^m R_i^x (d_i^{x+} + d_i^{x-}) + \sum_{r=1}^s R_r^g d_r^g + \sum_{f=1}^h R_f^b d_f^b] \\
 & \text{s.t. } \sum_{j=1}^n x_{ij} \lambda_j - d_i^{x+} + d_i^{x-} = x_{ik} \quad (i = 1, \dots, m), \\
 & \quad \sum_{j=1}^n g_{rj} \lambda_j - d_r^g - \xi g_{rk} = g_{rk} \quad (r = 1, \dots, s), \\
 & \quad \sum_{j=1}^n b_{fj} \lambda_j + d_f^b + \xi b_{fk} = b_{fk} \quad (f = 1, \dots, h), \\
 & \quad \sum_{j=1}^n \lambda_j = 1, \\
 & \quad \lambda_j \geq 0 \quad (j = 1, \dots, n), \\
 & \quad d_i^{x+} \geq 0 \quad (i = 1, \dots, m), \\
 & \quad d_i^{x-} \geq 0 \quad (i = 1, \dots, m), \\
 & \quad d_r^g \geq 0 \quad (r = 1, \dots, s), \\
 & \quad d_f^b \geq 0 \quad (f = 1, \dots, h) \text{ and} \\
 & \quad \xi: \text{unrestricted.}
 \end{aligned}$$

The difference of model (7) compared with model (1) and model (4) is that the slack variable related with the inputs is divided into two types: d_i^{x+} and d_i^{x-} and which symbolize the slacks of inputs under managerial disposability and natural disposability, respectively.

The joint performance is measured by:

$$\theta^* = 1 - [\xi^* + \varepsilon (\sum_{i=1}^m R_i^x (d_i^{x+*} + d_i^{x-*}) + \sum_{r=1}^s R_r^g d_r^{g*} + \sum_{f=1}^h R_f^b d_f^{b*})].$$

Where, all slack variables are the inefficiency levels and are resolute for the optimality of model (7).

3. DATA

The variables on the agriculture sector were obtained from the study of Nin-Pratt *et al.* (2015) and FAOSTAT (2016) for the year 2012. The analysis includes 25 LAC countries, divided by sub-regions (see Table 1).

As mentioned above this study uses five conventional agricultural input variables: *Animal feed* commodities, expressed in metric tons of maize equivalents. *Fertilizers* refers to the quantity of nitrogen (N), phosphate (P2O5) and potash (K2O), expressed in metric tons. *Capital stock* that includes (1) crop capital and (2) livestock capital, expressed at constant prices of 2005 as base year. *Labor* is the total economically active population in agriculture in thousands of people. *Land* involves land under temporary crops, temporary meadows for mowing or pasture, land under market and kitchen gardens, land that is temporarily fallow, land cultivated with permanent crops, and pasture land in thousands of hectares.

TABLE 1: AGRICULTURAL VARIABLES FOR 2012.

Country	Animal feed	Fertilizers	Capital Stock	Labor	Land	Agri. production	Agri. emissions
Andean Community:							
Bolivia	2091	47807	10807	2056	37596	3732400	23342
Colombia	14051	755150	112632	3484	42618	14014336	52263
Ecuador	7872	249324	21184	1219	7507	7335057	13734
Peru	4363	330161	24533	3728	24332	9613351	23450
Venezuela	4071	391819	30593	698	21600	7234275	35661
Caribbean:							
Bahamas	88	1086	31	4	14	35805	24
Barbados	153	1638	93	4	14	47349	57
Dominican Republic	3194	137784	11037	438	2352	2824180	7692
Guyana	358	20680	1047	49	1678	374843	1764
Jamaica	680	7028	2175	210	444	579658	637
Suriname	38	15244	688	33	73	134656	725
Trinidad and Tobago	82	5043	365	45	54	142744	319

Central America:							
Belize	124	3148	228	32	160	185608	319
Costa Rica	2139	123629	2366	317	1812	3061382	3394
El Salvador	1767	73035	2457	577	1572	1196889	2826
Guatemala	3669	226387	10685	2148	3809	4744677	8387
Honduras	2526	78117	4537	662	3235	2191396	5851
Mexico	26533	1837310	126539	7708	106705	38098572	82661
Nicaragua	197	70054	6316	343	5103	1609347	7759
Panama	626	49030	3927	244	2257	990944	3489
Southern Cone:							
Argentina	21200	1756310	70471	1388	149254	39609904	105825
Brazil	110119	11455415	233157	10478	275607	145545149	444704
Chile	16446	514777	22693	957	15755	8583679	11518
Paraguay	1287	432524	10209	851	21500	4282544	25127
Uruguay	1734	225654	23316	184	14230	4391247	23848

Source: Own elaboration with information from FAOSTAT (2016); Nin-Pratt, *et al.* (2015) and FAO (2017): country profiles.

On the other hand, a desirable output: *value of the gross agricultural production* is expressed in US dollars, a constant price of 2004-2006, which includes crop cultivation and livestock production. An undesirable output: *agricultural GHG emissions* are obtained from the FAOSTAT database and expressed in gigagrams of CO₂ equivalent (CO₂eq), which is made up of non-CO₂ gases, namely methane (CH₄) and nitrous oxide (N₂O).

Table 2 indicates the correlation between the inputs and outputs. It is necessary because the correlation between variables cannot be ignored in DEA methodology. The coefficients are high (at a 5% significance level), which indicates that there is a strong interaction between the variables and satisfy the RAM method requirement that outputs vary along with inputs.

TABLE 2: CORRELATION MATRIX BETWEEN INPUTS AND OUTPUTS.

Outputs	Inputs				
	I_1	I_2	I_3	I_4	I_5
G_1	0.990903	0.989066	0.91951	0.861371	0.962667
B_1	0.984842	0.993364	0.907245	0.835716	0.949685

Source: Own elaboration.

All the results have been by obtained with the Wolfram Mathematica program, which is at the disposal of the reader from the authors upon request.

4. RESULTS

It is important to note that both strategies analyzed, natural and managerial disposability, seek to satisfy the environment regulations. However, natural disposability dedicates a limited cooperative effort to reducing the amount of CO₂eq. emissions at the level that satisfies the amount required by the government regulation. Meanwhile, managerial disposability, dedicates management and engineering efforts to reducing CO₂eq. emissions by implementing technological innovation.

Thus, one of the main objectives of this study was to measure the integration of natural and managerial disposability (joint performance), because in a real production activity the natural and managerial disposability coexist in the DEA environmental assessment. Therefore, the third column in Table 3 exhibits the joint performance. Consequently, the results in Table 3 show five group of countries:

Firstly, the Bahamas, Brazil, Chile, Costa Rica and Mexico attained the maximum efficiency level (1.000) in the three efficiency measurements. They present the best performance when compared with the other LAC countries during 2012. It can be concluded that they not only care about obtaining their agricultural production targets, but also about satisfying the regulations to reduce the agricultural emissions (CO₂eq.) through technological innovation. More importantly, these results represent significant progress toward the vision of reconciling agricultural productivity and environmental performance for creating sustainable agriculture. So, these countries should be used as a benchmark for those countries with inefficient scores.

Secondly, Jamaica, Argentina, Guatemala, Barbados, Peru and Bolivia just accomplished full efficiency under natural disposability and managerial disposability when measured separately. Anyhow, it is important to note that Jamaica and Argentina exhibit comparatively high joint performance scores of 0.9944

and 0.9245, respectively. They were followed by Guatemala, Barbados and Peru with 0.8362, 0.8165 and 0.7973, respectively. The worst performance in this group is Bolivia with 0.3424, even though it is relatively poor compared with the other countries analyzed.

TABLE 3: EFFICIENCY LEVELS UNDER THE THREE EFFICIENCY MEASUREMENTS DURING 2012.

Country	Natural efficiency	Managerial efficiency	Joint performance
Bahamas	1.0000	1.0000	1.0000
Brazil	1.0000	1.0000	1.0000
Chile	1.0000	1.0000	1.0000
Costa Rica	1.0000	1.0000	1.0000
Mexico	1.0000	1.0000	1.0000
Jamaica	1.0000	1.0000	0.9944
Argentina	1.0000	1.0000	0.9245
Guatemala	1.0000	1.0000	0.8362
Barbados	1.0000	1.0000	0.8165
Peru	1.0000	1.0000	0.7973
Bolivia	1.0000	1.0000	0.3424
Colombia	0.7612	1.0000	0.6786
Ecuador	1.0000	0.8637	0.8347
Belize	1.0000	0.7602	0.7563
Trinidad and Tobago	1.0000	0.6388	0.6320
Uruguay	1.0000	0.4824	0.3897
Nicaragua	1.0000	0.4767	0.3737
Paraguay	1.0000	0.5909	0.3656
Suriname	1.0000	0.4815	0.3247
El Salvador	0.6372	0.8914	0.6372
Dominican Republic	0.7710	0.6840	0.6077
Honduras	0.9276	0.6812	0.5882
Venezuela	0.9399	0.4841	0.4841
Panama	0.7793	0.5318	0.4772
Guyana	0.5637	0.6422	0.3755

<i>Andean Community</i>	0.9402	0.8696	0.6274
<i>Caribbean</i>	0.9050	0.7781	0.6787
<i>Central America</i>	0.9180	0.7927	0.7086
<i>Southern Cone</i>	1.0000	0.8147	0.7360
<i>Averages</i>	0.9408	0.8137	0.6877

Source: Own elaboration.

Thirdly, Colombia only attained the maximum efficiency under managerial disposability. However, from a joint performance perspective, it exhibits a low efficiency score of 0.6786.

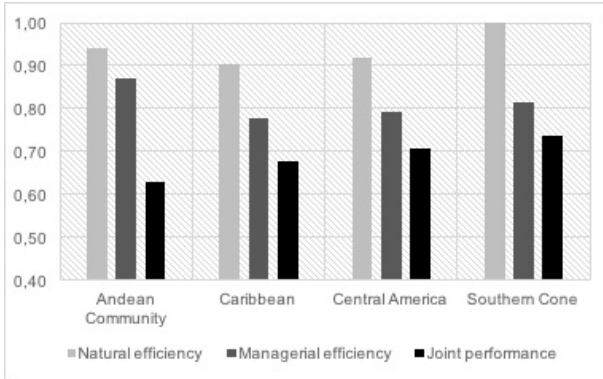
Therefore, it can be concluded that the three first groups have positively adopted the environmental regulation to reduce their CO₂eq. agricultural emissions by using technological innovation. Still, there are seven countries that respectively need to continue their effort to enhance their joint performance.

On the other hand, the fourth group (Ecuador, Belize, Trinidad and Tobago, Uruguay, Nicaragua, Paraguay and Suriname) only attained the maximum efficiency under natural disposability. Here, Ecuador and Belize exhibit joint performance scores of 0.8347 and 0.7563, respectively, which is a good position. They are followed by Trinidad and Tobago with 0.6320. Then, the worst position is for Uruguay, Nicaragua, Paraguay and Suriname with low joint performance scores of 0.3897, 0.3737, 0.3656 and 0.3247, respectively. These countries have negatively adopted the environment regulation. That is, the strategy of each country was -mostly- oriented toward decreasing the amount of inputs to reduce the amount of agricultural emissions (CO₂eq.) requested by the governmental regulation.

Lastly, El Salvador, the Dominican Republic, Honduras, Venezuela, Panama and Guyana have the worst performances compared to the other countries analyzed. These countries failed to obtain the maximum efficiency score in any of all efficiency measurements. Consequently, these countries should compare themselves to the efficient countries so that they adopt the best practices to enhance their efficiency scores.

Figure 1 and Table 3 show that the Southern Cone had the highest efficiency score under natural disposability (1.000). Next, the Andean Community did relatively well, with an efficiency score of 0.9402. Followed by Central America with 0.9180. The Caribbean came last with 0.9050. However, natural efficiency scores are slightly different between sub-regions (T). These results are supported by the Kruskal-Wallis H test, which shows the two-tailed hypothesis: (1) $H_0: T_1 = T_2 = T_3 = T_4$ and (2) $H_1: T_j \neq 0$. The statistic becomes a significance level of $H = 0.513$, which indicates that the null hypothesis (H_0) is accepted at the 5% level of significance because $0.513 < 7.81$ (the critical value of the X² distribution with a degree of freedom of 3). That is, there are no major efficiency differences under natural disposability between the sub-regions.

FIGURE 1: COMPARISON OF THE THREE EFFICIENCY MEASUREMENTS BETWEEN SUB-REGIONS DURING 2012.



Source: Own elaboration.

Moreover, Figure 1 and Table 3 show that no sub-region attained the maximum efficiency score under managerial disposability - their scores are even always below efficiency under natural disposability. However, the Andean Community exhibits the best position with an efficiency score of 0.8696. It is followed by the Southern Cone with 0.8147. Next are Central America and the Caribbean with 0.7927 and 0.7781, respectively. Nonetheless, managerial efficiency scores are slightly different between sub-regions. These results are supported by the Kruskal-Wallis H test, which shows the two-tailed hypothesis: (1) $H_0: T_1 = T_2 = T_3 = T_4$ and (2) $H_1: T_j \neq 0$. The statistic has a significance level of $H = 0.897$, and the null hypothesis (H_0) is accepted at the 5% level of significance because $0.897 < 7.81$ (the critical value of the X^2 distribution with a degree of freedom of 3). That is, there are no major efficiency differences under managerial disposability between the sub-regions.

Lastly, Figure 2 and Table 3 show that no sub-region attained the maximum efficiency score under joint performance - their scores are even always below efficiency under natural and managerial disposability. Yet, the Southern Cone shows the best position with an efficiency score of 0.7360. It is followed by Central America with 0.7086. Finally, are the Caribbean and the Andean Community with the low performance of 0.6787 and 0.6274, respectively. Nevertheless, joint performance scores are slightly different between sub-regions. These results are supported by the Kruskal-Wallis H test, which shows the two-tailed hypothesis: (1) $H_0: T_1 = T_2 = T_3 = T_4$ and (2) $H_1: T_j \neq 0$. The statistic has a significance level of $H = 0.844$, and the null hypothesis (H_0) is accepted at the 5% level of significance because $0.844 < 7.81$ (the critical value of the X^2 distribution with a degree of freedom of 3). This result confirmed that in LACs, there was no major technological innovation progress differences between the sub-regions to reduce agricultural emissions ($CO_2eq.$). Therefore, all

sub-regions need to continue their efforts to enhance their efficiency scores by using technological innovation.

4.1. MEASUREMENT OF RTS AND DTS

It is important to emphasize that the implications of RTS and DTS are completely opposite, however the existence of DTS depends on RTS. That is, the combination of RTS and DTS provides a strategic direction on how to enhance efficiency scores by controlling the agricultural activity size, and indicates if a country needs to introduce technological innovation to reduce pollution.

So, Table 5 shows that Argentina, Bahamas, Barbados, Belize, Bolivia, Brazil, Costa Rica, Jamaica, Nicaragua, Paraguay, Suriname, Trinidad and Tobago and Uruguay belong to constant RTS. Conceptually, they may maintain their agricultural activity's current size to keep their operational performance. Meanwhile, Chile, Colombia, the Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Honduras, Mexico, Panama, Peru and Venezuela exhibit decreasing RTS. Conceptually, a large size of the agricultural sector is not recommended for these countries, because their proportion of the value of the gross agricultural production is less than the increase in all factors.

It is important to note that since 2010 LACs have suffered six years of slowdown, including two of recession, and have halted social development (World Bank, 2017). Besides, LACs' GHG emissions contribution has been estimated at 10% of global emissions in 2012 (Sánchez and Reyes, 2015). Thus, from the economic growth perspective, in LACs it is not practical to maintain or to reduce their agricultural activity's current size. LACs need to keep themselves up in order to register a positive growth to increase the total wage bill (Moreno-Moreno *et al.*, 2017). Thus, it is better for LACs to use technological innovation that will be the key to enhancing their operational and environmental performance.

TABLE 4: TYPES OF RTS AND DTS.

Country	RTS	DTS
Argentina	Constant	Constant
Bahamas	Constant	Constant
Barbados	Constant	Increasing
Belize	Constant	Decreasing
Bolivia	Constant	Constant
Brazil	Constant	Constant
Chile	Decreasing	Constant
Colombia	Decreasing	Constant

Costa Rica	Constant	Decreasing
Dominican Republic	Decreasing	Decreasing
Ecuador	Decreasing	Decreasing
El Salvador	Decreasing	Increasing
Guatemala	Decreasing	Constant
Guyana	Decreasing	Decreasing
Honduras	Decreasing	Decreasing
Jamaica	Constant	Constant
Mexico	Decreasing	Constant
Nicaragua	Constant	Decreasing
Panama	Decreasing	Decreasing
Paraguay	Constant	Increasing
Peru	Decreasing	Constant
Suriname	Constant	Decreasing
Trinidad and Tobago	Constant	Decreasing
Uruguay	Constant	Increasing
Venezuela	Decreasing	Decreasing

Source: Own elaboration.

So, from the DTS point of view Table 5 shows that Argentina, Bahamas, Bolivia, Brazil, Jamaica, Chile, Colombia, Guatemala, Mexico and Peru belong to constant DTS, which implies that they should adopt technological innovation as an alternative to enhance their environmental performance. Meanwhile, Barbados, El Salvador, Paraguay and Uruguay exhibit increasing DTS, which indicates that it is strongly recommended for them to adopt technological innovation to reduce pollution. Besides, Belize, Costa Rica, Nicaragua, Suriname, Trinidad and Tobago, the Dominican Republic, Ecuador, Guyana, Honduras, Panama and Venezuela belong to decreasing DTS. They have an advantage compared with the other LACs: they do not immediately need technological innovation because their marginal environmental cost is decreasing. However, if their agricultural activity size varies without considering technological innovation, this is not recommended in the long term.

5. CONCLUSIONS

This empirical study demonstrated that in LACs during 2012 the efficiency under natural disposability appears comparatively higher (0.9408) than the efficiency under managerial disposability (0.8137) and joint performance (0.6877) (See Table 3). In general terms, LACs have negatively adopted the regulation for environmental protection. That is, they are more oriented toward reaching their agricultural production targets and secondly use technological innovation to reduce their pollutants.

However, between the 25 LACs evaluated during 2012, there are 18 countries which have reached the maximum efficiency under natural disposability (1.000). Meanwhile, 12 countries have attained the maximum efficiency under managerial disposability and only 5 countries have achieved the maximum efficiency score under joint performance. Here, Argentina, Bahamas, Brazil, Chile, Mexico and Costa Rica presented the best agricultural performance during 2012. These countries have gained widespread international recognition for their increasingly important role in agricultural productivity and for using technology innovation in agriculture to confront the important challenge of reducing their environmental footprint (ECLAC *et al.*, 2013; BEST, 2001; Bouroncle *et al.*, 2015). It can be concluded that a smaller number of LAC countries direct their efforts toward creating a sustainable and environmentally-friendly agriculture. Thus, those countries that had inefficiency levels should compare themselves to the efficient countries so that they adopt the best practices to enhance their efficiency scores.

Comparing sub-regions, the best performance in terms of natural disposability is in the Southern Cone. This is followed by the Andean Community with 0.9402. Next is Central America with 0.9180, and the Caribbean comes last with 0.9050. Nonetheless, the Kruskal-Wallis H test concluded that these sub-regions did not have major efficiency differences between them under natural disposability.

Meanwhile, from efficiency under the managerial perspective, all the sub-regions failed to attain the maximum efficiency score. Yet, the Andean Community shows a comparatively high efficiency score of 0.8696, followed by the Southern Cone with 0.8147. Then come Central America and the Caribbean with 0.7927 and 0.7781, respectively. Still, the Kruskal-Wallis H test concluded that these sub-regions did not have major efficiency differences between them under managerial disposability.

In terms of joint performance, i.e., when the natural disposability and managerial disposability coexist, all the sub-regions failed to attain the maximum efficiency score under the assumption of joint performance. Yet, the Southern Cone had a comparatively high efficiency score of 0.7360, followed by Central America with 0.7086. Then, come the Caribbean and the Andean Community with 0.6787 and 0.6274, respectively. It can be observed that the joint performance is always below efficiency under natural and managerial disposability. The Kruskal-Wallis H test concluded that there were no major technological

innovation progress differences between the sub-regions to reduce agricultural emissions (CO₂eq.).

Finally, under the natural disposability assumption, 13 countries exhibit constant RTS and 12 countries decreasing RTS. On the other hand, under the managerial disposability assumption, 11 countries show decreasing DTS, 10 constant DTS and 4 increasing DTS. The results suggest that for LAC countries, it is not simply a matter of varying the current size of their agricultural activity to improve their operational performance. Instead, they should direct their efforts toward creating a sustainable agriculture by implementing new technologies and developing their management to modernize agriculture to reduce pollution.

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