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MEASUREMENT OF AIRPORT EFFICIENCY. THE CASE OF COLOMBIA

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Since the mid-1990s, Colombia's main airports (including those with the highest traffic) have been privatized, transferring governance to private operators. The remaining airports in the network (the smallest ones) continue with public governance. Based on this, the objective of this research article is to know, analyse and even measure the airport efficiency in a context of structural reform and at the same time compare this with the measure in airports with public governance. The methodology used to carry out the study is the Data Envelopment Analysis, and this methodology uses only "technical variables" (that is, only those related to infrastructure). The main results of the research reveal higher efficiency indices in the major (or more important) airports, almost all of them under private governance, although there is also a group of them (usually very small airports) with very low efficiency levels.

Keywords: airport, privatization, governance, Data Envelopment Analysis, efficiency, Colombia

1. Introduction

The evaluation of airport efficiency has been a research area booming in recent years. These evaluations are important for all players in the industry, airport operators (public and private), regulatory agencies, governments (local, regional and national), and airlines. For this reason, a large number of articles on airport efficiency have been published in the last 15-20 years (lo Storto, 2018; Lai *et al*., 2012). Regarding the specific techniques adopted in the research, Data Envelopment Analysis (DEA) is one of the most used, started by the work of Gillen and Lall (1997), which was one of the first in the matter.

Many researches, which attempt to measure airport efficiency, cover their analysis at country level (or sometimes encompass continental regions). For instance, there are studies for airports in the United States (Sarkis, 2000; Sarkis and Talluri, 2004), Australia (Abbott and Wu, 2002), Japan (Yoshida and Fujimoto, 2004), the United Kingdom (Parker, 1999), Spain (Martín and Román, 2001), Italy (Malighetti *et al*., 2007; Barros and Dieke, 2008, 2007), Turkey (Ülkü, 2015; Kocak, 2011), etc. And at continental regional level, i.e., the simultaneous analysis of a set of airports from different countries (and even from different continents and worldwide), we can find the work of Adler and Berechman (2001), Oum *et al*. (2003, 2004, 2006), Lin and Hong (2006), Pels *et al*. (2001, 2003), Tsui *et al*. (2014), Ha *et al*. (2010), Lam *et al*. (2009), Yang (2010a, 2010b). It should be mentioned that for the Latin American region there is very little literature, only stand out: a study by Perelman and Serebrisky (2012) where the airport efficiency of several airports in the region was analysed; Barros (2008) examined the technical efficiency of airports in Argentina, and analysed the results in the context of the economic crisis during the 2003-2007 period; and finally Wanke (2013), and Pacheco and Fernandes (2003) measured the efficiency of airports in Brazil. There is no research (at least published) on the measurement of efficiency in Colombian airports.

So, this research, one of which objectives is to cover this gap in the scientific literature (geographically, both regionally and locally), will take as case study for the measurement of airport efficiency a set of airports in Colombia, the most important ones in the country, and both private and public governance. Air transport in Colombia has been experiencing significant and sustained growth for two decades, as a result of the liberalization of the industry (at the beginning of the 1990s) and which led to the entry of private capital into the airport sector (Díaz Olariaga and Avila, 2015). Since the mid-1990s, and in

several temporary phases, the country's main airports have been privatized (19 to date, the largest and most important in the network), understanding as such giving in concession (to private operators) only the governance of the airport (never the ownership) (Díaz Olariaga and Carvajal, 2016). Based on this, it is of great interest to know and measure airport efficiency in a context of structural reform (still in progress). Simultaneously, the efficiency of a set of airports will be measured, whose governance (to date) is 100% public, and this efficiency will be compared with the airports of the first group (with 100% private governance). And the methodology used to carry out the study is the Data Envelopment Analysis (DEA), which is a methodology used to estimate the relative efficiency of a variable without the need to know in depth the relationship that can occur between the inputs and outputs of a complex system.

2. Literature Review

In the last two decades, and worldwide, the academy has researched the impact of different forms of ownership on airport efficiency (lo Storto, 2018; Chen *et al*., 2017; Lai *et al*., 2012). And from a methodological point of view, Data Envelopment Analysis (DEA) has become the most popular tool for the analysis and measurement of efficiency.

Some studies find clear evidence of the influence of governance on airport efficiency, others cannot discover any relevant effect, and others show that the effect of governance on airport efficiency depends on many other factors, for example related to the market and the competitive environment, the governance structure (of the airport operator), the type of concession, and even the capacity of the airport to generate economies of scale. Researchers have used different samples, variables, time periods and research methods (lo Storto, 2018). Certain discrepancies between the results obtained in the research are due to differences in the research approach. Contradictory results can be found for the same or similar airport samples in different time frames (Gitto and Mancuso, 2012, Oum *et al*., 2003, 2006, 2008). The heterogeneities in the samples and the data sets make the comparative studies problematic and can strongly bias the efficiency analysis because the operating environments of the airports are very different (Adler *et al*., 2013; Marques *et al*., 2015).

Several researches support the idea that airport efficiency is influenced by the type of governance. In particular, some academics found that privatization increases airport efficiency (Adler and Liebert, 2014; Assaf, 2011, 2010; Gitto and Mancuso, 2012; Malighetti *et al*., 2007; Marques and Barros, 2011; Marques *et al*., 2015; Oum *et al*., 2006; Perelman and Serebrisky, 2012). Adler and Liebert (2014) found that operators of mixed-ownership airports with a public majority are not profitable. Malighetti *et al.* (2007) studied the efficiency of Italian airports applying a DEA model, they found a positive influence of private governance on airport efficiency. Marques and Barros (2011) investigated the effect that the regulation and governance of a sample of several European airports, their results conclude that airports with public governance are less efficient than airports with private governance. Oum *et al*. (2006) conducted extensive research on several airports in Asia-Pacific, Europe and North America, and with different types or formulas of governance, their study shows that airports with government majority governance (public) and multilevel governance are less efficient than airports with mostly private governance. A recent work by lo Storto (2018) finds dual results, that is, in the first place his research affirms that the results suggest that the heterogeneity of ownership can exert a substantial influence on airport efficiency; and secondly, it is detected that while airports with PPP structure have greater technical efficiency than the airports operated by public operators, the metafrontier analysis relating to the efficiency of costs and revenues does not provide evidence that the PPP airports work better. In fact, their results show that publicly managed airports achieve comparable or better performance in terms of revenue efficiency.

However, it is possible to find some research whose results showed that airports with public governance were more efficient than with private governance (Curi *et al*., 2010; Oum *et al*., 2008; Gutiérrez and Lozano, 2016; Martini *et al*., 2013). And on the other hand, some works (Lin and Hong, 2006; Gitto and Mancuso, 2012) determined that airport efficiency was not influenced by the airport's type of ownership.

Finally, some academics studied the combined effect of governance and other factors (for example: regulation, market competition, type of concession, etc.) on airport efficiency (Adler and Liebert, 2014; Albalate *et al*., 2014; Assaf and Gillen, 2012; Bel and Fageda, 2010; Curi *et al*., 2011; Gillen and Mantin, 2014). Adler and Liebert (2014) found that in relatively uncompetitive conditions public governance airports are less efficient than airports with entirely private governance, while in a competitive environment both operate equally efficiently. Assaf and Gillen (2012) evaluated the overall impact of the governance structure and economic regulation on airport efficiency in a large sample of

airports in Europe, North America and Australia; the authors found that the type of economic regulation affects efficiency rather than the type of governance. Curi *et al*. (2011) used *bootstrapped* DEA to estimate the technical efficiency of a set of Italian airports and their results led them to affirm that the typology of the concession contract could be a source of variation in efficiency. Gillen and Mantin (2014) corroborate these findings by developing a theoretical model to explore the compensation between the type of airport concession and aeronautical revenues; their model shows that privatization may not be recommended unless the potential of the concession's revenues is large enough.

3. Case Study

Since the mid-1990s, and in several temporary phases, called generations, the Colombian government gave in concession several airports in the country, a total of 19 to date, including the major and most important ones (and which handle the bulk of the air traffic in the entire network) of the 75 managed by the public aeronautical authority, in order to obtain better administration, modernization and expansion, operation, commercial exploitation and maintenance of the air terminals of greater use (Díaz Olariaga, 2017, 2016a, 2016b). As a result of public policies, both of privatization and of public and private investment in airport infrastructure, together with deregulation policies of the aviation sector where airfares have been fully liberalized since 2012 (Díaz Olariaga and Zea, 2018), in the last two and a half decades passenger transport (total) grew by 863% (Díaz Olariaga, 2018).

Thus, in Table 1, the information of the privatized airports that are part of this research is presented. To mention that after handing over the airport to the private operator, a significant technological and infrastructure modernization was verified, carried out in very different times according to the size of the airport and the initial investment volume (required by concession contract).

Table 1. Data of 100% private governance airports. *Source*: Aerocivil, 2018

Airport city	IATA Code	Year of privatization	PAX (2017)
Carepa	APO	2008	205362
Medellín	EOH	2008	1070158
Rionegro	MDE	2008	7325740
Barranquilla*	BAQ	2015	2576253
Cartagena	CTG	2010	4590151
Valledupar	VUP	2010	387634
Quibdó	UIB	2008	372618
Montería	MTR	2008	938460
Bogotá	BOG	2007	24694288
Riohacha	RCH	2010	149980
Santa Marta	SMR	2010	1686025
Cúcuta	CUC	2010	875519
Providencia	PVA	2007	71091
San Andrés	ADZ	2007	2328104
Barrancabermeja	EJA	2010	128895
Bucaramanga	BGA	2010	1565482
Corozal	CZU	2008	82675
Cali	CLO	2000	4858057

* The airport of the city of Barranquilla (BAQ) does not participate in the study since it was recently privatized (and there is not enough recent data for the analysis).

On the other hand, Table 2 shows information and details of a group of airports that, since always, have 100% public governance, and which are also airports that are candidates to be given in concession in the short or medium term. These airports are also part of the efficiency study, which will be compared with the first group (100% private governance airports). Figure 1 shows the geographical distribution of the airports under study.

Table 2. Data of 100% public governance airports. *Source*: Aerocivil, 2018

Airport city	IATA Code	PAX (2017)
Pereira **	PEI	1541340
Armenia	AXM	430997
Yopal	EYP	338963
Neiva	NVA	298934
Pasto	PSO	287965

** The airport of the city of Pereira (PEI) was given in concession in mid-2017, but will be handed over to the private operator in 2018, so for the purposes of this study (and use of statistical data) it can be considered, at the closing of 2017, as of public management.

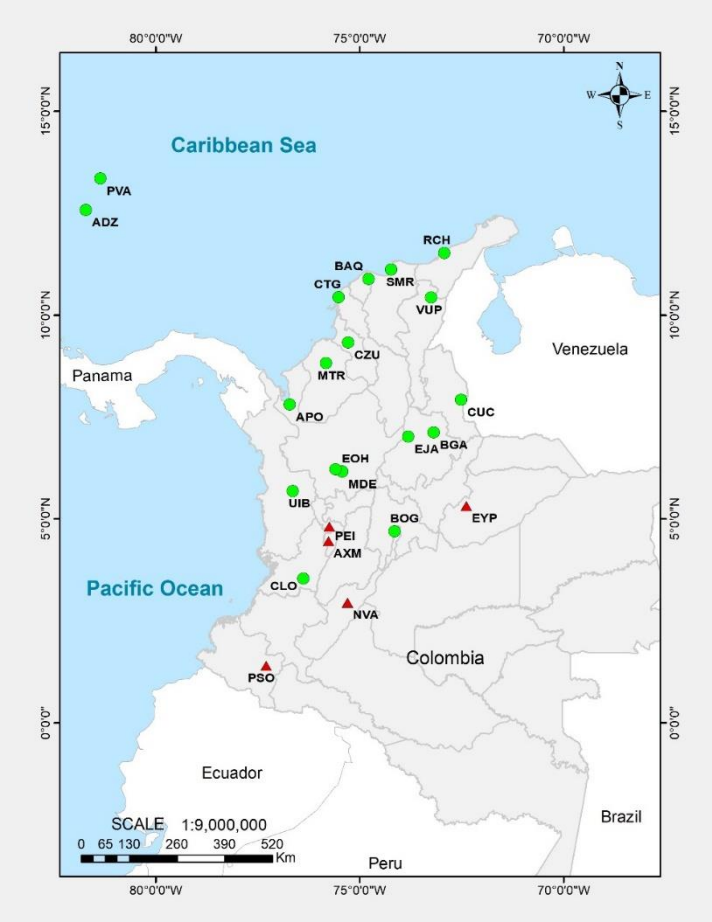

Figure 1. Location of Colombian airports under study; privatized airports (green circles), public airports (red triangles)

4. Methodology

4.1. Basis

The methodology of Data Envelopment Analysis (which arises from Rhodes' (1978) doctoral thesis and can be considered as an extension of Farrell's (1957) work), used in this research, is considered as a non-parametric solution to estimate the productivity of input factors in a system and the results of its transformation within the process with the use of linear programming (Charnes *et al*., 1978, 1994). The first DEA model, proposed by Charnes, Cooper and Rhodes (1978), called DEA-CCR, had an input orientation and assumed the existence of constant returns to scale. The second proposed DEA model, known as DEA-BCC (Banker *et al*., 1984), presents the hypothesis of variable returns to scale. In addition to these two important models, there are other less frequent DEA models in the literature. Thus, at least five other basic DEA models are identified: the additive model (Charnes *et al*., 1985), the multiplicative model (Charnes *et al*., 1982), the cone-ratio DEA model (Charnes *et al*., 1990), the assurance region DEA model (Thompson *et al*., 1986, 1990) and the super-efficiency model (Andersen and Petersen, 1993).

Thus, in his work Charnes *et al*., (1978) affirms that in a set of units considered as productive, and that can be compared to each other since their process of transformation of resources is similar (and to define a comparison framework), they name these productive units as DMU (Decision Making Units) and define three types of efficiency to achieve this comparison:

(a) Technical efficiency: the highest productivity unit among units of the same size is chosen as the reference unit.

(b) Scale efficiency: reflects the ability of the DMU to use resources or factors in optimal proportions.

(c) Overall efficiency: the highest productivity unit of those in the study is chosen as the reference unit.

Efficiency relations are measured with the coefficient obtained between the output results of the system (outputs) and the resources that supplied it at the beginning (inputs), with the following criterion (Charnes *et al*., 1981):

(a) Input oriented: seeks, given the level of outputs, the maximum proportional reduction in the vector of inputs while remaining in the production possibility frontier. A unit is not efficient if it is possible to decrease any input without altering its output.

(b) Output oriented: seeks, given the level of inputs, the maximum proportional increase of outputs, remaining within the production possibility frontier. A unit is not efficient if it is possible to increase any output without increasing any input and without decreasing any other output.

In general, two types of models are suggested for studies of efficiency calculation:

- CCR model: maximizing a quotient is equivalent to maximizing its numerator if its denominator remains constant, and when a quotient is less than the unit it is because the numerator is less than the denominator.
- BCC model: consists of the resolution of "n" maximization problems corresponding to each of the units whose efficiency is to be evaluated. The objective function chooses the weights that maximize the efficiency of the DMU being studied.

4.2. Methodological conceptualization

In this research, "overall efficiency" (or "global efficiency") is understood as the capacity of each analysed airport to make productive use of its input resources, regardless of its size in comparison with other units in the study. To start calculating the overall efficiency of the airports under study, and in accordance with the existing literature, it was decided that each airport would be measured as a DMU and for each one of them the variables that would be taken into account in the analysis as input and output variables were defined, all of them known as "technical variables"', that is, the input variables associated with the existing infrastructure (and its characteristics) at the airport, and the output variables associated with aeronautical operations (see Table 3), usually used in similar investigations (see summaries in: lo Storto (2018); Gutierrez and Lozano (2016); Wanke *et al*. (2016); Ahn and Min (2014)). This research does not use "financial variables"' or others of its kind (performance, income segmentation, commercial exploitation, productivity, etc.) because said information, considered confidential, is not provided by local airport operators.

Table 3. Definition of input and output variables of the analysis

DMU	INPUTS	OUTPUTS
Private governance airports (17): ADZ, SMR, CTG, PVA, MDE, CLO, APO, MTR, VUP, RCH, BOG, CZU, UIB, EJA, BGA, EOH, CUC **Public governance airports (5):** AXM, PEI, NVA, PSO, EYP	1. Number of runways. 2. Length of the runways. 3. Number of aircraft parking positions on the apron. 4. Built area of the passenger terminal building. 5. Area of the apron.	1. Operations (takeoffs / landings) 2. Passengers transported. 3. Air cargo transported.

The scenarios defined for the analysis were:

- A calculation scenario for private governance airports (17), a scenario for public governance airports (5) and a unified scenario to determine the overall efficiency per year of analysis of the airports under study (22).
- The period is set for the time between the years 2012-2017 (both inclusive) for private governance airports, as well as for public governance airports, where all the information for each DMU is available of the defined input and output variables.

Finally, and following the trend of the existing scientific literature, it was decided to use the DEA-CCR model, the most used for this type of studies, which offers the possibility of obtaining comparative returns to scale.

4.3. Approach of the DEA - CCR Model

The basic model

Initially the CCR model was proposed by Charnes *et al*. (1978). The measure of efficiency they adopted related the weighted sum of inputs with the outputs of each decision unit (DMU) and used linear optimization models to calculate the weights. In any case, the original model was not linear but fractional:

Modifications of the basic model

This original formulation was modified later (Charnes *et al*., 1979) so that the weights reach strictly positive values and, thus, avoid that the solution of the program did not consider all the factors and products in the calculation of the efficiency index while avoiding that the denominator of the efficiency quotient was null, and its value did not exist.

Consequently, the model is presented as follows (Tsui *et al*., 2014):

$$Max_{u,v}\ ho = \frac{\sum_{r=1}^{s} U_r\, Y_{ro}}{\sum_{i=1}^{m} V_i\, X_{io}},$$

subject to:

$$\frac{\sum_{r=1}^{s} U_r\, Y_{rj}}{\sum_{i=1}^{m} V_i\, X_{ij}} \leq 1\ \forall\ j: 1..n,$$

$$U_r, V_i\ \geq 0\ \forall\ r: 1..2 \quad \forall\ i: 1\ldots.m,$$

where:

h_o: Objective function. Measurement of efficiency,
Y_{rj}: *i*-th output of *j*-th DMU,
X_{ij}: *i*-th input of *j*-th DMU,
V_i: weights of inputs respectively (program solutions),
U_r: weights of outputs respectively (program solutions),
r: *i*-th output,
j: *i*-th input,
s: total numbers outputs,
m: total numbers inputs,
n: total numbers DMU.

5. Results

5.1. Efficiency of private governance airports

Table 4 presents the result of the calculation of the overall efficiency for the airports analysed, under 100% private governance, in the period 2012-2017 (both inclusive).

Table 4. Overall efficiency of private governance airports (2012-2017)

Airport	2012	2013	2014	2015	2016	2017	Average	Trend
BOG	92%	95%	98%	100%	100%	100%	97%	stable
UIB	92%	98%	96%	100%	99%	95%	97%	decreasing
EOH	95%	95%	95%	100%	92%	89%	94%	decreasing
MDE	75%	88%	90%	100%	100%	100%	92%	stable
CLO	74%	87%	90%	100%	100%	97%	91%	stable
BGA	82%	89%	95%	97%	88%	81%	89%	decreasing
CTG	73%	81%	80%	89%	94%	100%	86%	growing
ADZ	64%	73%	77%	89%	93%	100%	83%	growing
APO	65%	73%	80%	100%	87%	85%	82%	stable
PVA	71%	85%	86%	88%	61%	96%	81%	growing
SMR	59%	66%	66%	75%	79%	87%	72%	growing
EJA	53%	61%	69%	65%	55%	54%	59%	stable
MTR	41%	47%	51%	56%	59%	59%	52%	stable
CUC	45%	43%	45%	51%	44%	38%	44%	decreasing
VUP	36%	38%	44%	46%	49%	47%	43%	stable
CZU	22%	19%	21%	23%	26%	29%	23%	growing
RCH	14%	17%	21%	20%	23%	23%	20%	growing
Annual average	**62%**	**68%**	**71%**	**76%**	**73%**	**75%**	**71%**	

Table 4 is ordered by the average efficiency obtained in the analysis period, from highest to lowest and also show the trend obtained by the model. The average overall efficiency of this group of airports is 71% in the period analysed and its lowest value is presented in 2012 with 62% and its maximum value in the period under analysis is in 2015 with 76%. Figure 2 presents the average overall efficiency, for the period analysed, and for each airport.

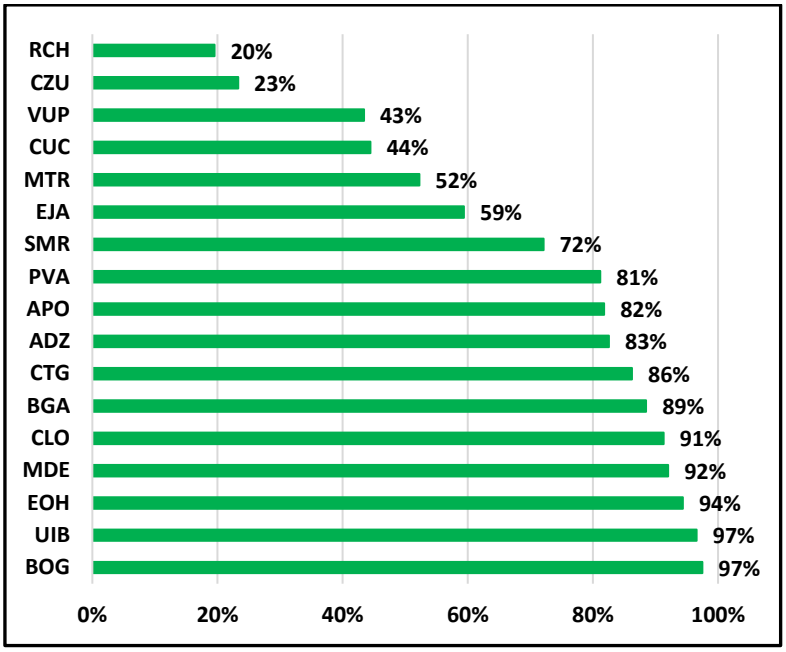

Figure 2. Average overall efficiency, private governance airports (2012-2017)

5.2. Efficiency of public governance airports

Table 5 presents the result of the calculation of overall efficiency for airports under 100% public governance in the period 2012-2017.

Table 5. Overall efficiency of public governance airports (2012-2017)

Airport	2012	2013	2014	2015	2016	2017	Average	Trend
EYP	99%	100%	100%	92%	84%	73%	91%	decreasing
AXM	66%	77%	81%	94%	96%	100%	86%	growing
PSO	72%	73%	77%	80%	77%	73%	75%	decreasing
PEI	63%	70%	72%	72%	78%	80%	73%	growing
NVA	50%	54%	48%	52%	51%	53%	51%	growing
Annual average	**70%**	**75%**	**76%**	**78%**	**77%**	**76%**	**75%**	

Table 5 is arranged by the average efficiency obtained in the analysis period from highest to lowest and includes the trend of the results. The average overall efficiency of this group of airports is 75% in the period analysed, its lowest value is in 2012 with 70% and its maximum value in the analysis period is in 2015 with 78%. Figure 3 presents the results of the average overall efficiency of the six years of the period under analysis (2012-2017) for each public governance airport.

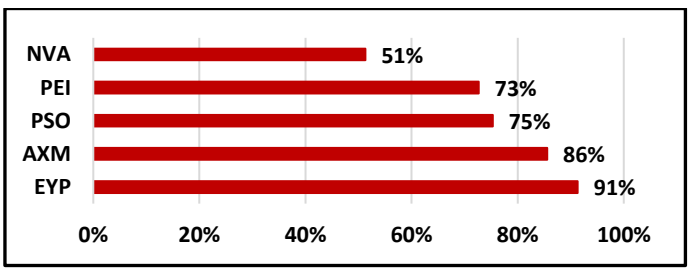

Figure 3. Average overall efficiency, public governance airports (2012-2017)

5.3. Comparative analysis

Figure 4 presents the results of the average overall efficiency of all airports analysed, both with public and private governance.

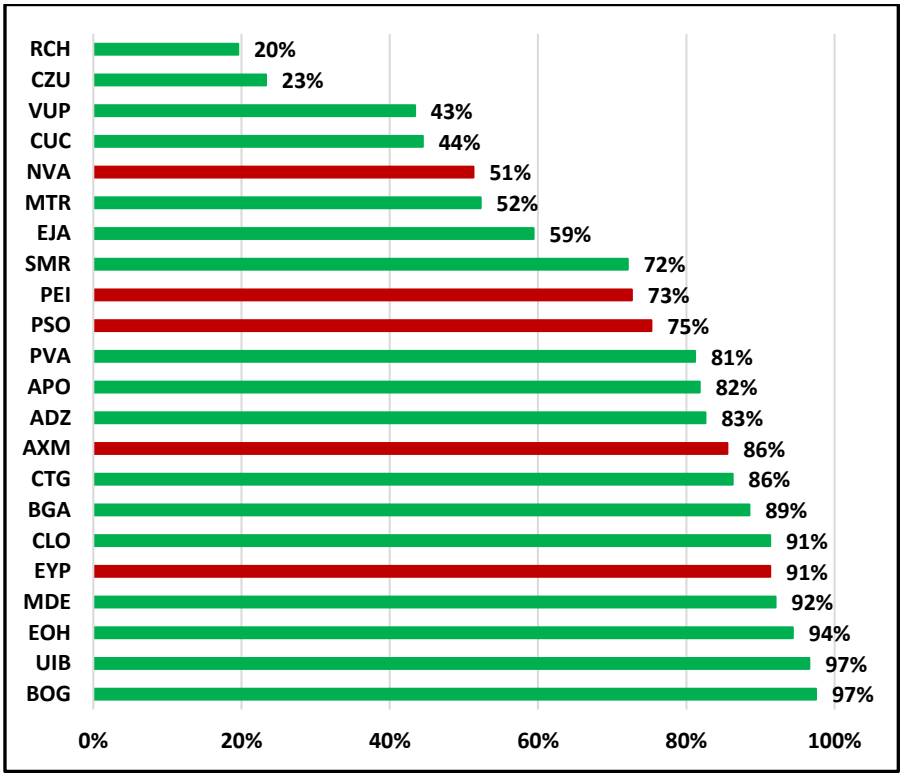

Figure 4. Average overall efficiency, by airport (with public and private governance), for the period analysed (2012-2017)

6. Discussion and Conclusions

In this article measures airport efficiency in a context of liberalized air transport market (Diaz Olariaga and Zea, 2018), of considerable level of global investment in airport infrastructure, public and private, with high growth maintained in the last two decades, and which is expected to maintain its current rate of development, at least in the short term. Therefore, in this research the efficiency of a set of airports of the Colombian network has been measured, divided into two groups, a group (of 17) with 100% private governance, and another group (of 5) with 100% public governance. The analysis period covers the last six years (2012-2017). Emphasizing that the adopted methodology (DEA) has used for the calculation only the so-called "technical variables", that is, those associated / related to the characteristics of infrastructure (and capacity) of the airports and the aeronautical activity (air traffic). The results obtained lead to the following conclusions:

a) Privatized airports (with 100% private governance) have high levels of efficiency but only the large airports (with greater air traffic), except for the (small) airport of Quibdó-UIB. Small privatized airports (that is, very low air traffic) have very low efficiency levels (except UIB mentioned above). Same situation with public governance airports.

b) The average efficiency of the group of airports with private governance is not very high in the years of the period analysed (consequence of a large subgroup of airports with very low efficiencies). Although it should be noted that this average has been growing in the period analysed.

c) Many of the privatized airports analysed show significant fluctuations (growth / decrease) of the efficiency levels in the period analysed. Likewise, a growth of the efficiency indices was verified in most of the airports in the analysed period (except in 3 or 4 cases).

d) For the year 2017 (last year of the analysis period) only 4 privatized airports, of the 17 analysed, have a maximum efficiency level (100%). In previous years some airports reached the maximum efficiency level (100%) but failed to maintain it.

e) The group of airports with 100% public governance is small (only 5) but they are medium / small airports (and medium or low air traffic) and they play a very important role in the Colombian domestic network due to their geographical location (and the cities they serve), and they are also candidate airports to be given in concession in the short and medium term (following the concessions policy of the Colombian government, in progress since the mid-1990s). The average efficiency index for the group is not very high but acceptable (75% for the entire period analysed).

f) The efficiency indices of public governance airports show fluctuations (growth / decrease) during the development of the analysed period, and except for a couple of cases (EYP and AXM), none reaches the maximum efficiency level in all the years of the period analysed. For the year 2017, except for one airport (AXM), the rest of them show low or very low efficiency levels.

g) In terms of private governance vs. public governance, not much can be conjectured since the largest airports in the country, whatever the nature of their governance, have high efficiency indices, and small airports the same trend but the other way around. Any apparent difference between these two groups of airports (large and small) in terms of efficiency could be due more to their relative size rather than their ownership or governance structure.

Ultimately, this study (the first of its kind in Colombia) is a great first approach to the analysis and evaluation of local airport efficiency, and especially when comparing the governance thereof, in the case of Colombia 100% public and/or 100% private (there are no other formulas). It is also important to advance in the coverage and scope of research incorporating new variables, in addition to techniques, such as financial, exploitation, performance, variables of regulatory origin, variables of the competition market, contractual variables (related to concession contracts), etc. This would allow us to know and evaluate much better the performance of the efficiency, determine more accurately if in reality privatization in Colombia improves airport efficiency, and it could even generate standards to be used by all airports in the network and thus be able to perform a rigorous comparative analysis between all the airports in the system.

It would be of great interest if the Colombian public regulatory authority developed, on the one hand, standards to be able to measure, evaluate and accurately compare the efficiency levels of the airports of the network, whatever their governance. And on the other hand, design and implement a (formal) set of inspection procedures to carry out the monitoring and evaluation of all airports. This would facilitate such synergy that would allow less efficient airports to improve their indicators but knowing exactly which ones, where and how to carry out improvement processes. And finally, with the existence of these standards it could be feasible to implement (economic) incentives to the most efficient airports and/or to penalize the least efficient ones if they do not improve their efficiency levels over time.

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