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Efficiency of Brazil's airports: Evidences from bootstrapped DEA and FDH estimates

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A B S T R A C T

This paper reports on the use of different approaches for measuring efficiency in 65 major Brazilian airports. Several programming based estimates were generated to allow testing for significant differences in returns-to-scale and input-decreasing/output-increasing potentials. The findings corroborate anecdotal and empirical evidences regarding a capacity shortfall within Brazilian airports, where the short-term potential for passenger/cargo consolidation per landing/takeoff is virtually nonexistent.

1. Introduction

In the past few years, accelerated economic growth has increased the demands for airport services in Brazil. Between 2003 and 2008, the number of air passengers grew at an average rate of 10% per year (McKinsey, 2010) and, although the cargo tonnage remained relatively stable over the period, its value-added has increased significantly (IPEA, 2010). This increasing air demand for reliable services has placed enormous pressure upon the Brazilian airport infrastructure. The situation is expected to get worse, as the country hosts the Soccer Word Cup (2014) and Olympic Games (2016).

This paper presents a benchmark and efficiency analysis of 65 Brazilian airports for 2009, looking at their returns to scale and at possibilities for passenger/cargo consolidation per landing/takeoff. Different approaches are used in a complementary fashion, not only for measuring the efficiency levels of the airports, but also for providing a assessment on the adequacy of the underlying convexity assumption regarding the data used; data envelopment analysis (DEA) and free disposal hull (FDH).

Despite the increased use of DEA to measure the efficiency of airports, there are few studies that make use of the bootstrapping methodology to account for measurement errors in its estimates. Initially introduced by Simar and Wilson (1998), bootstrapping allow sensitivity analyses on efficiency scores, as well as on scaling indicators, to be performed by repeatedly sampling from the original data. A sample distribution of these estimates is then obtained, from which confidence intervals may be derived (Cooper et al., 2007). The paper uses the bootstrapping methodology to test, among other things, for the presence of scale inefficiency and to determine the nature of returns to scale at the Brazilian airports.

2. Methodology

2.1. The data

Brazil has around 2500 civil airfields; 739 of them being public airports with the remainders private airfields that no aircraft can use without the agreement of the owner. Secondary data regarding a sample of 65 Brazilian public airports were obtained from the National Agency for Civil Aviation's webisite (http://www.anac.gov.br). The sample of 65 is comparable in size to similar DEA applications.

As regards the input/output variables, we focus on those relevant to assessing possibilities for passenger/cargo consolidation per landing/takeoff with all physical assets fixed; i.e., to efficiently use all the available aircraft capacity in the short-term to relief system pressure. As implied in Cooper et al. (2001), the number of decisions making units (DMUs) should be at least three times greater than the number of inputs and outputs. The single input collected from each airport is the number of landings and takeoffs per year. With respect to the outputs, we use passengers per year, kilos per year of express cargo and of mail. Correlation analyses indicate significant positive relationships between the single input and the output variables, which are, therefore, isotonic and justified to be included in the model (Wang et al., 2011).

2.2. Data envelopment analysis

DEA is used to address the problem of calculating relative efficiency for a group of DMUs using multiple measures of inputs and

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outputs. Given a set of DMUs, inputs, and outputs, DEA determines for each DMU a measure of efficiency obtained as a ratio of weighted outputs to weighted inputs. Consider a set of n observations on the DMUs. Each observation, DMU_j ($j = 1,\ldots,n$) uses m inputs x_{ij} ($i = 1,2,\ldots m$) to produce s outputs y_{rj} ($r = 1,2,\ldots s$). DMU_0 represents one of the n DMUs under evaluation, and x_{i0} and y_{r0} are the ith input and rth output for DMU_0. Eqs. (1) and (2) represent the envelopment and the multiplier models for both constant returns to scale (CRS) and varying returns to scale (VRS) frontier types (Zhu, 2003):

$$\begin{aligned}
&\min \theta - \varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+\right)\\
&s.t.\\
&\sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta x_{i0}, \forall i\\
&\sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{r0}, \forall r\\
&\lambda_j \geq 0, \forall j\\
&\left(\text{Add} \sum_{j=1}^{n} \lambda_j = 1 \text{ if VRS}\right)
\end{aligned} \tag{1}$$

$$\begin{aligned}
&\max \sum_{r=1}^{s} u_r y_{r0} + u_0\\
&s.t.\\
&\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} + u_0 \leq 0\\
&\sum_{i=1}^{m} v_i x_{i0} = 1\\
&u_r, v_i \geq 0
\end{aligned} \tag{2}$$

(Change from $u_0 = 0$ to u_0 free in sign if VRS).

Although the orientation of the model is not a consensual aspect of the efficiency models in airports (Marques and Simões, 2010), an input minimization orientation, which favors the public service view, is adopted. Under these circumstances, decision-makers should focus on "stressing" production inputs for a given level of output that may not necessarily be maximal. This happens because the output increasing potential should be interpreted with care, unless there is demand for it (Odeck and Alkadi, 2001).

Scale inefficiency is due to either increasing or decreasing returns-to-scale (RTS), and it can be assessed under both envelopment and multiplier models. As noted by Odeck and Alkadi (2001), the term $\sum_{j=1}^{n} \lambda_j$ is also known as scale indicator (SI_0) within the CCR frontier-type. Under its envelopment formulation, if $SI_0 = 1$, then constant RTS prevail at a given DMU; if $SI_0 > 1$, then decreasing RTS prevail, and if $SI_0 < 1$ there increasing RTS. With respect to the BCC frontier-type, under its multiplier formulation, it follows that increasing RTS prevail if $u_0 < 0$; decreasing, if $u_0 > 0$; and constant, if $u_0 = 0$ (Lin and Hong, 2006).

The fact that different orientations may lead to different RTS conclusions, regardless of the frontier-type considered (Zarepisheh et al., 2010). However, under what conditions envelopment and multiplier models generate different RTS characterizations, under the same orientation, is a frontier estimation issue that shall be further explored (Daraio and Simar, 2007), where the "real life" violation of the convexity assumption may be involved.

The convexity assumption that DEA relies on may, however, be difficult to argue in the real world because it implies additivity and divisibility. Its non-convex generalization, the free disposal hull (FDH) model, could be more adequate (De Witte and Marques, 2008) and used to test for the convexity assumption, shedding some light on the RTS characterization issue.

Although linear programming is typically not used to compute the efficiency scores within the FDH model (Simar and Wilson, 2004), its mixed integer formulation for the input oriented case could be simply obtained by assuming binary values for λ_j, that is, $\lambda_j \in \{0, 1\}$, altogether with the constraint $\sum_{j=1}^{n} \lambda_j = 1$ in Eq. (1). This binary constraint ensures that the efficiency score is only affected by observed production units, in contrast to a convex combination of quantities in DEA (De Witte and Marques, 2008).

If the efficient frontier is convex its Sheppard's distance functions observe the relationship, FDH $\subseteq$ BCC $\subseteq$ CCR (Simar and Wilson, 2004). The importance of bootstrap-based approaches, such as those used by Simar and Wilson and by Wilson (2008) for estimation on the efficiency frontier, should be put into perspective. As mentioned, the discussions on RTS in DEA models have been confined to "qualitative" characterizations in the form of identifying whether they are increasing, decreasing, or constant (BankCooper et al., 2007). These bootstrap approaches, however, can be used, among other things, to implement statistical tests of constant returns to scale versus varying returns to scale and convexity (Wilson, 2009).

The method used here departs that of Simar and Wilson (2004), which adapted the bootstrap methodology to the case of DEA/FDH efficiency estimators, and uses a Gaussian kernel density function for random data generation. All the computations are carried out with Maple codes and 1000 bootstrap replications were performed, following Simar and Wilson and Curi et al. (2011) on deriving statistical properties for each airport regarding bias estimation, efficiency correction, and confidence intervals (CIs). More specifically, 95% CIs were determined, not only for the set of CCR, BCC, and FDH distance/efficiency estimates, to eveluate the convexity assumption at a given airport, but also for SI_0 and u_0, to assess whether or not the rejection of the convexity assumption impacts the RTS characterization under the same orientation. Fig. 1 shows the steps taken to assess the RTS characterization based upon the CIs obtained for SI_0 and u_0.

3. Results

3.1. Initial DEA/FDH estimates

The efficiency rankings calculated using DEA/FDH models are given in Table 1, as well as the RTS characterization for each DMU. As expected, the FDH model yields higher average efficient estimates than do both DEA models. Specifically, the CCR model yields lower average efficiency estimates than the BCC model, with respective average values of 0.37 and 0.43. Also, the CCR model identifies marginally more inefficient airports, 60 versus 59, than the BCC model. This is not surprising, as the CCR model fits a Leontief production technology, whereas the BCC model features variables returns to scale, which are more flexible and reflect managerial efficiency apart from purely technical limits.

Fifty-five of the 65 Brazilian airports seem to be unambiguously experiencing IRS under both RTS characterizations. No airport appears to be unambiguously experiencing DRS. Discrepancies between RTS characterizations were found in ten cases, six of them within the largest Brazilian airports (Brasília, Galeão, Guarulhos, Campinas, Porto Alegre, and Congonhas), and all scale efficient, that is, located at the most productive scale size. According to Odeck and Alkadi (2001), a DMU may be scale inefficient if it experiments decreasing returns to scale by being too large in size, or if it is failing to take full advantage of increasing returns to scale by being too small. So far, these results suggest that most Brazilian airports are running short in capacity. Put in other words, the capacity of the airport is too small relative to the tasks that it performs.