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Productivity Change of UK Airports: 2000-2005

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Abstract

In this paper, the two innovative nonparametric models, the Luenberger productivity model and Luenberger–Hicks–Moorsteen productivity indicator are used to estimate the productivity of UK airports. These airports are ranked according to their total productivity for the period 2000-2005 showing that the majority of UK airports are not improving their efficiency in the period. Economic implications arising from the study are derived.

Keywords: productivity measurements, UK airports, data envelopment analysis, Luenberger productivity indicator and Luenberger–Hicks–Moorsteen productivity indicator.

JEL Classification:

1.Introduction

Productivity and technical efficiency analysis of airports is a well established research field (see Pels et al. (2001, 2003), Oum and Yu (2004), Yoshida (2004), Yoshida and Fujimoto (2004), Fung, Wan, Hui and Law (2007)). Several techniques have been proposed in the literature to measure productivity and technical efficiency such as the non-parametric (data envelopment analysis) DEA (see Gillen and Lall (1997), Parker (1999), Murillo-Melchor (1999), Gillen and Lall (2001), Adler and Berechman (2001), Fernandes and Pacheco (2002), Sarkis (2000), Sarkis and Talluri (2004), Yoshida and Fujimoto (2004)) and the parametric stochastic frontier model (see Pels, Nijkamp and Rietveld (2001, 2003)). More specific on productivity analysis, most papers adopts the Malmquist Index (Murillo-Melchor, 1999; Gillen and Lall, 2001), which is either based upon Shephardian input- or output distance function compatible with the objectives of cost minimization or revenue maximization (Färe and Primont, 1995). However, in some cases, it might be preferable to assume profit maximization, which is the traditional assumption in economic theory (Färe et al., 1994; Chambers, 1996; Chambers and Pope, 1996; Balk, 1998; Briec and Kerstens, 2004). In this article, the Luenberger productivity indicator is adopted and compared with the Luenberger–Hicks–Moorsteen productivity indicator.

The motivation for the present research is the following: First, productivity is a main issue in performance analysis since it encompasses technical efficiency and, therefore, analyses performance in a more broad view, justifying the present research. Productivity analysis is of paramount importance in regulation because, without a productivity analysis, regulators have to rely on balance sheet. However, in cases where all industry display inefficiency, how does the regulator identifies costs without inefficiency? Second, whereas productivity may be estimated by parametric techniques, the most popular approach employs non-parametric methods of DEA and the Malmquist productivity index. The advantage of using nonparametric frontier technologies is that they impose no a priori functional form on technology, nor any restrictive assumptions regarding input remuneration. Furthermore, the frontier nature of theses technologies allows capturing any productive inefficiency and offers a benchmark perspective. Third, UK airports are evolving in different ways, for example Heathrow, which has in March 2008 inaugurated the new terminal 5, has emerged as the main Hub airport at European level, while others UK airports lag behind. As these airports are highly regulated there is an obvious need for assessing its performance (Parker, 1999). Finally, the UK airports have been subject recently to acquisition by Spanish enterprises. In 2004, TBI PLC, the owner of three regional airports in England, Wales and Northern was acquired by a Spanish enterprise owned by AENA, the Spanish company that manages the Spanish airports, and Abertis, a Spanish construction company. In July 2006, British Airports Authority (BAA) was taken over by a consortium led by the Spanish transportation group, Grupo Ferrovial. These acquisitions introduce competition in the field which is reflected in productivity indicator.

The article is structured as follows. Section 2 presents the institutional setting on UK airports. Section 3 presents the literature survey. Section 4 presents the productivity models. Section 5 presents the data and the results. Section 6 discusses the results and the final section presents provides some concluding remarks.

2. Institutional Setting

British airports are owned and managed by one of three distinct entities, BAA, Manchester Airports PLC and TBI PLC or by independent city airports. BAA is the owner and operator of seven British airports and operator of several airports in Italy and the USA, making it one of the world’s largest transport-sector companies. It also owns British Airline. In July 2006, BAA was taken over by a consortium led by the Spanish transportation group, Grupo Ferrovial. As a result, the company was delisted from the London Stock Exchange (where it had previously been part of the FTSE100 index) and the company name was subsequently changed from BAA plc to BAA Limited.

Manchester Airports PLC, formed in 1986, manages several English city airports and is characterised by being a public limited company owned by local authorities. Following the purchase of a majority shareholding in Humberside Airport in 1999 and the acquisition of East Midlands Airport and Bournemouth Airport in 2001, the company was restructured to create the Manchester Airport Group. Although Manchester Airport Group is registered as a public limited company, its shares are not quoted or for sale on the Stock Exchange. Manchester City Council has a majority shareholding (55%) with each of nine other councils holding 5% each.

TBI PLC is the owner of three regional airports in England, Wales and Northern Ireland. In 2004, TBI was acquired by a Spanish enterprise owned by AENA, the Spanish company that manages the Spanish airports, and Abertis, a Spanish construction company. The company has also expanded into international airport management under contract.

The UK airports are regulated by the Civil Aviation Authority (CAA) since 1986. However, 21 years of regulation have not sharpened the UK airports on productivity, Scott (2004). Therefore, the present research contributes to identify the UK airports frontier of best practices.

Insert Table 1

3. Literature Survey

There is extensive literature on benchmarking applied to airports (Humphreys and Francis, 2002; Graham, 2005). However, as the frontier models improve and data sets became public available, there is room to continue the innovation on this research field.

In Table 2, presents the models, inputs and outputs used in the various papers published in airport efficiency.

Insert Table 2

It can observe be observed that a conventional approach to the analysis of airports is to separate activities into terminals and movements (Gillen and Lall, 2001; Pels, Nijkamp and Rietveld, 2001; Pels, Nijkamp and Rietveld, 2003). Several papers compare the DEA model with the frontier model (Pels, Nijkamp and Rietveld, 2001; Pels, Nijkamp and Rietveld, 2003, Hooper and Hensher, 1997), while others combine principal component analysis with a DEA model (Adler and Berechman, 2001). Furthermore, others rely on the homogenous stochastic frontier models to analyse airport efficiency (Pels, Nijkamp and Rietveld, 2001, 2003). Therefore, our use of the Luenberger productivity indicator and Luenberger–Hicks–Moorsteemodel productivity index is innovative in this context.

4. The Method

Inefficiency in input usage or output production became crucial in measuring productivity change (Caves, Christensen, and Diewert, 1982). The mathematical programming technique, DEA is used, to compute changes in productivity over time. A key advantage of this approach is that it provides a convenient way of describing multi-input, multi-output production technology without having to specify functional forms[1]. In this study, the total factor productivity (TFP) changes is decomposed to provide a better understanding of the relative importance of various components over the study period. TFP changes encompass all types of productivity change, and these can be decomposed into the two components, technological change (TC) and efficiency change (EC).

TC measures shifts in the production frontier or measures productivity changes that are due to innovation. EC measures changes in the position of a production unit relative to the frontier. If existing resources are not fully utilized in production initially, one expects a significant increase in EC. Malmquist's productivity index is widely used in many fields (e.g., Färe et al., 1994). However, the limitation of this productivity index is that one must choose to adopt either an output- or input-oriented approach in Shephardian distance functions. The choice depends on whether one assumes revenue maximization or cost minimization to represent the sample since input-oriented measure has a dual in the cost-efficiency measure and the output-oriented measure has its dual in the revenue measure of efficiency (Färe and Primont, 1995).

The recently developed Luenberger productivity indicator was introduced by Chambers and Pope (1996). The term "indicator" is used for measures defined in terms of differences (Diewert, 2005). This indicator employs more general characterization technology, called proportional distance function that is a dual to the profit function, and a generalization of Shephardian

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[1] Like all techniques, DEA has strengths and weakness. Since DEA is a data-driven technique, measurement error, missing variables, and unmeasured quality differences can cause problems. Analogous problems exist for econometrics and other empirical techniques. Statistical hypothesis tests and confidence intervals are difficult to implement within DEA

distance functions (Chambers, Chung, and Färe, 1998). Thus, the methodology of using a Luenberger productivity indicator is more in line with the profit function framework.

Briec and Kerstens (2004) propose the alternative Luenberger–Hicks–Moorsteen productivity indicator, which is a profitability indicator and does not have a specific orientation. They provide the necessary and sufficient conditions to obtain equality between Luenberger-Hicks-Moorsteen and Luenberger output (or input) oriented productivity indicators. They conclude, however, that Luenberger-Hicks-Moorsteen and Luenberger output- and input-oriented productivity indicators in general differ, since the conditions needed for their equality are strong and unlikely to be met in empirical work. These two indicators have not been compared empirically in the literature. This study compares the two indicators empirically under variable returns to scale (VRS), since the assumption of CRS might be too strong.

4.1 The Model

In this section, the productivity in the airport industry is analyzed. The productivity is measured by using two independent measures: the Luenberger productivity indicator and the Luenberger–Hicks–Moorsteen productivity indicator.

The Luenberger Productivity indicator

The Luenberger productivity indicator, which is a nonparametric frontier technology approach to measure productivity, does not require that a choice be made between input and output orientations (Chambers, 1996). Since the Luenberger productivity indicator is consistent with both output and input-oriented perspectives, it is a generalization of, and superior to, the Malmquist productivity index (Luenberger, 1992a, 1992b, 1995; Chambers, Chung, and Färe, 1998).

The Luenberger productivity indicator that employs a proportional distance function and allows for inefficiency in each decision-making unit is applied in the present research. Using the proportional distance function specification, our problem can be formulated as follows. Let $x = (x^1,...,x^N) \in \boldsymbol{R}^N_+$ and $y = (y^1,...,y^M) \in \boldsymbol{R}^M_+$ be the vectors of inputs and output, respectively, and define the technology set by $P_t \equiv \{(x_t, y_t)$: x_t can produce $y_t\}$. The technology set, P_t, consists of all feasible input vectors, x_t, and output vectors, y_t, at time period t and satisfies certain axioms, which are sufficient to define meaningful proportional distance functions (see Balk, 1998). The estimation of efficiency relative to production frontiers relies on the theory of distance or gauge functions. Luenberger (1992a, 1992b) generalizes the previous notion of distance functions as a shortage function and provides a flexible tool capable of taking account of both input contractions and output improvements when measuring efficiency. This shortage function, also known as a directional distance function, is the dual to the profit function (Luenberger, 1992b; Chambers, Chung, and Färe, 1998).

The proportional distance function is a special case of the shortage function. The proportional distance function at t is defined as:

$$(1) \quad D^t\left(\mathrm{x}_t, \mathrm{y}_t\right) = \max\left\{\delta : ((1-\delta)\mathrm{x}_t, (1+\delta)\mathrm{y}_t) \in P_t\right\}$$

where δ is the maximal proportional amount by which output, y_t, can be expanded and input, x_t, can be reduced simultaneously given the technology, P^t. DEA involves a set of mathematical programming techniques used to estimate the relative efficiency of production units and to identify best-practice frontiers. The DEA formulation calculates the Luenberger productivity indicator under variable returns-to-scale (VRS) by solving the following optimization problem (Chambers, Färe, and Grosskopf, 1996):

$$
(2) \qquad
\begin{aligned}
& D^{t}(\mathrm{x}_{\mathrm{t}},\mathrm{y}_{\mathrm{t}}) = \max\nolimits_{\delta,\lambda} \delta \\
& \quad s.t. \quad Y_{t}\lambda \geq (1+\delta)\, y_{t}^{i} \\
& \qquad\qquad X_{t}\lambda \leq (1-\delta)\, x_{t}^{i} \\
& \qquad\qquad N1'\lambda = 0 \\
& \qquad\qquad \lambda \geq 0
\end{aligned}
$$

where δ is the efficiency index for province *i* in year *t*, *N1* is an identity matrix, λ is an N×1 vector of weights which is the proportionality factor and same for both of inputs and output, and Y_t and X_t are the vectors of output, y_t, and inputs, x_t. To estimate productivity change over time, several proportional distance functions, including both single-period and mixed-period distance functions for each province and each time period, are needed. For the mixed-period distance function, there are two years, *t* and *t+1*. For example, $D^{t}(x_{t+1}, y_{t+1})$ is the value of the proportional distance function for the input–output vector for period *t+1* and technology in period *t*.

As for Luenberger productivity indicators, several proportional distance functions are needed to estimate the change in productivity over time. The Luenberger productivity indicator, TFP(L), defined by Chambers (1996), Chambers, Färe, and Grosskopf (1996) and Chambers (2002), can be decomposed into two components as follows:

$$
(3) \qquad
\begin{aligned}
TFP(L) &= \left[\mathrm{D}^{\mathrm{t}}(\mathrm{x}_{\mathrm{t}},\mathrm{y}_{\mathrm{t}}) - \mathrm{D}^{\mathrm{t+1}}(\mathrm{x}_{\mathrm{t+1}},\mathrm{y}_{\mathrm{t+1}})\right] \\
&\quad + \frac{1}{2}\left[\left(\mathrm{D}^{\mathrm{t+1}}(\mathrm{x}_{\mathrm{t+1}},\mathrm{y}_{\mathrm{t+1}}) - \mathrm{D}^{\mathrm{t}}(\mathrm{x}_{\mathrm{t+1}},\mathrm{y}_{\mathrm{t+1}})\right) + \left(\mathrm{D}^{\mathrm{t+1}}(\mathrm{x}_{\mathrm{t}},\mathrm{y}_{\mathrm{t}}) - \mathrm{D}^{\mathrm{t}}(\mathrm{x}_{\mathrm{t}},\mathrm{y}_{\mathrm{t}})\right)\right],
\end{aligned}
$$

where the first difference represents EC and the second term, which is an arithmetic mean two differences, represents TC.

The Luenberger–Hicks–Moorsteen Productivity indicator

Briec and Kerstens (2004) introduce the difference-based Luenberger–Hicks–Moorsteen productivity indicator, TFP(LHM). They define TFP(LHM) using both input- and output-oriented Luenberger productivity indicators. The input- and output-oriented Luenberger productivity indicators for period *t* is defined as follows :

$$(4) \quad L_o^t\left(\mathrm{x}_\mathrm{t}, \mathrm{y}_\mathrm{t}, 0, \mathrm{y}_{\mathrm{t+1}}\right) = D^t(\mathrm{x}_\mathrm{t}, \mathrm{y}_\mathrm{t}; (0, g_o^t)) - D^t(\mathrm{x}_\mathrm{t}, \mathrm{y}_{\mathrm{t+1}}; (0, g_o^{t+1}))$$

$$(5) \quad L_i^t\left(\mathrm{x}_\mathrm{t}, \mathrm{y}_\mathrm{t}, \mathrm{x}_{\mathrm{t+1}}, 0\right) = D^t(\mathrm{x}_{\mathrm{t+1}}, \mathrm{y}_\mathrm{t}; (g_i^{t+1}, 0) - D^t(\mathrm{x}_\mathrm{t}, \mathrm{y}_\mathrm{t}; (g_i^t, 0))$$

When $g_i^t = \mathrm{x}_t$ and $g_o^t = \mathrm{y}_\mathrm{t}$, the output- and input-oriented directional distance functions are as follows:

$$(6) \quad D^t\left(\mathrm{x}_t, \mathrm{y}_t; (0, g_o^t)\right) = \max\left\{\delta : (\mathrm{x}_\mathrm{t}, (1+\delta)\mathrm{y}_\mathrm{t}) \in P_t\right\}$$

$$(7) \quad D^t\left(\mathrm{x}_t, \mathrm{y}_t; (g_i^t, 0)\right) = \max\left\{\delta : ((1-\delta)\mathrm{x}_t, \mathrm{y}_t) \in P_t\right\}$$

The Luenberger–Hicks–Moorsteen productivity indicator defined by Briec and Kerstens (2004) is as follows:

$$(8) \quad \begin{aligned} &TFP(LHM) = \\ &\frac{1}{2}\left[\begin{array}{l} \left(D_t^o(\mathrm{x}_t, \mathrm{y}_t) - D_t^o(\mathrm{x}_t, \mathrm{y}_{t+1})\right) - \left(D_t^i(\mathrm{x}_{t+1}, \mathrm{y}_t) - D_t^i(\mathrm{x}_t, \mathrm{y}_t)\right) + \\ \left(D_{t+1}^o(\mathrm{x}_{t+1}, \mathrm{y}_t) - D_{t+1}^o(\mathrm{x}_{t+1}, \mathrm{y}_{t+1})\right) - \left(D_{t+1}^i(\mathrm{x}_{t+1}, \mathrm{y}_{t+1}) - D_{t+1}^i(\mathrm{x}_t, \mathrm{y}_{t+1})\right) \end{array}\right] \end{aligned}$$

The above indicator can be decomposed into TC and EC. For example, TC is:

$$\text{TC(LHM)} = \left[\left(D^i_{t+1}(\mathrm{x}_{t+1}, \mathrm{y}_{t+1}) - D^i_t(\mathrm{x}_{t+1}, \mathrm{y}_{t+1}) \right) - \left(D^o_{t+1}(\mathrm{x}_{t+1}, \mathrm{y}_{t+1}) - D^o_t(\mathrm{x}_{t+1}, \mathrm{y}_{t+1}) \right) \right].$$

The residual represents EC.

5. Data and Results

The paper use a balanced panel comprising twenty-seven UK airports during six years from 2000/01 to 2004/05 (162 observations) obtained in Cruickshank, Flannagan and Marchant's Airport Statistics [CRI - Centre For The Study of Regulated Industries, University of Bath (several years)]. Inputs in this study are total operational cost , average number of employees, and fixed assets. Outputs are total passengers, total cargo tonnage, aircraft movements. Monetary magnitudes are expressed in £'000 pounds, deflated by the GDP deflator and denoted at prices of 2000 (see Table 3).

Insert TABLE 3

In this study, two models to measure productivity changes are applied. Separate frontiers are estimated for each year, and shifts in the frontiers over time are used to measure productivity changes. For each airport, the arithmetic mean of the Luenberger productivity indicators and the Luenberger–Hicks–Moorsteen productivity indicators (both difference methods) are estimated to obtain a combined value for each index in each year (Balk, 1998). Values larger than zero represent increases in productivity.

Insert Table 4

Table 4 summarizes the results. Detailed analysis is provided below. Overall Luenberger TFP change is about –0.106 from 2000 to 2005, or about –0.027 per year. This decreasing trend is mainly caused by TC because average TC is about –0.026 per year while average EC is about -0.01. Therefore, performance of UK airports has been decreasing during our study period. Nine of out 27 airports record positive TFP score on average as shown in Figure 1. Bristol and Newcastle show the highest increases in the study periods. On the other hand, Bornemouth, Biggin Hill, and Southend record the lowest score.

Insert Figure 1

Next the Luenberger–Hicks–Moorsteen productivity indicators also displayed in table 4 are interpreted. The results indicate productivity changes with a potential for output saving and the efficient use of inputs. The average TFP change is –0.155 for the period. Average TC is about –0.108 per year while average EC is about -0.047. Comparing Luenberger–Hicks–Moorsteen productivity indicators with those of Luenberger indicators, it is found that many of the indicators of TFP, TC, and EC are decreasing, which indicates reduced efficiency over time. Although their magnitudes appear to be quite different, the Luenberger and Luenberger–Hicks–Moorsteen indicators appear to be qualitatively similar.

Insert Table 5

Average productivities sorted by ownership are provided in Table 5. The BAA has larger score than average and especially EC shows the positive change on average. Manchester Airports plc, on the other hand, shows lower scores than average. TBI pls has highest scores in many productivity indicators and better than BAA and Manchester Airports plc.

Insert table 6

Although the average annual values are positively correlated, given simple correlations in Table 6, airport-specific productivity changes differ quite substantially in some cases. Since both TC and EC are components of TFP, each is positively correlated with TFP. Both of the Luenberger indicators and Luenberger–Hicks–Moorsteen indicators show that each of TC and EC is positively correlated though the relationships are weak. These imply that decreases in the production frontier are associated with less catching up when both the efficient use of inputs and/or output expansion are considered. The results indicate once frontier groups decrease their production levels, then the other inefficient groups' score decreases.

6. Discussion

In this paper the arithmetic mean of the Luenberger productivity indicators and the Luenberger–Hicks–Moorsteen productivity indicators are estimated for the UK airports, 2000-2005. The general conclusion is that performance of the majority of UK airports has been decreasing during our study period. Nine of out 27 airports record positive TFP score. Luenberger Productivity indicators on average are shown in Figure 1. Bristol and Newcastle show the highest increases in the study periods. On the other hand, Bornemouth, Biggin Hill, and Southend record the lowest score. Furthermore, the Luenberger and Luenberger–Hicks–

Moorsteen indicators present similar results. Additional, TBI pls has highest scores in many productivity indicators and better than BAA and Manchester Airports plc.

How are the paper result interpreted? The results signify that UK airports are not improving their efficiency in the period and the causes of this behavior are not identified in the present research, but are clearly blamed on the airport management, because the inputs and outputs analyzed are managed by the management and on the regulatory entity, which are not forcing the airports to improve their efficiency, as it regulates the main airports restricting prices according to balance sheets, Fernandes and Pacheco (2007). In a situation that all airports are decreasing their efficiency, the prices reflect cost and inefficiency, but the regulator assumes that it reflects only costs.

How this paper does compares with alternative research on UK airports? This paper is directly comparable with Parker (1999) but the CCR-DEA efficiency scores and BCC-DEA efficiency scores overestimates the efficiency scores, Boussemart et al. (2003) and the period and the units analyzed are distinct, signifying that an accurate comparison cannot be made. The paper is also comparable with Barros (2008b) who reach similar conclusion with a stochastic random frontier model. Furthermore, the paper is comparable with Jessop (2003) but the methods used are distinct and so no clear comparison can be made.

What is the policy implication of the present research? The policy implication is the following: First, benchmark procedure should be adopted by the regulatory agency. Regulation based on frontier models overcomes the restriction to restrict prices based only on financial accounts. Second, airports managerial companies, the BAA (British Airports Authority), Manchester Airports PLC, TBI PLC and independent city airports should benchmark each against each other in other to upgrade their productivity based in the best performing unity.

Finally, airports managers should be aware that performance should be based in technical efficiency as a well in technological change. Technical efficiency is decomposed in pure (managerial) efficiency and scale economies and technological change is due to investment. Therefore, there is room for the UK airport managers to promote productivity improvement in their airports.

7. Conclusion

The performance of UK airports has been decreasing during our study period. Benchmarks are provided for improving the operations of poorly performing UK airports based in the methodology adopted in the present research: The Luenberger productivity indicator and Luenberger–Hicks–Moorsteen productivity indicator. The results are similar for both methods. The policy implication is derived. More research is needed to confirm the present conclusions.

References

Adler, N., Berechman, J., 2001. Measuring Airport Quality from the Airlines Viewpoint: An Application of Data Envelopment Analysis. Transport Policy, 8, 171-181.

Balk, B.M. 1998. *Industrial Price, Quantity, and Productivity Indices: The Micro-Economic Theory and an Application*. Boston: Kluwer.

Barro, R.J., and Sala-i-Martin, X.X. 1995. *Economic Growth*. New York: McGraw Hill.

Barros, C.P., Sampaio, A., 2004. Technical and Allocative Efficiency in Airports. International

Journal of Transport Economics, 31, 355-377.

Barros, C.P. Dieke, P.U.C., 2007. Performance Evaluation of Italian Airports with Data Envelopment Analysis. Journal of Air Transport Management, 13, 184-191.

Barros, C.P., 2008A. Technical change and productivity growth in airports: A case study. Transportation Research, Part A. (forthcoming).

Barros, C.P. and Dieke, P.U.C., 2008. Measuring the Economic Efficiency of Airports: A Simar-Wilson Methodology Analysis. Transportation Research Part E (forthcoming).

Barros, C.P. 2008B. The Technical Efficiency of UK Airports. Mimeo.

Boussemart, J.P., W. Briec, K. Kerstens, and J.C. Poutineau. 2003. "Luenberger and Malmquist Productivity Indices: Theoretical Comparisons and Empirical Illustration." *Bulletin of Economic Research* 55 (4):391–405.

Briec, W. and K. Kerstens. 2004. "A Luenberger-Hicks-Moorsteen Productivity Indicator: Its Relation to the Hicks-Moorsteen Productivity Index and the Luenberger Productivity Indicator." *Economic Theory* 23:925–939.

Caves, D.W., L.R. Christensen, and W.E. Diewert. 1982. "The Economic Theory of Index Numbers and the Measurement of Input, Output and Productivity." *Econometrica* 50(6):1393–1414.

Chambers, R.G. 1996. "A New Look at Input, Output, Technical Change and Productivity Measurement." Working paper, University of Maryland, 96–03.

Chambers, R.G. 2002. "Exact Nonradial Input, Output, and Productivity Measurement." *Economic Theory* 20: 751–765.

Chambers, R.G., Y. Chung, and R. Färe. 1998. "Profit, Directional Distance Functions, and Nerlovian Efficiency." *Journal of Optimization Theory and Applications* 98:351–364.

Chambers, R.G., R. Färe, and S. Grosskopf. 1996. "Productivity Growth in APEC Countries." *Pacific Economic Review* 1:181–190.

Chambers, R.G., and R.D. Pope. 1996. "Aggregate Productivity Measures." *American Journal of Agricultural Economics* 78:1360–1365.

Charnes, A., W.W. Cooper, E. Rhodes. 1978. "Measuring Efficiency of Decision Making Units." *European Journal of Operations Research* 2:429–444.

Chavas, J.P. 2000. "Variations on Invariance or Some Unpleasant Nonparametric Arithmetic: Comment." *American Journal of Agricultural Economics* 79:231–233.

Cruickshank, A.; Flannagan, P. and Marchant, J. (several years). *Airport Statistics*, CRI - Centre For The Study of Regulated Industries, University of Bath, U.K.

Debreu, G. 1951. "The Coefficient of Resource Utilization." *Econometrica* 19:273–292.

Diewert, W.E. 2005. "Index Number Theory Using Differences Rather than Ratios." *American Journal of Economics and Sociology* 64:347–395.

Färe, R., S. Grosskopf, M. Norris, and Z. Zhang. 1994. "Productivity Growth, Technical Progress, and Efficiency Change in Industrialized Countries." *American Economic Review*

84(1): 66–83.

Färe, R., S. Grosskopf, and O. Zaim. 2002. "Hyperbolic Efficiency and Return to the Dollar." *European Journal of Operational Research* 136:671–679.

Färe, R., and D. Primont. 1995. *Multi-Output Production and Duality: Theory and Applications*. Boston: Kluwer.

Fernandes, E., and Pacheco, R. R., 2002. Efficiency Use of Airport Capacity. Transportation Research : Part A. Policy and Practice, 36, 225-38.

Fernandes, E. and Pacheco, R.R. (2007) Airport management: a strategic approach. Transportation, 34,1, 129-142.

Farrell, M.J. 1957. "The Measurement of Productive Efficiency." *Journal of the Royal Statistical Society* 120:253–281.

Fung, M.K.Y., Wan, K.K. H., Hui, Y.V., Law, J.S., 2007. Productivity Changes in Chinese Aiports 1995-2004. Transportation Research Part E (forthcoming).

Gillen, D., Lall, A., 1997. Non-Parametric Measures of Efficiency of US Airports. International Journal of Transport Economics, 28, 283-306.

Gillen, D., Lall, A., 2001. Developing Measures of Airport Productivity and Performance: An Application of Data Envelopment Analysis. *Transportation Research*, *Part E*, 33, 261-273.

Graham, A., 2005. Airport Benchmarking: A Review of the Current Situation. Benchmarking: An International Journal, 12, 99-111.

Griliches, Z. 1994. "Productivity, R&D and the Data Constraint." *American Economic Review* 84(1):1–23.

Hooper, P.G., Hensher, D. A., 1997. Measuring Total Factor Productivity of Airports: An Index Number Approach. Transportation Research: Part E- Logistics and Transportation Review, 33, 249-59.

Hulten, C.R., E.R. Dean, and M.J. Harper. 2001. *New Developments in Productivity Analysis*. Chicago: The University of Chicago Press.

Humphreys, I., Francis, G., 2002. Performance Measurement: A Review of Airports. International Journal of Transport Management, 1, 79-85.

Jessop, A. 2003. Blockmodels with maximum concentration, *European Journal of Operational Research.* 148 : 56–64.

Luenberger, D.G. 1992a. "Benefit Functions and Duality." *Journal of Mathematical Economics* 21:461–481.

Luenberger, D.G.. 1992b. "New Optimality Principles for Economic Efficiency and Equilibrium." *Journal of Optimization Theory and Applications* 75:221–264.

Mukherjee, K., S.C. Ray, and S.M. Miller. 2001. "Productivity Growth in Large US Commercial

Banks: The Initial Post–Deregulation Experience." *Journal of Banking and Finance* 25:913–939.

Murillo-Melchor, C., 1999, An Analysis of Technical Efficiency and Productive Change in Spanish Airports Using the Malmquist Index. International Journal of Transport Economics 26, 271-92.

Oum, T.; Zhang, A. and Zhang, Y. (2004) Alternative Forms of Economic Regulation and Their Implications for Airports. Journal of Transport Economics and Policy, 38,217-246.

Parker, D., 1999. The Performance of the BAA Before and After Privatisation. Journal of Transport Economics and Policy 33, 133-146.

Pels, E., Nijkamp, P., Rietveld, P., 2003. Inefficiency and Scale Economics of European Airport Operations. Transportation Research Part E 39, 341-361.

Pels, E., Nijkamp, P. Rietveld, P., 2001. Relative Efficiency of European Airports. Transport Policy 8, 183-192.

Ray, S.C., and E. Desli. 1997. "Productivity Growth, Technical Progress, and Efficiency Change in Industrialized Countries: Comment." *American Economic Review* 87 (5):1033–1039.

Sarkis, J., 2000. Operational Efficiency of Major US Airports. Journal of Operation Management 18, 335-251.

Sarkis, J., Talluri, S., 2004. Performance-Based Clustering for Benchmarking of US Airports. Transportation Research Part A 38, 329-346.

Scott, P., 2004 Economic regulation of airport in the UK. Occasional paper 21. CRI- Centre for the Study of Regulated Industries.

Yoshida, Y., Fujimoto, H.,2004. Japanese-Airport Benchmarking with DEA and Endogenous-Weight TFP Methods: Testing the Criticism of Over-investment in Japanese Regional Airports. Transportation Research Part E 40, 533-546.

Yoshida, Y., 2004. Endogenous-Weight TFP Measurement: Methodology and its Application to Japanese-Airport Benchmarking. Transportation Research Part E 40,151-182.

Zofío, J.L., and C.A.K. Lovell. 2001. "Graph Efficiency and Productivity Measures: An Application to US Agriculture." *Applied Economics* 33:1433–1442.

Table 1: Characteristics of the U.K. Airports in the Analysis (2005)

No.	Airport	Aircraft Movements (000)	Total operating costs (000)	Owned by BAA	Owned by Manchester Airports plc	Owned by TBI plc
1	Heathrow	84	20600	1	0	0
2	Gatwick	39	18500	1	0	0
3	Stansted	5	5200	1	0	0
4	Southampton	108	76000	1	0	0
5	Glasgow	7	7300	1	0	0
6	Edinburgh	10	8700	1	0	0
7	Aberdeen	44	17800	1	0	0
8	Manchester	17	11700	0	1	0
9	Bournemouth	53	26800	0	1	0
10	Humberside	11	10700	0	1	0
11	Nottingham	113	43500	0	1	0
12	Birmingham	11	13300	0	0	0
13	Newcastle	245	247700	0	0	0
14	Belfast	93	54600	0	0	1
15	Cardiff	470	701600	0	0	1
16	Luton	56	29600	0	0	1
17	Blackpool	12	8800	0	0	0
18	Bristol	33	19000	0	0	0
19	Durham	41	23400	0	0	0
20	Exeter	76	42800	0	0	0
21	Highlands	212	198800	0	0	0
22	Leeds	52	23900	0	0	0
23	Liverpool	17	10200	0	0	0
24	Biggin Hill	59	34900	0	0	0
25	London City	38	10700	0	0	0
26	Norwich	2	4000	0	0	0

27	Southend	177	119500	0	0	0
	Mean	77	66281	0.259	0.148	0.111
	Median	44	20600	—	—	—
	Standard Deviation	100	139716	—	—	—

Note: airports not belonging to BAA, Manchester or TBI are Independent city airports

Table 2: Research into Airport Efficiency

Papers	Method	Units	Inputs	Outputs
Gillen and Lall (1997)	DEA-BCC model and a Tobit model	21 US airports	i) *Terminal services model*: 1) Number of runways 2)Number of gates 3)Terminal area 4)Number of baggage collection belts 5) Number of public parking spots ii) *Movement model*: 1)Airport area 2)Number of runways 3) Runway area 4) Number of employees	i)*Terminal services model*: 1)Number of passengers 2)Pounds of cargo ii) *Movements model* 1)Air carrier movements 2)Commuter movements
Parker (1999)	DEA-BCC and CCR models	32 U.K. regulated airports, 1979/1980 to 1995/1996. In a second model, 22 airports are analysed from 1988/89 to 1996/97	1) Number of employees, 2) Capital input estimated as an annual rental based on a real rate of return of 8% each year applied to net capital stock, 3) Other inputs defined as the residual of total operating costs.	1) Turnover, 2) Passengers handled, 3) Cargo and mail business
Murillo-Melchor (1999)	DEA-Malmquist	33 Spanish civil airports, 1992 to 1994	1) Number of workers, 2) Accumulated capital stock proxied by amortisation, 3) Intermediate expenses	Number of passengers
Gillen and Lall (2001)	DEA-Malmquist	22 major US airports, 1989 to 1993	i) *Terminal services model*: 1) Number of runways, 2) Number of gates, 3) Terminal area, 4) Number of employees, 5) Number of baggage collection belts, 6) Number of public parking places.	i) *Terminal services model*: 1) Number of passengers, 2) Number of pounds. ii) *Movement model*: 1) Air carrier movements, 2) Commuter movements.

			ii) *Movement model*: 1) Airport area, 2) Number of runways, 3) Runway area, 4) Number of employees	
Pels, Nijkamp and Rietveld (2001)*	DEA-BCC model.	34 European airports, 1995 to 1997	1) Terminal size in square meters, 2) Number of aircraft parking positions at the terminal, 3) Number of remote aircraft parking positions, 4) Number of check-in desks, 5) Number of baggage claims.	i) *Terminal model*: 1) Number of passengers. ii) *Movement model*: 1) Aircraft transport movements.
Pels, Nijkamp and Rietveld (2001)*	Stochastic frontier model.	34 European airports, 1995 to 1997	1) Constant, 2) Number of baggage claim units, 3) Number of parking positions at the terminal, 4) Number of remote parking positions.	i) *Terminal model*: 1) Number of passengers. ii) *Movement model*: 1) Aircraft transport movements.
Adler and Berechman (2001)	DEA-BCC with Principal Component Analysis.	26 European airports	1) Passenger terminals, runways, 2) Distance to city centres, 3) Minimum connecting times in minutes.	1)Principal components obtained from a questionnaire on airlines.
Fernandes and Pacheco (2002)	DEA.	16 Brazilian airports, 1998	1) Airport surface area in m2, 2) Departure lounge in m2, 3) Number of check-in counters, 4) Curb frontage in meters, 5) Number of vehicle parking spaces, 6) Baggage claim area in m2.	Domestic passengers.
Pels, Nijkamp and Rietveld (2003)**	DEA-BCC model.	33 European airports, 1995 to 1997	i) *Terminal model*: 1) Airport surface area, 2) Number of aircraft parking positions at terminal, 3) Number of	i) *Terminal model*: 1) Annual number of domestic and international movements ii) *Movement model*: 1)

			remote aircraft parking positions, 4) Number of runways; 5) Dummy z variables for slot-coordinated airports and 6) Dummy z variable for time restrictions. ii) *Movement model*: 1) Number of check-in-desks, 2) Number of baggage claim units; 3) Annual number of domestic and international movements.	Annual number of domestic and international passengers.
Pels, Nijkamp and Rietveld (2003)**	Stochastic frontier model	As above.	As above.	As above.
Sarkis (2000)	Several DEA models, including the CCR and BCC models.	43 US airports from 1990-1994.	1) Operating costs, 2) Employees, 3) Gates, 4) Runways.	1) Operating revenues, 2) Aircraft movements, 3) General aviation, 4) Total passengers, 5) Total freight.
Sarkis and Talluri (2004)	DEA-CCR and cross-efficiency DEA model from Doyle and Green (1994)	43 US airports from 1990-1994.	1)Operating costs, 2) Employees, 3) Gates, 4) Runways.	1) Operating revenue, 2) Aircraft movements, 3) General aviation, 4) Total passengers, 5) Total freight.
Barros and Sampaio (2004)	DEA - allocative Model.	10 Portuguese airports 1990-2000.	1) Number of employees, 2) Capital proxied by the book value of physical assets, 3) Price of capital, 4) Price of labour.	1) Number of planes, 2) Number of passengers, 3) General cargo, 4) Mail cargo, 5) Sales to planes, 6) Sales to passengers.
Yoshida (2004)	Endogenous-Weight method	43 Japanese airports, 2000.	1) Runway length, 2) Terminal size.	1) Passenger loading, 2) Cargo handling, 3) Aircraft movement.
Yoshida and Fujimoto (2004)	DEA-CCR, DEA-BCC and Input distance	43 Japanese airports, 2000.	1) Runway length, 2) Terminal size, 3) Monetary access cost, 4) Time access cost, 5)	1)Passenger loading, 2)cargo handling, 3)aircraft movement.

	function.		Number of employees in terminal building.	
Barros and Dieke (2007)	Multiple DEA models	31 Italian airports, 2001-2003	1) Labour cost, 2) Capital invested, 3) Operational costs excluding wage costs.	1) Number of planes, 2) Number of passengers, 3) General cargo. 4) Handling receipts, 5) Aeronautical sales, 6) Commercial sales.
Fung, Wan, Hui and Law (2007)	Malmquist DEA model	25 regional Chinese airports, 1995-2004.	1) Runway length, 2) Terminal size.	1) Passengers handled, 2) Cargo handled, 3) Aircraft movements.
Barros (2008A)	Homogenous stochastic frontier model	10 Portuguese airports, 1990-2000	1) Operating costs, 2) Price of capital, 3) Price of labour.	1) Sales to planes, 2) Sales to passengers, 3) Non-aeronautical fee.
Barros and Dieke (2008)	DEA two-stage model	31 Italian airports, 2001-2003	1) Labour costs 2) Capital invested 3) Operational costs excluding labour costs. *Second-stage variables*: 4) Hub 5) WLU 6) Private 7) North.	1) Number of Planes 2) Number of Passengers 3) General Cargo 4) Handling receipts 5) Aeronautical sales 6) Commercial sales.

* The paper by Pels, Nijkamp and Rietveld (2001) presents two methods for analysing efficiency. We therefore present the paper in two separate entries in order to explain the techniques.

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Table 3: Characteristics of the Variables

Variables	Definition	Minimum	Maximum	Mean	Standard deviation
Outputs					
Number of Passengers	Number of passengers who arrive and depart from the airport in million	3	67673	7334.135	13452.604
General Cargo	Number of tons of cargo that arrive and depart from the airport in million	0	1412	86.654	260.036
Aircraft Movement	Number of aircraft landing and departing in million	2	470	75.753	96.974
Inputs					
Employees	Average number of employees	48	4052	503.851	777.245
Operational cost	Operational costs of airports in million pounds	3600	701600	60733	122137.5
Fixed Assets	Value of fixed assets in million pounds	932	6497600	365678	952486

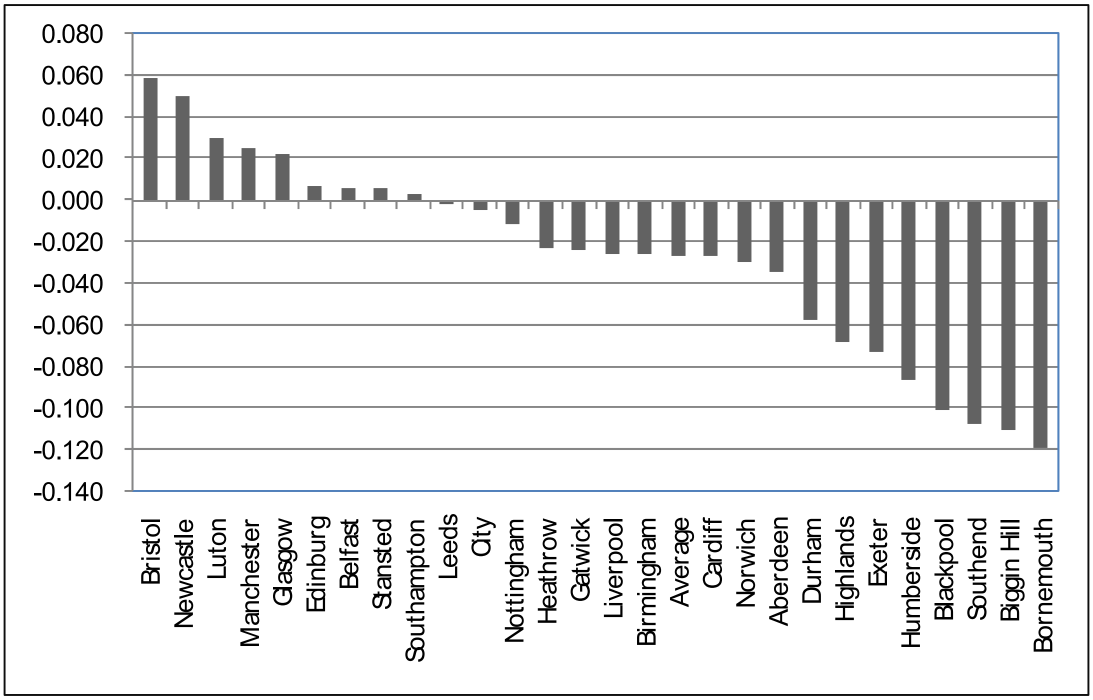

Figure 1. Average Change of TFP: 2000-2005

Table 4 Average Changes in Productivity

	Luenberger productivity indicator			Luenberger–Hicks–Moorsteen productivity indicator		
Airports	TFP(L)	TC(L)	EC(L)	TFP(LHM)	TC(LHM)	EC(LHM)
Heathrow	-0.023	-0.023	0.000	-0.035	-0.002	-0.034
Gatwick	-0.024	-0.024	0.000	-0.016	0.028	-0.044
Stansted	0.006	0.006	0.000	0.020	0.020	0.000
Southampton	0.003	-0.040	0.043	-0.010	-0.114	0.104
Glasgow	0.023	0.022	0.000	0.049	0.051	-0.002
Edinburg	0.007	0.007	0.000	0.032	0.032	0.000
Aberdeen	-0.034	-0.034	0.000	-0.069	-0.069	0.000
Manchester	0.025	-0.007	0.033	0.129	-0.056	0.184
Bornemouth	-0.119	-0.058	-0.061	-0.565	-0.215	-0.350
Humberside	-0.086	-0.044	-0.043	-0.221	0.053	-0.274
Nottingham	-0.011	-0.031	0.020	0.004	-0.050	0.054
Birmingham	-0.026	-0.018	-0.008	0.029	0.066	-0.038
Newcastle	0.050	0.025	0.025	0.138	0.093	0.045
Belfast	0.007	0.002	0.005	0.023	0.012	0.011
Cardiff	-0.027	-0.027	0.000	-0.062	-0.011	-0.051
Luton	0.030	0.030	0.000	0.087	0.087	0.000
Blackpool	-0.100	-0.086	-0.014	-0.275	-0.039	-0.236
Bristol	0.059	0.041	0.017	0.113	0.076	0.037
Durham	-0.058	-0.002	-0.055	-0.083	0.073	-0.156
Exeter	-0.073	-0.057	-0.016	-0.037	0.083	-0.121
Highlands	-0.068	-0.082	0.014	-0.067	-0.270	0.204
Leeds	-0.001	0.020	-0.021	0.021	0.068	-0.047
Liverpool	-0.025	0.008	-0.034	-0.011	0.069	-0.080
Biggin Hill	-0.110	-0.110	0.000	-0.232	-0.232	0.000
City	-0.005	-0.005	0.000	-0.021	-0.021	0.000
Norwich	-0.029	-0.097	0.068	-0.240	-0.524	0.284
Southend	-0.107	-0.107	0.000	-2.881	-2.118	-0.763
Average	-0.027	-0.026	-0.001	-0.155	-0.108	-0.047

Table 5 Summary of Productivity Changes by Ownership

	Luenberger productivity indicator			Luenberger–Hicks–Moorsteen productivity indicator		
	TFP(L)	TC(L)	EC(L)	TFP(LHM)	TC(LHM)	EC(LHM)
British Airports Authority	-0.006	-0.012	0.006	-0.004	-0.008	0.004
Manchester Airports plc	-0.048	-0.035	-0.013	-0.163	-0.067	-0.096
TBI pls	0.003	0.002	0.002	0.016	0.029	-0.013
The others	-0.040	-0.035	-0.003	-0.286	-0.205	-0.055
All	-0.027	-0.026	-0.001	-0.155	-0.108	-0.047

Table 6. Correlations of Productivity Changes

	Luenberger productivity indicator			Luenberger–Hicks–Moorsteen productivity indicator		
	TFP(L)	TFP(LHM)	TC(L)	TC(LHM)	EC(L)	EC(LHM)
TFP(L)		–	–	–	–	–
TFP(LHM)	0.226		–	–	–	–
TC(L)	0.688	0.211		–	–	–
TC(LHM)	0.221	0.670	0.188		–	–
EC(L)	0.236	0.017	0.006	0.177		–
EC(LHM)	0.336	0.158	0.008	0.040	0.006	