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Productivity Growth and Biased Technological Change in UK Airports

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Abstract: In this paper we estimate the total factor productivity of UK airports using a Malmquist index. Productivity change is factored into an index of efficiency change and an index of technological change. Technological change is further decomposed into indexes that measure the bias in the production of outputs, the bias in the employment of inputs, and the magnitude of the shift in the production frontier. Airports are ranked according to their productivity change for the period 2000-2005. The majority of UK airports did not improve their efficiency during the period. Economic implications are derived.

Keywords:
UK airports, productivity growth, biased technological change, policy implications

1. Introduction

Research on the technical efficiency and productivity of airports has adopted two alternative methods of measuring efficiency: non-parametric DEA (data envelopment analysis) (Sarkis, 2000, Gillen and Lall, 2001; Adler and Berechman, 2001; Fernandes and Pacheco, 2002; Sarkis and Talluri, 2004; Yoshida and Fujimoto, 2004; and Barros and Dieke, 2008) and the parametric stochastic frontier model (Pels, Nijkamp and Rietveld; 2001, 2003; Barros, 2008a). Oum, Adler, and Yu (2006) have analyzed the effects of privatization and ownership forms on airport efficiency.

The motivation for the present research is the following: First, in prior research on UK airports' technical efficiency, Barros (2008b) estimated a stochastic frontier model and found that the majority of UK airports were not improving their efficiency after 2000. Barros' results contrast with prior research by Parker (1999) on BAA (British Airports Authority) airports. However, the cause for declining technical efficiency is unclear and therefore an issue justifying more research. Second, recent acquisitions of UK airports by Spanish enterprises have increased competition. In 2004, TBI PLC, the owner of three regional airports in England, Wales, and Northern Ireland was acquired by a Spanish enterprise owned by AENA, the company that manages the Spanish airports, and Abertis, a Spanish construction company. In July 2006, BAA was taken over by a consortium led by the Spanish transportation group, Grupo Ferrovial. These acquisitions introduced competition in the field which is reflected in different efficient performance. Finally, while UK airports' technical efficiency has been analysed using DEA and stochastic frontier models, the productivity growth of those airports has not been analysed, further justifying the present research. Therefore the aim of this research is to investigate total factor productivity change of the UK airports using a Malmquist index. (Färe and Grosskopf 1996) The Malmquist index decomposes productivity change into gains or losses due to efficiency change and gains or losses due to technological change. Furthermore, our method relaxes the assumption of Hicks' neutrality in the production of outputs and use of inputs by allowing for biased technological change to occur. Our method identifies the source of the bias in technological change.

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 BAA, Manchester Airports PLC, TBI PLC, and 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. 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 as a PLC (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 PLC, its shares are not quoted or sold on the London Stock Exchange. Manchester City Council has a majority shareholding (55%) with each of nine other city councils holding 5% each. Therefore Manchester group is a public limited company.

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.

In 2008, the International Air Transport Association (IATA) challenged the UK's Civil Aviation Authority's decision to allow costs at London airports to rise by a massive 50% between 2008 and 2013, concluding that the regulators had proved to be impotent in defending the interests of travellers against monopoly practices. However, responding to the Office of Fair Trading's probe into UK airports, the Easy Jet CEO said that consumers need better protection from the airport operators who behave like local monopolists, pushing up prices to hide their own inefficiencies. So, whilst Easy Jet supports the break-up of BAA Company, the BAA argues that consumers will not benefit from having BAA replaced by a series of 'Mini' monopolists. Table 1 presents some ownership characteristics of UK airports.

Table 1: Characteristics of the U.K. Airports in the Analysis (2006)

No.	Airport	Aircraft Movements (000)	Ownership (private=1, public=0)	Owned by BAA	Owned by Manchester Airports PLC	Owned by TBI PLC	Regulation
1	Heathrow	472954	1	1	0	0	1
2	Gatwick	254004	1	1	0	0	1
3	Stansted	180729	1	1	0	0	1
4	Southampton	45109	1	1	0	0	0
5	Glasgow	97610	1	1	0	0	0
6	Edinburgh	117312	1	1	0	0	0
7	Aberdeen	94665	1	1	0	0	0
8	Manchester	217396	0	0	1	0	0
9	Bournemouth	14041	0	0	1	0	0
10	Humberside	11342	0	0	1	0	0
11	Nottingham	56224	0	0	1	0	0
12	Birmingham	113668	0	0	0	0	0
13	Newcastle	55164	0	0	0	0	0
14	Belfast	43780	1	0	0	1	0
15	Cardiff	20689	1	0	0	1	0
16	Luton	87690	1	0	0	1	0
17	Blackpool	13028	0	0	0	0	0
18	Bristol	59845	0	0	0	0	0
19	Durham	53632	0	0	0	0	0
20	Exeter	14481	0	0	0	0	0
21	Highlands	62433	0	0	0	0	0
22	Leeds	36330	0	0	0	0	0
23	Liverpool	43312	0	0	0	0	0
24	Biggin Hill	4834	0	0	0	0	0
25	London City	61179	0	0	0	0	0
26	Norwich	20894	0	0	0	0	0
27	Southend	1548	0	0	0	0	0
	Mean	83477	0.370	0.259	0.148	0.111	0.148
	Median	55164	—	—	—	—	—
	Standard Deviation	100361	—	—	—	—	—

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

3. Technical efficiency and Productivity in airports

While there is extensive literature on benchmarking applied to a diverse range of economic fields, the scarcity of studies regarding European airports bears testimony to the fact that this is a relatively under-researched topic (Humphreys and Francis, 2002; Humphreys, Francis and Fry (2002), Graham, 2005). Researchers using the DEA model include Gillen and Lall (1997, 2001), Parker (1999), Murillo-Melchor (1999), Pels, Nijkamp and Rietveld (2001, 2003), Adler and Berechman (2001), Martin and Román (2001), Fernandez and Pacheco (2002), Sarkis (2000), Sarkis and Talluri (2004), Barros and Sampaio (2004), Yoshida (2004), Yoshida and Fujimoto (2004), Lin and Hong (2006), Barros and Dieke (2007, 2008), and Fung, Wan, Hui and Law (2008). Researchers adopting stochastic frontier models to measure efficiency include Pels et al. (2001, 2003); Martín–Cejas (2002); Yoshida (2004); Yoshida and Fujimoto (2004), and Barros (2008a, 2008b). A careful description of the inputs used and outputs produced by airports in these studies is provided by Barros and Dieke (2008). Traditional inputs employed by airports include the number of employees and estimates of the capital stock including passenger terminals, baggage collection belts, terminal size, runway length and numbers, and/or the book value or operating costs of capital. Airport outputs include number of passengers, pounds of cargo, air carrier movements, or operating revenues.

We extend the efficiency studies cited above by estimating total factor productivity for UK airports using a Malmquist index. In addition to measuring efficiency change from period to period, our method allows for biased technological change in the production of airport outputs and in the use of airport inputs.

4. Method

We estimate efficiency and total factor productivity change for UK airports using DEA (data envelopment analysis). The DEA method constructs a best-practice technology from observed DMUs (decision-making units). An advantage of the DEA method is that it allows one to measure the performance of DMUs which produce multiple outputs using multiple inputs. In addition, the DEA method does not require the researcher to specify an ad hoc functional form nor make unwarranted assumptions regarding the error structure when estimating efficiency using stochastic methods. However, a disadvantage of the DEA method is that all deviation of a DMU's performance from best-practice methods is attributed to inefficiency, even though some of the deviation might be due to random error.

The reciprocal of the Shephard (1970) input distance function serves as a measure of Farrell (1957) input efficiency. Linking input efficiency indexes across time allows us to estimate the Malmquist productivity index. This index can be decomposed into change in resource use due to efficiency change and change in resource use attributable to technological change. Furthermore, we use the approach of Färe and Grosskopf (1996) and decompose technological change into an index of output biased technological change, an index of input biased technological change, and an index of the magnitude of technological change.

Holding outputs constant, the reciprocal of the input distance function gives the ratio of minimum inputs required to produce a given level of outputs to actual inputs employed, and serves as a measure of technical efficiency. Let $x^t = (x_1^t, ..., x_N^t)$ represent a vector of *N* non-negative inputs in period *t* and let $y^t = (y_1^t, ..., y_M^t)$ represent a vector of

M non-negative outputs produced in period t. The input requirement set in period t represents the feasible input combinations that can produce outputs and is represented as

$$L^t(y) \quad = \quad \{x: \quad x \text{ can produce } y\}. \tag{1}$$

The isoquant for the input requirement set is defined as

$$ISOQ\ L^t(y) = \{x: \ \frac{x}{\lambda} \notin L^t(y), \ \text{for } \lambda > 1\}. \tag{2}$$

The Shephard input distance function is defined as

$$D_i^t(y,x) \quad = \quad \max\{\lambda: \ \frac{x}{\lambda} \in L^t(y)\}. \tag{3}$$

The reciprocal of the Shephard input distance function equals the ratio of minimum inputs to actual inputs employed and serves as a measure of Farrell input technical efficiency. Efficient DMUs use inputs that are part of the $ISOQ\ L^t(y)$ and have $D_i^t(y,x)=1$. Inefficient DMUs have $D_i^t(y,x)>1$.

We estimate the reciprocal of the Shephard input distance function using linear programming methods called DEA. We assume that there are k=1,…,K DMUs. The DEA piece-wise linear constant returns to scale input requirement set takes the form:

$$L^t(y) = \{x: \sum_{k=1}^{K} z_k^t x_{kn}^t \le x_n, n = 1,...,N, \sum_{k=1}^{K} z_k^t y_{km}^t \ge y_m, m = 1,...,M, z_k^t \ge 0, k = 1,...,K\}. \tag{4}$$

The DEA input requirement set takes linear combinations of the observed inputs and outputs of the K DMUs using the K intensity variables, z_k^t, to construct a best-practice technology. The N+M inequality constraints associated with inputs and outputs imply that no less input can be used to produce no more output than a linear combination of observed inputs and outputs of the K DMUs. Constraining the K intensity variables to be non-negative allows for constant returns to scale.

To compute input technical efficiency for DMU "*o*" we solve the following linear programming problem:

$$1/D_i^t(y,x) = \max_{z,\lambda}\{\lambda^{-1} : \sum_{k=1}^{K} z_k^t x_{kn}^t \le \lambda^{-1} x_{on}^t,\ n=1,...,N,$$
$$\sum_{k=1}^{K} z_k^t y_{km}^t \ge y_{om}^t, m=1,...,M,\ z_k^t \ge 0, k=1,...,K\}. \qquad (5)$$

Following Färe and Grosskopf (1996) and Weber and Domazlicky (1999) total factor productivity growth can be estimated using the Malmquist input-based index of total factor productivity growth. This index can be decomposed into separate indexes measuring efficiency change and technological change. Efficiency change measures "catching up" to the frontier isoquant while technological change measures the shift in the frontier isoquant from one period to another. The Malmquist input based productivity index (*MALM*) takes the form

$$MALM = \sqrt{\frac{D_i^{t+1}(y^{t+1},x^{t+1})}{D_i^{t+1}(y^t,x^t)} x \frac{D_i^t(y^{t+1},x^{t+1})}{D_i^t(y^t,x^t)}}. \qquad (6)$$

Rearranging (6) yields

$$MALM = \frac{D_i^{t+1}(x^{t+1},y^{t+1})}{D_i^t(x^t,y^t)} x \sqrt{\frac{D_i^t(x^t,y^t)}{D_i^{t+1}(x^t,y^t)} x \frac{D_i^t(x^{t+1},y^{t+1})}{D_i^{t+1}(x^{t+1},y^{t+1})}}, \qquad (7)$$

where efficiency change is represented by $EFFCH = \frac{D_i^{t+1}(y^{t+1},x^{t+1})}{D_i^t(y^t,x^t)}$ and technological progress is represented by $TECH = \sqrt{\frac{D_i^t(y^t,x^t)}{D_i^{t+1}(y^t,x^t)} x \frac{D_i^t(y^{t+1},x^{t+1})}{D_i^{t+1}(y^{t+1},x^{t+1})}}$. Values of *MALM*, *EFFCH*, or *TECH* less (greater) than one indicate productivity growth (decline), gains (losses) in efficiency, and technological progress (regress).

Färe and Grosskopf (1996) show how the technological change index can be further decomposed into the product of three separate indexes of output biased technological change (*OBTECH*), input biased technological change (*IBTECH*), and the magnitude of technological change (*MATECH*). These indexes take the form:

$$OBTECH = \sqrt{\frac{D_i^t(y^{t+1}, x^{t+1})}{D_i^{t+1}(y^{t+1}, x^{t+1})} x \frac{D_i^{t+1}(y^t, x^{t+1})}{D_i^t(y^t, x^{t+1})}}, \quad IBTECH = \sqrt{\frac{D_i^{t+1}(y^t, x^t)}{D_i^t(y^t, x^t)} x \frac{D_i^t(y^t, x^{t+1})}{D_i^{t+1}(y^t, x^{t+1})}}, \text{ and}$$
$$MATECH = \frac{D_i^t(y^t, x^t)}{D_i^{t+1}(y^t, x^t)}, \text{ where } TECH = OBTECH \; x \; IBTECH \; x \; MATECH. \tag{8}$$

Figure 1 illustrates the construction of the input distance function and the components of the Malmquist input based productivity index. The input requirement set in period 1 includes all points to the northeast of the isoquant $L^1(y)$. We assume that technological progress occurs from period 1 to period 2 with the input requirement set in period 2 including all points to the northeast of the isoquant $L^2(y)$. The DMU for which we calculate efficiency and productivity change employs input vector A in period 1 and in period 2 it employs input vector E. In both periods the DMU produces the same level of output (y), but uses excessive inputs and is technically inefficient. The input distance function in period 1 is $D_i^1(y, x^1) = \frac{0A}{0B}$ and in period 2 the input distance function is $D_i^2(y, x^2) = 0E/0D$. The two inter-period input distance functions are calculated as $D_i^1(y, x^2) = \frac{0E}{0F}$ and $D_i^2(y, x^1) = \frac{0A}{0C}$. The Malmquist index is calculated as $MALM = \sqrt{\frac{0E/0D}{0A/0C} x \frac{0E/0F}{0A/0B}}$. Efficiency change is calculated as $EFFCH = \frac{0E/0D}{0A/0B}$ and technological change is calculated as $TECH = \sqrt{\frac{0A/0B}{0A/0C} x \frac{0E/0F}{0E/0D}} = \sqrt{\frac{0C}{0B} x \frac{0D}{0F}}$.

Figure 2 illustrates the construction of the index of input biased technological change. The isoquant in period 1 is represented by $L^1(y)$. We again assume technological progress and draw two alternative isoquants represented by $L^{21}(y)$ and $L^{22}(y)$. Technological progress is Hicks' neutral if the MRS (marginal rate of substitution) between two inputs remains constant, holding the input mix constant. Technological progress is x_1-saving and x_2-using if the MRS between the two inputs increases, holding the input mix constant. Technological progress is x_1-using and x_2-saving if the MRS between the two inputs decreases, holding the input mix constant. The isoquant $L^{21}(y)$ represents a x_1-saving and x_2-using bias. The isoquant $L^{22}(y)$ represent an x_1-using and x_2-saving bias. From period 1 to period 2 the ratio of the two inputs changed such that $\left(\frac{x_1}{x_2}\right)^{t+1} > \left(\frac{x_1}{x_2}\right)^{t}$. If technological progress shifts the isoquant to $L^{21}(y)$ in period 2 the index of input bias is $IBTECH = \sqrt{\frac{0B}{0C}\frac{0D}{0F}} = \sqrt{\frac{0B/0C}{0F/0D}}$. Given that $0B/0C > 0F/0D$ then *IBTECH*>1 and the technology exhibits an x_1-saving and x_2-using bias. If instead, technological progress shifted the isoquant to $L^{22}(y)$ in period 2, the index of input bias would be $IBTECH = \sqrt{\frac{0B}{0C}\frac{0G}{0F}} = \sqrt{\frac{0B/0C}{0F/0G}}$. In this case, we have $0B/0C < 0F/0G$ so that *IBTECH*<1 and the technology exhibits an x_1-using and x_2-saving bias. The possible alternatives for input bias between inputs *j* and *k* are summarized in the following table.

Table 2. Input biased technological change and changes in the input mix

Input mix	$IBTECH > 1$	$IBTECH < 1$
$\left(\frac{x_j}{x_k}\right)^{t+1} > \left(\frac{x_j}{x_k}\right)^{t}$	x_j-saving, x_k-using	x_j-using, x_k-saving

$\left(\frac{x_j}{x_k}\right)^{t+1} < \left(\frac{x_j}{x_k}\right)^{t}$	x_j-using, x_k-saving	x_j-saving, x_k-using

To investigate output biased technological change we represent the technology by the output possibility set: $P^t(x) = \{y: \quad x \text{ can produce } y\}$. The output possibility set is an alternative to the input requirement set for representing the technology in that $x \in L^t(y)$ if and only if $y \in P^t(x)$. The Shephard output distance function takes the form:

$$D_o^t(x^t, y^t) = \min\{\theta: \quad (y/\theta) \in P^t(x)\} \tag{9}$$

where $P^t(x)$ is the output possibility set for period t. Under constant returns to scale the Shephard input distance function equals the reciprocal of the Shephard output distance function. (Färe and Primont, 1995) That is, $D_i^t(y^t, x^t) = D_o^t(x^t, y^t)^{-1}$. Therefore, given constant returns to scale we can write the index of output biased technological change as

$$OBTECH = \sqrt{\frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^t(x^{t+1}, y^{t+1})} x \frac{D_o^t(x^{t+1}, y^t)}{D_o^{t+1}(x^{t+1}, y^t)}}. \tag{10}$$

Figure 3 illustrates the construction of the index of output biased technological change assuming technological progress between period 1 and 2. The output possibility set in period 1 is given by $P^1(x)$. Technological progress with respect to outputs is Hicks' neutral if the marginal rate of transformation between two outputs is constant, holding the mix of outputs constant. Hicks' neutral technological progress is illustrated by the parallel shift of the production possibility set to $P^{HN}(x)$. Technological progress is biased in favor of output 1 (y_1-producing) if the marginal rate of transformation between outputs 1 and 2 increases, holding the mix of outputs constant. Technological progress is biased in favor of output 2 (y_2-producing), if the marginal rate of transformation between the two outputs is less in period 2 holding the output mix constant. The output possibility set given by $P^{21}(x)$ illustrates a y_1-producing output bias and the output possibility set given by $P^{22}(x)$ illustrates a y_2-producing output bias.

In period 1 a DMU is observed to produce an output vector represented by point A. The output distance function is calculated as $D_o^1(x, y^1) = \frac{0A}{0B}$. In period 2, the DMU is observed to produce output vector E. If the technology shifts to $P^{21}(x)$ in period 2, the output distance function in period 2 is $D_o^2(x, y^2) = \frac{0E}{0F}$ and the index of output biased technological change is $OBTECH = \sqrt{\frac{0E/0F}{0E/0D} x \frac{0A/0B}{0A/0C}} = \sqrt{\frac{0D/0F}{0B/0C}} > 1$. Thus, since $\frac{y_1^{t+1}}{y_2^{t+1}} < \frac{y_1^t}{y_2^t}$ and *OBTECH*>1, the technology is y_1-producing. If the technology shifted to $P^{22}(x)$ in period 2, the output distance function would be calculated as $D_o^2(x, y^2) = \frac{0E}{0G}$ and output biased technological change is $OBTECH = \sqrt{\frac{0E/0G}{0E/0D} x \frac{0A/0B}{0A/0C}} = \sqrt{\frac{0D/0G}{0B/0C}} < 1$. Given that $\frac{y_1^{t+1}}{y_2^{t+1}} < \frac{y_1^t}{y_2^t}$ and *OBTECH*<1, the technology is y_2-producing. The possible alternatives for output bias between outputs *m* and *q* are summarized in the following table.

Table 3. Output biased technological change and changes in the output mix

Output mix	*OBTECH*>1	*OBTECH*<1
$\frac{y_m^{t+1}}{y_q^{t+1}} < \frac{y_m^t}{y_q^t}$	y_m-producing	y_q-producing
$\frac{y_m^{t+1}}{y_q^{t+1}} > \frac{y_m^t}{y_q^t}$	y_q-producing	y_m-producing

In the next section we calculate input technical efficiency and the components of the Malmquist input-based productivity index for UK airports and examine the bias in the use of inputs and production of outputs found in the technological change index.

5. Data and Empirical Results

We use a balanced panel comprising twenty-seven UK airports during five years from 2000/01 to 2004/05 (135 observations) obtained in Cruickshank, Flannagan and Marchant's *Airport Statistics* [CRI - Centre For The Study of Regulated Industries, University of Bath (several years)]. The variables were transformed as described in Table 4, where monetary magnitudes are expressed in £'000 pounds, deflated by the GDP deflator and denoted at prices of 2002.

Table 4: Descriptive Statistics of the Data

Variable	**Description**	Minimum	Maximum	Mean	Standard Deviation
	Outputs				
Passengers	Passengers in each airport in number (000)	5	64328	6585.4	13485.8
Cargo	Cargo in each airport in tons (000)	0	1385	97.3	270
Movements	Aircraft movements at each airport in number (000)	14	466	100.9	89.2
	Inputs				
Labor	Number of employees in each airport	48	3304	525.3	774.7
Fixed Assets	Value of fixed assets of each airport in pounds (000)	1	3458	304.9	707.8
Other Costs	Value of other costs (total costs minus wages minus depreciation costs of fixed assets) in pounds (000)	2124	316700	30052.1	63002.5

We assume that airports transform labor measured in number of employees, capital measured as the deflated value of fixed assets, and other inputs measured as deflated other costs into three outputs. The three outputs are passengers, cargo shipments, and aircraft movements. Table 5 presents the estimates of input technical efficiency, $1/D_i(x,y)$, by year. In 2000/01 thirteen airports defined the technological frontier isoquant. The frontier airports are Heathrow, Gatwick, Stansted, Southampton, Edinburg, Aberdeen, Nottingham, Cardiff, Luton, Blackpool, Leeds, Biggin Hill, and City. Nine airports-Stansted, Southwick, Edinburg, Aberdeen, Nottingham, Newcastle, Luton, Bristol, and City-defined the frontier in 2004/05. Average efficiency in 2000/01 was 0.85 indicating that the average airport could produce its output using only 85% of its current inputs if it adapted the best-practice techniques of the thirteen frontier airports. By 2004/05, average efficiency declined to 0.76.

Table 5. Input technical efficiency (geometric means)

Year	mean	std. dev.	minimum	maximum	# of frontier airports
2000/01	0.85	0.19	0.32	1	13
2001/02	0.74	0.26	0.16	1	11
2002/03	0.77	0.20	0.28	1	8
2003/04	0.75	0.23	0.25	1	9
2004/05	0.76	0.23	0.29	1	9

Table 6 presents the geometric mean estimates of productivity change and its components. Values of *MALM*, *EFFCH*, *TECH*, *OBTECH*, *IBTECH*, and *MATECH* less than one indicate productivity gains, increases in efficiency, or technological progress. Values of *MALM*, *EFFCH*, *TECH*, *OBTECH*, *IBTECH*, and *MATECH* greater than one indicate productivity loss, decreases in efficiency, or technological regress. The year to year changes show that average total factor productivity increased only from 2001/02 to 2002/03. During this period, airports became more efficient and experienced technological progress. In the other three periods, average airport efficiency declined ($EFFCH>1$) and the average airport experienced technological regress ($TECH>1$) or no technological change ($TECH=1$).

Table 6. Components of Productivity Change (geometric means)

	MALM	*EFFCH*	*TECH*	*OBTECH*	*IBTECH*	*MATECH*
2000/01 to 2001/02	1.63	1.16	1.41	0.83	0.97	1.76
2001/02 to 2002/03	0.90	0.95	0.95	0.99	0.96	0.99
2002/03 to 2003/04	1.04	1.04	1.00	0.98	0.96	1.06
2003/04 to 2004/05	1.03	0.99	1.05	0.98	0.96	1.11

In Table 7 we identify the number of airports that experience a saving/using bias in the relative use of inputs. The three inputs are labor (x_1), capital (x_2), and other costs (x_3). A majority of airports experienced a labor-saving/other cost-using input bias except in the 2001/02 to 2002/03 period. With respect to capital and other costs, the results are mixed. During 2000/01 to 2001/02 and 2002/03 to 2003/04 a slight majority of airports experienced a capital-saving and other costs-using input technological bias. However, during 2000/01 to 2001/02 and 2003/04 to 2004/05 a slight majority of airports experienced a capital-using/other cost saving input technological bias.

Table 7. Input Biased technological change

<table>
<tr><td colspan="6"># of Airports for which:</td></tr>
<tr><td></td><td></td><td>$\left(\frac{x_1}{x_3}\right)^{t+1} > \left(\frac{x_1}{x_3}\right)^{t}$</td><td>$\left(\frac{x_1}{x_3}\right)^{t+1} < \left(\frac{x_1}{x_3}\right)^{t}$</td><td>$\left(\frac{x_2}{x_3}\right)^{t+1} > \left(\frac{x_2}{x_3}\right)^{t}$</td><td>$\left(\frac{x_1}{x_3}\right)^{t+1} < \left(\frac{x_1}{x_3}\right)^{t}$</td></tr>
<tr><td rowspan="3">2000/01 to 2001/02</td><td>IBTECH>1</td><td>3 (x_1-saving)</td><td>3 (x_1-using)</td><td>3 (x_2-saving)</td><td>3 (x_2-using)</td></tr>
<tr><td>IBTECH<1</td><td>8 (x_1-using)</td><td>12 (x_1-saving)</td><td>9 (x_2-using)</td><td>11 (x_2-saving)</td></tr>
<tr><td>Neutral</td><td colspan="2">1</td><td colspan="2">1</td></tr>
</table>

2001/02 to 2002/03	*IBTECH*>1	6 (x_1-saving)	3 (x_1-using)	5 (x_2-saving)	4 (x_2-using)
	IBTECH<1	15 (x_1-using)	2 (x_1-saving)	13 (x_2-using)	4 (x_2-saving)
	Neutral	1		1	
2002/03 to 2003/04	*IBTECH*>1	0 (x_1-saving)	7 (x_1-using)	3 (x_2-saving)	4 (x_2-using)
	IBTECH<1	1 (x_1-using)	16 (x_1-saving)	5 (x_2-using)	12 (x_2-saving)
	Neutral	3		3	
2003/04 to 2004/05	*IBTECH*>1	1 (x_1-saving)	3 (x_1-using)	1 (x_2-saving)	3 (x_2-using)
	IBTECH<1	7 (x_1-using)	15 (x_1-saving)	11 (x_2-using)	11 (x_2-saving)
	Neutral	1		1	

In Table 8 we identify the number of airports that experience a bias in the production of the relative outputs. Recall that the three outputs are passengers (y_1), cargo (y_2), and aircraft movements (y_3). With respect to passengers and aircraft movements a majority of airports in each year experienced output biased technological change in favour of aircraft movements, although eight airports in 2001/02 to 2002/03 and six airports in 2003/04 to 2004/05 experienced neutral technological change in the production of these two outputs. For cargo shipments and aircraft movements, the results are mixed, with nineteen airports experiencing a aircraft movement-producing bias in 2000/01 to 2001/02, but fourteen airports experiencing a cargo-producing bias in 2002/03 to 2003/04. In the last three periods between eight and ten airports experienced neutral technological change in these two outputs.

Table 8. Output biased technological change

# of Airports for which:					
		$\left(\frac{y_1}{y_3}\right)^{t+1} > \left(\frac{y_1}{y_3}\right)^{t}$	$\left(\frac{y_1}{y_3}\right)^{t+1} < \left(\frac{y_1}{y_3}\right)^{t}$	$\left(\frac{y_2}{y_3}\right)^{t+1} > \left(\frac{y_2}{y_3}\right)^{t}$	$\left(\frac{y_1}{y_3}\right)^{t+1} < \left(\frac{y_1}{y_3}\right)^{t}$
2000/01 to 2001/02	*OBTECH*>1	0 (y_1-producing)	0 (y_3-producing)	0 (y_2-producing)	0 (y_3-producing)
	OBTECH<1	24 (y_3-producing)	2 (y_1-producing)	19 (y_3-producing)	6 (y_2-producing)
	Neutral	1		2	
2001/02 to 2002/03	*OBTECH*>1	0 (y_1-producing)	3 (y_3-producing)	2 (y_2-producing)	0 (y_3-producing)
	OBTECH<1	14 (y_3-producing)	2 (y_1-producing)	6 (y_3-producing)	9 (y_2-producing)
	Neutral	8		10	
2002/03 to 2003/04	*OBTECH*>1	7 (y_1-producing)	1 (y_3-producing)	1 (y_2-producing)	3 (y_3-producing)
	OBTECH<1	9 (y_3-producing)	7 (y_1-producing)	2 (y_3-producing)	13 (y_2-producing)
	Neutral	3		8	
2003/04 to 2004/05	*OBTECH*>1	4 (y_1-producing)	1 (y_3-producing)	1 (y_2-producing)	3 (y_3-producing)
	OBTECH<1	14 (y_3-producing)	2 (y_1-producing)	7 (y_3-producing)	7 (y_2-producing)
	Neutral	6		9	

We re-estimated the components of the Malmquist index over the entire period for each airport and report the results in Table 6. We first note that the airports that defined the frontier in both 2000/01 and 2004/05-Stansted, Southampton, Edinburg, Aberdeen, Nottingham, Luton, and City-experienced no change in efficiency. Thus, for these airports *EFFCH*=1. Of the remaining airports, thirteen experienced declines in efficiency (*EFFCH*>1) and seven experienced gains in efficiency (*EFFCH*<1). The change in the technical efficiency score is defined as the diffusion of best-practice technology in the management of the activity and is attributed to investment planning, technical experience, and management and organization in the airports.

Technological change is a consequence of innovation, i.e. the adoption of new technologies by best-practice airports. The technological change index is greater than one for many airports and has an average value of 1.123, which indicates technological regress. Ten airports experienced technological progress (*TECH*<1) and seventeen airports experienced technological regress (*TECH*>1). Only two airports (Heathrow and Manchester) had *OBTECH*>1 indicating technological regress in the production of outputs, while the remaining twenty-five airports had *OBTECH*<1 indicating technological progress in the production of the three outputs. For the index of input bias, seven airports experienced technological regress in the use of inputs used to produce the 2000/01 vector of outputs. However, for the magnitude of technological change, eighteen airports experienced technological regress (*MATECH*>1). We note four airports-Southampton, Aberdeen, Nottingham, and City- operated on the frontier isoquant in both 2000/01 and 2004/05, but experienced technological regress driven by the magnitude of technological change. This result can be explained by the isoquant for 2000/01 intersecting the isoquant for 2004/05 as illustrated in Figure 4. In period 1 (2000/01), an airport produces on the isoquant at point A and in period 2 (2004/05), the airport produces on the isoquant at point B. In both periods the airport is efficient, so *EFFCH*=1. However, the magnitude of technological change is given by the ratio $MATECH = \frac{0A/0A}{0A/0C} = 0C/0A > 1$, indicating technological regress. Clearly, the intersection of the two isoquants indicates a technological bias in the use of inputs. Finally, for the Malmquist index, total factor productivity declined (MALM>1) for nineteen airports and increased (MALM<1) for only eight airports. Three other airports-Stansted, Edinburg, and Luton-produced on the frontier and experienced technological progress during the period, although Edinburg had *MATECH*>1.

Table 9. Total Factor Productivity Change for the UK airports: 2000/01 to 2004/05

	Airport	*MALM*	*EFFCH*	*TECH*	*OBTECH*	*IBTECH*	*MATECH*
1	Heathrow	1.132	1.116	1.014	1.033	0.996	0.986
2	Gatwick	1.092	1.176	0.929	0.997	1.002	0.930
3	Stansted	0.884	1.000	0.884	0.981	0.959	0.939
4	Southampton	1.462	1.000	1.462	0.680	0.822	2.614
5	Glasgow	0.881	1.007	0.875	0.988	0.975	0.908
6	Edinburg	0.939	1.000	0.939	0.941	0.948	1.054
7	Aberdeen	1.319	1.000	1.319	0.904	0.952	1.534
8	Manchester	0.580	0.649	0.894	1.001	1.031	0.866
9	Bornemouth	4.890	2.514	1.945	0.607	0.997	3.212
10	Humberside	3.106	1.684	1.844	0.649	0.898	3.167
11	Nottingham/East Middlands	1.107	1.000	1.107	0.752	0.814	1.807
12	Birmingham	0.967	1.103	0.877	0.949	0.955	0.967
13	Newcastle	0.895	0.946	0.945	0.835	0.980	1.156
14	Belfast	1.047	0.951	1.101	0.817	0.955	1.411
15	Cardiff	1.564	1.205	1.298	0.706	1.000	1.840
16	Luton	0.786	1.000	0.786	0.908	0.896	0.966
17	Blackpool	4.359	1.703	2.559	0.337	1.179	6.439
18	Bristol	0.785	0.873	0.900	0.784	1.017	1.129
19	Durham	1.553	1.641	0.946	0.868	1.014	1.075
20	Exeter	2.171	0.986	2.201	0.484	1.008	4.509

21	Highlands	1.675	0.562	2.982	0.841	0.978	3.625
22	Leeds	1.289	1.123	1.147	0.753	0.975	1.561
23	Liverpool	1.531	1.259	1.216	0.707	0.968	1.776
24	Biggin Hill	13.200	1.705	7.745	0.741	0.898	11.640
25	City	1.062	1.000	1.062	0.976	0.905	1.203
26	Norwich	1.386	0.517	2.680	0.660	0.948	4.283
27	Southend	28.830	3.111	9.265	0.906	1.006	10.160
	Mean (geometric)	1.613	1.123	1.437	0.786	0.963	1.896
	Mean (arithmetic)	2.981	1.216	1.886	0.808	0.966	2.658
	Median	1.289	1.000	1.107	0.835	0.975	1.534
	Std. Dev	5.724	0.559	2.014	0.170	0.069	2.756

Note: *MALM* = *EFFCH* x *TECH*
TECH = *OBTECH* x *IBTECH* x *MATECH*
Numbers may not multiply because of rounding error.

6. Conclusions

In this paper we used DEA to estimate the Malmquist input-based index of total factor productivity for twenty-seven UK airports operating during 2000/01 to 2004/05. Productivity change was factored into an index of efficiency change and an index of technological change. Throughout the period, UK airports experienced average decreases in productivity, which confirms previous research by Barros (2008b). The decline in productivity occurs because airports on average became less efficient and experienced technological regress during the period. When we broke the index of technological change into separate indexes of output bias, input bias, and an index of the magnitude of technological change we found a clear bias in the use of inputs and the production of outputs. A majority of airports experienced a labor-saving/other cost-using input bias. For capital and other costs, the results were mixed. We also found that a majority of airports experienced a bias in favor of producing aircraft movements relative to passengers. For cargo shipments and aircraft movements the result on biased technological change is mixed, with some airports experiencing a bias in favor of producing cargo shipments and other airports experiencing a bias in favor of aircraft movements. Our estimates of productivity change and technological bias indicate that the traditional growth accounting method, which assumes Hicks neutral technological change, is not appropriate for analyzing changes in productivity for UK airports.

No clear relationship emerges between ownership and productivity improvement nor ownership and regulation. Of the four airports managed by the Manchester airport group, only Manchester airport experienced an increase in productivity. For the three airports operated by TBI PLC, only Luton experienced an increase in productivity. Finally, only three of the seven airports overseen by BAA experienced productivity growth. In addition, for the three regulated airports, only Stansted experienced productivity growth. Further research is needed to confirm the present results.

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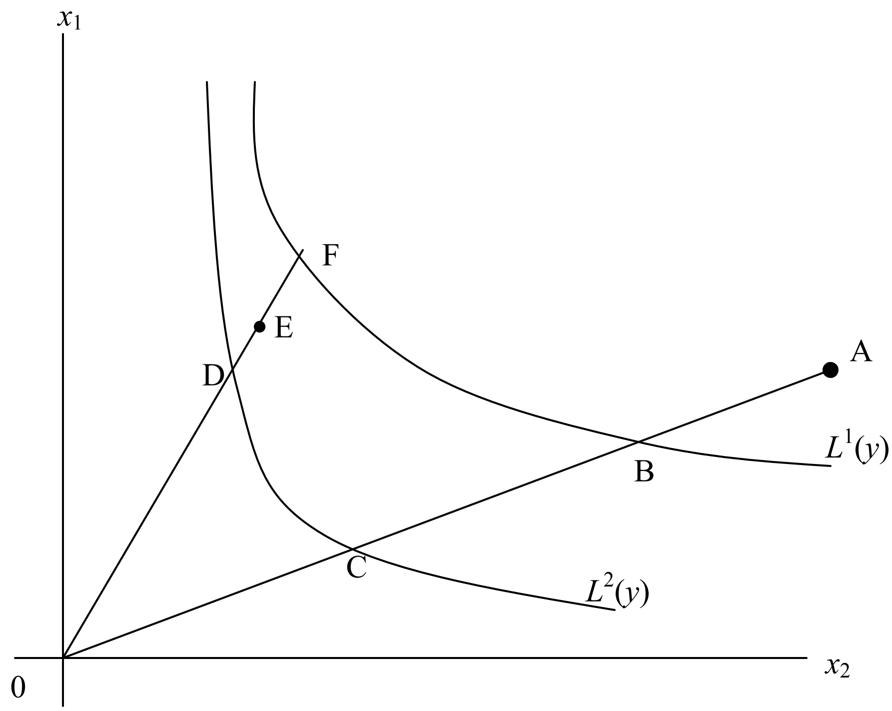

Figure 1. Input requirement sets and the Malmquist input based productivity index.

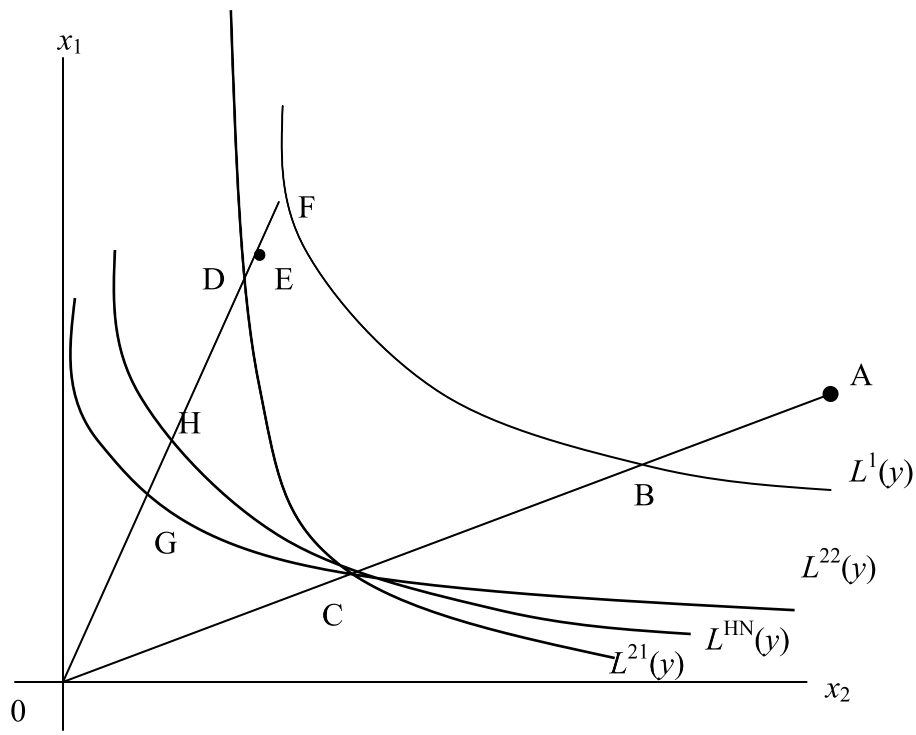

Figure 2. Input Requirement Sets ($L(y)$) and Input Biased Technological Change

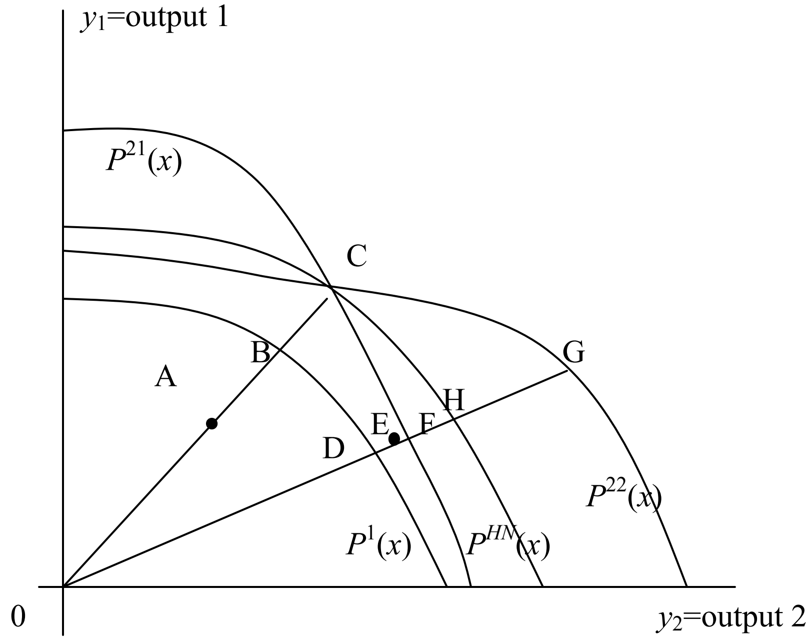

Figure 3. Production Possibility Sets ($P(x)$) and Output Biased Technological Change

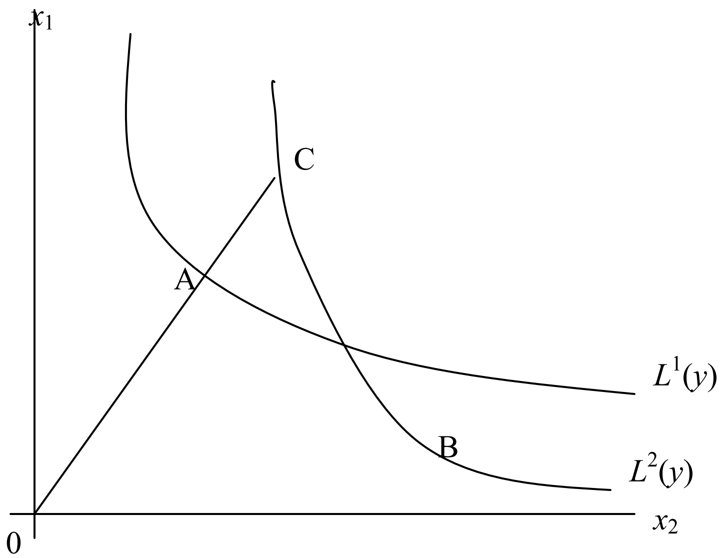

Figure 4. Illustration of Technological Regress for Frontier Airports.