Technical Efficiency in International Air Transport

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TECHNICAL EFFICIENCY IN INTERNATIONAL AIR TRANSPORT

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Abstract. The paper estimates technical efficiency in International Air Transport, within the framework of Stochastic Frontier Analysis. It is based on Panel Data for twenty four (24) companies worldwide, over the time period 1991-2002 and employs the Cobb-Douglas specification of the production function. A first finding of our investigation is that air transportation companies, worldwide, experienced (almost) constant returns to scale. A second interesting result is that technical efficiency of air transportation companies, worldwide, ranged between 37% and 100% with an average equal to about 89%. However, the industry's performance worldwide in terms of technical efficiency does not follow a clear trend in time, whereas some differences in performance depending on the corporation's continent of origin are observed. More precisely, the American, Australian and Asian have left behind the European companies. Also, the level of technology experienced a slight increase, while the privatization of very few air transportation companies in our data set does not seem to have any systematic impact on them in terms of technical efficiency. Finally, the results are compared with those yielded by the linear programming approach and the estimates are found to be very consistent with the results using Data Envelopment Analysis.

Keywords: Air Transportation, Technical Efficiency, S.F.A., D.E.A., Panel Data.

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INTRODUCTION

Technical efficiency refers to the ability of a firm to minimize input use in the production of a given output vector, or the ability to obtain maximum output from a given input vector (Kumbahakar et al, 2000). The index of technical efficiency is very important, because it indicates the ability of a firm to survive in a competitive environment.

The purpose of the present paper is the estimation of technical efficiency for a selected number of companies of the international air transportation industry. The competition among the airlines rapidly increased in the 1970s, after the deregulation of the U.S. air transportation industry. Specifically, in 1978 Air Deregulation Act reformed the relationship between the airlines companies and the state. The consequences of this deregulation in the international airlines industry were dramatic (Rodrigue et al, 2006). These reforms increased competition, lowered prices, increased services, and generally brought substantial benefits for consumers (Bailey et al, 1985; Kasper, 1988).

The deregulation of the European airlines started ten years later. The effects of the U.S. deregulation in the industry influenced the European Commission (E.C.) to introduce certain reforms to promote competition and thus increase the efficiency and production of the European airlines (Fethi et al, 2000). As for Asian countries, they are still bound by very restrictive bilateral agreements. However, the threat posed by the creation of international alliances between American and European carriers pushed them toward liberalization (Oum and Lee, 2002).

Under these circumstances, many carriers have been fundamentally restructured in order to survive the competition pressure. Alliances between carriers have been contracted, and other carriers have been merged. Finally, some carriers unable to carry through competition, bankrupted. Consequently, in order to survive competition, airlines must increase their technical efficiency measures. To this end, many techniques in measuring technical efficiency have been developed. These techniques have widespread appeal, because both policymakers and industry managers are concerned about measuring performance. These techniques can be used as decision making tools, since they indicate areas of deficiency and direction for change (Alam and Sickles, 2000).

In this paper technical efficiency of international air transportation industry is estimated with the use of Stochastic Frontier Analysis (S.F.A.). The data set consists of a panel of twenty four (24) international carriers in the time period 1991-2002. The paper compares the levels of efficiency between American, European and Asian carriers. Finally, we briefly compare the SFA-technical efficiency measures with estimates by Data Envelopment Analysis (D.E.A.).

REVIEW OF THE LITERATURE

Very few studies on technical efficiency of the air transportation industry in developed countries use frontier methodologies. Good et *al.* (1993), using Stochastic Frontier Analysis (SFA), compared technical efficiency and productivity growth, among the four largest European airlines and eight of their American counterparts over the time period 1976-1986. The selected time period is an interesting one, since it begins just after the informal steps of the U.S. deregulation, and ends just before the introduction of the first wave of reforms in Europe.

The analysis showed that U.S. carriers were nearly 15% more efficient than European airlines, throughout the study period. Moreover, the U.S. average technical efficiency increased from 77% (1976) to 79.4% (1986) (0.24% average annual increase), while, the European average increased from 62.9% (1976) to 64.7% (1986) (0.18% average annual increase).

Schecfczyk (1993), using D.E.A., measured the operational performance for a panel of 15 international airlines for the year 1990. The most efficient airlines were Singapore Airlines, Cathay Pacific, Federal Express and UAL Corporation, with 100% efficiency scores. The European airlines in the sample (British Airways, Iberia, KLM and Lufthansa) were less efficient. Schecfczyk (1993) continued his analysis in order to determine the relationship between these efficiency scores and some strategic variables, e.g. profitability, focus of the airline, revenue growth and load factors.

Distexhe and Perelman (1994), measured technical efficiency for thirty three (33) international airlines, over the time period 1977-1988. The airlines were categorized into three groups: Asia-Oceania, North America and Europe. DEA was used to construct several production frontiers of airlines activities. The results suggested that average levels of technical efficiency in the eighties were higher than those obtained in the seventies. Singapore Airlines, Japan Airlines, American Airlines, TWA, Lufthansa, Finnair, and Air France, appeared the most efficient carriers. Generally, the airlines from Asia-Oceania, achieved the best scores during the study period, while, European carriers were, on average, less efficient than the others in the sample. Moreover, American and European airlines obtained low scores, over the 1980-1982 time span because of the second oil crisis.

Alam and Sickles (1997) evaluated technical efficiency of the US airline industry and explored some of the long-run properties of these scores, and specifically, the link between market structure and economic performance. The objective of their study was to test the hypothesis that competitive pressure enhances relative efficiency. DEA scores of technical efficiency for a sample of eleven (11) U.S. carriers were quarterly observed, during the time period 1970-1990. The time period 1970-1990, was very important for the US airline industry, because over this period, competition among the airlines increased because of deregulation. The results indicate that the scores move together and, in fact, the firms are becoming more alike one another in terms of efficiency.

Also, continuing their analysis of the U.S. airline industry, and using the same linear programming techniques (DEA and FDH) as before for the same sample of US carriers, Alam and Sickles (1998) provided the association between two firm performance measures: relative technical efficiency and stock market returns.

Fethi et *al.* (2000) investigated the determinants of the performance of the European airline industry. The panel data set consists of seventeen European airlines, over the period 1991-1995. The technical efficiency of individual airlines was calculated by using Data Envelopment Analysis (DEA). The determinants of these (in)efficiency scores were defined by using a Tobit model. This analysis aimed to explain the variation in calculated efficiencies to a set of explanatory variables as impact of concentration, ownership, degree of specialization, average stage length, route network density, load factor, and the effects of liberalization. The variables which were used in DEA model were similar to Schecfczyk (1993).The findings confirmed the negative effects of concentration and subsidy policies, on individual efficiencies. The state ownership, however, did not seem to effect the efficiency scores of individual airlines, in the study period. Furthermore, the findings suggested that in order to remain competitive and efficient, the European airlines need to improve their service quality.

Fethi et *al.* (2001) continued their efficiency and productivity analysis of the European airline industry, over the time period 1991-1995, using a modification of the DEA approach. The purpose of the study was to determine whether the measured effects of airline market liberalization have resulted in efficiency changes both in level and dispersion for the companies involved. Compared with DEA results, the average efficiency performance is much higher but it was not possible to determine a liberalization effect on technical efficiency.

Inglada et *al.* (2004) compared the economic and technical efficiency of international airlines, within the new liberalization framework that characterizes the time period 1996-2000. For this purpose, two stochastic frontiers are estimated, one for cost function, and the other for production function. The data consists of twenty (20) international air carriers, over the time period 1996-2000. Seven of these carriers are European, six North American, one Canadian, two Mexican, and four Asian. Four air carriers from Northeast Asia are the most efficient. The European and American carriers are behind. Generally, the results suggest large benefits of increasing competition, in terms of efficiency, in Asian airline industry. From the end of the 1980s, the national company monopoly was broken and entry was granted to second level companies, whose interests left a powerful mark on air transport policy in Asia. As a consequence, the Asia air market is powerful and very rapidly growing.

METHODOLOGICAL FRAMEWORK

Farrell (1957) was the first to provide us with the definition of technical efficiency and until the late 1970s its empirical application was very limited. However, Aigner *et al.* (1977), introduced the stochastic frontier production function, and Meeusen and van den Broeck (1977) considered the Cobb-Douglas production function with a composed multiplicative disturbance term. Since then, Farrell's idea became a standard tool for estimating technical (in)efficiency of various sectors and industries.

Three main approaches have been developed for the measurement of technical efficiency: parametric (deterministic and stochastic), non-parametric based on D.E.A. and productivity indices based on growth accounting and index theory principles (Coelli *et al*., 1998). D.E.A. and S.F.A. are the most commonly used methods for calculating the technical efficiency of a firm.

The S.F.A. approach requires a functional form in order to estimate the frontier production function and is based on the idea that the data is contaminated with measurement errors and other noise (Bauer, 1990). The D.E.A. approach uses linear programming techniques to estimate a piece–wise frontier that envelops the observations and requires no specific functional form for the production function (Fried *et al.* 1993). Also, an advantage of the D.E.A. approach is that multiple inputs and outputs can be considered simultaneously. However, D.E.A. cannot discriminate between inefficiency and noise, and tends to produce overestimated inefficiency measures, a fact which is the most important disadvantage of D.E.A. in comparison to S.F.A. For a detailed comparison of the two approaches (Bauer 1990).

The specification of the adopted model starts with the assumption that the technology applied in the production process can be described by a twice differentiable production function which relates the flow of output with various inputs of production. In algebraic terms the stochastic production frontier (SPF) can be expressed as:

$$y = f(\boldsymbol{X},\boldsymbol{\beta})exp(\varepsilon),\ \varepsilon = (v-u),\ u>0 \quad (1)$$

where: y is the observed output quantity; f is the deterministic part of the frontier production function, $\boldsymbol{X}$ is a vector of the input quantities used by the firm, $\boldsymbol{\beta}$ is a vector of parameters to be estimated, v is a symmetrical random error and u is a one-sided non-negative random error term representing technical efficiency. It is assumed that f is finite for every $\boldsymbol{X}$, and continuous for all nonnegative y and $\boldsymbol{X}$. The elements of v represent the conventional normal distribution of random elements including measurement errors, minor omitted variables, and other exogenous factors beyond the firm's control. The elements of u indicate shortfalls of the firm's production units from the efficient frontier.

The rationale of the so-called "composed error" specification is that production is subject to two random disturbances of different origin. The positive disturbance u expresses the fact that each firm's output lies on or below its frontier. Any deviation is the result of factors controllable by the firm, such as technical efficiency, the capability of the producer and his/her employees, the defective and damaged products, etc. However, the frontier itself may vary randomly over time for the same firm and consequently the frontier is stochastic, with random disturbance v, which expresses external to the firm events, such as statistical noise, observation and measurement error, luck, climate, and exogenous shocks beyond the control of the production unit. Thus, technical efficiency is measured by the ratio:

$$TE = y \,/\, [f(\boldsymbol{X})exp(v)] = exp(-u)$$

and has a value between 0 and 1, with 1 defining a technically efficient firm. Given a parametric functional form for f and distributional assumptions about u and v, equation (1) can be estimated by Ordinary Least Squares (O.L.S.).[4]

More specifically, equation (1) is written as:

$$ln(y) = ln[f(\boldsymbol{X})] + v - u \quad (2a)$$

$$ln(y) = -\mu + ln[f(\boldsymbol{X})] + (v-u+\mu) \quad (2b)$$

where:

$$\mu = E(u)>0.$$

The estimation of the S.P.F. by O.L.S. leads to consistent estimators for all the parameters, μ included, under the assumption that v is normally and u is half-normally distributed. The rationale behind normality is simply convenience at the estimation stage plus the fact that we lack information upon which to base alternative stochastic specification assumptions.[5]

Estimation of equation (2) by O.L.S. gives the residuals e_i , i = 1, 2, …, N. The second and third central moments of the residuals, $m_2(e)$ and $m_3(e)$ respectively, are calculated, as known, as follows:

$$m_2(e) = [1/(N-k)] \cdot \Sigma\, e_i^2 \quad (3a)$$

[4] Equation (1) could be estimated using the Maximum Likelihood (ML) method (Aigner *et al.* 1977). However, the O.L.S. estimators have statistical properties at least as desirable as those of the ML estimators (Olson *et al.* 1980), are easier to obtain and tend to provide encouraging results (Kumbhakar and Lovell, 2000).

[5] Half-normal and exponential distributions are traditionally employed for u. However, these two assumptions lead to very similar estimates (Caves and Barton 1990).

$$m_3(e) = [1/(N-k)] \cdot \Sigma e_i^3 \quad (3b)$$

where:

N is the number of observations and k is the number of regressors, the constant term included. Then, we estimate σ^2_u and σ^2_v using the formulae (Georganta 1993):

$$\sigma^2_u = [(\pi/2)[(\pi/(\pi-4)]m_2(e)]^{2/3} \quad (4a)$$

$$\sigma^2_v = m_2(e) - [(\pi-2)/\pi)]\ \sigma^2_u \quad (4\beta)$$

Following Battese and Coelli (1988), the point measure of technical efficiency is:

$$TE_i = E(exp\{-u_i\}/\varepsilon_i) = [[1-F[\sigma-(M_i^*/\sigma)]/[1-F(-M_i^*/\sigma)]exp[-M_i^* + (\sigma^2/2)] \quad (5)$$

where: F denotes the distribution function of the standard normal variable. Also:

$$M_i^* = (-\sigma^2_u\varepsilon_i)(\sigma^2_u + \sigma^2_v)^{-1} \quad (6a)$$

$$\sigma^2 = \sigma^2_u\, \sigma^2_v\, (\sigma^2_u + \sigma^2_v)^{-1} \quad (6b)$$

DATA

The panel data set consists of annual observations of twenty four (24) international airline companies over the time period 1991-2002. The choice of the analyzed airline companies was subject to data availability. Also, it was based on the kind of service they offer since all the carriers of the sample had to be oriented mainly towards passengers' transportation. The carriers should also serve as international (and domestic) carriers, while they should annually carry at least 2.500.000 passengers. Finally, all the carriers of the sample should be large-scale over the time period.

The airlines come from the major markets, all over the world. Specifically, five (5) among them are from the U.S.: United Airlines, American Airlines, Delta Airlines, Northwest Airlines, and Continental Airlines; eight (8) from Europe: British Airways (U.K.), Swissair (Switzerland), Lufthansa (Germany), Air France (France), KLM (Holland), SAS (Scandinavia), Alitalia (Italy), and Iberia (Spain); seven (7) from southeast Asia: Japan Airlines (Japan), Singapore Airlines (Singapore), All Nippon Airlines (Japan), Cathay Pacific (Hong-Kong), Korean Airlines (Korea), Thai International (Thailand), and Garuda (Indonesia); one (1) carrier comes from Canada: Air Canada; two (2) from South America: Aeromexico (Mexico), and Varig Airlines (Brazil); finally, one (1) comes from Australia: Qantas Airways.

The airline companies of the sample are private, public or mixed. Moreover, four (4) of them changed ownership type during the study period. Specifically, Swissair, Lufthansa and SAS, which until 1996 were mixed, and then became private, and the Brazilian Varig, which until 1996 was private, and then became mixed.

The data set consists of four (4) variables. The inputs are: the total annual labor in persons employed (pilots, co-pilots, cabin attendants, etc.), the total annual available aircraft capacity, and the total annual energy expanded (fuel and oil). The single output is the total annual available passenger-kilometers. Each of these variables reflects the operational characteristics of each carrier. The main source of the data is Air Transport World (Vol. 29-40, June 1992-June 2003).

EMPIRICAL RESULTS

From a methodological point of view the question of efficiency is examined by using the Cobb-Douglas or the translog production function. In this paper, the functional form of the production function for S.F.A. was specified as a Cobb-Douglas. Specifications such as the translog provide the opportunity to characterize the data in a more flexible way. However, it tends to be seriously over-parameterized. As Coelli *et al.* (1998) noted the translog estimates are likely to suffer from degrees of freedom and multicollinearity problems resulting in inefficient estimates. Thus, the adopted functional form, corresponding to equation (1) is:

$$lnY = a_o + a_1 T + a_2 \, lnK + a_3 \, lnL + a_4 lnE + v - u \quad (8)$$

where: Y is a measure of output, T is a measure of time expressing technological change, K a measure of capital stock, L is a measure of labor, and E a measure of energy spending. Table 1 presents the estimate of the production function.[6]

Table 1: Production function estimate

Determinant	Value	T-statistic
a_0	1.464	3.526*
a_1	0.027	4.831*
a_2	0.279	5.277*
a_3	0.257	4.068*
a_4	0.468	9.284*
R^2	0.834	
S.E.E.	0.317	

Turning now to the regression results reported in Table 1, we can see that the estimated coefficients are highly significant for all parameters. Consequently, there is no need to remove any variable from the model. The regression explains a very high 83.4% of the variability of output, and there is no evidence of autocorrelation of the residuals as was tested using the relevant procedures. These results show that the model used provides very good fit to the data.

Since the total production and the regressors are expressed in logarithms, the coefficients are interpretable as output elasticities. As known, returns to scale (R.T.S.) are calculated from the sum of the inputs' coefficients as[7]:

$$R.T.S. = a_2 + a_3 + a_4 = 0.279 + 0.257 + 0.468 = 1.004$$

This result implies that the air transportation industry experiences constant returns to scale. Finally, since a_1 which expresses the average annual growth rate of technology was found to be equal to 2.7%, the positive effect of technological progress in the model is confirmed.

The next step is, through equation (5), to estimate the annual technical efficiency (T.E.) for each carrier, for the 1991-2002 time span. Summary statistics for technical efficiency are presented in Table 2. The same data was employed to estimate technical efficiency through

[6] It should be noted that technical efficiency is estimated for a single firm over the period 1970-1997 with respect to the firm's time series performance and not with respect to other similar firms since the firm is, practically, a monopoly in the market. In this case, our analysis pinpoints the year(s) that the firm enjoyed its most efficient operation.

[7] Note that if: (i) $a_1 + a_2 + a_3 = 1$, then there are constant returns to scale, (ii) $a_1 + a_2 + a_3 < 1$, decreasing returns to scale and (iii) $a_1 + a_2 + a_3 > 1$, increasing returns to scale.

D.E.A (Synodinos, 2005). The efficiency estimates computed by D.E.A. are used for the comparison with the S.F.A. estimates (Table 2).

Table 2: Results of efficiency estimates

Carrier	S.F.A.	D.E.A.
United airlines	0.983	0.688
American airlines	0.954	0.627
Delta airlines	0.981	0.688
Northwest airlines	0.986	0.704
British airways	0.975	0.607
Japan airlines	0.994	0.825
Continental ailines	0.977	0.683
Swissair	0.700	0.475
Lufthansa	0.736	0.405
Air france	0.800	0.457
Qantas airways	0.994	0.744
Singapore airlines	1.000	0.938
KLM	0.987	0.728
All Nippon airlines	0.956	0.660
Aeromexico	0.889	0.592
SAS	0.479	0.259
Cathay pacific	0.997	0.826
Korean airlines	0.973	0.557
Alitalia	0.781	0.423
Air Canada	0.882	0.520
Thai international	0.991	0.713
Garuda	0.830	0.595
Iberia	0.752	0.433
Varig airlines	0.880	0.504

The results show that the average technical efficiency of almost all the carriers (except one), is over 70% while technical efficiency of fourteen of the twenty four carriers is over 95%. Figure 1 shows the average technical efficiency, by continent of origin. The U.S. carriers are on average the most efficient carriers, with an average technical efficiency equal to 97.64%. The Asian carriers follow with 96.30%, and then the South American carriers with 88.36%, while, the European carriers with 77.63% are the least efficient.

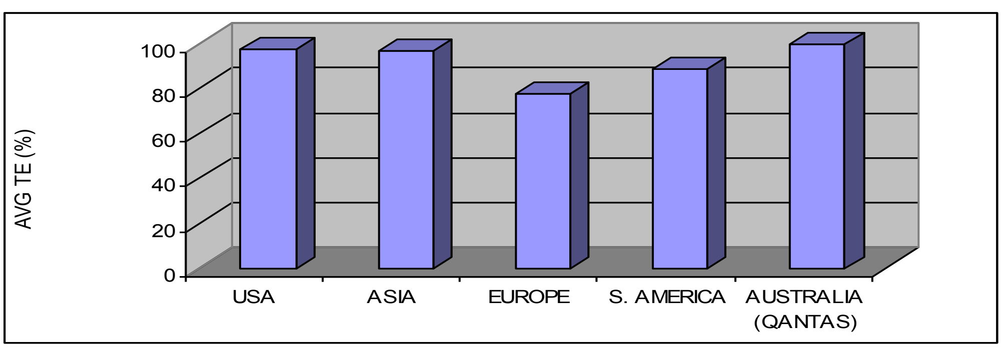

Figure 1: Average technical efficiency by continent of origin (%)

Next, figure 2 suggests that the time period 1991-2002 could be separated in two sub-periods: First, in the 1991-1997 time span, in which there is an increase in technical efficiency from an average 84.14% (1991) to 92.39% (1997), corresponding to an 1.37% average annual increase, and in the 1997-2002 time span, in which there is a decrease in the average technical efficiency from 92.39% (1997) to 86.56% (2002), corresponding to an 1.16% average annual decrease. In the 1996-1999 time span we observe the highest values in terms of technical efficiency (over 90%).

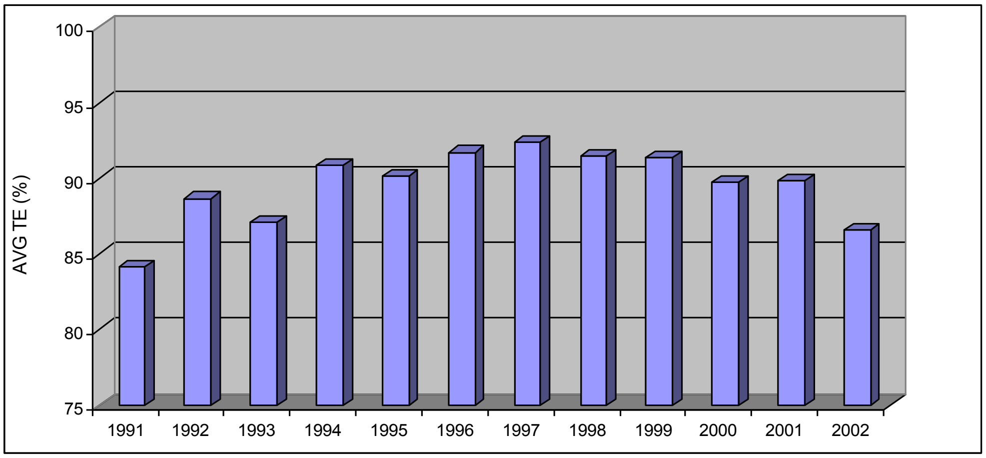

Figure 2: Average annual technical efficiency (%)

Also, in Figure 3 we investigate graphically the hypothesis that private carriers appear to be more efficient than public ones. Actually, figure 3 indicates that the private carriers are indeed the most technical efficient. Specifically, the technical efficiency measures of eleven of the thirteen private carriers range over 95%. The carriers with mixed state ownership appear slightly less efficient than the private ones. Finally, public carriers appear far less efficient. In fact, the average technical efficiency of private carriers is equal to 96.48%, of mixed carriers equal to 91.18% and of public carriers equal to 79.06%.

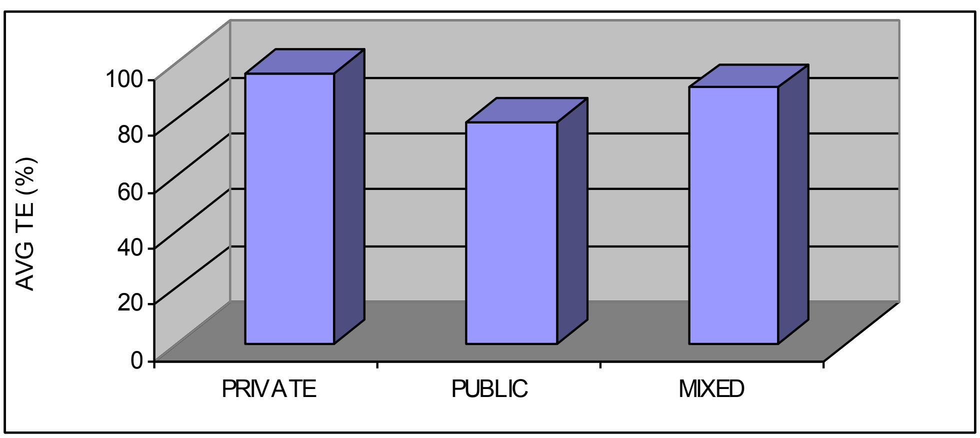

Figure 3: Average technical efficiency per state ownership (%)

Regarding the carriers which changed ownership state within the study period, Figure 4 suggests that, the levels of technical efficiency before and after the change are approximately the same. It's accordingly assumed that the change of the state ownership didn't affect their technical efficiency performance.

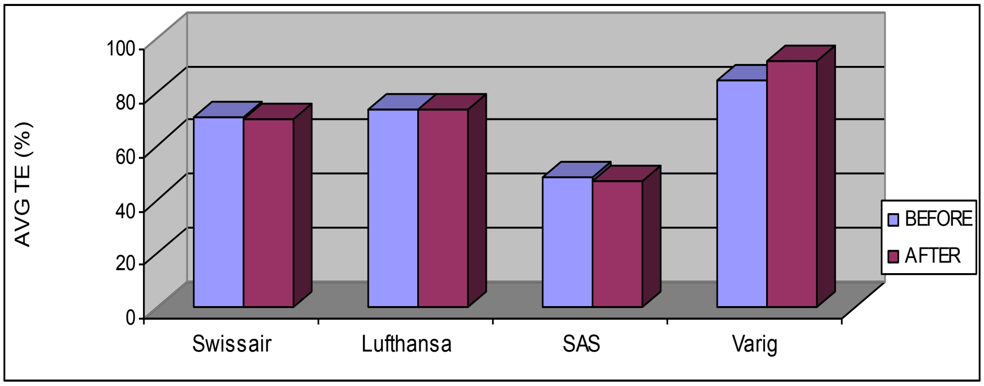

Figure 4: Average technical efficiency and change of the state ownership (%)

COMPARISON WITH D.E.A.

Table 2 presented the average technical efficiency of each carrier of the sample, estimated by the two different approaches, the parametric S.F.A. and the non-parametric D.E.A. (Synodinos, 2005) for the 1991-2002 time span. Not surprisingly, the average technical efficiency estimated by D.E.A. is lower than the one estimated by S.F.A. as D.E.A. attributes the entire distance from the frontier to inefficiency. In other words, D.E.A. cannot discriminate between inefficiency and noise. Actually, Figure 5 illustrates that the S.F.A. and D.E.A. estimates of technical efficiency follow a similar pattern with a small time delay.

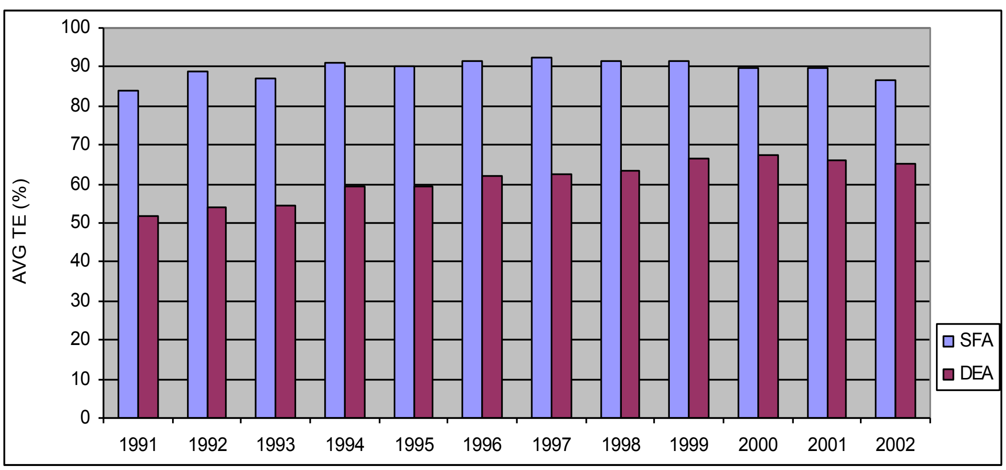

Figure 5: Average annual technical efficiency (%)

Actually, most of the studies using both D.E.A. and S.F.A. report such conclusions (see, for instance, Bruemmer 2001). This difference stems from the different methodology used, i.e. in D.E.A. the frontier is determined by the best practice observed. However, the correlation coefficient and the ranking correlation index confirm the consistency of the empirical results derived by these two different methodologies (Bryce et al, 1998).More precisely, the correlation coefficient of the estimates of the two different methods (see Table 2) is 80%, which is considered as high for this type of investigations. Meanwhile, Table 3 illustrates the carriers' ranking. The corresponding ranking correlation is 97%, which is also very high. This means that, regardless of the method used, the carriers' ranking is almost the same.

Table 3: Airlines' ranking

Ranking	S.F.A.	D.E.A.
1	Singapore Airlines	Singapore Airlines
2	Cathay Pacific	Cathay Pacific
3	Japan Airlines	Japan Airlines
4	Qantas Airways	Qantas Airways
5	Thai International	KLM
6	KLM	Thai International
7	Northwest Airways	Northwest Airways
8	United Airlines	United Airlines
9	Delta Airlines	Delta Airlines
10	Continental Airlines	Continental Airlines
11	British Airways	All Nippon Airlines
12	Korean Airlines	American Airlines
13	All Nippon Airlines	British Airways
14	American Airlines	Garuda Airlines
15	Aeromexico	Aeromexico
16	Air Canada	Korean Airlines
17	Varig Airlines	Air Canada
18	Garuda Airlines	Varig Airlines
19	Air France	Swissair
20	Alitalia	Air France
21	Iberia	Iberia
22	Lufthansa	Alitalia
23	Swissair	Lufthansa
24	SAS	SAS

More specifically, Singapore Airlines is the most technical efficient carrier, with both estimates. Cathay Pacific, Japan Airlines, Qantas Airways, Thai International, KLM, Northwest Airlines, United Airlines, and Delta Airlines also rank in the top positions of the sample. Continental Airlines, British Airways, Korean Airlines, All Nippon Airlines, American Airlines, Aeromexico, and Air Canada, rank in the middle positions, while, Varig Airlines, Lufthansa, Swissair, Air France, Alitalia, and Iberia rank in the lower positions, including SAS, which ranked last, regardless of the method used.

Next, as can be seen in Table 4 the S.F.A. and D.E.A. annual estimates of technical efficiency are highly correlated. The highest correlations are found for the years 1993 (89.8%) and 1991 (89.5%). On the other hand, the lowest correlation is found for the year 2000 (67.5%).

Table 4: TE estimates' correlation by year

Year	Correlation
1991	0.895
1992	0.853
1993	0.898
1994	0.866
1995	0.879
1996	0.776
1997	0.731
1998	0.763
1999	0.773
2000	0.675
2001	0.762
2002	0.823

Furthermore, regardless of the methodology used, the U.S. and the Asian carriers appear to be the most technically efficient. The carriers from South America follow, while, the European carriers are far less efficient. In other words, both methodologies produce consistent results in terms of the continent of origin (see Figure 6).

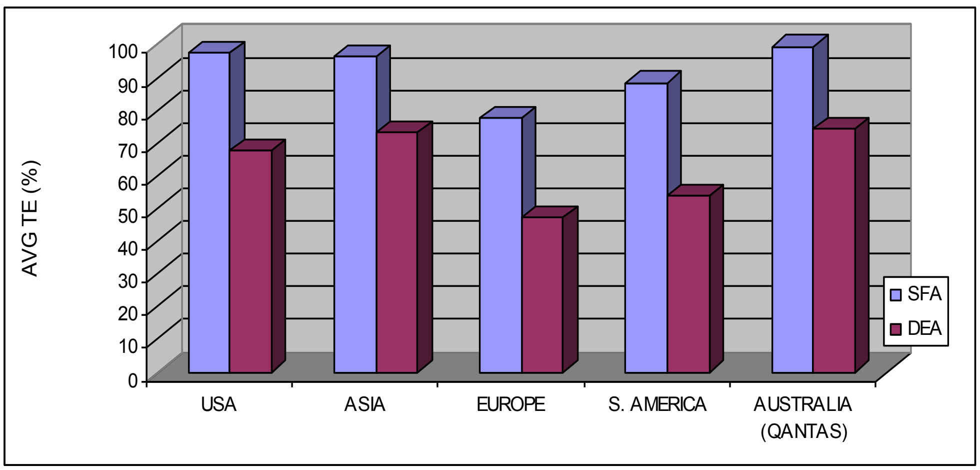

Figure 6: Average technical efficiency by continent of origin (%)

Also, as is illustrated in Figure 7, similarly with SFA, in DEA the private carriers are the most efficient. The mixed carriers are less efficient, while the public are the least efficient. Finally, with regard to the carriers which changed state ownership, neither in DEA nor in SFA, the changes in the efficiency measures, before and after the state ownership change, suggests that this change affected the carriers' performance, over the study period.

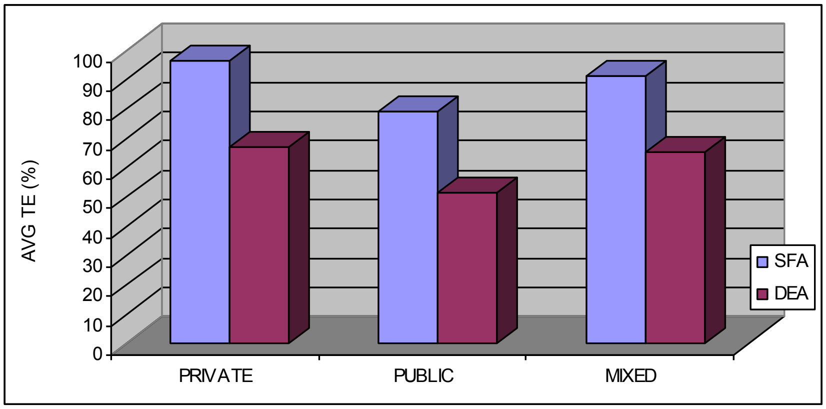

Figure 7: Average technical efficiency by state ownership(%)

Our empirical results are consistent, in general terms, with the findings by Good et *al.* (1993), Schefczyk (1993) and Inglada et *al.* (2004). For instance, all these studies conclude that the Asian and U.S. carriers appear to be the most technically efficient. More specifically, Singapore Airlines and Cathay Pacific rank in the top positions in most of these studies. Contrary to this, the European carriers are considerably less efficient, except for KLM and British Airways.

CONCLUSION

The present paper estimated technical efficiency in International Air Transport, within the framework of Stochastic Frontier Analysis (S.F.A.). It was based on Panel Data for twenty four (24) airline carriers worldwide, over the time period 1991-2002 by employing the Cobb-Douglas specification of the production function.

A first finding of our investigation was that air transportation carriers, worldwide, experienced constant returns to scale. A second interesting result was that technical efficiency of air transportation carriers, worldwide, ranged between 37% and 100% with an arithmetic average equal to about 89%. However, the industry's performance worldwide in terms of technical efficiency did not follow a clear trend in time, whereas some differences in performance depending on the corporation's continent of origin were observed. More precisely, the American, Australian and Asian have left behind the European companies. Also, the level of technology experienced a slight increase, while the privatization of very few air transportation companies in our data set did not seem to have any systematic impact on them in terms of technical efficiency.

Finally, the results were compared with those yielded by the linear programming approach and the estimates were found to be very consistent with the results using Data Envelopment Analysis (D.E.A.)

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