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# **European Airlines: a Stochastic DEA study of efficiency with market liberalisation<sup>1</sup>**

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## **Abstract**

Stochastic DEA constructs production frontiers that incorporate both inefficiency and stochastic error. This results in a closer envelopment of the mean performance of the companies in the sample and diminishes the effect of extreme outliers. We use the Land, Lovell and Thore (1993) model incorporating information on the covariance structure of inputs and outputs to study efficiency across a panel of 17 European airlines in the 1990s during the early phase of liberalisation. After allowing for stochastic error in computing the relative efficiencies we conclude that the airlines that were efficient in 1995 resembled those that were efficient in 1993 but not those in 1991. The airlines that were efficient in 1995 were the larger companies.

**Keywords:** Liberalisation, stochastic DEA, airlines

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## 1. Introduction

Why are we interested in the efficiency and productivity analysis of a particular industry? There are often two objectives in the mind of researchers when important policy changes have occurred. The first is to evaluate the effects of the policy change and for this we look for sharp differences in the performance of companies depending on the extent to which they have responded. The second objective is to provide the closest envelopment of the observed data, and for this purpose a wide range of Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) models have been developed. The dilemma of model choice depends on the trade off between minimal specification which favours DEA and allowing for stochastic error in measuring company efficiency which favours SFA.

In the past few years the theoretical papers of Land, Lovell and Thore (1993) (LLT) and Olesen and Petersen (1995) (OP) have offered the interesting prospect of stochastic data envelopment analysis SDEA. This can be interpreted as a way of allowing for stochastic error in the standard DEA model. One objective of this paper is to apply this approach to the study of the liberalisation of the European airline industry over the period 1991-5. In particular we explore the LLT model which treats the constraints in an envelopment form of DEA as subject to chance. The second objective of the paper is to determine whether the measured effects of airline market liberalisation have resulted in efficiency changes both in level and dispersion for the companies involved. When all of the observations are treated as deterministic so that all variation is attributed to relative inefficiency it is easy to overstate the effect of policy changes in the short term. Consequently we expect that the SDEA model, if it can be successfully applied will

reduce the clarity of the policy conclusions. The question is whether any strong conclusions will remain about the effect of the liberalisation after we provide the closer envelopment of the data that goes with the SDEA model.

The structure of the paper is as follows. Section 2 describes the policy background while section 3 reviews other non-parametric airline studies. Section 4 describes the SDEA model and its implementation and also provides an interpretation. Section 5 describes the data to be used and section 6 summarises the empirical results. Section 7 concludes.

## **2. The Evolution of Regulatory Policy in the Europe airlines industry**

The regulation of international aviation was initiated with the Paris convention of 1919. It was accepted that states have sovereignty rights over the air space above their territory. This directly involved national governments in the regulation of the industry. Control was mainly handled with a set of *ad hoc* arrangements between nations. The rules on certain economic rights, however, were not set till the 1944 Chicago Conference.

The Conference, involving fifty-two nations, was organised to discuss the possibility of establishing a multilateral agreement in order to develop international air services. Mainly this agreement aimed to deal with three aspects of international transport: the exchange of traffic rights, or 'freedoms of the air'; the control of tariffs; and the control of frequencies and capacities (Doganis, 1991:26). The participant nations were only able to reach agreement in the first two freedoms and no multilateral agreement was reached on the other freedoms.

Over the years, bilateral air services agreements have emerged to regulate all essential elements related to the exchange of air services between nations. Most bilateral agreements involved only the national carriers, from the individual states. The Bermuda agreement signed between the UK and the US in 1946 became a model for many other bilateral agreements. In particular, an agreement would determine the load capacity and frequencies. With restrictive ‘pooling agreements’, the individual states could share the capacity and the revenue earned from those routes. This led to a regulated duopoly where the participants were usually the government owned national carriers. The governments strictly controlled entry into the industry by refusing to licence competitors. Secured with such agreements, the interests of “flag” carriers were always protected. As a result, competition was eliminated.

In the 1957 Treaty of Rome, which aimed to establish economic integration in the European Community, the position of air transport was not clear. Whilst Article 3 of the Treaty applied to road, rail and inland waterways, the air and sea transport were exempted from the competition rules of the Treaty until a Community-wide policy could be developed. A considerable pressure for the liberalisation in European aviation came from the European Commission (EC) to direct the extent to which regulatory policy has been relaxed in Europe. The EC is the largest international body in European aviation whose attitudes towards liberalisation have significant implications not only for the EC members but the other states as well. Indeed, the increasing number of liberalised bilateral agreements between the EC airlines and other European carriers necessitated changes in the ongoing system to create a multilateral liberalisation, thus provide an important stimulus towards a freer market within the EC.

The EC had suggested reforms in 1972 to open aviation to competition, but a decisive push to liberalise air transport in the European Union came with the experience of deregulation in the US domestic airlines, signing of the single European Act and the 'Nouvelles Frontieres' case in 1986. This resulted in three 'liberalisation packages' that were agreed in December 1987, June 1990 and July 1992.

The First Liberalisation Package of measures provided for limited freedom to compete on cheap fares, but offered multiple designation on the busier routes, and less restrictive capacity sharing agreements, which entitled either country to operate up to 60% of capacity (Vincent and Stasinopoulos, 1990).

The Second Package of reforms allowed more flexible conditions on setting fares and improving market access. Deep discount fares, for example, were introduced without requiring government approval. The lower limit was reduced from 45% in the 1987 package to 30% of the reference economy fare. Restrictions imposed on capacity shares were gradually removed and aimed to be fully eliminated by January 1993 – the date of the Single Market for European aviation (Stasinopoulos, 1992).

Integrating aviation within the overall framework of the EC policies for the Single Market forced the EC to agree the Third Liberalisation Package with more drastic measures. It was aimed to create a more competitive environment for European aviation. Airlines could set their own tariffs freely, subject to the safeguards against the predatory pricing or excessive prices. The opening of access to all intra-Community routes, i.e. the cabotage rights, will be gradual and completed in 1997. With respect to licensing there will not be any discrimination in favour of flag carriers. Any technically and financially

sound Community airline can obtain license and fly on any EC route (Stasinopoulos, 1993).

It had taken so long to bring European countries to reach a consensus on a multilateral agreement. However, triple package of measures to liberalise the market gradually were aimed to achieve this purpose. January 1993 witnessed the emergence of open skies within Europe after the legislators of the EU applied the principles of a single market to the airlines industry even though it had been indeed difficult to eliminate the conflicts of interest in an industry traditionally entrenched in national interest with the vast majority of carriers state-owned.

### **3. Literature Survey: Non-parametric Airlines Applications**

This section reviews four studies where the nonparametric strength of DEA is used to measure the efficiency and productivity of the airlines industry. Schefczyk (1993) presented a model to measure operational performance for airlines. The inputs were available tonne kilometre (ATK), operating cost, and non-flight assets. The outputs were revenue passenger kilometre (RPK) and non-passenger revenue. Based on this model, DEA was used to analyse the performance of fifteen large international airlines for the year, 1990.

Four airlines, Cathay Pacific, Federal Express, Singapore Airlines and UAL Corporation appeared the most efficient airlines with 100% efficiency scores. All four European airlines in the sample, British Airways, Iberia, KLM and Lufthansa were inefficient, with the efficiency scores less than 100%. Schefczyk continued his analysis

with regression analysis to determine the relationship between these efficiency scores and some strategic variables, e.g. profitability, focus of the airline, revenue growth or load factors. The findings implied that the efficient, well-utilised and passenger-focused airline was most likely to be profitable.

Distexhe and Perelman (1994) aimed to evaluate the consequences of deregulation by measuring the airlines' technical efficiency and productivity growth over the period 1977 to 1988. The sample was composed of thirty-three airlines operating in scheduled international markets in three groups: Asia and Oceania, Europe and North America. DEA was used to construct several production frontiers of airline activities. Then, they followed the approach by Färe, Grosskopf, and Roos (1992) to estimate the Malmquist productivity index and decompose this index into technological progress or efficiency change. The production technology was defined with two inputs and one output. The inputs were labour and capital. Labour was measured in terms of the number of flying personnel and capital was by total available aircraft capacity weighted by the number of days. The output was available tonne kilometre, in freight and passenger services.

The results suggested that, regardless of the method used, the average levels of technical efficiency in the eighties were higher than those obtained in the seventies. The European carriers, on average, were technically less efficient than the other carriers in the sample. Among the European carriers, Lufthansa, KLM and Air France recorded high efficiency scores, whereas British Airways, Alitalia and Swissair could not achieve more than 80% efficiency level. The results for small carriers improved when the two characteristics were taken into account, e.g. Finnair and Aer Lingus recorded higher efficiency scores. The results obtained by the Malmquist indices of productivity were



similar to the findings achieved by DEA. Lufthansa, Finnair and Air France obtained the best results along with the Japan Airlines, Singapore Airlines, American and TWA. North American and European airlines obtained low scores during the period 1980-1982 due to the impact of the second oil crisis. “The Asia and Oceania” group achieved best scores in all periods due to their ability to gain from technological process.

In the study by Good, Nadiri, Roeller, and Sickles (1995) efficiency and productivity differentials between European and US carriers are identified. The authors used two alternative methodologies – a parametric one using statistical estimation, and a nonparametric one using a linear programming technique. Moreover, the firm-specific and time-dependent efficiency and productivity differences were used to rank carriers through time. Finally, they simulated the potential benefits that could be achieved were the airlines operated under less regulated environments. The data set covered the period of 1976-1986 and consisted of a panel data of the eight largest European carriers and the eight largest American airlines. A set of three airline inputs was constructed in a similar way as in the previously review studies. Additionally, three characteristics of airline output and two characteristics of the capital stock were calculated. These were load factor, stage length, a measure of network size, the percent of the fleet (wide-bodied), the percent of the fleet (turboprop propulsion).

The results of this study showed that the US carriers were around 15-20% relatively more efficient. This was also confirmed with the lower productivity growth of European. However, allocative inefficiencies were present in both European carriers, with most of the inefficiency coming from over-utilisation of materials with less capital. Among the European carriers, only Lufthansa and British Airways showed positive trends in their

efficiency scores. The authors suggested that the institutional and organisational developments in these companies were the primary reasons of their success. Moreover, it was calculated that European carriers would save approximately \$4 billion per year (in 1986 dollars) if they became productively efficient as the US carriers, which operated under deregulation.

Fethi (2000) investigated the performance of European airlines industry for a panel data set of 17 airlines European airlines over the period of 1991-1995. Three methodologies were used in this study: DEA, Tobit analysis, and DEA based Malmquist productivity index. The technical efficiency of individual airlines was examined using the non-parametric frontier methodology, the Data Envelopment Analysis (DEA). To investigate the determinants of efficiency, Tobit model was used. This analysis aimed to explain the variation in calculated efficiencies to a set of explanatory variables, i.e. impact of concentration, ownership, degree of specialisation, average stage length, route network density, load factor, effects of liberalisation. The variable selection procedure was similar to Schefczyk (1993).

The empirical findings confirmed the detrimental effects of concentration and subsidy policies on individual efficiencies. The state ownership however, did not provide an impediment for being efficient in this sample. Further, the findings suggested that in order to remain competitive and efficient, the European airlines needed to maintain their service quality – increase the load factors.

The DEA based Malmquist productivity index results indicated that the airlines experience productivity growth in only one period (1993-94) which stemmed from the increase in technical efficiencies. The remaining periods (1991-92 and 1994-95)

exhibited productivity decline which could be explained by a deterioration of the performance of best practice airlines, whereas in 1992-93, the decline occurs due to the divergence from best practices on the part of the remaining airlines. Small airlines (i.e. Aer Lingus, Air Malta, Cyprus Airways and Icelandair) experienced negative growth rates within the study period whereas some larger airlines (i.e. Air France, Alitalia, Austrian Airlines, British Airways, Iberia and Air Portugal) experienced positive average annual growth rates.

#### 4. Stochastic DEA: Theory and Model

The procedure for DEA measurement of input based technical efficiency is well known. We take each firm in turn and compare it with the reference set of the whole industry. This is represented by the input requirements set for a given level of outputs, which is bounded below by the isoquant. The object here is to find the largest reduction in the firm's actual input usage which will allow it to remain in the input requirements set, i.e. achieve a position on the efficient frontier isoquant determined by the observations on the industry as a whole.

Doing this for each firm in turn we identify the firm's  $q$  value. This is the firm's Farrell efficiency:  $0 \leq q \leq 1$ . Values of  $q = 1$  indicate that the firm is already one of those which defines the frontier and is 100 per cent efficient. The firm's inefficiency is  $(1-q) \times 100\%$ . In what follows it is necessary to examine particular output and input constraints which can be written in terms of  $s$  outputs:  $y_{rj}, r = 1K s, j = 1K n$  and  $m$  inputs:  $x_{ij}, i = 1K m, j = 1K n$  for the  $n$  different producing units (airlines). The input

requirement set is defined by the following inequalities for each producing unit in turn. The producing unit under observation is subscripted '0' to distinguish it from all of the producing units together:  $j = 1, \dots, n$

$r^{\text{th}}$  typical output constraint:

$$\mathbf{y}_r' \mathbf{l} - y_{r0} \geq 0 \quad \text{i.e.} \quad \sum_{j=1}^{j=n} y_{rj} \mathbf{l}_j - y_{r0} \geq 0 \quad r = 1, \dots, s$$

$i^{\text{th}}$  typical input constraint:

$$\mathbf{x}_i' \mathbf{l} - x_{i0} \mathbf{q} \leq 0 \quad \text{i.e.} \quad \sum_{j=1}^{j=n} x_{ij} \mathbf{l}_j - x_{i0} \mathbf{q} \leq 0 \quad i = 1, \dots, m$$

We measure the producing unit's technical efficiency by calculating the following linear programme for the firm in question (now subscripted 0):

$$\begin{aligned} \min \mathbf{q} \quad & \text{s.t.} \\ \mathbf{y}_r' \mathbf{l} - y_{r0} & \geq 0 \\ \mathbf{x}_i' \mathbf{l} - x_{i0} \mathbf{q} & \leq 0 \end{aligned}$$

We now return to the chance constrained DEA problem described by LLT (1993). This allows the constraints to hold with probability level  $\mathbf{a} \in (0,1)$  i.e. with less than certainty:

$$\begin{aligned} \min \mathbf{q} \\ \text{s.t.} \\ \Pr\left(\mathbf{y}_r' \mathbf{l} - y_{r0} \geq 0\right) & \geq \mathbf{a} \quad r = 1, \dots, s \\ \Pr\left(\mathbf{x}_i' \mathbf{l} - x_{i0} \mathbf{q} \leq 0\right) & \geq \mathbf{a} \quad i = 1, \dots, m \end{aligned}$$

Charnes and Cooper (1963) show how to use the idea of a modified certainty equivalent to transform this stochastic linear programming problem into a deterministic non-linear programming problem. The difference between the firm's output and the reference weighted outputs of all the firms is treated as a random variable. The difference between the firm's input adjusted for its efficiency and the reference weighted inputs of all the firms in the industry is also treated as a random variable.

We begin with the constraints relating to the outputs, and re-write them as below. In these steps we assume that the random variable has a finite positive variance so that the standard deviation:  $\left( \text{var}\left( \mathbf{y}_r' \mathbf{I} - y_{ro} \right) \right)^{\frac{1}{2}}$  can be used as a divisor

Now assume the random variable representing the output shortfall is normally distributed:

$$\left( \mathbf{y}_r' \mathbf{I} - y_{ro} \right) \sim N \left[ E \left( \mathbf{y}_r' \mathbf{I} - y_{ro} \right), \text{var} \left( \mathbf{y}_r' \mathbf{I} - y_{ro} \right) \right]$$

Using  $\Phi(z)$  to represent the cumulative distribution function of the standard normally distributed variable we write the standard normal deviate as  $z = \Phi^{-1}(\mathbf{a})$  for given  $\mathbf{a}$ . Consequently

$$\Phi \left( \frac{E(\mathbf{y}_r' \mathbf{I} - y_{ro})}{\left( \text{var}(\mathbf{y}_r' \mathbf{I} - y_{ro}) \right)^{\frac{1}{2}}} \right) \geq \mathbf{a}$$

and so

$$\frac{E(\mathbf{y}_r' \mathbf{I} - y_{ro})}{\left( \text{var}(\mathbf{y}_r' \mathbf{I} - y_{ro}) \right)^{\frac{1}{2}}} \geq \Phi^{-1}(\mathbf{a})$$

giving:

$$E(\mathbf{y}_r' \mathbf{I} - y_{ro}) \geq z \left( \text{var}(\mathbf{y}_r' \mathbf{I} - y_{ro}) \right)^{\frac{1}{2}}$$

This completes the transformation of the probabilistic version of the linear output constraint into a deterministic non-linear form using what Charnes and Cooper (1963) refer to as a modified certainty equivalent. It is useful to write it in a slightly more general form as follows.

$$\mathbf{y}_r' \mathbf{I} + (\mathbf{E}\mathbf{y}_r - \mathbf{y}_r)' \mathbf{I} - z \left( \text{var}(\mathbf{y}_r' \mathbf{I} - y_{ro}) \right)^{\frac{1}{2}} \geq E y_{ro}$$

Turning now to the input constraints, these are initially expressed as:

$$\Pr(\mathbf{x}_i' \mathbf{I} - x_{io} \mathbf{q} \leq 0) \geq \mathbf{a}$$

together with the normality assumption:

$$(\mathbf{x}_i' \mathbf{I} - x_{io} \mathbf{q}) \sim N \left[ E(\mathbf{x}_i' \mathbf{I} - x_{io} \mathbf{q}), \text{var}(\mathbf{x}_i' \mathbf{I} - x_{io} \mathbf{q}) \right]$$

Proceeding as before we therefore write:

$$\frac{E\left(\mathbf{x}_i' \mathbf{l} - x_{i0} \mathbf{q}\right)}{\left(\text{var}\left(\mathbf{x}_i' \mathbf{l} - x_{i0} \mathbf{q}\right)\right)^{\frac{1}{2}}} \leq -\Phi^{-1}(\mathbf{a})$$

and

$$E\left(\mathbf{x}_i' \mathbf{l} - x_{i0} \mathbf{q}\right) \leq -\Phi^{-1}(\mathbf{a}) \left(\text{var}\left(\mathbf{x}_i' \mathbf{l} - x_{i0} \mathbf{q}\right)\right)^{\frac{1}{2}}$$

This completes the transformation as in the output case, but again we can write the transformed non-linear constraint in a slightly more general form:

$$\mathbf{x}_i' \mathbf{l} + (\mathbf{E}\mathbf{x}_i - \mathbf{x}_i)' \mathbf{l} + z \left(\text{var}\left(\mathbf{x}_i' \mathbf{l} - x_{i0} \mathbf{q}\right)\right)^{\frac{1}{2}} - Ex_{i0} \mathbf{q} \leq 0$$

We are now in a position to implement stochastic DEA as a deterministic non-linear programming problem.

For clarity of setting up the model, LLT (1993) suggest that the problem can be restated in non-matrix terms. Using  $Z_{1-\mathbf{a}}$  to denote the critical value of  $z$  from the standard normal tables, we have for the mean performance case:

**min**  $\mathbf{q}$

*s.t.*

$$\sum_{j=1}^{j=n} y_{rj} \mathbf{l}_j + \sum_{j=1}^{j=n} (Ey_{rj} - y_{rj}) \mathbf{l}_j - Z_{1-\mathbf{a}} \left[ \sum_{j=1}^{j=n} \sum_{k=1}^{k=n} \mathbf{m}_j \mathbf{m}_k (\text{cov}(y_{rk} y_{rj})) \right]^{\frac{1}{2}} \geq Ey_{r0}$$

$r = 1 \text{K } s$

$$\sum_{j=1}^{j=n} x_{ij} \mathbf{l}_j + \sum_{j=1}^{j=n} (Ex_{ij} - x_{ij}) \mathbf{l}_j + Z_{1-\mathbf{a}} \left[ \sum_{j=1}^{j=n} \sum_{k=1}^{k=n} \mathbf{n}_j \mathbf{n}_k (\text{cov}(x_{ik} x_{ij})) \right]^{\frac{1}{2}} - Ex_{i0} \mathbf{q} \leq 0$$

$i = 1 \text{K } m$

In this restatement:

$$\mathbf{m}_j = \mathbf{l}_j, \text{ for } j = 1 \dots n, j \neq 0 \text{ and } \mathbf{m}_j = \mathbf{l}_j - 1, \text{ for } j = 0$$

and

$$\mathbf{n}_j = \mathbf{l}_j, \text{ for } j = 1 \dots n, j \neq 0 \text{ and } \mathbf{n}_j = \mathbf{l}_j - \mathbf{q}, \text{ for } j = 0$$

This is a non-linear programming problem in the variables:  $\mathbf{q}$ ,  $\mathbf{l}_j$ ,  $\mathbf{m}_j$  and  $\mathbf{n}_j$ . Specifically it has a linear objective and  $(s + m)$  quadratic inequality constraints with additional restrictions on the variables to ensure positive variance terms. The re-statement of the realisation case is proceeded analogously and is shown in Lovell (1993, p. 34-5)

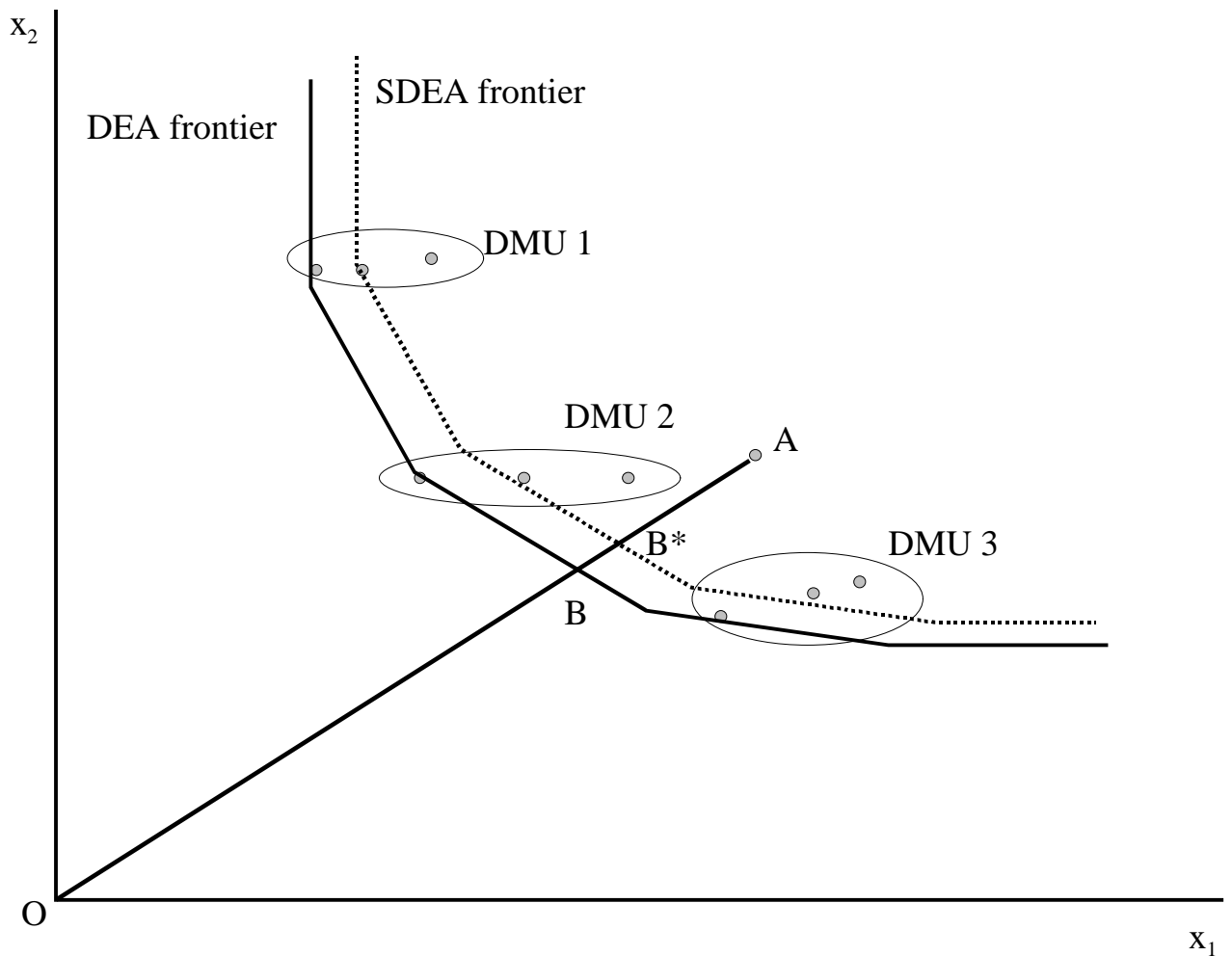
To implement this programme we have used the algorithm of Lasdon et al (1978) which is widely available in many spreadsheet and symbolic programming applications, see Kendrick (1996).

What is the intuition behind SDEA? LLT provide one form of insight using the density function of the random error, but we can also borrow another diagrammatic intuition from the paper by Olsen and Petersen (1995). This is shown in figure 1 below.

In this diagram we illustrate observations on a panel of producing or decision making units (DMUs 1 –3) for the case of two inputs and one output. The boundary of the input requirements set is defined by the isoquant. In deterministic DEA the individually most efficient realisations define the frontier shown by the solid line. However, in implementing SDEA we are in effect looking for confidence regions around each producing unit's observations within the panel. These are shown as grouped within the ellipses shown around sets of observations. Olesen and Petersen describe the SDEA frontier as being evaluated relative to the centre of these confidence regions. As a



consequence, the SDEA frontier associates extreme outliers with the stochastic error term and this has the effect of moving the frontier closer to the bulk of the producing units. Some realisations will then lie above the frontier and in evaluating the realisation model these observations will have a super-efficiency larger than unity.



**Figure 1 SDEA and DEA frontiers**

In the diagram the DEA frontier passes through the most extreme observations of the three DMUs 1, 2, and 3, while the SDEA frontier passes through the centre of the confidence regions around the observations for these DMUs. We can see that particular

observations will have a SDEA efficiency larger than unity. The observation at A has two efficiency scores:  $OB/OA$  for the DEA frontier and  $OB^*/OA$  for the SDEA frontier. The SDEA score will usually be greater but never lower than the DEA efficiency score. The distance between the two frontiers represents the role of the stochastic error term in accounting for the variation in production performance. The larger is the variance of the sample, the larger will be the confidence ranges for the data and therefore the greater will be the distance between DEA and SDEA frontiers. In other words a sample with a wide variation in inputs and outputs observed for each unit will ascribe more of the variation in performance to the stochastic error than a sample with a narrow variation over the panel. In some cases we may find that a widely varying panel has two properties:

The *mean performance* of the units clusters around unity (100 percent efficiency) because the SDEA frontier has shifted so far towards the units which lie below the DEA frontier, and the *extreme performance* or individual realisation of some of the most successful observations lies well in excess of 100 percent. Such results would indicate that the sample contained a very large degree of measurement error and other stochastic influences, and consequently only the mean performance frontier is of relevance in using the results for such purposes as yardstick competition.

## **5. Data**

The panel data consists of annual observations on 17 airlines over the period of 1991 and 1995. The names of the airlines and their countries of origin are as follows: Aer Lingus (Ireland), Air France (France), Air Malta (Malta), Alitalia (Italy), Austrian Airways (Austria), British Airways (United Kingdom), Cyprus Airways (Cyprus), Finnair

(Finland), Iberia (Spain), Icelandair (Iceland), KLM (The Netherlands), Lufthansa (Germany), Sabena (Belgium), SAS (Scandinavia), Swissair (Switzerland), Air Portugal (Portugal) and Turkish Airlines (Turkey). A relatively short time frame is used for the panel because we do not wish to confuse the policy effects with the secular trend of technological change. We argue that by concentrating on the years 1991-95 we are able to capture the immediate short term effects of liberalisation without picking up major technological shifts in the industry.

Except for the two privately owned airlines, British Airways and Icelandair, the airlines in the sample are 'flag' carriers with varying degrees of state ownership. Because there would be many non-Community national 'flag' carriers which are also affected by the recent reforms, our sample considers the members of the AEA in which all Community member airlines are included alongside the non-Community ones. Because of data limitations, Adrian, Balkan, British Midland, Czech Airlines, Yugoslav, Luxair, Malev and Olympic Airways are excluded from the sample.

To specify the inputs and outputs, the model by Schefczyk (1993) is adopted. Each of the inputs and outputs in the model reflects the operational characteristics of the airline industry. The inputs are available tonne kilometre (ATK); operating cost; and non-flight assets. The two outputs are revenue passenger kilometre (RPK) and non-passenger revenue. ATK is for the aircraft capacity obtained to include both passenger and non-passenger inputs. Operating cost is obtained by excluding the capital and aircraft costs already reflected in ATK and non-flight assets are included to reflect all assets not already reflected by ATK. These assets are mainly the reservation systems, hotels and other facilities. RPK is used as a proxy for the passenger-flight related output whereas non-passenger revenue reflects all other output that

is not passenger-flight related, such as cargo. For all monetary conversions, purchasing power parities by OECD are used.

The data are based on three sources. ATK and RPK are obtained from International Air Transport Association (IATA) World Air Transport Statistics; non-flight assets are from the annual reports of the companies and the rest is from the International Civil Aviation Organisation (ICAO) Financial Data Series. The rapid growth of the European airlines is apparent from Table 1, which displays the summary statistics of the data set. There is an increase in the aircraft capacity obtained. Operating costs, however, decrease in the year 1995. Non-flight assets also show a fall in 1994, but reveal a sharp increase in the final year. There is an increasing trend in the passenger revenues whereas non-passenger revenues decrease in the final year. The last feature of the data is that there are enormous variations among the airlines in the sample, which is evidenced by large deviations of the variables. This is because there are very small and very large airlines in the sample.

**Table 1.** *Descriptive statistics for European airlines, 1991-1995*

	<b>ATK</b>	<b>OC</b>	<b>NFA</b>	<b>RPK</b>	<b>NPA</b>
<b>1991</b>					
Mean	3977.4	2260.7	1442.1	16442.4	690.3
Standard deviation	4348.3	2181.8	1185.3	17189.3	690.5
Minimum	131.2	48.6	12.2	1284.2	19.3
Maximum	13005.6	6848.8	3427.4	63190.5	2502.0
<b>1992</b>					
Mean	4382.6	2526.1	1592.8	20375.7	752.9
Standard deviation	4778.3	2557.0	1326.5	21995.6	842.9
Minimum	267.9	51.1	27.3	1284.2	20.5
Maximum	14371.5	7926.3	3801.8	80265.4	2959.9
<b>1993</b>					
Mean	4730.9	2649.8	1698.8	20359.2	766.6
Standard deviation	5228.7	2631.7	1438.7	22008.2	864.3
Minimum	192.3	54.3	25.1	1284.2	21.7
Maximum	15869.1	8224.5	4590.3	80265.4	2941.9
<b>1994</b>					
Mean	5024.6	2816.6	1598.8	21925.1	840.3
Standard deviation	5546.0	2925.7	1312.4	23944.9	988.4
Minimum	417.8	65.9	24.8	2361.1	21.0
Maximum	16989.4	9239.9	3800.5	86395.4	3478.8
<b>1995</b>					
Mean	5384.0	2554.8	2873.2	23575.4	658.5
Standard deviation	5945.5	2574.1	6491.9	25540.1	638.3
Minimum	444.7	71.7	29.8	2555.5	23.9
Maximum	18456.1	9638.8	27781.9	94002.6	2481.6

**Notes:** **ATK**; available tonne kilometre; **OC**; operating cost; **NFA**; non-flight assets; **RPK**; revenue passenger kilometre; **NPA**; non-passenger revenue.

## 6. Empirical results

In order to implement the SDEA model for our panel of 17 European airlines for the years 1991-95 we have calculated both mean performance and annual realisation versions of the model. There are two purposes in writing this paper. One is to consider the effect of using chance constraints rather than deterministic constraints on a well established

DEA efficiency analysis. The effect of using chance constraints is possibly more clear when attention is concentrated on the mean performance. The other purpose is to consider whether the measurement of the efficiency effects of liberalising the airlines is sensitive to the assumptions of stochastic errors in the data. The liberalisation effects can be seen more clearly in looking at the performance of individual annual realisations.

Beginning with the mean performance results, we examined a number of different cases. To analyse the effect of changing the probability of violating the constraints, the model was implemented for each of the airlines using two different  $\alpha$  levels, where  $\alpha$  is the upper limit on the probability that the constraints are satisfied. Remember that in this formulation,  $\alpha$  represents the probability weight attached to the variance of the output or input slack in the envelopment constraints. As  $\alpha$  falls toward its lower limit of 0.5 the variance term becomes less important and the model approaches the deterministic DEA version.

We also then considered whether there could be a difference in the way that stochastic factors affected the output and input constraints. The original paper by Land, Lovell and Thore (1993) provides different reasoning for the assumption of chance constraints depending on whether outputs or inputs are being considered. Consequently the model was also implemented for each of the airlines with, first, all constraints stochastic and then with only input constraints stochastic and finally with only output constraints stochastic. This gives a six-fold classification of results for the mean performance of the panel. We can add for comparison the deterministic DEA results for the mean performances of the airlines in the sample. The results are shown in Table 2.

**Table 2.** Average efficiency in different models

Average efficiency (standard deviation) in model	Probability level $\alpha = 0.95$	Probability level $\alpha = 0.8$
All constraints stochastic	1 (0)	1 (0)
Input constraints stochastic	0.99 (0.02)	0.99 (0.03)
Output constraints stochastic	0.98 (0.06)	0.98 (0.06)
Deterministic DEA ( $\alpha = 1$ )	0.95 (0.07)	0.95 (0.07)

These results are exactly in line with the theoretical predictions of the LLT model. Compared with the deterministic DEA results the average efficiency performance is much better. Indeed in the case where all constraints are stochastic the amount of variation in the data is such that all of the perceived inefficiencies can be attributed to stochastic error. In the case where input constraints are stochastic and output constraints are deterministic which implies measurement error only for inputs the drop in average efficiency is negligible. A larger drop in average efficiency with a greater standard deviation of performance is recorded in the case where output constraints are treated as stochastic and the input constraints are treated as deterministic. Our interpretation of these results is that the findings are ambiguous. On the one hand, allowing for measurement error in inputs removes virtually all of the perceived inefficiency in the mean performances of the airlines. The deterministic DEA results therefore could be reflecting differences in the way that inputs are recorded or measured. On the other hand allowing for measurement error only in outputs still leaves a degree of inefficiency in the industry. It is the unexplained variability of input usage that is reflected in the airlines relative performance.

The individual airlines which are inefficient in the mean performance case are shown next in Table 3.

**Table 3.** *Technically inefficient airlines*

Inefficient airlines	Probability level $\alpha = 0.95$	Probability level $\alpha = 0.8$
Input constraints stochastic	British Airways	Air Malta, British Airways, Sabena
Output constraints stochastic	Sabena	Iberia, Sabena

As the model allows more of the outliers to reflect inefficiency rather than stochastic error ( $\alpha$  takes a lower value) the number of inefficient companies rises. Although one company Sabena is inefficient in both versions, the other remaining inefficient companies differ according to whether it is the input constraints or the output constraints which are allowed to be stochastic. This may reflect inefficiency in input choice in the case of British Airways and Air Malta, and output uncertainty in the case of Iberia. We can ask whether these inefficient companies share common characteristics. Among the airlines we have distinguished two major characteristics of interest to the liberalisation issue: size and ownership.

Table 4 classifies the airlines in the sample by the size of the fleet and the percentage of state ownership in 1995. It is apparent that Sabena are both heavily state owned and small airlines, whereas British Airways is at the opposite extreme, a large privately owned airline. The conclusion that is emerging from this mean performance data is that by 1995 it was much too soon to conclude that the liberalisation process had succeeded in greatly improving the efficiency of the privately owned airlines relative to the state



owned airlines. The time required for policy to work is clearly longer than had been anticipated and the degree of liberalisation implemented may be far short of that required.

**Table 4.** *Size and ownership of airlines in 1995*

Airline	No. of aircraft in fleet	State ownership %
Aer Lingus	38	100
Air France	230	99.3
Air Malta	11	96.4
Alitalia	158	86.4
Austrian	35	51.9
British Airways	309	0
Cyprus Airways	9	80.5
Finnair	57	60.7
Iberia	160	99.8
Iceland Air	15	0
KLM	125	38.2
Lufthansa	327	35.7
Sabena	85	61.8
SAS	203	50
Swissair	75	21
Air Portugal	34	100
Turkish Airlines	73	98.2

We turn now to consider the realisations for different years of the sample. As expected in the model, several individual airline realisations have efficiency scores in excess of unity. However although the LLT model suggests these should be rare occurrences, the results suggest that such observations are relatively frequent. This suggests again that when we allow for the variance of the data, the model does have difficulty in identifying inefficient airlines. The volatility of the results is emphasised by the performance ranking for the SDEA efficiency scores shown in Table 5, where we have chosen three representative years from the beginning, middle end of the end of the

sample period. It is apparent that the different companies change efficiency ranking position quite significantly in the period under observation. For example, each of the companies which is designated most efficient in one year is much further down the table towards the least efficient in another year.

The correlations between the rankings and between the post-liberalisation realised stochastic efficiencies and size and ownership are shown in Table 6. Again the major impression is that data volatility is making it difficult to arrive at firm results. Two conclusions are possible. After allowing for stochastic error in computing the relative efficiencies we conclude:

- The airlines that were efficient in 1995 resembled those that were efficient in 1993 but not those in 1991
- The airlines that were efficient in 1995 were the larger companies

**Table 5.** *SDEA efficiency rankings 1991-5*

Ranking of SDEA efficiency scores	1991	1993	1995
Aer Lingus	6	2	11
Air France	2	4	14
Air Malta	17	12	15
Alitalia	13	1	7
Austrian	3	15	10
British Airways	5	9	1
Cyprus Airways	16	13	16
Finnair	11	3	9
Iberia	15	11	8
Iceland Air	4	13	17
KLM	12	8	5
Lufthansa	10	6	2
Sabena	8	17	13
SAS	7	10	6
Swissair	14	5	3
Air Portugal	9	7	4
Turkish Airlines	1	16	12

**Table 6.** *Efficiency score correlations*

Rank correlations for SDEA models	Efficiency in 1991 & 1993	Efficiency in 1993 & 1995	Efficiency in 1991 & 1995	Efficiency in 1995 and size	Efficiency in 1995 and ownership
	-0.178	0.416	-0.105	0.600	-0.299

What can we conclude from the SDEA realisation results? It is certainly not possible to determine a strong liberalisation effect on technical efficiency. There is some stability in the set of efficient companies towards the end of the sample period, but these efficient companies are generally the largest rather than those that have been privatised. More generally, it is clear that allowing for stochastic errors in DEA efficiency measurement

reduces the researcher's ability to make strong comparisons. SDEA does allow us to incorporate stochastic error into non-parametric multiple output and multiple input efficiency studies. In doing so it offers a closer envelopment of the observed data which is a primary objective of the efficiency and productivity analysis research. However this closer envelopment is obtained at the cost of reduced attribution of efficiency differences which is another objective of the research.

## **7. Conclusion**

The European airlines industry is undergoing a stage of critical restructuring. The reform packages were introduced in an effort to put pressure on governments to create a more competitive environment. The Third Liberalisation package, which was in effect from January 1993, has been regarded as a serious step into substantial liberalised Europe aviation.

Similar with the expectations from the US experience, a strongly held view is that liberalisation reforms will bring a significant dimension in providing the forces of a truly competitive market that real competition can thrive. Further, this could lower prices and increase consumer benefits, thus enhance productivity in the industry.

Indeed, it is important to learn from the lessons of US experience. Adopting fully the US style deregulation is unlikely for Europe since there are many individual states along with various institutions that have interests in the way liberalisation policy evolves. However, it is expected from all parties to put more effort to establish a long term structure for European airlines which is facing pressures from recent globalisation trends.

One of the lessons of US deregulation showed an increase in mergers and alliances. It is imperative to consider the likely effects of a similar concentration in European aviation whilst creating a more competitive market. Additionally, it is vital to consider the future effects of state ownership, subsidies and the infrastructure constraints on the productivity of the industry.

As a matter of fact, the European airlines industry during its early phase of liberalisation process provides a fascinating case study, which prompts us to carry out a comparative performance analysis. In this paper we have pursued two objectives. The first is to implement one of the stochastic DEA models in the existing literature. In doing this we have largely confirmed the predictions of the model in providing a closer envelopment of the data and identifying super efficient realisations. However one of the consequences of allowing for stochastic error in the efficiency and productivity analysis is that in achieving a closer envelopment we have fewer strong conclusions to offer about measured efficiency.

This reflects on our second objective of measuring the efficiency consequences of the liberalisation programme. It is apparent that the volatility of the data on the input and output performance of the European airlines makes it very difficult to come to firm conclusions about the short term efficiency effects of the liberalisation package. Using the stochastic models developed here we are unable to find a strong effect from ownership to technical efficiency in the time frame considered. There is however a relationship between inefficiency and smallness of fleet size so that further work on scale effects in the SDEA model is required. We suggest that the SDEA approach is fruitful

and certainly should be used in conjunction with conventional deterministic DEA, but clearly much work remains to be done on the foundations of this approach.

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