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TFP GROWTH, CHANGE IN EFFICIENCY, AND TECHNOLOGICAL PROGRESS IN THE U.S. AIRLINE INDUSTRY: 1970 TO 1981

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ABSTRACT

The Airline Deregulation Act of 1978 unleashed market forces that have led to a number of changes in the U.S. airline industry. Using a "best-practice" cost function approach, this paper reports some of the airlines' early adaptations to this new environment. Specifically, the paper presents estimates of the properties of the best-practice technology, measures of cost efficiency, and changes in observed total factor productivity (TFP) growth for the U.S. airline industry in the 1970s and early 1980s. These results are obtained using a panel data set of 12 U.S. airlines during the period from 1970:IQ to 1981:IVQ and using two new empirical techniques. The first technique enables a multiproduct system of cost and input share equations to be estimated, allowing for cost inefficiency. The second technique is then employed to decompose observed TFP growth into technological progress, change in cost efficiency, scale effects, and network effects. These analytical techniques provide useful insights into individual airline performance in the last years of full Civil Aeronautics Board regulation and in the first years of regulatory reform.

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I. Introduction

The U.S. airline industry has undergone many changes in the 10 years since the Airline Deregulation Act (ADA) of 1978. New carriers entered in the late 1970s, hub-and-spoke networks became the norm in the early 1980s, frequent flier plans gained wide acceptance and, finally, many mergers and some failures occurred, particularly in 1986. These events can be explained largely by the technology available to the airline industry and by the cost performance of those airlines in operation at the time of the ADA.

This paper employs two new empirical techniques to provide insights into these events. The first, developed by Bauer, Ferrier, and Lovell (1988), estimates a stochastic multiproduct cost frontier. In contrast to techniques proposed by Schmidt (1984), Melfi (1984), and Bauer (1985), this technique "solves" the Greene Problem in that it models in a qualitatively consistent way the relationship between the disturbances on the input share equations and the allocative inefficiency term in the cost equation.[1] While this technique does not model the relationship between the allocative inefficiency terms in the cost and input share equations explicitly, as in these earlier papers, one can obtain estimates of firm- and time-specific cost inefficiency by extending a technique developed by Jondrow, Lovell, Materov, and Schmidt (1982).

The second empirical technique decomposes observed total factor productivity (TFP) growth into various components related to returns to scale, technological progress, and changes in cost efficiency, a technique fully developed in Bauer (1988). Separating observed TFP into these components provides insights into the dynamic behavior of the airlines.

This paper is divided into five sections. Section II contains a brief overview of the airline industry under CAB regulation, reviews Farrell's (1957) measures of cost efficiency, and discusses why the airlines may have been cost inefficient under regulation. Section III presents the empirical techniques used to obtain estimates of the cost frontier and to decompose the observed measure of TFP growth. Section IV briefly describes the data set and reports and discusses the empirical results. Section V concludes with a discussion of how these results help explain some of the airlines' adaptations to their new environment.

II. Airline Regulation and Cost Efficiency

The Civil Aeronautics Board (CAB) maintained tight control over the domestic airline industry from 1938 to 1978. The CAB regulated all the major phases of airline operations, including the routes that airlines could serve and the fares they could charge.[2] The allocation of new routes or the. approval of mergers was often dictated by the CAB's mandate to "promote the industry," which the CAB usually interpreted as "preserve the financial viability of the existing firms in the industry." Airlines that fell into financial difficulty often received profitable new routes to bail them out, reducing the incentive to operate efficiently.

Costs also rose because regulation impaired the airlines' bargaining power with their labor unions. Airlines produce a service that cannot be stored in anticipation of a strike. Thus, when an airline suffered a strike, it lost much of its market to its competitors. When the strike ended, the airline had no way of winning back its passengers. It could not offer discounted fares, as United Airlines did successfully after a pilots' strike in the summer of 1985. Thus, an airline's best strategy was to accede to the union demands, content with the expectation that in time other airlines would be forced to increase their labor compensation commensurately. Eventually, the CAB would be forced to approve across-the-board fare increases to cover the increased labor costs.

Accordingly, the regulated environment both restricted and protected the airlines, reducing the pressure on them to minimize their costs. Yet the cost function remains the standard by which the performance of individual firms should be measured. Furthermore, the cost function embodies the cost-minimizing technology that will influence the market structure that will evolve in the airline industry under deregulation. The definitions that follow will be useful here.

If a firm operates at minimum cost, it is cost efficient; if not, it is cost inefficient. Farrell (1957) developed a measure of overall cost efficiency and decomposed that measure into measures of technical efficiency (using proportionally too much of all inputs) and allocative efficiency (using the wrong mix of inputs). These efficiency measures can be readily defined by referring to figure 1, where the isoquant yy' is associated with the firm's given rate of output, the isocost curve ww' is determined by the input prices facing the firm, and the input vector x^{Θ} is observed producing the firm's given rate of output.

The measure of overall cost efficiency is E^{Θ}-oa/oc, the ratio of minimum cost to observed cost (note the implicit use of the set of isocost curves). The measure of technical efficiency is E^{T}-ob/oc, the ratio of cost when the firm operates on the isoquant (using the observed input mix) to observed cost.

Finally, the measure of allocative efficiency is $E^A = oa/ob$, the ratio of cost on the isoquant (using the observed input mix) to minimum cost. These measures have the following three properties: (1) each measure is bounded by zero and one, (2) $E^O = E^T \cdot E^A$, and (3) one minus any of these measures is the proportion by which costs could be lowered if that form of inefficiency were eliminated.

Although this paper evaluates the performance of the airline industry relative to the cost frontier before and immediately after the deregulation of the industry, airline deregulation was, unfortunately, a process, not a discrete act at a specified time. In fact, "regulatory reform" is a more accurate term for the process, since the Department of Transportation and the Federal Aviation Administration, respectively, continue to regulate international service and safety. The ADA passed in 1978, and its provisions were phased in gradually, with the CAB lingering on the scene until 1985. Determining just when deregulation began is further complicated because the CAB itself began to grant the airlines more control over their routes and fares as early as 1975. "Peanut" and "Supersaver" fares were two examples of the CAB's willingness to cede some autonomy to the airlines.[3]

This paper assumes that the deregulated era began on January 1, 1979, but this arbitrary assumption leaves several problems associated with pre- and post-deregulation cost efficiency comparisons. A number of external shocks to the airline industry occurred in the brief span between 1979 and 1981. In 1979, oil prices increased sharply; recessions occurred in the first half of 1980 and the second half of 1981; and in the summer of 1981, the air traffic controllers went on strike. These shocks certainly affected the airlines' adjustment to their new environment, but are not modeled explicitly here.

III. Empirical Techniques

In general, the cost system to be estimated can be written

$$(1)\quad \ln C_{nt} = \ln C(y_{nt}, w_{nt}, z_{nt}, t) + u_{nt} + v_{nt},$$

$$s_{int} = s_i(y_{nt}, w_{nt}, z_{nt}, t) + e_{int},$$

where C_{nt} and s_{int} are the observed cost and input shares, respectively. The arguments in the cost and input share equations (subscripts will be suppressed for the sake of convenience) are defined as follows: y is the vector of outputs, w is the vector of input prices, z is the vector of network characteristics, and t is a time index.[4]

The disturbances have the following interpretations: In the cost equation, the cost inefficiency term, u, allows for an increase in observed cost over minimum cost attributable to technical and allocative inefficiency and is assumed to follow a truncated-normal distribution with mode μ and underlying variance σ_u^2 such that $u \geq 0$. The noise term, v, allows for variations in conditions such as the weather that affect costs but that are beyond the firm's control. This term is assumed to be independent of u and to follow a normal distribution with a finite variance of σ_v^2. Strictly speaking, it is incorrect to model the disturbances in the cost and input share equations as being independent, since allocative inefficiency in the cost equation will clearly depend on the disturbances in the input share equations. However, as Schmidt (1984) pointed out, these terms will tend to be uncorrelated, since both negative and positive deviations from efficient shares raise costs.

In the input share equations, the vector disturbance, e, allows for both allocative inefficiency and noise on the input share equations and is modeled as a normal random variable with a mean α and a covariance matrix Ω.[5] These sources of deviations of observed input shares from cost-efficient input shares may be either positive or negative, since a firm may over- or underemploy a given input. The equation permits persistent deviations of observed input shares from cost-efficient input shares by the vector mean a. Ideally, this disturbance, e, would be related to the inefficiency term in the cost equation, but flexible functional forms such as the translog preclude the derivation of an analytic representation of this relationship (see Bauer, Ferrier, and Lovell, 1988). Some researchers, notably Schmidt (1984), Melfi (1984), and Bauer (1985). have approximated this relationship, but there is no compelling reason to prefer these previous approaches to the one employed here--namely, modeling the disturbances on the cost and input share equations in a qualitatively consistent fashion.

The likelihood function for this system can be written as

$$
\begin{aligned}
(2)\quad \ln L = & -\frac{TNM}{2}\ln(2\pi) - \frac{TN}{2}\ln\sigma^2 - \frac{TN}{2}\ln|\Omega| \\
& - \frac{1}{2\sigma^2}\sum_t\sum_n (\ln C_{nt} - \ln C(y_{nt}, w_{nt}, z_{nt}, t) - \mu)^2 \\
& + \sum_t\sum_n \ln[1 - F^*(\sigma^{-1}(-\frac{\mu}{\lambda} - (\ln C_{nt} - \ln C(y_{nt}, w_{nt}, z_{nt}, t))\lambda))] \\
& - (TN)\ln[1 - F^*((-\frac{\lambda}{\sigma})(\lambda^{-2}+1)^{1/2})] - \frac{1}{2}\sum_t\sum_n (e_{nt}-\alpha)'\,\Omega^{-1}\,(e_{nt}-\alpha),
\end{aligned}
$$

where $\sigma^2=\sigma_u{}^2+\sigma_v{}^2$, $\lambda=\sigma_u/\sigma_v$, and $F^*(\cdot)$ is the standard normal distribution function.[6] Maximum likelihood estimates can be obtained for all the parameters in (2), and these estimates will be asymptotically efficient. One can perform a number of specification tests using likelihood ratio tests similar to those proposed by Stevenson (1980).

While estimating the cost frontier yields useful information about best-practice technology (such as output cost elasticities, price elasticities of substitution, and the rate of change in technological progress), estimates of overall cost inefficiency yield additional information about individual firm performance over time. The steps required to obtain estimates of these terms are discussed below.

First, the technique of Jondrow, Lovell, Materov, and Schmidt (1982) is extended to adjust for the estimation of a cost frontier--not a production frontier--and for the use of an inefficiency disturbance that is a truncated-normal--not a half-normal random variable (the latter being a special case of the former). The conditional density of u given $\xi=u+v$ is

$$(3)\quad f(u|\xi)=\frac{1}{\sqrt{(2\pi\sigma_*^2)}}\left[1-F\left(\frac{-\mu}{\sigma\lambda}-\frac{\xi\lambda}{\sigma}\right)\right]^{-1}\exp\left[-\frac{1}{2\sigma_*^2}\left(u-(\xi\sigma_u^2+\mu\sigma_v^2)/\sigma^2\right)^2\right],$$

for $u \geq 0$,

which is just a normal random variable, $N((\xi\sigma_u^2+\mu\sigma_v^2)/\sigma^2,\sigma_*^2)$, truncated at zero, where $\sigma_*^2 = \sigma_u^2\sigma_v^2/\sigma^2$. One can use either the mode or the mean of this conditional distribution as a point estimate of u,

$$(4) \qquad M(u|\xi) = (\xi\sigma_u^2+\mu\sigma_v^2)/\sigma^2, \text{ and}$$

$$(5) \qquad E(u|\xi) = \sigma_*\left[\frac{f(-\eta)}{1-F(-\eta)} - \eta\right]$$

where $\eta=\mu/(\sigma\lambda)+\xi\lambda/\sigma$. Materov (1981) has shown that the mode can be interpreted as the maximum likelihood estimator of u, given $\xi=u+v$. Note that, in practice, the terms required to compute $M(u|\xi)$ and $E(u|\xi)$ are unobserved and must be replaced by estimates of these parameters. Asymptotically, the measurement errors on these terms disappear as the sample size increases; however, u would still be known imperfectly since ξ contains only imperfect information about u.[7]

Given estimates of the cost frontier and cost efficiency, one can use the technique described below to decompose observed TFP into its various components. For multiproduct firms, observed TFP growth can be defined as

$$(6) \quad TFP = \dot{y}^P - \dot{F}, \text{ where } \dot{y}^P = \sum_j \frac{p_j y_j}{R}\dot{y}_j, \; R = \sum_i p_i y_i, \text{ and } F = \sum_i \frac{w_i x_i}{C}\dot{x}_i,$$

where y^P, F, w_i, x_i, and C refer to the revenue-weighted index of output, a cost share index of aggregate input usage, the price of the i-th input, the observed use of the i-th input, and the observed cost, respectively.[8,9]

Using the **same** basic steps outlined in Bauer (1988), one can show the observed TFP growth for a multiproduct firm to be equal to the following expression in the presence of network effects:

$$(7)\quad \dot{TFP} = \left[1 - \sum_j \epsilon_{cy_j}(y,w,z,t) \right] \dot{y}^c + \dot{E} - \dot{C}(y,w,z,t)$$

$$- \sum_k \epsilon_{cz_k}(y,w,z,t)\, \dot{z}_k + \sum_i [s_i - s_i(y,w,z,t)]\, \dot{w}_i + (\dot{y}^p - \dot{y}^c),$$

$$\text{where } \dot{y}^c = \sum_j \left[\frac{\epsilon_{cy_i}}{\sum_j \epsilon_{cy_j}} \right] \dot{y}_j .$$

This expression breaks down the total factor productivity growth into terms related to ray returns to scale, changes in cost efficiency, technological progress, and changes in the network. Thus, observed TFP growth depends not only on changes in outputs (if there are nonconstant ray returns to scale) and technological progress (which is the standard decomposition), but also on changes in network characteristics and cost efficiency. Improvements in the network and increases in cost efficiency over time raise the observed TFP growth, whereas declines in both lower it.

The last two terms are leftovers. The last term simply measures any effect nonmarginal cost pricing may have on the observed measure of observed TFP growth. Denny, Fuss, and Waverman (1981) have shown that $y^p = y^c$ under marginal cost and proportional markup pricing. The next-to-last term adjusts for any bias introduced by measuring aggregate input usage with observed rather than least-cost input shares.

IV. Results

This section describes the results obtained by estimating the system of equations described in the previous section with data from the U.S. airline industry. First, the choice of an appropriate functional form is considered. Then the data set employed in this study is described. Finally, the empirical results are reported, and their implications discussed.

The following **translog** system of cost and input share equations was estimated--again, omitting firm and time subscripts:

$$
\begin{aligned}
(8)\quad \ln C &= \ln C(y,w,z,t) + u + v \\
&= \beta_o + \sum_i \beta_{y_i} \ln y_i + \sum_i \beta_{w_i} \ln w_i + \beta_{1df} \ln z_{1df} + \beta_{stgl} \ln z_{stgl} + \beta_t t \\
&\quad + 1/2 \sum_i \sum_j \beta_{y_i y_j} \ln y_i \ \ln y_j + \sum_i \sum_j \beta_{y_i w_j} \ln y_i \ \ln w_j \\
&\quad + 1/2 \sum_i \sum_j \beta_{w_i w_j} \ln w_i \ln w_j + u + v, \text{ and}
\end{aligned}
$$

$$
\begin{aligned}
(9)\quad s_i &= s_i(y,w) + \omega_i \\
&= \beta_{w_i} + \sum_i \beta_{y_j} \ln y_j + \sum_j \beta_{w_i w_j} \ln w_j + \omega_i, \quad i = 1,\ldots,M.
\end{aligned}
$$

The network and time variables were not interacted with input prices, in order to reduce the number of parameters to be estimated and to lessen the effects of multicollinearity. Symmetry and linear homogeneity in input prices impose the following restrictions on the cost system:

$$(10) \qquad \beta_{w_i w_j} = \beta_{w_j w_i}, \ \sum_i \beta_{w_i} = 1, \ \sum_j \beta_{w_i w_j} = \sum_j \beta_{y_i w_j} = 0, \ \forall \ i,j.$$

By construction, $\sum_i s_i(y,w)=1$, so that one input share equation **must** be dropped before estimation to avoid singularity. **Barten** (1969) has shown that, asymptotically, the parameter estimates are invariant as to which input share equation is dropped.

The data set employed in this paper was constructed by Robin Sickles using the AIMS 41 form that all interstate airlines were required to submit periodically as part of the CAB's regulation of the industry.[10] The panel of data is composed of 12 firms over 48 quarters from 1970:IQ to 1981:IVQ. The airline industry is considered to produce revenue passenger miles (y_P) and revenue cargo ton miles (y_c) using four inputs: labor (L), capital (K), energy (E), and materials (M). Labor is an aggregate of 55 separate labor accounts. Capital is a combination of flight equipment, ground equipment, and landing fees. Energy is the quantity of fuel used, converted to BTU equivalents. Materials is an aggregate of 56 different accounts composed mainly of advertising, insurance, commissions, and passenger meals.

Two additional and important variables account for the network through which airlines supply their output, since the network will influence the cost of supplying any given level of output. The network variables included in this study are the average load factor, z_{ldf} (the proportion of an airline's capacity actually sold in a given quarter), and the average stage length,

z_{stgl} (the average distance of an airline's flights in a given quarter). These two network characteristics are incorporated into the two translog cost models as presented in equation (8).

The maximum likelihood estimators of the parameters of this cost system are reported in table 1. These parameters derive from a model slightly more restricted than the one developed in section III. Instead of the more general truncated-normal distribution, the half-normal distribution was assumed for the cost inefficiency term in the cost equation. This is equivalent to restricting $\mu=0$, a restriction that could not be rejected using a likelihood ratio test based on these results and on those of the more general model.

Since the data had been standardized about the sample means before estimation, the linear terms in the translog functional form describe some of the economic properties of the cost function for the "average" firm in the industry. The estimates for β_{Y_P} and β_{y_c} indicate that the typical airline experiences roughly constant ray returns to scale, since a 1-percent increase in revenue passenger miles and revenue cargo ton miles increases costs by approximately 0.856 percent and 0.140 percent, respectively, for a combined total of 0.996 percent if both outputs were increased by 1 percent. White (1979) surveyed the then-existing literature on scale economies in the airline industry and also found no evidence for increasing returns to scale for the typical airline.[11]

The estimates of the various output elasticities for each firm averaged over time appear in table 2. The largest four airlines (American, Delta, Eastern, and United) have all exhausted the cost savings to be gained from increasing their scale of operations radially. The smallest four airlines (Frontier, North Central, Ozark, and Piedmont) all enjoy some room for expanding their operations.

Figure 2 graphs the estimated multiproduct cost function to illustrate how costs vary with the level and mix of outputs. Input prices and the network variables are held at their sample averages. The cost function has a fairly constant slope, suggesting that there are roughly constant returns to scale over a wide range of outputs and that there are few cost savings from joint production. In fact, an airline producing one-tenth of the average levels of passenger and cargo output has a ray cost elasticity of 0.880, whereas an airline producing 10 times the average levels of output has a ray cost elasticity of 1.09, so that there is some curvature.

Figure 3, which plots the cost contours as the amounts of the two outputs vary (again, holding the other variables at their averages), illustrates the lack of economies or diseconomies of joint production. These cost contours are fairly flat except near the two axes (this observation is more clearly seen in figure 1). Over most regions, there is a fairly constant trade-off between passenger output and cargo output as measured by total costs. A formal test of economies of scope is not possible here since the translog cost function is undefined if one of the outputs is zero. Also, since no firms in the sample produced just one of the outputs, and since the translog functional form is guaranteed to be a good approximation of the true cost funtion only at a point, it would be difficult to gauge how much credence to give such a test even if it could be performed. It can be shown that a firm producing the average amount of both outputs does not exhibit cost complementarities, since $\frac{\partial C^2}{\partial y_p \partial y_c} > 0$.

The typical cost-efficient firm would spend about 10.0 percent on capital, 46.9 percent on labor, 23.2 percent on energy, and the remaining 19.9 percent on materials, given the parameter estimates that correspond to the linear terms for capital, labor, energy, and materials. Table 3 presents estimates of the price elasticities of substitution averaged over time. All of the own-price elasticities of substitution are negative and inelastic. The derived demand for capital is the most elastic, whereas the demand for energy is the least elastic.

The cross-price elasticities of substitution are even more inelastic. The derived demand for capital is the most elastic, rising 0.702 percent when the price of labor increases 1 percent. In short, there appear to be few opportunities for substitution among the various inputs in the airline industry.

The network and time index parameters all have the expected signs. Increasing the average load factor 10 percent lowers costs by about 6.6 percent, and increasing the average stage length 10 percent lowers costs 2.9 percent, all other variables held constant. Increasing the average load factor or the average stage length enables an airline to serve the same level of outputs with fewer flights. Inputs are used more effectively, with fewer costly takeoffs and landings. The coefficient on the time index indicates that technological progress was advancing at a rate of 0.274 percent a quarter, implying that the cost frontier is shifting down at a rate of slightly more than 1 percent a year.[12] This is slower than the rate found by Sickles, Good, and Johnson (1986), who estimated a generalized-Leontief system of equations related to a distorted profit function.

There is support for the presence of cost inefficiency in the data since

λ is statistically significant. Under the null hypothesis that $\lambda=0$, only noise is present. Also, the statistical significance of one of the three estimated α_i's (the one for capital) further supports the presence of cost inefficiency in general and allocative inefficiency in particular. The airlines tended to overemploy capital, underemploy labor, and use a roughly appropriate share of energy and materials over time.

The three possible estimates for the firm inefficiency measures appear in table 4a.[13] The estimates of cost inefficiency by firm are remarkably invariant to the estimator employed, yielding cost inefficiency estimates of approximately the same level across measures for each firm and the same ranking of firms from most to least efficient.[14] While these estimates of cost inefficiency may seem large (the overall average is about 7 percent), in fact they may be biased downward since no airline in the sample operated near the cost frontier.

Bailey, Graham and Kaplan (1985) used 1981 accounting data to compare the cost of three airlines (United Airlines, Piedmont, and Southwest) serving a 200-mile route. Even after adjusting for differences in the quality of service, seating densities, flight crew complements, and aircraft utilization rates, Piedmont's and United's costs (which the adjustments lowered by 25 percent) were still 50 percent higher than Southwest's--an airline not included in this data set since it never came under CAB regulation.

Table 4b presents cost inefficiency estimates, pre- and post-deregulation. The average level of inefficiency in the industry rose about 10 percent on average from 1979 to 1981. The estimates of inefficiency for seven of the 12 airlines increased, and for four airlines the increase exceeded 20 percent. This is exactly the opposite of what one would have expected to happen.

Figure 4 plots the deseasonalized average level of cost inefficiency in the airline industry over time. Peaks in cost inefficiency coincide closely with recessions (roughly 1970, 1974, the first half of 1980, and the second half of 1981), with oil price shocks (early 1974 and early 1979), and with air traffic controller strikes (summer 1981).

The relationship between cost inefficiency and changes in regulatory control is more difficult to infer. The CAB's internal reforms allowing discount fares in 1977 and allowing airlines some latitude to set their own fares in 1978 (airlines could raise their fares 10 percent above or 70 percent below the Standard Industry Fare Level (SIFL) set by the CAB without approval) did appear to reduce cost inefficiency. If the ADA, passed in October 1978, further improved airline cost efficiency, the effect was more than offset by the many shocks that buffeted the industry since 1979.

These results differ somewhat from the results found by Sickles, Good, and Johnson (1986). Using their distorted profit framework, they found a fairly uniform convergence from high foregone profits at the beginning of the 1970s to almost no foregone profits by 1981. They credit the largest reductions in foregone profits to internal reforms the CAB undertook before the ADA, such as creating the SIFL, permitting multiple route authorizations, promoting easier entry into new markets, and speeding approval of discount fares.

Of course, one would like to have more current data to determine the long-run effect of the ADA on cost efficiency in the industry. Interestingly, of the eight airlines that have gone bankrupt or have been acquired since 1981, five had increases in their estimates of cost inefficiency. Of the four airlines that have maintained their independence, the average estimate of cost inefficiency of only one increased.

Table 5 reports the results of the TFP decomposition technique. The observed TFP grew, on average, for all of the firms, although a great deal of variation occurred across firms. Much of this increase is the result of technological progress which, as reported earlier, increased the TFP growth at a rate of 0.274 percent a quarter. The scale effect was a significant source of TFP gains for the smaller airlines, which were free to grow under the regulatory reform process, but not for the largest four airlines. The inefficiency effects varied considerably from airline to airline, but were generally small. Over time, however, changes in the airlines' networks have generally boosted productivity. The average load factors and stage lengths of the airlines have risen (although unevenly across airlines), each resulting in increases in the observed TFP of about the same order of magnitude as those attributable to technological progress.

The biases in the observed measure of TFP as a result of nonmarginal cost pricing (the output effect) and as a result of the observed input shares not being equal to the least cost input shares (the price effect) exert only a small effect on the observed TFP. In general, these estimates indicate that the observed measure of TFP is a biased estimate of technological progress, not just because of the scale and output effects--as Denny, Fuss, and Waverman (1981) have shown--but also because of the efficiency, network, and input price effects.

Tables 6a and 6b show the changes in observed TFP growth before and after deregulation, respectively. The observed TFP growth dropped sharply after . deregulation. Most of this drop is a result of the lower load factors experienced by the airlines for much of the period after deregulation. The load factor effect went from increasing the observed TFP growth by 0.41

percent before deregulation to decreasing it 0.36 percent after deregulation. This result is understandable given that the airline industry is highly procyclical; load factors generally plummet during a sluggish economy like the one that prevailed from 1980 to 1981.

The airlines apparently made good use of their new freedom to set their own route structures. The stage length effect on observed TFP growth more than doubled after deregulation, from 0.21 percent to 0.53 percent per quarter. The scale effect also led to faster observed TFP growth after deregulation, primarily because the smaller airlines moved toward the minimum efficient scale. All but Continental among the larger airlines eliminated the drag on observed TFP growth by adjusting their mix of outputs or reducing their scale of operations.

V. Analysis and Conclusions

This paper describes and helps explain the airline industry's early adaptations to the new deregulated environment. First, the existence of a significant amount of cost inefficiency in the airline industry (about 6.8 percent before 1979) explains the rush of new entrants into the industry once the CAB no longer inhibited entry. The absence of an increase in cost efficiency as late as 1981 suggests that the airline industry is not perfectly contestable. Events in the industry do suggest that competition may exercise its guiding hand, as the firms whose cost efficiency increased tended to survive, while all but one of the others went bankrupt or were taken over.

Second, opportunities for substitution among inputs are limited, implying that the airlines pass through much of the oil price increases as higher costs that ultimately reach travelers as higher fares. Thus, the airlines were distressed in the early 1980s by downturns in the national economy, and they were also hurt by the oil price jump in 1979. Both of these shocks caused the drop in average load factors in the 1979-1981 period, and caused the load factor effect on observed TFP growth to drop from 0.41 percent'to -0.36 percent per quarter on average. The limited substitutability among inputs also helps to explain why the airlines as a group have been so eager to control their labor costs, at a time when their competitors need not necessarily match wage increases.

The airlines did take advantage of their new freedom to set their own route structures after deregulation, and from 1979 to 1981, the observed TFP growth rose 0.32 percent faster per quarter as a result of the airlines' increasing their average stage lengths. But without the airlines' new freedom to set their own fares--and particularly their ability to offer restricted discount fares--average load factors might have been even lower. At the end of this sample, the airline industry as a whole had started to move aggressively toward hub-and-spoke networks, and these results make it clear why they would want to. Hub-and-spoke networks tend to increase average stage lengths and load factors, both of which lower airline costs. United Airlines introduced another technique in 1981 for increasing average load factors, the now ubiquitous frequent-flier plans.

The last major development in the airline industry since deregulation is the merger wave that hit the industry in 1986. The largest airlines had exhausted any scale or scope economies by late 1981. Thus, one can base no explanation for the merger wave on the argument that airlines were trying to achieve minimum efficient scale. One could, however, argue that the adoption of hub-and-spoke networks has increased the minimum efficient scale in the industry. Unfortunately, one cannot use the data in this study to test this hypothesis, except to reiterate that if hub-and-spoke networks increase average stage lengths and load factors, they could partially offset any diseconomies of scale.

The switch to hub-and-spoke route networks and the demands they place on acquiring gate space and takeoff and landing slots at the most desirable airports best explain the 1986 merger wave. Given the difficulties in acquiring these resources (gates typically are leased for long periods and landing slots tend to be grandfathered to their current carriers), it is easier and probably cheaper for an airline to expand by purchasing another airline with the desired gate space and landing slots than to expand. internally.

In conclusion, two relatively new empirical techniques helped to shed light on changes that have occurred in the airline industry in the last 10 years. One would like to extend this data set closer to the present to determine whether the airlines have actually increased their cost efficiency since 1981. One could also study whether the switch to hub-and-spoke networks caused a shift in the cost function that makes a larger scale of operations more desirable. These issues must be addressed in future research.

Footnotes

1. The issue of how to model the relationship between the disturbances on the cost equation and the input share equations, given that deviations from cost-efficient input shares should raise observed costs, is frequently referred to as the Greene Problem (see Greene, 1980).

2. For a more complete economic analysis of the airline industry under CAB regulation, see Douglas and Miller (1974).

3. Two excellent texts on the early deregulatory experience are Bailey, Graham, and Kaplan (1985) and Meyer and Oster (1981).

4. The network characteristics are anything that affects the firm's costs of delivering the output or service to consumers.

5. Since technical efficiency is the equiproportional over employment of all inputs, it does not appear in the input share equations.

6. One input share equation must be dropped to avoid singularity.

Kopp and Diewert (1982) developed a technique for further decomposing the estimate of overall cost efficiency into estimates of technical and allocative inefficiency, and Zieschang (1983) improved the technique. This technique was employed, but it yielded estimates of technical and allocative efficiency that were pot bounded by zero and one. The problem may be that while the estimated cost function is usually concave in input prices in the neighborhood of the observed input prices, the cost function is not globally concave in input prices. Imposing global concavity in input prices may solve this problem, but this was not attempted.

8. Variables with a dot over them are defined to be the time rate of change in the variable $(d\ln z/dt)$.

9. Denny, Fuss, and Waverman (1981) discuss the properties of this definition of multiproduct total factor productivity growth in more detail.

10. For a more detailed description of this data set, see Sickles (1985).

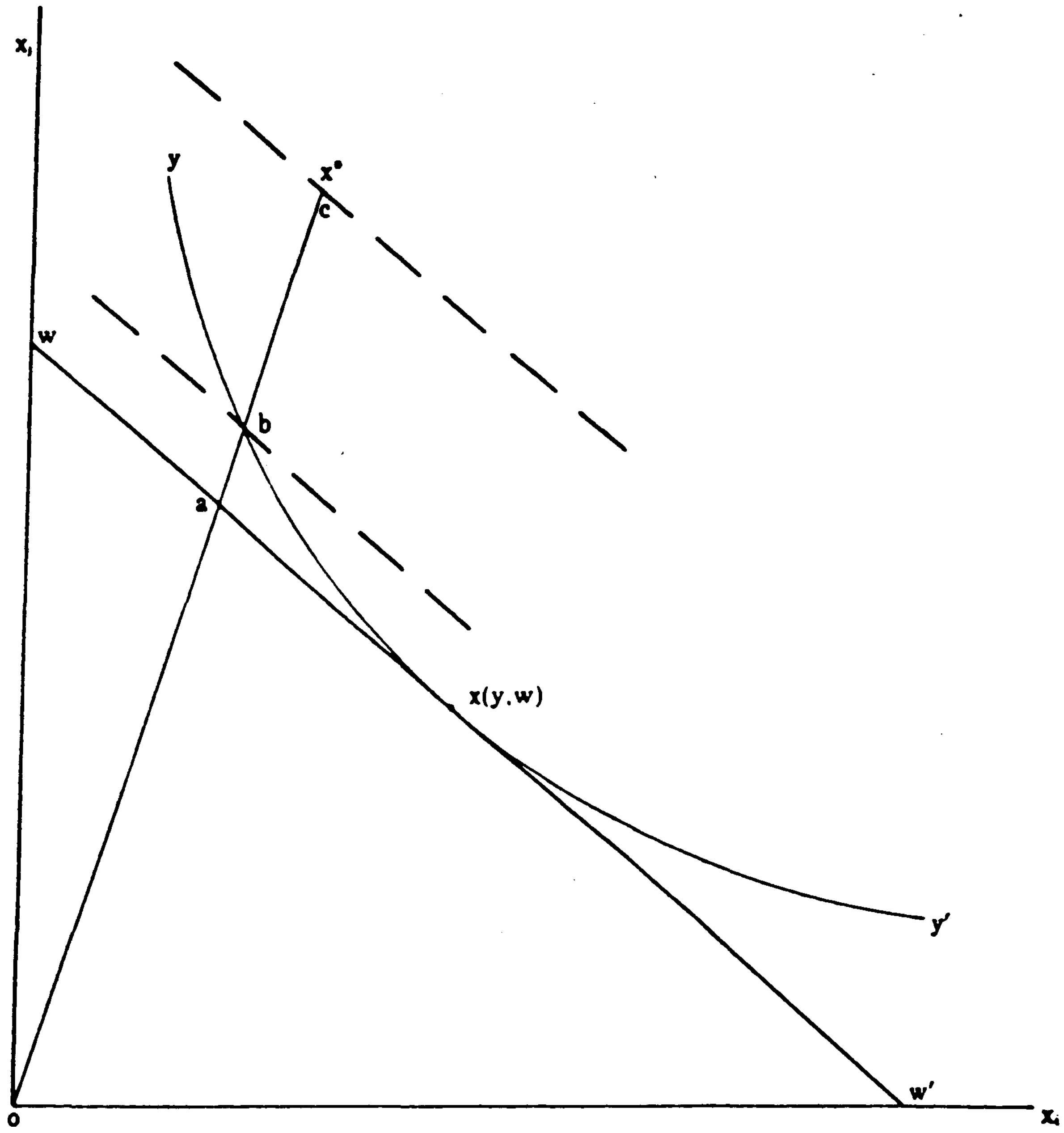
11. Most of these studies explicitly treated the airlines as single-product firms, so it is reassuring to note that this result holds in a multiproduct generalization.

12. Given the particular form of the translog-type function that was estimated, technological progress is constrained to be the same for all firms over time. This formulation is imposed to limit the number of parameters to be estimated and to reduce the effects of multicollinearity.

13. For some Monte Carlo results on the properties of these types of estimators, see Waldman (1984).

14. These estimates of cost inefficiency are the increases in log cost, which are roughly the proportion by which observed cost exceeds minimum cost. To obtain the Farrell measure of cost efficiency, raise e to the negative of these values.

Figure 1 Cost-Minimization Problem



Source: Author's calculations.

Table 1

MLE Parameter Estimates

Parameters	Estimate	Asymptotic Standard Error
$\sqrt{\sigma}$	0.328961	0.011959
$\sqrt{\lambda}$	1.136091	0.142654
β_o	19.368848	0.036376
β_{yP}	0.855741	0.013566
β_{y_c}	0.140263	0.013380
β_K	0.099889	0.015654
β_L	0.469013	0.043650
β_E	0.232090	0.024935
β_{ldf}	-0.663032	0.041049
β_{stgl}	-0.292790	0.020772
β_t	-0.002744	0.001055
$1/2\,\beta_{y_p y_p}$	0.085471	0.019229
$\beta_{y_p y_c}$	-0.121785	0.028829
$\beta_{y_p K}$	-0.036898	0.003079
$\beta_{y_p L}$	0.044412	0.004507
$\beta_{y_p E}$	0.006407	0.002081
$1/2\,\beta_{y_c y_c}$	0.061784	0.012200
$\beta_{y_c K}$	0.030902	0.002478
$\beta_{y_c L}$	-0.040931	0.003587
$\beta_{y_c E}$	0.005638	0.001655
$1/2\,\beta_{KK}$	-0.001860	0.002050*
β_{KL}	0.019602	0.003266
β_{KE}	-0.019293	0.001967
$1/2\,\beta_{LL}$	0.050961	0.005694
β_{LE}	-0.063920	0.005064
$1/2\,\beta_{EE}$	0.061453	0.000928
α_K	0.087048	0.015658
α_L	-0.061833	0.043642*
α_E	-0.021023	0.024930*

*<u>Not</u> statistically significant at the 0.01 level of significance.

Source: Author's calculations

Table 2

Output Cost Elasticities

Airline	Passenger	Cargo	Ray
AA (American)	0.859	0.176	1.035
AL (Allegheny/now US Air)	0.901	0.034	0.935
BR (Braniff)	0.823	0.149	0.972
CO (Continental)	0.782	0.187	0.969
DL (Delta)	0.938	0.080	1.019
EA (Eastern)	0.942	0.083	1.025
FL (Frontier)	0.887	0.016	0.903
NC (North Central)	0.827	0.068	0.896
OZ (Ozark)	0.799	0.077	0.877
PI (Piedmont)	0.862	0.021	0.884
UA (United)	0.873	0.174	1.047
WA (Western)	0.880	0.095	0.975

Table 3

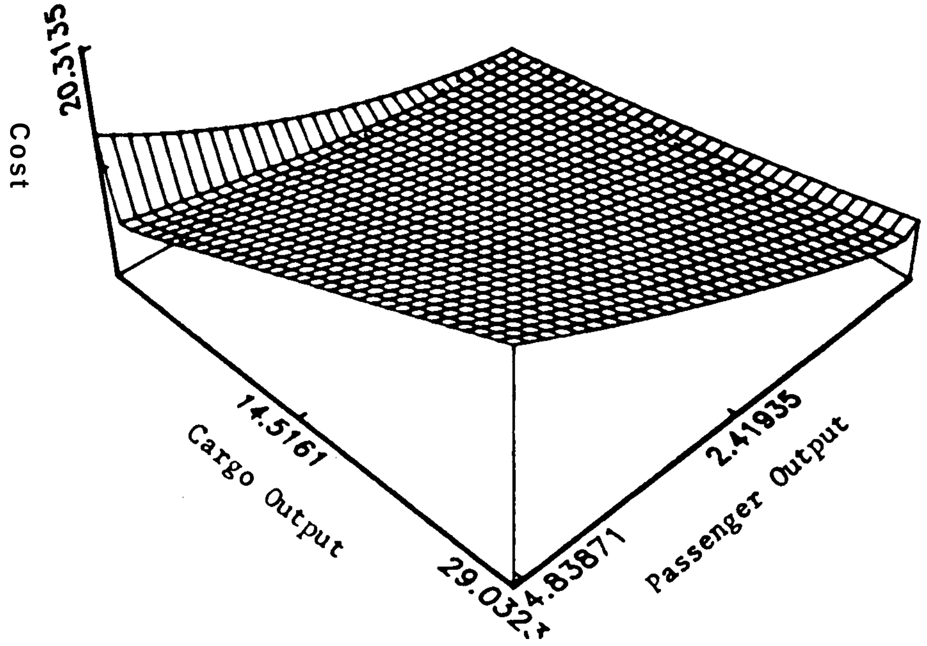
Price Elasticities of Substitution

Input pair[1]	Elasticity
KK	-0.941
LL	-0.298
EE	-0.064
MM	-0.343
KL	0.702
KE	-0.009
KM	0.248
LE	0.065
LM	0.094
EM	-0.028
LK	0.139
EK	-0.017
MK	0.327
EL	0.109
ML	0.220
ME	0.007

[1] The key to decoding these input pairs is the following: $\frac{\partial \ln x_i(y,w,z,t)}{\partial w_j} = \epsilon_{ij}$.

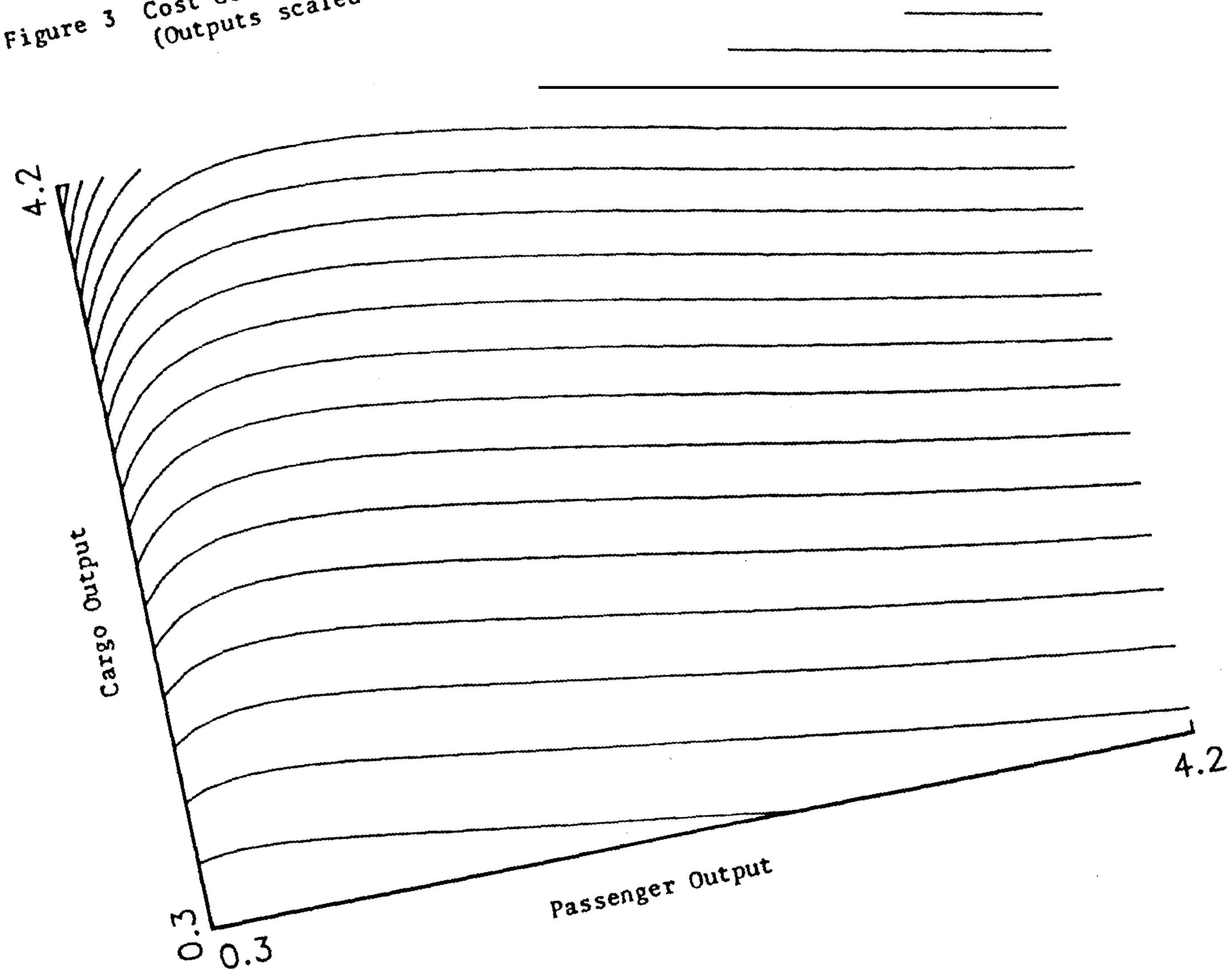
Source: Author's calculations

Figure 2 Joint Cost Function



Source: Author's calculations.

Figure 3 Cost Contours
(Outputs scaled as a proportion of the average firm)



Source: Author's calculations.

Table 4a

Cost Inefficiency Estimates (increase in log cost)

Airline	$\bar{\xi}$	$E(u\|\xi)$	$M(u\|\xi)$
AA	0.096	0.075	0.060
AL	0.148	0.101	0.093
BR	0.074	0.066	0.048
CO	0.012	0.051	0.023
DL	-0.013	0.040	0.004
EA	0.165	0.108	0.103
FL	-0.012	0.041	0.007
NC	0.058	0.060	0.037
OZ	0.130	0.092	0.082
PI	0.056	0.060	0.038
UA	0.076	0.072	0.053
WA	0.028	0.053	0.027
Overall	0.068	0.068	0.048

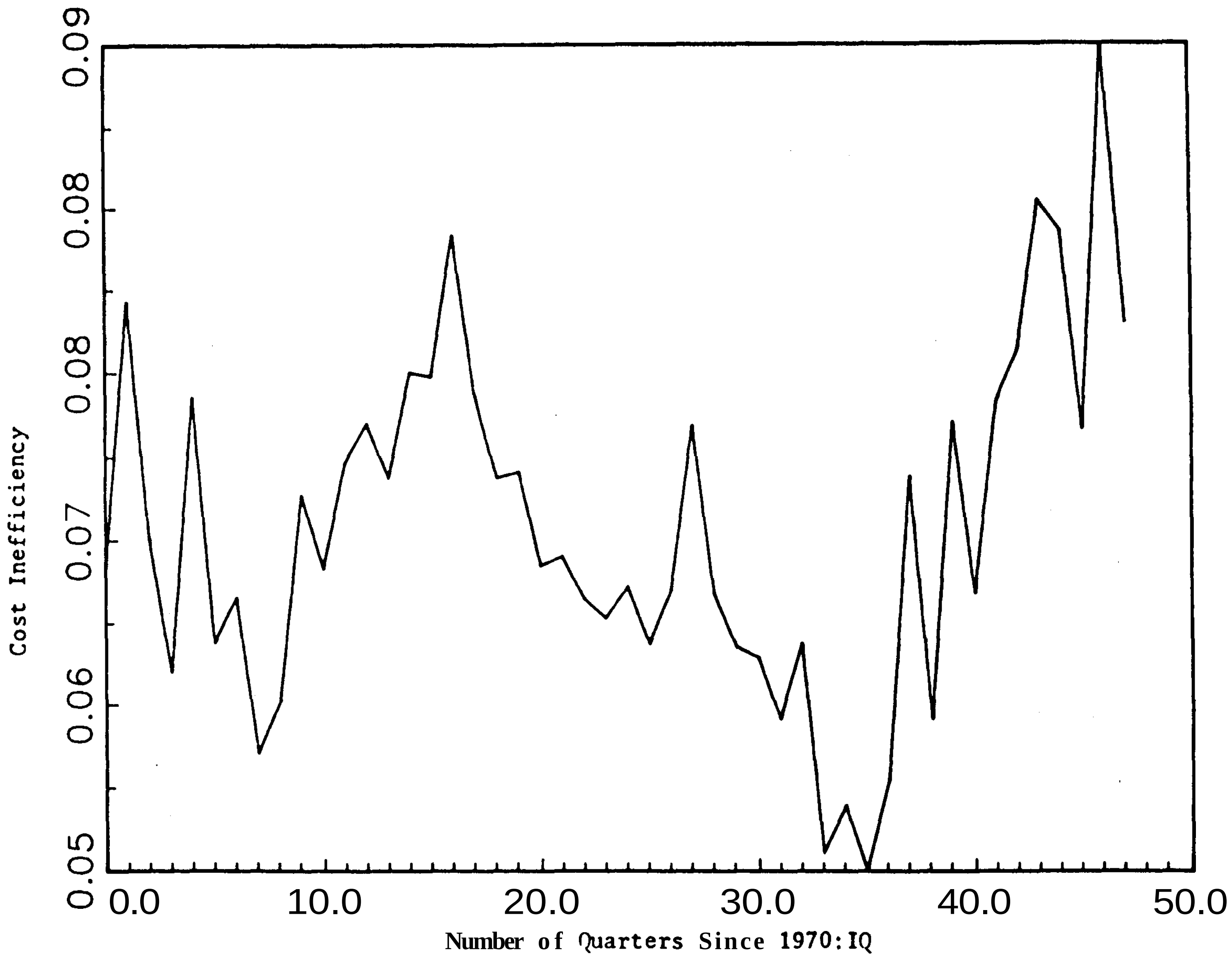
Table 4b

Cost Inefficiency Estimates Pre- and Post-Deregulation, Using $E(u|\xi)$ (increase in log cost)

Airline	1970:IQ-1978:IVQ	1979:IQ-1981:IVQ
AA	0.074	0.078
AL	0.091	0.129
BR	0.066	0.067
CO	0.040	0.081
DL	0.041	0.037
EA	0.117	0.082
FL	0.039	0.045
NC	0.056	0.072
OZ	0.083	0.122
PI	0.060	0.059
UA	0.072	0.069
WA	0.056	0.042
Overall	0.066	0.073

Source: Author's calculations.

Figure 4 Cost Inefficiency (E(u/e))



Source: Author's calculations.

Table 5

TFP Decomposition
(Average quarterly rate of change, in percent)

Airline	TFP	Scale Effect	Output Effect	Eff. Effect	Technical Change	Price Effect	Load Factor	Stage Length
AA	0.7070	-0.0189	0.0686	-0.0063	0.274	-0.1270	0.3584	0.1578
AL	0.9892	0.2140	-0.0626	-0.1945	0.274	-0.0976	0.4873	0.3682
BR	0.5656	0.0377	0.1717	0.0294	0.274	-0.0814	0.0041	0.1297
CO	0.4006	0.0517	0.1058	-0.0261	0.274	-0.1101	-0.0017	0.1066
DL	0.3304	-0.0109	0.0011	-0.0180	0.274	-0.0632	0.0093	0.1378
EA	0.3636	-0.0174	0.0085	-0.0489	0.274	-0.1216	0.2038	0.0648
FL	1.0879	0.2108	-0.0817	-0.0435	0.274	-0.1497	0.4287	0.4490
NC	1.6555	0.4639	-0.0385	-0.1132	0.274	0.0098	0.4256	0.6335
OZ	0.8937	0.2694	-0.0417	-0.0717	0.274	-0.1033	0.0492	0.5175
PI	1.4593	0.3548	0.0116	0.0256	0.274	-0.0225	0.3069	0.5086
UA	0.7017	-0.0284	0.0430	0.0576	0.274	-0.1400	0.3020	0.1931
WA	0.5565	0.0483	-0.0237	0.0317	0.274	-0.1120	0.3249	0.1342
Overall	0.8107	0.1317	0.0148	-0.0308	0.274	-0.0937	0.2303	0.2835

[1] The TFP reported in these tables is best defined as being the estimated observed change in total factor productivity, since it is obtained by summing the various components.

Source: Author's calculations.

Table 6a

TFP Decomposition--Before Deregulation
(Average quarterly rate of change, in percent)

Airline	TFP	Scale Effect	Output Effect	Eff. Effect	Technical Change	Price Effect	Load Factor	Stage Length
AA	0.9462	-0.0442	0.0854	0.0972	0.274	-0.1298	0.5113	0.1520
AL	1.1287	0.2463	0.0119	-0.2422	0.274	-0.1195	0.6689	0.2889
BR	0.6842	0.0472	0.2067	0.1344	0.274	-0.0804	-0.0590	0.1608
CO	0.5714	0.0692	0.1440	0.0329	0.274	-0.1229	0.1299	0.0440
DL	0.5800	-0.0289	0.0085	0.0304	0.274	-0.0787	0.3000	0.0743
EA	0.6752	-0.0401	0.0169	0.0682	0.274	-0.1339	0.4702	0.0195
FL	1.2268	0.2376	-0.0678	-0.0409	0.274	-0.1369	0.6263	0.3342
NC	1.8774	0.4352	0.0474	0.0027	0.274	-0.0413	0.7654	0.3936
OZ	1.1392	0.3449	0.0060	0.0239	0.274	-0.1528	0.2220	0.4209
PI	1.0446	0.2723	0.0890	-0.0554	0.274	-0.1013	0.1957	0.3700
UA	0.9015	-0.0683	0.0441	0.1348	0.274	-0.0983	0.5302	0.0847
WA	1.0211	0.0740	-0.0181	0.1542	0.274	-0.1663	0.5690	0.1340
Overall	*0.9830*	0.1288	0.0478	0.0283	0.274	-0.1135	0.4108	0.2064

Table 6b

TFP Decomposition--After Deregulation
(Average quarterly rate of change, in percent)

Airline	TFP	Scale Effect	Output Effect	Eff. Effect	Technical Change	Price Effect	Load Factor	Stage Length
AA	-0.0758	0.0639	0.0135	-0.3448	0.274	-0.1178	-0.1418	0.1769
AL	0.5326	0.1084	-0.3063	-0.0384	0.274	-0.0261	-0.1068	0.6274
BR	0.1774	0.0067	0.0570	-0.3141	0.274	-0.0848	0.2104	0.0279
CO	-0.1586	-0.0056	-0.0191	-0.2195	0.274	-0.0683	-0.4321	0.3117
DL	-0.4866	0.0481	-0.0231	-0.1766	0.274	-0.0124	-0.9424	0.3454
EA	-0.6562	0.0572	-0.0191	-0.4320	0.274	-0.0816	-0.6681	0.2130
FL	0.6331	0.1229	-0.1274	-0.0521	0.274	-0.1918	-0.2177	0.8249
NC	0.9293	0.5580	-0.3200	-0.4924	0.274	0.1771	-0.6864	1.4185
OZ	0.0904	0.0224	-0.1977	-0.3845	0.274	0.0585	-0.5163	0.8336
PI	2.8163	0.6247	-0.2417	0.2907	0.274	0.2356	0.6707	0.9620
UA	0.0477	0.1022	0.0393	-0.1949	0.274	-0.2766	-0.4446	0.5479
WA	-0.9642	-0.0264	0.0261	-0.3324	0.274	0.0513	-1.0730	0.1159
Overall	*0.2405*	0.1402	-0.0932	-0.2242	0.274	-0.0281	-0.3624	0.5337

Source: Author's calculations.

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