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**Long Run Properties of Technical
Efficiency in the U.S. Airline Industry**

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ABSTRACT

Long Run Properties of Technical Efficiency in the U.S. Airline Industry

by Ila M. Semenick Alam and Robin C. Sickles*

This paper takes an innovative approach to test the relationship between technical efficiency and the market structure hypothesis which states that competitive pressure enhances relative efficiency. DEA and FDH time series of technical efficiency scores, for a panel of 11 US airlines observed quarterly during 1970-1990, are examined for cointegration and convergence. For almost all firm pairs (>90% for both efficiency measures), the null hypothesis of cointegration cannot be rejected; meanwhile, the null of no cointegration is rejected for approximately one-third of the firm pairs. Furthermore, convergence tests document less dispersion in firm performance over time. These results indicate that the scores move together and, in fact, the firms are becoming more alike one another in terms of efficiency.

ZUSAMMENFASSUNG

Langfristige Eigenschaften der technischen Effizienz in der US-Luftfahrtindustrie

In diesem Beitrag wird ein innovativer Ansatz entwickelt, um die Beziehung zwischen technischer Effizienz und der Marktstrukturhypothese zu überprüfen, die besagt, daß Wettbewerbsdruck die relative Effizienz erhöht. Die DEA- und FDH-Zeitreihen der technischen Effizienz für ein Panel-Datensatz von 11 US-Fluggesellschaften, die während der Periode 1970 bis 1990 beobachtet wurden, werden im Hinblick auf Kointegration und Konvergenz analysiert. Für nahezu alle Unternehmenspaare (mehr als 90% bei beiden Effizienzmaßen) kann die Nullhypothese der Kointegration nicht zurückgewiesen werden, wo hingegen die Nullhypothese, daß keine Kointegration vorliegt, für etwa ein Drittel der Unternehmenspaare zurückgewiesen wird. Außerdem zeigt der Konvergenztest, daß die Streuung des Unternehmenserfolgs im Zeitablauf abnimmt. Die Ergebnisse deuten darauf hin, daß die Effizienzwerte sich auf einander zu bewegen und daß in der Tat, die Unternehmen im Hinblick auf Effizienz sich immer ähnlicher werden.

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1. INTRODUCTION

An industry's production technology is the set of all feasible pairs of input-output vectors. The production frontier consists of those combinations which, under existing production processes, maximize output production for given input levels or, conversely, minimize input usage for given output levels. Firms not operating on this frontier are identified as technically inefficient.

The frontier literature has largely been concerned with documenting inefficiency of firms in various sectors. Technical efficiency techniques have a wide-spread appeal because both government policy makers and industry managers are concerned about productive performance. More importantly, upon determination of efficiency differentials, these techniques can be used as decision making tools since they indicate areas of deficiency and direction for change.

Our objective, beyond simply presenting evidence of technical inefficiency, is to explore some of the long-run properties of these scores. Specifically we are interested in the link between market structure and performance first made explicit in Leibenstein's (1966) article on X-efficiency which states that, given "proper motivations", firms can achieve increased efficiency. A prime motivational factor is the degree of competitive pressure. Studies have become more formalized with the introduction of technical efficiency measurement techniques which are useful tools to measure and partition X-inefficiency (Leibenstein and Maital, 1992). Caves and Barton (1990), for example, consider the relationship between technical efficiency levels and competitive conditions for 285 US industries. Overall they find support for public policies designed to maintain competition among producers since these policies promote efficiency. Other studies focus on sectors such as utilities (*e.g.*, Reifschneider and Stevenson, 1991), since the dependency between efficiency and competitive pressure has significant regulatory relevance. Button and Weyman-Jones (1992) find, in their literature survey, that those industries subject to bureaucratic control generally exhibit lower efficiency levels than those which are competitive or weakly regulated.

We take a unique approach to empirically examine this relationship between competitive forces and the time pattern of technical efficiency. Our procedure is made possible by bringing together recent advances in various areas of the economics literature. In the technical efficiency arena, studies focused exclusively on cross-sectional results until developments in the parametric estimation of technical efficiency (Cornwell, Schmidt and Sickles, 1990; hereafter CSS) and generalizations of the linear programming approaches (Tulkens and Vanden Eeckaut, 1995) allowed the recent exploitation of panel data sets. The ability to capture the dynamic nature of a firm's performance relative to its competitors has stimulated even greater interest in the topic. However, little is known about the time series nature of technical efficiency. To explore the dynamics, we introduce the

concepts of cointegration and convergence to this literature in order to determine if, under increasing competitive forces, the technical efficiency scores of firms move together in the long run (cointegration) or, in fact, move closer together over time (convergence). Evidence of these time series characteristics would be indicative of a greater concern among firms to maintain high relative technical efficiency. To this end, we use developments in the cointegration (including those by Kwiatkowski, Phillips, Schmidt and Shin, 1992; hereafter KPSS), and convergence literatures (including those by Färe, Grosskopf, Norris and Zhang, 1994; hereafter FGNZ).

The US airline industry from 1970 to 1990 is an ideal candidate for this analysis since, over this period, competition among the airlines increased due to deregulation¹. The importance of studying technical efficiency in this industry is highlighted by previous papers which have found technical inefficiency to be a much greater source of distortion than that which is due to allocative inefficiency². Furthermore, US airlines continue to face substantial upheavals in the form of mergers, failures, bankruptcy filings, reorganizations and operating loss reports. This apparent inability of the industry to reach equilibrium, has raised concern that the future is bleak in terms of the number of carriers which will survive and prosper. One other empirically attractive feature of this industry, a consequence of the strict filing requirements imposed by the federal government, is the wealth of accessible data not available in most other industries.

The paper is organized as follows: section 2 briefly discusses the methodologies; section 3 describes the production data set; section 4 contains the empirical findings; section 5 concludes.

2. METHODS

2.1. *Efficiency Measurement.* Assume a panel with $n=1,\dots,N$ firms, $t=1,\dots,T$ periods, $j=1,\dots,J$ inputs and $k=1,\dots,K$ outputs. Thus, x_{jnt} is the level of input j used by firm n in period t and y_{knt} is the level of output k produced by firm n in period t . Further, assume

¹ The airline industry moved from service-based to price-based competition under deregulation.

² See for example, Sickles, Good and Johnson (1986), Sickles (1987), Good, Nadiri and Sickles (1992), and Good, Roller and Sickles (1993, 1994). These results are somewhat at variance with the finding of Atkinson and Cornwell (1994) who use airline data covering the subset period 1970-1981. However, for industries in general, the empirical evidence overwhelmingly finds that allocative inefficiency is trivial compared to technical inefficiency (Leibenstein and Maital, 1992). Furthermore, Berger and Hannan (1994) have preliminary empirical evidence from the banking industry showing that the potential social loss over time from firms operating inefficiently is many times larger than the loss from mispricing that typically accompanies a concentrated market structure and the exercise of market power. This is because the inefficiency loss is present for each unit produced, while the “welfare triangle” loss applies only to customers who do not receive the product because of the higher prices.

an intertemporal³ production set where input and output observations from all time periods are used. The production technology, \mathbf{S} , is

$$(1) \quad \mathbf{S} = \{(x, y) \mid x \in \mathfrak{R}^J_+, y \in \mathfrak{R}^K_+, (x, y) \text{ is feasible}\}$$

The efficiency scores are the distances from the frontier. An output-based distance function⁴, OD, is defined as

$$(2) \quad \text{OD}(x,y) = \min\{\lambda \mid (x, y/\lambda) \in \mathbf{S}\}$$

Holding the input vector constant, this expression expands the output vector as much as possible without exceeding the boundaries of \mathbf{S} . An output efficient firm has a score of 1 while an output inefficient firm has $\text{OD}(x,y) < 1$. We utilize the methods of Data Envelopment Analysis (DEA) and Free Disposal Hull (FDH) to define the boundary of \mathbf{S} ⁵.

2.2 Data Envelopment Analysis. DEA creates an “envelope” of observed production points (Charnes, Cooper and Rhodes, 1978). It provides for flexible piecewise linear approximations to model the “best-practice” reference technology. Programming methods require neither the assumption of cost minimization or profit maximization nor the specification of a production function. The intertemporal output-based efficiency score is obtained from the following linear programming model:

$$(3) \quad [\text{OD}(x_{nt}, y_{nt})]^{-1} = \max \lambda_{nt}$$

subject to

$$\lambda_{nt} y_{knt} \leq \sum_n \sum_t w_{nt} y_{knt}, \quad k = 1, \dots, K,$$

$$\sum_n \sum_t w_{nt} x_{jnt} \leq x_{jnt}, \quad j = 1, \dots, J,$$

$$w_{nt} \geq 0, \quad n = 1, \dots, N; t = 1, \dots, T$$

³ Reference sets can also be contemporaneous (data from only one time period are used) or sequential (data from the first time period up to the time period s , $t=1, \dots, s$ where $s \leq T$, are used) (Tulkens and Vanden Eeckaut, 1995). We adopt the intertemporal approach since it allows us to compare various measures of technical efficiency. The Malmquist Index discussed later uses the contemporaneous definition but is able to capture the relationship between time periods.

⁴ The input-based distance function is $\text{ID}(x,y) = \max\{\lambda \mid (x/\lambda, y) \in \mathbf{S}\}$. Under constant returns to scale, $\text{OD}(x,y) = [\text{ID}(x,y)]^{-1}$.

⁵ A third method, Stochastic Frontiers (SF), is an econometric approach which, unlike DEA and SFA, requires *a priori* specification of technology to describe the boundary. For completeness we also calculated efficiencies using the translog functional form and the CSS approach. However, because the SF estimates are log-linear in time and, by definition, are automatically cointegrated they are not very illuminating with respect to our cointegration hypothesis.

where the condition on the weights, w_{nt} , gives constant returns to scale (CRS)⁶.

2.3. Free Disposal Hull. Compared to DEA, FDH imposes one less restriction on the data: it does not require that convex combinations of every observed production plan be included in the production set (Deprins, Simar and Tulkens, 1984). Thus, an FDH score is relative to an observed point on the frontier and, since managers can look at an actual rather than a theoretically possible alternative in order to modify current practices and improve performance, it is argued that FDH is more valuable for managerial decision making. The FDH frontier is obtained by replacing the last line in Equation (3) with $\sum_n \sum_t w_{nt} = 1$, $w_{nt} \in \{0, 1\}$, $n=1, \dots, N$, $t=1, \dots, T$.

2.4. Second Stage Regression. The efficiency results obtained from DEA and FDH are regressed⁷ on a matrix of firm characteristics as well as on firm and time dummies⁸. The residuals from this regression provide the appropriate measure of performance since they capture the efficiency score minus the effects of these other characteristics⁹.

2.5. Cointegration. Cointegration analysis examines the existence of stationary relationships between nonstationary variables. For a stationary time series x_t , a shock has only a temporary effect on x_t , x_t has a finite variance and its autocorrelation function declines quickly to zero as the distance between neighboring data points in the x_t series increases. If the series has a unit root, however, the series is nonstationary. It is said to be integrated of order one, $x_t \sim I(1)$, if first differencing results in a stationary series. In general a series is integrated of order d , $I(d)$, if it becomes stationary after differencing d times. An $I(1)$ series is permanently affected by a shock, has a variance approaching infinity as T goes to infinity and had an autocorrelation function which does not decline quickly.

It is usually necessary to first-difference a non-stationary time series before it can be used in a regression, otherwise spurious results may be obtained. This practice is necessary but regrettable since information is lost upon differencing. Suppose, however, you have two $I(1)$ variables, x_t and y_t . If there exists a θ such that a linear combination of these variables, $x_t + \theta y_t$, is $I(0)$ then first differencing is unnecessary. In such an instance, x_t and y_t

⁶ Various restrictions on the sum of the w_{nt} 's would result in non-increasing, non-decreasing or variable returns to scale. See Seiford and Thrall (1990) for a detailed discussion. We use CRS since research on returns to scale in the airline industry has indicated this to be the case; for example, see CSS and Caves, Christensen and Diewert (1982). Also, using SF, we test the CRS restriction with our data and fail to reject ($F(1,827) = 3.01 < 3.85 = 5\%$ critical value).

⁷ Since the dependent variable (either DEA or FDH scores) is bounded by 0 and 1, it is censored. The problem is one of single censoring since there are several cases where technical efficiency equals 1 but no cases where the score is 0. To account for this, tobit analysis is performed. Correlations between the second stage OLS regressions and the tobit regressions are very high.

⁸ This second stage regression is necessary to control for differences in input and output characteristics since, under DEA and FDH, only inputs and outputs can be included in the initial calculations. Note that under SF the characteristics as well as the time and firm dummies are simply included in the original translog functional form.

⁹ We thank an anonymous referee for this observation.

are said to be cointegrated and θ is the cointegration factor. Cointegrated variables cannot move too far away from one another; in contrast, a lack of cointegration suggests that the variables have no long term link. The primary goal of this paper is to identify and explain the long run dynamics between efficiency score time series of the airlines in our sample. Anecdotal evidence suggests that deregulation has led to more efficient use of resources among the airlines. Thus, efficiency scores should track one another over time as carriers attempt to follow each other's efficiency advances in order to remain competitive. If a firm's efficiency scores do not exhibit cointegration with those of its counterparts, this may indicate the firm's inability to capitalize on technology other carriers are employing.

To discover if cointegration is present between carriers, we first test each carrier's series for a unit root using the standard augmented Dickey Fuller (ADF) approach. Then we test the null hypothesis of no cointegrating vector using the Johansen maximum likelihood procedure. In addition, we also test for unit roots using the direct residual-based KPSS test of a null of stationarity. The motivation behind this test is the well-known problem of low power in standard unit root tests. KPSS have a null of trend stationarity versus an alternative of difference stationary. Shin (1994) extended KPSS to a null of cointegration and derived the appropriate critical values. These authors suggest that standard tests with a null of no cointegration be used in conjunction with their test in order to reach more definitive answers about a series' characteristics.

2.6. *Convergence.* Tests of convergence, originating in the economic growth literature (Baumol, 1986), determine whether or not there is a closing of the gap between inefficient and efficient carriers over time. One approach regresses the carriers' average growth rates in technical efficiency on the log of the carriers' efficiency scores at the beginning of the sample period. A negative coefficient indicates convergence. In other words, the higher a firm's initial level of efficiency, the slower that level should grow. This phenomenon is the result of the public good nature of technology which causes spillover effects from leaders to followers as the laggards learn from the innovators and play "catch-up".

We also utilize a more sophisticated approach involving a Malmquist productivity index procedure. This method, based on the geometric mean of two Malmquist indices, is able to account for changes in both technical efficiency (catching up) and changes in frontier technology (innovation). In a study of industrialized countries, FGNZ note that this decomposition allows for a more comprehensive measure of productivity growth convergence since earlier endeavors failed to distinguish between these two components. Application of this technique to microeconomic level studies is a logical extension.

Whereas our earlier comparisons of the different methods of calculating technical efficiency necessitated an intertemporal production set, the Malmquist index requires the

contemporaneous version. Thus, due to rank considerations, only the DEA approach can be used to calculate the index. The production technology, output distance function and DEA linear programming problem (Equations (1)-(3)) are amended such that input-output combinations from only period t are used. In addition, the productivity index requires another output distance function which is calculated between periods, $OD_t(x_{t+1}, y_{t+1}) = \min\{\lambda | (x_{t+1}, y_{t+1}/\lambda) \in \mathbf{S}_t\}$. This expression has the technology of time t and scales outputs in time $t+1$ such that (x_{t+1}, y_{t+1}) is feasible in period t . The observed input-output combination may not have been possible in time t ; hence, the value of this expression can exceed one which would represent technical change.

To circumvent the arbitrary choice of time period, the output based Malmquist index is defined as a geometric mean of Malmquist indices:

$$(4) \quad M(x_{t+1}, y_{t+1}, x_t, y_t) = \frac{OD_{t+1}(x_{t+1}, y_{t+1})}{OD_t(x_t, y_t)} * \left\{ \frac{OD_t(x_{t+1}, y_{t+1})}{OD_{t+1}(x_{t+1}, y_{t+1})} \frac{OD_t(x_t, y_t)}{OD_{t+1}(x_t, y_t)} \right\}^{1/2}$$

$$= E_{t+1} * A_{t+1}$$

This index captures the dynamics of productivity change by incorporating data from two adjacent periods: E_{t+1} , reflects changes in relative efficiency while A_{t+1} , reflects changes in technology between t and $t+1$. For the index, a value below 1 indicates productivity decline while a value exceeding 1 indicates growth. Similarly, for the index components, values below 1 signify a performance decline while values above 1 signify an improvement.

3. DATA

The airline production data set consists of quarterly observations from 1970 through 1990 on 11 US carriers: American (AA), Continental (CO), Delta (DL), Eastern (EA), Frontier (FL), Ozark (OZ), Piedmont (PI), Trans World (TW), United (UA), USAirways (US) and Western (WA). Not all airlines span the entire period: Frontier ends 1986II¹⁰ because it merged into People Express in 1985 which merged into Continental in 1987; Ozark ends 1986III since it merged into TWA in 1986; Piedmont and Western end 1986IV because the former was absorbed by USAirways in 1987 while the latter was acquired by Delta in 1986¹¹.

¹⁰ Roman numerals I, II, III and IV refer to first, second, third and fourth quarters, respectively.

¹¹ The data often end prior to the actual merger date because, once merger announcements are made, data reporting accuracy may decline; thus, a more conservative approach to data collection was adopted.

The primary source for the data is the Civil Aeronautics Board (CAB)/DOT Form-41 schedules. The reporting requirements of these air carriers are quite extensive and, as of 1970, the data are rigorously audited to maintain a high degree of accuracy. The Form-41 is therefore a rich and definitive source of data for industry analysis. Attention is restricted to the traditional certificated carriers because a routine of data reporting was well established at the time of deregulation¹². This data set builds upon that originally constructed by Sickles (1985) and Sickles, Good and Johnson (1986). This version of the data includes several additional years of data and provides the largest, cleanest data available on the production of US scheduled air transport. The procedure used in constructing the updated version of the data set has changed considerably over the last decade. In particular, changes in the reporting requirements for the CAB/DOT Form-41 have been significant. In order to maintain consistency over time, data from all versions of Form-41 must be mapped into a single version. The objective was to maintain as much detail as possible in all areas of air carrier production in order to increase the usefulness of the data set for various studies. In those cases where price and quantity pairs of a specific input (output) are constructed, several sub-components to that input (output) are first constructed. These are aggregated into a single input (output) using a multilateral Tornqvist-Theil index number procedure. The result of this procedure is a price index (much like the consumer price index) which aggregates price information for commodities with disparate physical units. When the total expenditure of the input (output) category is divided by this price index, an implicit quantity index is produced.

The data set consists of 9 variables. The inputs are flight capital (K: number of planes), labor (L: pilots, flight attendants, mechanics, passenger and aircraft handlers and other labor), energy (F: gallons of aircraft fuel) and materials (M: supplies, outside services and non-flight capital). The aggregate output variable is the quantity of revenue output (RTM: revenue ton miles). Four control variables are also calculated. The first two describe airline output characteristics: aircraft stage length (STAGE) and load factor (LOADF). STAGE, the average length of route segments, is found by dividing flights into aircraft miles. A small stagelength means a carrier's aircraft spend only a short period of each flight at an efficient altitude. LOADF, the average fullness of a carrier's aircraft, provides a measure of service quality and is often used as a proxy for service competition. A low load factor, indicative of a large number of planes on a particular route, is a measure of high service quality. Deregulation has switched the focus from service quality, *i.e.* high number of flights, to price competition causing load factor to increase as service has declined. The second two control variables describe capital stock characteristics: average size of the carrier's aircraft (KSIZE) and the percentage of a carrier's fleet which is jet (PJET). These variables provide measures of the potential productivity of

¹² New entrants can be added to this data set with some difficulty. However, it should be remembered that these carriers have little experience in providing the often burdensome reporting required by Form-41 and that noncompliance results in virtually no sanctions. Consequently, new entrant data tends to be of significantly lower quality.

capital. For example, as KSIZE increases more services can be provided without a proportionate increase in factors such as flight crew, passenger and aircraft handlers and landing slots. PJET provides a measure of aircraft speed: jets fly approximately three times as fast as turboprops and they require proportionately less flight crew resources.

4. EMPIRICAL RESULTS

Technical efficiency scores are obtained using K, L, M and F as inputs and RTM as output. For DEA and FDH this results in 857 linear programming problems each. Firm dummies, firm dummies interacted with time and the control variables (STAGE, LOADF, KSIZE and PJET) are included in the second stage regression¹³.

4.1 *Cointegration.* It is first necessary to test each carrier's time series for unit root behavior. The unit root results from the ADF and KPSS tests are reported in Table 1. For four of the DEA series (DL, OZ, TW and US) and four of the FDH series (CO, DL, TW and WA) there is strong unit root evidence since the null of a unit root cannot be rejected while the null of stationarity can be rejected at the 5% level. Three more series under DEA (AA, CO and FL) and under FDH (AA, EA and OZ) probably have unit roots since the unit root null cannot be rejected at 5% and the stationarity null can be rejected at 10%. Furthermore, there are two series under DEA (EA and UA) and under FDH (UA and US) for which the ADF test indicates a unit root at the 5% level while KPSS test statistics are only slightly smaller than the 10% critical value; it is concluded these series are probably nonstationary and are included in the cointegration step. We conclude that WA under DEA and PI under FDH are stationary since both tests concur at the 5% level. This leaves PI under DEA and FL under FDH. For these series neither the unit root nor the trend stationary hypotheses can be rejected. Under these circumstances the conclusion is that not enough evidence exists to decide between a unit root and stationarity so we exclude these series from the cointegration analysis.

The results of the Johansen test of cointegration between carriers exhibiting unit root behavior are presented in Table 2¹⁴. Of the 36 pair combinations for DEA, 10 reject the null hypothesis of no cointegration at the 10% or less level (the pair UA & US at 10.3% is included in this tally); this represents 28% of the pairs. Another 2 pairs (DL & US, EA & UA) are significant around the 13% level which increases the percentage to 33% of pairs. Of the 36 pairs under FDH, 13 (or 36%) reject the null hypothesis of no cointe-

¹³ The same set of variables was utilized for the SF analysis.

¹⁴ In addition, we force-merged the airlines during the *ex ante* period, found the efficiency measures and tested these for unit roots and cointegration. The results are highly correlated with those presented in the body of the text. We also considered combinations of more than 2 carriers but no cointegration patterns emerged.

gration at the 10% or less level.

The Shin test results are reported in Table 3. Of 72 possible pairs under DEA, 66 (92%) do not reject the null of cointegration at the 5% level; of 72 possibilities under FDH, 70 (97%) do not reject cointegration at the 5% level. Pairs cointegrated under Johansen are also cointegrated, in at least one direction, under Shin. For example, consider CO & UA DEA results. This pair is strongly cointegrated under both tests (the null of no cointegration is rejected and the null of cointegration cannot be rejected). DL & OZ under DEA are cointegrated under Johansen while, under Shin, cointegration is detected only when OZ is regressed on DL. This situation suggests that the relationship is one-sided: OZ is dependent on DL but the reverse is not true. Note that, when the relationship does not go in both directions, it is always the smaller carrier which is dependent on the larger carrier (under DEA, OZ on DL, FL on UA, FL on DL, FL on TW; under FDH, OZ on TW). This pattern indicates that smaller carriers are taking cues from the larger carriers' strategies.

For the remaining pairs, the Shin test indicates cointegration while the Johansen test indicates no cointegration. For these pairs we need more information in the form of longer time series to make a definitive assessment of the presence of cointegration¹⁵. These results may be an artifact of low power or may be due to the fact that the technical efficiency scores are fractionally integrated¹⁶. Certainly, however, the cointegration null results are suggestive of a long run relationship between almost all of the carriers which satisfy the unit root requirement.

4.2. *Convergence.* Table 4 presents the results of regressing average growth rates on a constant and the initial efficiency levels. High inverse correlations are apparent. The slopes are negative and significantly different from zero in all cases supporting the convergence hypothesis that technological advances have become dispersed throughout the industry.

Table 5 is a summary of the efficiency change component of the Malmquist productivity index. We are most interested in the E_{t+1} component from Equation (4) since it is indicative of how similar the carriers are becoming over time. Means¹⁷ are taken to obtain each carrier's average performance over the entire period, pre-deregulation (1970-1978) and

¹⁵ Davis and Tanner (1995, for example, have found that the length of the data set is critical to detecting cointegration. Short data sets may not identify a cointegration relationship which appear when more data become available.

¹⁶ Such series fall between an $I(0)$ and $I(1)$ process. Examination of this possibility could be pursued using the ARFIMA approaches outlined in Cheung and Lai (1993), Cheung and Diebold (1994) and Mikkelsen (1994).

¹⁷ As FGZ point out, it is necessary to take multiplicative (geometric) means because the Malmquist index is multiplicative.

post-deregulation (1979-1990)¹⁸. In addition, means for each year over the sample are provided. Recall that values above one indicate improvement while values below one indicate deterioration. To calculate average increase or decrease per quarter, subtract 1 from the values in the table.

Consider the sample averages. Efficiency changes were slightly above one only in the post-deregulation period. Over the complete period and in the pre-deregulation years, firms were, on average, falling behind rather than catching-up to the frontier. Under regulation firms, on average, moved away from the frontier at a rate of 1.48% per annum (-0.37% per quarter) as compared to the 0.2% per annum (0.05% per quarter) convergence rate after deregulation. Thus, the industry switched from a relatively large path of divergence to a small, but positive, rate of convergence. A larger percentage of years post-deregulation (8 of 12) than pre-deregulation (3 of 9), have values of efficiency change exceeding 1 which indicates that firms generally moved closer together after 1978 than before 1978. Also note that all carriers post-deregulation have efficiency change components that exceed the sample average of 0.9963 for pre-deregulation.

Now consider individual airline performances. Piedmont stands out since it dramatically improves after deregulation and becomes the leader in terms of efficiency change (1.0098 translates into 0.98% per quarter). Post-deregulation performances of Frontier and Ozark show considerable improvement in terms of their ability to catch-up to innovations (from -0.33% and -0.45% to 0.59% and 0.03% per quarter, respectively). The quality of Piedmont's, Frontier's and Ozark's growth capabilities may have been the impetus behind the larger carriers desire to absorb them¹⁹.

The Big Three carriers -- American, Delta and United -- do not stand out as leaders in this context. If one compares the efficiency change component for these carriers with the averages over the sample, an interesting pattern emerges: under regulation they do as well and usually better than average but under deregulation they usually perform below average (this is true also of the Malmquist Index and Technical Change component). Perhaps these carriers, because of their size, have a built-in inflexibility (*e.g.*, labor contracts and route commitments) and could neither innovate nor “catch-up” as quickly as some of their smaller counterparts after deregulation. Unlike some of the smaller carriers, however, these three airlines are still operating; in this regard, they were able to take advantage of network size.

¹⁸ Deregulation was a long process. The Airline Deregulation Act became effective in October, 1978 (1978IV). It was initiated by CAB and ultimately lead to the agency's demise in 1984 with residual responsibilities passed on to DOT. Values for Eastern in 1990 have been excluded from this analysis because the airline performed far below the other carriers just before its demise, thus skewing the results for the industry.

¹⁹ Ozark, Frontier and Piedmont (in that order) are also the top three performers post-deregulation in terms of technical change. Furthermore, Frontier and Ozark show improvement in total factor productivity (from 1.15% and 0.85% to 1.28% and 0.94% per quarter, respectively).

The Malmquist Index drops from 0.92% to 0.18% per quarter after 1978. This is due to the decline in the technical change component after 1978. Although this is the first application of the Malmquist Index decomposition to the airlines, this result is consistent with other studies which have focused on technical change using a cost function approach. Kumbhakar (1992), for example, analyzed the airlines from 1970-1984 and found technical progress declined during the 1980-1984 period. Similarly, Baltagi, Griffin and Rich (1995), examined the airlines from 1971-1986 and found the rate of pure technical change declined from 1978-1986. The technical progress drop indicates that the airlines did not push out the production frontier as aggressively after 1978. Our results indicate that there are fewer innovations and effort is instead being focused on catching-up to the frontier. Attention to efficiency change has caused convergence since the airlines, on average, are closer to the frontier.

5. CONCLUSIONS

Market structure theory suggests that, as an industry becomes more competitive, it becomes more important for a firm within that industry to perform efficiently relative to other firms if it is going to survive. This theory suggests two time series patterns. First, the efficiency scores of the firms within the industry should be cointegrated. If not, then efficiency-enhancing technological advances made by one firm are not adopted by another firm and the two firms' efficiency scores move apart. The firm which fails to follow innovations will eventually be driven out of the industry because its inputs are not being efficiently converted into outputs. Second, the efficiency scores of the firms within the industry should exhibit convergence over time. In other words, the scores should move closer together as firms realize that success in an increasingly competitive environment requires that they close efficiency gaps and become more alike one another in terms of technical efficiency. The evidence presented here is indicative of cointegration and convergence and hence provides empirical evidence to support these hypotheses. In addition, to explore the connection between efficiency patterns and competition further, we calculated concentration numbers.²⁰ Overall, concentrations have decreased implying

²⁰ This discussion is drawn from Singal (1996). Assume that at a point in time, there are $i=1, \dots, I$ routes with an associated $n=1, \dots, N$ airlines on that route. For each route, the squared market shares of each airline were summed to get a Herfindahl-Hirshman (HH) concentration index for that route:

$$HH_i = \sum_{n=1}^N s_{ni}^2 \text{ where } s_{ni}^2 \text{ is the squared market share for each airline } n \text{ on route } i$$

Next, to get an airline specific concentration measure in each time period, each route concentration measure was weighted by the fraction of the airline's total passenger revenue miles on that route. The weighted carrier concentration formula is:

that competitive forces have increased during the period 1979²¹ to 1990. We take the change in concentration over this time period since an airline's dynamic technical efficiency behavior will be affected more by how the competitive forces are moving over time rather than by the level. We calculate two series: one is a ranking of the airlines based on the change in concentration and the other is the number of times each airline exhibits strong evidence of cointegration. Then we calculate the correlation between these series using the seven airlines which survive the entire time period.²² The correlation should be positive since the larger the change in the concentration ratio, the greater the competitive pressure and the more likely the airline should be cointegrated. We find correlations of 0.823 (0.023 significance level) for DEA and 0.344 (0.434) for FDH. These results support the idea that the degree competition and the time pattern of efficiency are related.²³

Potential future research includes the rigorous identification of the reasons for differences in efficiency and the presence or absence of comovement (whether long run or short run) and convergence between airlines. Institutional aspects of the industry such as the extent of marketing undertaken by each firm, evidence of potential collusion between carriers and the ownership of computer reservations systems could be explored to determine how they influence the findings.

Finally, empirical evidence in support of theoretical statements, such as the market structure-technical efficiency relationship examined here, is of great import. Significant results act as validation of not only the theory itself but also of the concept that underlies technical efficiency measurement: namely, that these techniques are capturing some firms' inability to operate at their most efficient level. Analysis of other such qualitative theories dealing with the dynamic nature of technical efficiency are now attainable due to developments in the literature allowing the exploitation of panel data sets. For example, the authors have also explored the relationship between technical efficiency and stock market performance (Alam and Sickles, 1996). Since profitability and, hence, firm valuation

$$CC_n = \sum_{i=1}^I \left(\frac{PRM_{ni}}{PRM_n} \right) (HH_i)$$

where PRM_{ni} = Total passenger revenue miles for carrier n on route i

and PRM_n = Total passenger revenue miles for carrier n in a given time period

The larger the value for the index, the more concentrated the markets an airline faces and, hence, the less competitive pressures; such a carrier would not have a large number of routes in direct competition with other carriers

²¹ The earliest time period for which concentration numbers can be calculated is 1979. Prior to this, the data source for these calculations, the Origin and Destination Survey (DB1A), did not record price data and, therefore, revenue passenger miles are unavailable.

²² The time frame for the other four carriers is too short to be informative.

²³ We focus on the fact that we obtain the correct sign for the correlations.

depend in part on how efficiently a firm utilizes available technology, stock prices and efficiency are intrinsically linked. As a result, innovations in a firm's technical efficiency level, viewed as new information to investors about the firm's ability to allocate its resources, should be correlated with stock market returns. We determine that the returns from a type of arbitrage investment strategy averages 18% per annum. This result provides further validation of technical efficiency methodologies and highlights this fertile area for future exploration.

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