Economies of Density versus Economies of Scale: Why Trunk and Local Service Airline Costs Differ

Douglas W. Caves; Laurits R. Christensen; Michael W. Tretheway

The RAND Journal of Economics, Volume 15, Issue 4 (Winter, 1984), 471-489.

Stable URL:
http://links.jstor.org/sici?sici=0741-6261%28198424%2915%3A4%3C471%3AEODVEO%3E2.0.CO%3B2-S

Rand Journal of Economics
Vol. 15, No. 4, Winter 1984

Economies of density versus economies of scale: why trunk and local service airline costs differ

Douglas W. Caves*

Laurits R. Christensen*

and

Michael W. Tretheway**

There has been a perception that U.S. trunk airlines had an inherent cost advantage over smaller regional airlines because of economies of scale. We have formulated a general model of airline costs, which we estimate by using panel data on large and small airlines. Differences in scale are shown to have no role in explaining higher costs for small airlines. The primary factor explaining cost differences is density of traffic within an airline's network. Also of major importance is the average length of individual flights.

1. Introduction

■ In the literature on the U.S. airline industry there are two widely held beliefs regarding the structure of costs. First, there are rapidly declining unit costs of service within any city-pair market (Bailey and Panzar, 1981; Keeler, 1978; White, 1979). Second, there are approximately constant returns to scale for airline systems that have reached the size of the U.S. trunk carriers (Caves, 1962; Douglas and Miller, 1974; Keeler, 1978; White, 1979). A third, more tentatively held belief is that there are scale economies available to be exploited by carriers smaller than the trunks (which is to say, smaller carriers have higher unit costs than the U.S. trunk carriers) (Keeler, 1978).

The first belief is largely a matter of faith or *a priori* reasoning, since data are not available on costs for particular routes. The second has been borne out by several studies that show very similar unit costs for trunk airlines which differ greatly in size. The third view derives principally from the finding by Eads, Nerlove, and Raduchel (1969) of substantial system scale economies for the U.S. local service airlines. This finding appears

* University of Wisconsin-Madison and Christensen Associates.

** University of British Columbia.

An early version of this article entitled "A Reexamination of Scale Economies for U.S. Trunk Airlines" was presented at the Econometric Society Meetings in Denver, Colorado, September, 1980. Our research has benefited greatly from financial support from the National Science Foundation, the University of Wisconsin Graduate School, and the Civil Aeronautics Board, from research assistance by Robert Windle, Kenneth McClelland, Paul Feldman, and Chris Lankey, and from helpful discussions with Gary Chamberlain, John Geweke, Trevor Heaver, and Joseph Swanson. We are also indebted to numerous past and present staff members of the Civil Aeronautics Board for assistance in data development.

to be confirmed by a casual inspection of airline costs. For example, in 1978 variable costs came to 7.7¢ per passenger-mile for the trunk airlines but 11.2¢ per passenger-mile for the local service airlines.[1]

This substantial difference in cost would seem to imply that the local carriers would have difficulty competing with the trunk carriers in the newly deregulated environment. Similarly, the still smaller new carriers should have even higher unit costs than the locals. These implications, however, are belied by two developments since deregulation. First, the locals have been able to gain market share at the expense of the trunks (Graham and Kaplan, 1982). Second, new carriers have entered the market and have been able to compete successfully against both the local service and trunk carriers.

The purpose of this article is to explore the apparent paradox of small air carriers with a purported unit cost disadvantage competing successfully against the large trunk carriers. We do this by developing a model of costs for airline services. The model is based on a panel data set for the years 1970 through 1981 comprised of all trunk and local service airlines.[2] Our model of airline costs is novel in that it includes two dimensions of airline size—the size of each carrier's service network and the magnitude of passenger and freight transportation services provided. This allows us to make the crucial distinction between returns to density (the variation in unit costs caused by increasing transportation services within a network of given size) and returns to scale (the variation in unit costs with respect to proportional changes in both network size and the provision of transportation services).

We find substantial economies of density for air carriers of all sizes within our sample. This confirms the belief in declining unit costs for specific airline markets. We also find constant returns to scale for the trunk carriers, thus confirming the second belief. Our final finding is that constant returns to scale also hold for the local service carriers. This finding refutes the third belief, and is consistent with the observed ability of the locals to compete with the trunks in markets of equal density and length. We cannot willy-nilly extrapolate these results to smaller networks, such as those of the new carriers. But the fact that several new carriers appear to have a good chance of surviving might lead one to believe that there is no substantial cost disadvantage even for airlines with very small networks.

Although our findings seem to contradict the trunk-local cost differential cited above, the contradiction is explained by differences in the network characteristics between trunks and local service carriers. The average number of cities served by the locals is virtually the same as that of the trunks, but the density of traffic is much lower, and the average distance between takeoff and landing (stage length) is much shorter. Unit costs decline markedly as density of service and average stage length increase. Costs also vary inversely with average load factor, and until recently the locals had lower load factors than the trunks.

In Section 2 we develop a general model of airline costs that emphasizes the important role of the airline network. Section 3 describes the panel data used to estimate the parameters of the cost structure. Parameter estimates and basic conclusions are presented in Section 4, and the robustness of the conclusions with respect to model form and type of estimator is explored in Section 5. Section 6 uses our estimated cost model to explain the difference in trunk and local service airline costs. In Section 7 we draw upon the recent development of contestability theory and its application to the airline

---

[1] Variable costs include fuel, labor, and materials costs, which account for more than 80% of airline costs. The categories "trunk" and "local service" are no longer used by the CAB, but they continue to be used in the literature. Carriers included in these two categories are listed in Table 1 in Section 3.

[2] It would be desirable to include new carriers in the panel, but this is precluded by insufficient data. The new carriers are not required to file the same data as the trunks and locals.

industry to analyze the welfare implications of our cost function results for the deregulated airline industry.

2. A general model of airline costs

■ All previous studies of airline costs of which we are aware have used data either for large carriers (the trunks) or for small carriers (the locals). None of the studies attempted to estimate a model that would simultaneously explain the structure of airline costs for both large and small carriers. The prevailing view seemed to be that large and small carriers faced different cost structures, which could only be modelled separately.

We have not encountered any cogent argument to support the position of size-related differences in cost structures. We believe that it should be possible to capture any differences that do exist by specification of a sufficiently general model of airline costs. Accordingly, we introduce the general total cost function:

$$CT = f(Y, P, W, Z, T, F), \tag{1}$$

where CT is total cost, Y is output, P represents the network, W is a vector of factor prices, Z is a vector of control variables, T is a vector of time shifts, and F is a vector of firm-specific shifts in the cost function, as described below. The model that we propose is general in several senses. First, we choose a translog form for f so that the model is a second-order approximation to any general cost function. Second, we introduce control variables (Z) to reflect airline characteristics. We include average stage length and average load factor, both of which have been emphasized by previous investigators.[3] We also include the number of points served, as an indicator of the size of the airline network.[4] Third, we take advantage of the fact that our panel data set (a time series of cross sections) allows specification of intercept shifts for each firm and for each year. The inclusion of these shift factors (binary variables) precludes biases in the coefficients of the included explanatory variables that might arise from the exclusion of variables such as unmeasurable aspects of network that are constant over time for a given firm.[5]

Traditionally, the level of output has been used to represent firm size in industry cost studies. Recently, however, writers have begun to distinguish between firm size and level of output. We believe that it is particularly important to make such a distinction for industries in which services are provided over a network of geographically distributed points. Cost per unit of output may vary substantially among firms, depending on the nature of the networks they serve. For example, one might expect a lower level of unit costs if a given level of output were provided over a smaller number of cities.

Several authors have used route-miles as a measure of network size in studies of the railroad industry.[6] This measure is ambiguous for airlines, however. It is not clear how

---

[3] Average stage length is the average distance between takeoffs and landings. Load factor is the ratio of seat miles sold to seat miles actually flown.

[4] In the parlance of logistics, the number of points served is a measure of the number of nodes in a network. Average stage length is a measure of the length of the links between the nodes. In addition, by including both output and load factor in the model, one can make inferences concerning the impact on costs of increased service offerings on links.

[5] When using time series data, researchers generally include a time trend or annual time effect to prevent bias of the output coefficient arising from shifts of the cost function due to technical progress, an unmeasurable variable. A similar effect may occur in the cross section dimension. The cost function may shift from one firm to the other because of unmeasured variables—perhaps some unmodelled aspect of a carrier's network. As with the technical progress case, this poses an estimation problem if the shifts are correlated with output or other regressors. See Mundlak (1961, 1978) for discussion of proper estimation techniques.

[6] See Caves, Christensen, Tretheway, and Windle (1984) for a review of studies of network effects in the railroad industry.

many city-pair routes should be counted in determining route-miles. Furthermore, the route-miles data that are available do not conform to any particular standard.[7]

Airline networks can be described according to numerous attributes. A common distinction in recent literature is hub-and-spoke networks vs. linear networks, but much greater detail of description would be possible. To be useful for econometric analysis, however, distinctions must be simple and readily quantifiable. After considering a number of alternatives, we settled upon the number of points served (P) as the single most important attribute of an airline network.[8]

The inclusion of points served in the cost function along with output permits us to distinguish between returns to density and returns to scale in airline operations. We define returns to density as the proportional increase in output made possible by a proportional increase in all inputs, with points served, average stage length, average load factor, and input prices held fixed. This is equivalent to the inverse of the elasticity of total cost with respect to output:

$$RTD = \frac{1}{\epsilon_y},$$

where ϵ_y is the elasticity of total cost with respect to output. Returns to density are said to be increasing, constant, or decreasing, when RTD is greater than unity, equal to unity, or less than unity, respectively. We use the terms increasing returns to density and economies of density interchangeably. Economies of density exist if unit costs decline as airlines add flights or seats on existing flights (through larger aircraft or a denser seating configuration), with no change in load factor, stage length, or the number of airports served.

We define returns to scale as the proportional increase in output *and points served* made possible by a proportional increase in all inputs, with average stage length, average load factor, and input prices held fixed. This is equivalent to the inverse of the sum of the elasticities of total cost with respect to output and points served:

$$RTS = \frac{1}{\epsilon_y + \epsilon_p},$$

where ϵ_p is the elasticity of total cost with respect to points served.[9] Returns to scale are said to be increasing, constant, or decreasing, when RTS is greater than unity, equal to unity, or less than unity, respectively. We use the terms increasing returns to scale and "scale economies" interchangeably. Scale economies exist if unit costs decline when an airline adds flights to an airport that it had not been serving, and the additional flights cause no change in load factor, stage length, or output per point served (density).

Estimation of (1) requires that we specify a functional form. We adopt the translog functional form proposed by Christensen, Jorgenson, and Lau (1973), which has been

[7] The last year for which the CAB compiled a route-miles measure for each airline was 1978. The individuals responsible for compiling the data indicated to us that route-miles were not comparable from carrier to carrier or even from year to year.

[8] An airport, rather than a city, constitutes a point. Thus, an airline serving two airports in New York City would have two New York points. Points that a carrier was authorized to serve but did not actually serve during the year were not counted. We obtained the number of points data from the CAB publication, *Airport Activity Statistics* (December 31 issue for each year).

[9] Under this definition RTS is conditional on the firm-specific shifts, F, in the sample. Caves, Christensen, Tretheway, and Windle (1984) generalized RTS to account for possible relationships among output, network, and the firm-specific shifts. They found that the generalization did not substantially alter the estimate of RTS for U.S. railroads. Estimation of the more general concept of RTS requires a large cross sectional dimension to the sample so that "between" estimates can be computed. We attempted to use the approach with our airline data set, but the degrees of freedom were too limited to attain any degree of precision in the estimation of RTS.

widely used in recent cost studies. Christensen and Greene (1976) and several others have demonstrated the favorable attributes of the translog for studying scale economies. The translog is a flexible form in the sense of providing a second-order approximation to an unknown cost function. We write the translog total cost function with time and firm intercept shifts or effects included as:

$$\ln CT = \alpha_0 + \sum_T \alpha_T + \sum_F \alpha_F + \alpha_Y \ln Y + \sum_i \beta_i \ln W_i + \sum_i \phi_i \ln Z_i$$
$$+ \tfrac{1}{2}\delta_{YY}(\ln Y)^2 + \tfrac{1}{2} \sum_i \sum_j \gamma_{ij} \ln W_i \ln W_j + \tfrac{1}{2} \sum_i \sum_j \psi_{ij} \ln Z_i \ln Z_j$$
$$+ \sum_i \rho_{Yi} \ln Y \ln W_i + \sum_i \mu_{Yi} \ln Y \ln Z_i + \sum_i \sum_j \lambda_{ij} \ln W_i \ln Z_j, \quad (2)$$

where $\gamma_{ij} = \gamma_{ji}$, $\Psi_{ij} = \Psi_{ji}$ the α_T are time-period effects, and the α_F are firm effects. A cost function must be homogeneous of degree one in input prices, which implies the following restrictions on the parameters of the translog cost function:

$$\sum_i \beta_i = 1, \qquad \sum_i \gamma_{ij} = 0 \quad (\forall j), \qquad \sum_i \rho_{Yi} = 0, \qquad \sum_i \lambda_{ij} = 0 \quad (\forall j). \quad (3)$$

Shephard's (1953) lemma implies that the input shares (C_i) can be equated to the logarithmic partial derivatives of the cost function with respect to the input prices:

$$C_i = \beta_i + \sum_j \gamma_{ij} \ln W_j + \rho_{Yi} \ln Y + \sum_j \lambda_{ij} \ln Z_j. \quad (4)$$

It has become standard practice to specify classical disturbances for (2) and (4) and to estimate the parameters of the cost function by treating (2) and (4) as a multivariate regression. We follow this procedure, using a modification of Zellner's (1962) technique for estimation. To overcome the problem of singularity of the contemporaneous covariance matrix, we delete one of the share equations before carrying out the second stage of Zellner's technique for estimation. The resulting estimates are asymptotically equivalent to maximum likelihood estimates. Moreover, the use of all equations at the first stage ensures that the estimates are invariant to the choice of equation to be deleted at the second stage.

3. Data

■ Our data consist of annual observations on all the trunk and local service airlines from 1970 through 1981. There are 15 airlines in the sample for the full period and six additional airlines for shorter periods. See Table 1 for details. There are a total of 208 observations.

We employ five categories of inputs: labor, fuel, flight equipment, ground property, and equipment (*GPE*), and all other inputs. We refer to the last category as materials. Labor price is formed as a multilateral index of 15 categories of employees.[10] Fuel price is dollars per gallon. Flight equipment price results from a multilateral index of nine aircraft categories with value shares based on the current annual cost to lease one plane of the appropriate type. *GPE* cost is measured by applying a capital service price reflecting interest, economic depreciation, capital gains, and taxes to a stock of *GPE* capital formed by using the perpetual inventory method.[11] Within each year the price of materials is

[10] See Caves, Christensen, and Diewert (1982) for a theoretical discussion of multilateral index procedures. Caves, Christensen, and Tretheway (1981) apply this theory to the measurement of airline inputs.

[11] We note that both types of capital are measured on a replacement cost method. Flight equipment uses what could be described as a "one-plane-of-size-k" method. If technical change makes a particular type of aircraft obsolete, however, its lease cost will fall, and thus our measure of capital used in production will fall.

TABLE 1 U.S. Trunk and Local Service Airlines* (Observations Available for 1970–1981, Unless Otherwise Noted)

Trunk Airlines		Local Service Airlines	
American		Air West[1]	1970–1980[4]
Braniff		Frontier	
Continental		North Central	1970–1978[5]
Delta		Ozark[1]	
Eastern[1]		Piedmont	
National[1]	1970–1979[2]	Republic	1979–1981[5]
Northeast	1970–1971[3]	Southern	1970–1978[5]
Northwest[1]		Texas International[1]	
Pan American		U.S. Air	
TWA[1]			
United[1]			
Western			

* These designations were used by the CAB until 1981.

[1] Except the following years, which were deleted due to a strike in excess of 25 days: Eastern, 1980; National, 1970, 1974, 1975; Northwest, 1970, 1972, 1978; TWA, 1973; United, 1979; Air West, 1972, 1979; Ozark, 1973, 1979, 1980; Texas International, 1974, 1975.

[2] National merged with Pan American on January 1, 1980.

[3] Northeast merged with Delta on August 1, 1972.

[4] Air West merged with Republic on October 1, 1980, but reported data separately for 1980.

[5] North Central and Southern merged on July 1, 1979, to form Republic.

assumed constant across firms. Annual change in materials prices is given by a Tornqvist index of seven categories of materials input. To reduce the number of parameters we must estimate we used the multilateral index procedure to aggregate materials and the two types of capital. We refer to the resulting input as capital-materials.[12]

We recognize four categories of outputs: revenue passenger-miles (*RPM*) of scheduled service, *RPM* of charter service, revenue ton-miles (*RTM*) of mail, and *RTM* of all other freight. Scheduled service accounts for the bulk of revenues for all trunk and local service carriers. Because of the small revenue shares for the other outputs, we do not believe that cost function estimation using the distinct outputs would be fruitful. Thus, we have aggregated the four output types by using the multilateral index procedure.

The model incorporates two characteristics of airline operation, load factor and average stage length. Average stage length is the average distance between takeoffs and landings. Load factor is the ratio of seat miles sold to seat miles actually flown.

In Table 2 we give means of the data for the trunks, locals, and combined airlines for the year 1976, one of the midyears of the sample.[13]

4. Estimates of the structure of airline costs

■ Using the model developed in Section 2 and the data described in Section 3, we proceed to estimate the U.S. airline total cost function. The regressors are all normalized

[12] We explored models which disaggregate these inputs and found they did not alter our conclusions regarding returns to density or scale.

[13] Our procedures for data development are discussed in more detail in Caves, Christensen, and Tretheway (1981), which also displays a considerable amount of data for the trunk carriers. These procedures were refined, updated, and extended to the local service carriers in Caves, Christensen, and Tretheway (1983).

TABLE 2 Means of Variables Used in the Study for the Year 1976

	Combined Airlines	Trunks	Locals
RPM Scheduled Service (millions)	9.33	15.01	1.52
RPM Charter Passenger (millions)	.63	1.04	.07
RTM Mail (millions)	.052	.086	.005
RTM Other Freight (millions)	.21	.35	.01
Number of Points Served	63	66	59
Average Stage Length (miles)	480	685	197
Load Factor* (%)	.54	.55	.52
Total Cost (billions of $)	.91	1.42	.20
Number of Employees	15,300	23,700	3,800
Average Wage (pilots and copilots)	48,200	54,700	39,300
Fuel Price ($/gal.)	.32	.32	.31
Gallons of Fuel (million)	498	789	98

* Scheduled passenger service.

by removing their sample means. There are 53 parameters to be estimated, and we present full details of the regression results in the Appendix. In Column 1 of Table 3 we present the first-order coefficients of the translog function explaining airline costs.

Since total cost and the regressors are in natural logarithms and have been normalized, the first-order coefficients are all interpretable as cost elasticities evaluated at the sample mean. All of these coefficients have the expected signs and are highly significant. The elasticities of cost with respect to the factor prices are equivalent to shares in total cost. Thus, at the sample mean, labor accounts for approximately 36% of airline

TABLE 3 First-Order Coefficients of Cost Functions* (Standard Errors in Parentheses)

Regressor	(1) Unrestricted Translog Total Cost Function	(2) Total Cost Function Restricted to First-Order Terms	(3) Unrestricted Translog Variable Cost Function	(4) Translog Total Cost Function Restricted to Zero for Firm Effects
Output	.804	.824	.719	.922
	(.034)	(.029)	(.043)	(.019)
Points Served	.132	.128	.139	.155
	(.031)	(.029)	(.033)	(.024)
Stage Length	−.148	−.140	−.046	−.220
	(.054)	(.039)	(.055)	(.024)
Load Factor	−.264	−.261	−.145	−.284
	(.070)	(.066)	(.071)	(.079)
Labor Price	.356	.357	.422	.357
	(.002)	(.003)	(.002)	(.018)
Fuel Price	.166	.166	.196	.166
	(.001)	(.004)	(.001)	(.001)
Capital-Materials Price**	.478	.478	.382	.477
	(.002)	(.003)	(.002)	(.002)
Capacity			.153	
			(.045)	

* See Appendix for full regression results.

** Materials price for the variable cost function.

costs, while fuel accounts for nearly 17% and capital and materials account for 48%.[14] Both stage length and load factor have the expected negative relationship with total cost. A 1% increase in average stage length implies a decrease in cost of .15%, and a 1% increase in load factor implies a decrease in cost of .26%.

As one would expect, there is a strong positive relationship between total cost and output when all other factors are fixed. A 1% increase in output leads to a .80% increase in cost. The inverse of this, 1.24 with a standard error of .05, is returns to density at the sample mean. For a given level of output and the other factors, we find a positive and statistically significant relationship between cost and points served; the elasticity is .13. The sum of the first-order coefficients on output and points served provides the elasticity of total cost with respect to a proportionate change in output and points served in the neighborhood of the sample mean. The sum is .94 with a standard error of .04. The inverse of the sum is 1.07 with a standard error of .05. Thus, we cannot reject the hypothesis of constant returns to scale at the sample mean.

The finding of constant returns to scale at the midpoint of our sample does not necessarily imply that either the trunks or local airlines have constant returns to scale. The sample mean reflects an averaging of the characteristics of the trunks and locals. To assess the scale and density characteristics of the trunks and locals we must evaluate them at points that are relevant to the two sets of carriers.

In Table 4 we present the means of the output characteristics for the trunks and locals for the total observation period 1970–1981. Over the full sample period output for the average trunk carrier was nearly ten times as great as for the average local service carrier, while average stage length for the trunks was more than triple that of the locals.

TABLE 4 Returns to Density and Scale at Sample Means of Trunks, Locals, and Pooled Data Set (Standard Errors in Parentheses)

	Total Cost		Means of Covariates				Variable Cost	
1970–1981	Returns to Density	Returns to Scale	Output*	Points	Stage Length	Load Factor	Returns to Density	Returns to Scale
Pooled Mean	1.243 (.053)	1.068 (.049)	.288	64.9	407	.540	1.179 (.061)	.988 (.057)
Trunks Mean	1.235 (.061)	1.068 (.052)	.733	66.3	673	.556	1.119 (.071)	.965 (.060)
Locals Mean	1.254 (.073)	1.069 (.077)	.074	62.9	197	.517	1.265 (.083)	1.019 (.085)
1970								
Pooled Mean	1.271 (.060)	1.058 (.055)	.167	63.0	338	.447	1.241 (.072)	.980 (.064)
Trunks Mean	1.253 (.061)	1.025 (.050)	.516	61.2	639	.520	1.124 (.077)	.917 (.061)
Locals Mean	1.295 (.090)	1.101 (.093)	.041	65.2	152	.427	1.379 (.114)	1.050 (.098)
1976								
Pooled Mean	1.225 (.052)	1.046 (.051)	.273	60.0	390	.543	1.161 (.062)	.966 (.060)
Trunks Mean	1.218 (.060)	1.054 (.055)	.731	61.9	651	.553	1.106 (.075)	.952 (.065)
Locals Mean	1.234 (.073)	1.035 (.075)	.070	57.4	193	.529	1.234 (.084)	.983 (.084)
1981								
Pooled Mean	1.235 (.055)	1.093 (.048)	.505	71.9	571	.578	1.105 (.056)	1.003 (.054)
Trunks Mean	1.235 (.065)	1.109 (.056)	.968	75.3	797	.584	1.075 (.067)	1.010 (.062)
Locals Mean	1.236 (.059)	1.068 (.059)	.171	66.6	328	.568	1.154 (.058)	.991 (.063)

* Output scaled to 1.000 for Delta 1977.

[14] The fuel share grew from 11% to 27% for the trunks from 1970 to 1981. For the locals it grew from 10% to 26%.

TABLE 5 Own-Price Elasticities and Elasticities of Substitution Computed at Sample Mean for Unrestricted Translog Total Cost Function (Standard Errors in Parentheses)

Own-Price Elasticities		Elasticities of Substitution*	
Labor	−.17	Labor vs. Fuel	−.29
	(.07)		(.09)
Fuel	−.01	Labor vs. Capital-Materials	.46
	(.02)		(.14)
Capital-Materials	−.21	Fuel vs. Capital-Materials	.24
	(.05)		(.06)

* Positive indicates substitutes, negative indicates complements.

On the other hand, points served and average load factor were quite similar for the trunks and locals—the trunks being approximately 10% greater in both cases. Evaluation of returns to density and scale at the trunk and local means reveals negligible differences at these two widely separated points. Returns to scale are 1.07 for both the trunks and the locals, while returns to density are 1.25 for the locals and 1.24 for the trunks.

It is possible that focusing on the means for the full 1970–1981 period obscures some important differences during the period. Thus, we also present results in Table 4 for trunk and local means for individual years. For the sake of brevity, we present only the first and last year and one of the middle years—1970, 1976, and 1981.[15] The disparity in output and stage length between the trunks and locals was greatest in 1970 and declined substantially by 1981. The trunk-to-local-mean-output ratio was 12.6 in 1970 and 5.7 in 1981, the corresponding stage length ratios were 3.4 in 1970 and 2.4 in 1980. The mean load factor for the locals was considerably lower than that of the trunks in 1970 (.43 vs. .52), but by 1981 they were practically identical (.57 and .58). The trunk mean of points served grew from 61 in 1970 to 75 in 1981, while the local mean was in the mid-60s in both years (in spite of a decline into the 50s in 1976). For none of these different sample points is it possible to reject the hypothesis of constant returns to scale. On the other hand, the hypothesis of constant returns to density must be rejected at each of the points observed. In all cases the point estimate is between 1.21 and 1.28.

In Table 5 we present the estimated own-price elasticities of each of the three inputs and the Allen-Uzawa cross elasticities of substitution for the sample mean. The own-price elasticities are all of the correct sign and relatively small in absolute value, indicating inelastic demand. Capital-materials is found to be substitutable for both labor and fuel. Labor and fuel are found to be complements, however.

5. Robustness of estimates of the structure of airline costs

■ In this section we explore the robustness of our central findings with respect to returns to scale and density. We estimate both less restrictive and more restrictive versions of the translog model. In all cases we continue to find constant returns to scale and increasing returns to density for both trunk and local airlines.

The translog cost function contains numerous second-order and interaction terms. The coefficients on these terms do not enter directly into our computations at the sample mean, but they have an indirect effect because they are estimated simultaneously with the coefficients on the first-order terms. An unrestricted translog form often provides results that are dominated by second-order and interaction terms at extreme sample

[15] We have compiled the results for the rest of the years. There are no significant differences between these years and those appearing in Table 4.

points. This raises the legitimate concern of whether the estimated first-order effects are unduly affected by the second-order terms.

In our current investigation the estimated translog form does have some undesirable features at the extremes of our sample. In particular, although the neoclassical curvature or regularity conditions are satisfied in the neighborhood of the sample mean and for 105 out of 208 observations, the conditions are violated at extreme sample points.[16]

Wales (1977) has shown that curvature problems at extreme data points do not necessarily undercut the validity of elasticity estimates at the sample mean. Nonetheless, we believe that the credibility of our elasticity estimates will be increased if we can show that they do not depend strongly on the particular set of second-order coefficients that we have estimated. To this end we have estimated several restricted versions of the translog form to assess the robustness of the elasticity estimates. We have found them to be extremely robust. To illustrate we present in Column 2 of Table 3 the parameter estimates from the most restricted version of the translog form—that with all of the second-order and interaction coefficients restricted to be zero.[17]

The coefficients for the simplified translog form (Column 2 of Table 3) are remarkably similar to the first-order coefficients from the basic translog model (Column 1 of Table 3). The output and load factor coefficients are increased slightly in absolute value, and the stage length coefficient is decreased, but the changes are small relative to the standard errors of the coefficients. The simplified model has constant elasticities of cost with respect to output and points served. They imply returns to scale of 1.05 everywhere (with a standard error of .04); thus, on the basis of this model we cannot reject constant returns to scale anywhere within (or outside) our sample. Returns to density are 1.21 everywhere (with a standard error of .043).

We have found that our results are robust with respect to substantial simplification of our model of airline costs. We now explore whether the results are robust to some further complications of the model. Caves, Christensen, and Swanson (1981) have discussed the estimation of returns to scale under the specification used above (static equilibrium) and the alternative specification of partial static equilibrium. The latter specification allows the possibility that firms are not in static equilibrium with respect to one or more factors of production.

There are two plausible arguments supporting the position that airlines have not maintained the optimal level of capacity throughout the 1970s. First, demand for airline services is highly variable over business cycles. Even though there is an active second-hand market for aircraft, airlines are reluctant to dispose of temporary excess capacity because asset prices are depressed during recessions. Second, it is widely held that CAB regulation led airlines to maintain excess capacity. In light of these arguments, we follow the approach of Caves, Christensen, and Swanson (1981) in specifying a variable cost function, conditional on the level of airline capacity.[18]

The translog variable cost function takes the same form as the total cost function, with the following exceptions: (a) variable cost replaces total cost as the regressed, (b) the price of capital and materials is replaced by the price of materials as a regressor, and (c)

---

[16] See Caves and Christensen (1980) for discussion of regularity conditions in the context of the translog form. The positive coefficients on the first-order price terms are sufficient for regularity at the sample mean. The further a data point is from the sample mean, the more important the second-order term becomes in the calculation of the regularity condition. The concavity problems in this study are due to the very rapid increase of fuel prices during the 1970s. Models which allowed more flexibility in the functional form for input prices were successful in increasing the number of observations satisfying the conditions. Since these models did not change the estimate of *RTS* and *RTD*, we opted to present the less complicated model.

[17] The *F*-test for testing the restrictions implied by the first-order only model was 134.5. The 1% critical value of this test is 1.92.

[18] See Brown and Christensen (1981) for further discussion of the translog variable cost function.

a capacity variable is introduced as a regressor, which interacts with all the other regressors in addition to having its own first- and second-order coefficients.[19]

In Column 3 of Table 3 we present the first-order coefficients of the translog variable cost function. Full details of the regression are presented in the Appendix. The coefficient on capacity is .15, indicating that at the sample mean, *ceteris paribus,* a 1% increase in capacity would result in a .15% increase in variable costs. This is consistent with excess capacity for the airline industry. The estimated variable cost function implies that a movement to the optimal level of capacity would lead to total costs which were only 83% as high as those observed.[20] The elasticity of variable cost with respect to capacity is larger for the trunk airlines before deregulation, .24 in 1970 and .23 in 1976, but declines to .16 by 1981, a value near the sample mean.

With the introduction of capacity into the cost function, the roles of stage length and load factor are reduced both in terms of magnitude and statistical significance. The points served coefficient is virtually unchanged, but the output coefficient is reduced by approximately 10%. The labor and fuel price coefficients have increased, thereby reflecting the larger shares of labor and fuel in variable cost than in total cost.

We must compute returns to density and scale from the variable cost function by using formulas that correspond to the same concepts discussed in Section 2 for the total cost function. The formulas involve the same coefficients as for the total cost function except for the additional multiplicative factor of unity minus the elasticity of variable cost with respect to capacity.[21] Thus, returns to density are simply:

$$RTD = (1 - \epsilon_k)/\epsilon_y.$$

For the full period sample mean this is (1 − .153)/.719 = 1.18 (with a standard error of .06). Returns to scale have the same formula, except that the elasticity of variable cost with respect to output is replaced by the sum of elasticities of variable cost with respect to output and points served:

$$RTS = (1 - \epsilon_k)/(\epsilon_y + \epsilon_p).$$

For the full period sample mean this is (1 − 1.53)/(.719 + .139) = .99 (with a standard error of .06).

We see that, like the total cost function, the variable cost function yields an estimate of returns to scale at the sample mean that is very close to unity—constant returns to scale. Also like the total cost function, the variable cost function indicates increasing returns to density, although the estimate is somewhat lower for the variable cost function. In the right-hand panel of Table 4 we present returns to density and scale from the variable cost function evaluated at all the same points as for the total cost function. We find no significant departures from constant returns to scale for either the trunk or local carriers. All of the estimates of returns to density show significant economies of density for the local carriers. The point estimates for the trunks also indicate economies of density, but none of them is sufficiently significant to cause rejection of a test of constant returns to density.

All of our estimating equations include a constant effect for each firm. Mundlak (1961, 1978) advocated this approach to prevent bias in the coefficients due to the

---

[19] Capacity is measured as the sum of the annual service flows (measured in constant 1977 dollars) from flight equipment and ground property and equipment. This, rather than a constant dollar valuation of the capital stock, is the correct measure of capacity to produce output in any given year.

[20] For given values of output, input prices, and control variables we find the level of capital that equates capital's value of marginal product with its price. Variable costs are simulated with this quantity and then added to capital costs to get total costs with an optimal level of capital.

[21] See Caves, Christensen, and Swanson (1981) for discussion.

ommission of variables that are constant over time for a given firm and correlated with the other explanatory variables. An unmeasurable aspect of network might be an example of such a variable. To demonstrate the bias that can arise from omitting correlated firm effects we show in Column 4 of Table 3 the first-order coefficients that result from imposing the restriction that the firm effects, α_F, are zero.[22] It is readily apparent that this model yields very different conclusions regarding returns to scale and density. Specifically, without firm effects one is led to the erroneous conclusions that there are diseconomies of scale ($RTS = .93$) at the sample mean, and that returns to density are much lower, 1.08 versus 1.24.

6. Explanation of the difference in total costs for trunk and local service airlines

■ In Section 1 we noted that variable costs for the local service carriers exceeded those of the trunk carriers by a substantial amount—11.2¢ vs. 7.7¢ per passenger-mile in 1978. This translates into a percentage difference of 38%, [100(ln 11.2 − ln 7.7)]. We return to the question of the cost difference between the trunks and locals on the basis of our figures for total cost, and the explanation in terms of an estimated total cost function.

Using the cost function estimates in Column 1 of Table A1 in the Appendix, we predict total cost at the sample mean of the covariates for both the trunks and local carriers, and find a difference of 44%. This difference in trunk and local unit costs is even larger than the previously discussed 38% variable cost difference. We emphasize that this large difference is not a result of differences in carrier size, since we have found constant returns to scale. Rather, it is due to differences in service characteristics, as we now show.

The 44% difference in fitted total cost is the sum of differences explained by the covariates and differences that are unexplained except by the firm dummy variables. The firm dummy variables indicate that at any given level of the covariates unit costs for the local service carriers would be 14% below those of the trunk carriers.[23] This represents factors not included explicitly in our model, such as differences in managerial efficiency, differences in network structure not captured by the points-served variable, etc. The 14% difference is in the opposite direction of the overall difference in unit costs. Therefore, there is a 58% difference in unit costs that is explained by the covariates in the total cost function; that is, the model provides an explanation, based on firm characteristics, for unit costs of the locals to be 58% higher than those of the trunks.

The 58% difference cannot be directly assigned to individual firm characteristics because the regressors include interactions of pairs of characteristics. Caves, Christensen, and Diewert (1982) have shown, however, that the components of the Tornqvist (1936) index provide a decomposition into portions attributable to specific characteristics that is exact for an aggregator function of the translog form, even with a full set of interaction terms. Therefore, we use the Tornqvist index to decompose the 58%. The portion due to characteristic X is given by:

$$-1/2[(\partial \ln CT/\partial \ln X)_T + (\partial \ln CT/\partial \ln X)_L](\ln X_T - \ln X_L),$$

where T denotes trunk, L denotes local, and X is any characteristic except output. For output ($X = Y$) the same formula would apply if we were decomposing total cost. Since the decomposition is for average cost (CT/Y), the term ($\ln Y_T - \ln Y_L$) must be added.

---

[22] Hausman and Taylor (1981) proposed a χ^2-test statistic for the presence of correlated firm effects. Our computed value of this statistic is 80.2, whereas the 1% critical value is 48.25.

[23] The 14% is obtained by averaging the individual firm effects across the locals and across the trunks, with each effect weighted by the number of times the firm enters the sample. The difference between the average trunk and average local effect is .142.

TABLE 6 Difference in Unit Cost for Trunk and Local Service Airlines Explained by Fitted Total Cost Function

Amount of Difference to Be Explained		
Difference between Local Service and Trunk Fitted Unit Cost (Total Cost Model)		43.5%
Less Amount Due to Firm Dummy Variables		−14.2%
Amount to Be Explained by Regressors		57.7%
Difference in Unit Costs As Explained by:		
Output		45.0%
Average Stage Length		17.6%
Average Load Factor		1.7%
Points Served		−.7%
Input Prices		
Labor Price	−3.8	
Capital-Materials Price	−2.1	
Fuel Price	.0	
Subtotal		−5.9%
Total Explained Difference		57.7%

The decomposition of the 58% difference in unit costs between trunks and local service airlines is presented in Table 6. An overwhelming portion of the total difference, 45%, is explained by the difference in level of output, that is, density of service for a given size of network. The only other factor of major significance is average stage length, which accounts for 18% of the unit cost difference. The differences in average load factor and points served account for only 2% and −1%, respectively. Trunk airlines pay, on average, higher prices per unit for labor, materials, and capital services, but the same price for fuel. Taken together, this gives the locals a 6% advantage in unit costs.

From this decomposition we see that the observed difference between trunk and local average unit costs is explained by differences in characteristics of the firms, particularly by lower density of service and shorter stage lengths for the locals. Casual comparison of trunk and local unit costs might lead one to conclude that the locals operate in a region of increasing returns to scale. By distinguishing between density and scale economies, we see that this is not the case. The locals will not lower unit cost by increasing the scale of their operations. Only by increasing traffic density and stage length can they significantly lower their average costs.

7. Welfare analysis of the structure of airline costs

■ We conclude with a brief discussion of the implication of our findings for the likely behavior of the airline industry under deregulation. The key question of interest with respect to airlines is whether one should expect unregulated markets to produce socially desirable outcomes. The relevant concept of a market is, we believe, a city-pair. Although our analysis has been conducted by using a firm's systemwide cost data, our results can be used to provide some evidence on conduct in city-pair markets.

Our finding of significant economies of density, at least for the local service airlines, which typically operate in the less dense markets, confirms the belief in declining unit costs within a given network and therefore within city-pair markets. Traditional economic theory held that such a characteristic requires entry and price regulation to achieve an acceptable outcome in terms of social welfare (Scherer, 1980). But the recent analysis of

Baumol and Willig (1981) challenges the traditional position. They develop a model of a market characterized by declining unit costs and show that there are conditions under which such a market will produce socially desirable results. Two conditions that are sufficient for such an outcome are first, contestability of airline markets, and second, the existence of a sufficient magnitude of fixed (but not sunk) costs.

In the recent literature on contestability and industry structure, the airline industry has frequently been used as an illustration of an industry with a high degree of contestability (Bailey, 1981; Baumol, Panzar, and Willig, 1982). The essence of the case is that under deregulation, airline entry and exit are characterized by relatively low costs, few of which are sunk (Bailey and Panzar, 1981). The transition to a deregulated equilibrium characterized by contestable markets has not been instantaneous. Bailey and Baumol (1984, pp. 130–131) discuss several factors that have diminished contestability during the period immediately following deregulation. The importance of these factors, such as nonoptimal networks and widely divergent cost structures among carriers, should decline as the regulatory era recedes into history. If this happens, the contestability of airline markets will be enhanced.[24]

With regard to the second condition, our model confirms the existence of fixed costs associated with airline networks. That is, an air carrier incurs substantial costs associated with the size of the network to be served, regardless of the level of output provided within that network. The model of Baumol and Willig (1981) indicates that if these fixed costs are of sufficient magnitude and are not sunk, then prices are sustainable and there can exist a welfare optimum without government regulation. Sustainable prices are prices that will cover costs yet not invite entry or "cream-skimming." Several observers have argued that few if any airline costs are sunk, but further analysis is required to determine whether the fixed costs of particular networks are of sufficient size to achieve the favorable result spelled out by Baumol and Willig (1981).[25]

Such determination requires global knowledge of the cost surface. Our analysis, by integrating the local service and trunk carriers into a single model, provides information on the nature of cost over a much wider range of output than previous studies. But a definitive welfare analysis will require information on cost for carriers such as the recent entrants, which have very small networks and low levels of output within these networks. Further research in this area is required.

Appendix

TABLE A1 **Estimated Coefficient of Translog Cost Functions (Standard Errors in Parentheses)**

Regressor	Unrestricted Translog Total Cost Function	Total Cost Function Restricted to First-Order Terms	Unrestricted Translog Variable Cost Function	Translog Total Cost Function Restricted to Zero for Firms Effects
First-Order Terms				
Constant	13.243	13.216	13.006	13.153
	(.045)	(.035)	(.049)	(.019)
Output	.804	.824	.719	.922
	(.034)	(.029)	(.043)	(.013)
Points Served	.132	.128	.139	.155
	(.031)	(.029)	(.033)	(.024)

[24] As Bailey and Baumol (1984) note, one factor which may continue to impede contestability is the nonmarket allocation of landing slots at major airports.

[25] With regard to the absence of sunk costs, see Bailey and Panzar (1981). Also see Eads (1972), who argues that used aircraft markets are nearly perfect.

TABLE A1 ***(Continued)***

Regressor	Unrestricted Translog Total Cost Function	Total Cost Function Restricted to First-Order Terms	Unrestricted Translog Variable Cost Function	Translog Total Cost Function Restricted to Zero for Firms Effects
Stage Length	−.148 (.054)	−.140 (.039)	−.046 (.055)	−.220 (.024)
Load Factor	−.264 (.070)	−.261 (.066)	−.145 (.071)	−.284 (.079)
Labor Price	.356 (.002)	.356 (.003)	.422 (.002)	.357 (.002)
Fuel Price	.166 (.001)	.166 (.004)	.196 (.001)	.166 (.001)
Materials-Capital Price*	.478 (.002)	.478 (.003)	.382 (.002)	.477 (.002)
Capacity			.153 (.045)	
<u>Second-Order Terms</u>				
$(\text{Output})^2$	.034 (.054)		.092 (.343)	−.114 (.048)
$(\text{Points})^2$	−.172 (.152)		−.219 (.150)	−.429 (.114)
Output-Points	−.123 (.064)		.182 (.121)	.205 (.058)
$(\text{Labor Price})^2$	.166 (.026)		.170 (.027)	.170 (.025)
$(\text{Fuel Price})^2$	.137 (.003)		.156 (.004)	.136 (.003)
$(\text{Materials-Capital Price})^2$	.150 (.022)		.142 (.024)	.153 (.021)
Labor-Fuel	−.076 (.005)		−.092 (.006)	−.076 (.005)
Labor-Materials	−.090 (.023)		−.078 (.025)	−.093 (.022)
Fuel-Materials	−.060 (.005)		−.064 (.006)	−.060 (.005)
$(\text{Stage Length})^2$	.068 (.155)		−.201 (.174)	−.139 (.125)
$(\text{Load Factor})^2$	.047 (.617)		−.602 (.935)	−.758 (.842)
Stage Length-Load Factor	−.354 (.190)		−.572 (.261)	−1.022 (.240)
Output-Labor	−.009 (.005)		−.087 (.018)	−.008 (.005)
Output-Fuel	.018 (.003)		.057 (.011)	.017 (.003)

TABLE A1 ***(Continued)***

Regressor	Unrestricted Translog Total Cost Function	Total Cost Function Restricted to First-Order Terms	Unrestricted Translog Variable Cost Function	Translog Total Cost Function Restricted to Zero for Firms Effects
Output-Materials	−.010 (.004)		.031 (.018)	−.009 (.004)
Points-Labor	.036 (.007)		.030 (.008)	.035 (.007)
Points-Fuel	−.032 (.004)		−.042 (.005)	−.030 (.004)
Points-Materials	−.004 (.007)		.012 (.008)	−.005 (.007)
Stage Length-Labor	−.028 (.008)		−.014 (.009)	−.028 (.008)
Stage Length-Fuel	−.003 (.005)		−.011 (.006)	−.001 (.005)
Stage Length-Materials	.031 (.007)		.025 (.009)	.029 (.007)
Load Factor-Labor	.073 (.024)		.131 (.030)	.070 (.024)
Load Factor-Fuel	−.063 (.014)		−.116 (.019)	−.059 (.014)
Load Factor-Materials	−.011 (.024)		−.016 (.030)	−.011 (.023)
Output-Stage Length	−.050 (.085)		.239 (.189)	.178 (.073)
Output-Load Factor	.036 (.119)		.057 (.448)	.449 (.129)
Points-Stage Length	.218 (.111)		.173 (.114)	−.217 (.091)
Points-Load Factor	.118 (.154)		−.215 (.176)	−.768 (.195)
$(\text{Capacity})^2$			.440 (.276)	
Capacity-Labor			.083 (.017)	
Capacity-Fuel			−.031 (.010)	
Capacity-Materials			−.053 (.016)	
Capacity-Output			−.262 (.301)	
Capacity-Points			−.334 (.097)	
Capacity-Stage Length			−.134 (.149)	

TABLE A1 ***(Continued)***

Regressor	Unrestricted Translog Total Cost Function	Total Cost Function Restricted to First-Order Terms	Unrestricted Translog Variable Cost Function	Translog Total Cost Function Restricted to Zero for Firms Effects
Capacity-Load Factor			.239 (.384)	
Time Dummies				
1970	.169 (.018)	.162 (.017)	.186 (.019)	.213 (.023)
1971	.159 (.017)	.164 (.016)	.174 (.018)	.204 (.022)
1972	.105 (.014)	.115 (.015)	.121 (.015)	.134 (.021)
1973	.111 (.014)	.118 (.014)	.126 (.014)	.138 (.021)
1974	.086 (.013)	.088 (.014)	.088 (.013)	.089 (.021)
1975	.077 (.013)	.080 (.013)	.075 (.013)	.082 (.021)
1976	.043 (.012)	.044 (.013)	.040 (.012)	.046 (.020)
1978	−.043 (.015)	−.051 (.014)	−.045 (.015)	−.053 (.022)
1979	−.083 (.019)	−.100 (.016)	−.105 (.019)	−.097 (.024)
1980	−.022 (.017)	−.011 (.016)	−.060 (.017)	−.035 (.022)
1981	−.033 (.018)	−.016 (.017)	−.084 (.020)	−.037 (.022)
Firm Dummies				
American	.163 (.044)	.153 (.022)	−.032 (.054)	
Braniff	−.084 (.042)	−.065 (.033)	−.025 (.047)	
Continental	−.121 (.048)	−.125 (.038)	−.081 (.051)	
Eastern	.125 (.025)	.101 (.019)	.088 (.027)	
National	−.064 (.061)	−.088 (.043)	.021 (.063)	
Northeast	−.088 (.091)	−.110 (.069)	.157 (.107)	
Northwest	−.177 (.038)	−.159 (.027)	−.251 (.038)	

TABLE A1 ***(Continued)***

Regressor	Unrestricted Translog Total Cost Function	Total Cost Function Restricted to First-Order Terms	Unrestricted Translog Variable Cost Function	Translog Total Cost Function Restricted to Zero for Firms Effects
Pan Am (premerger)	.031 (.081)	.014 (.046)	−.135 (.085)	
Pan Am (postmerger)	.034 (.068)	.008 (.040)	−.148 (.072)	
TWA	.151 (.051)	.144 (.027)	−.039 (.060)	
United	.137 (.041)	.097 (.024)	−.087 (.057)	
Western	−.104 (.048)	−.122 (.039)	−.064 (.051)	
Air West	−.101 (.071)	−.047 (.061)	.082 (.082)	
Frontier	−.245 (.074)	−.186 (.058)	−.060 (.085)	
North Central	−.092 (.075)	−.060 (.061)	.097 (.084)	
Ozark	−.149 (.079)	−.102 (.067)	.030 (.091)	
Piedmont	−.144 (.078)	−.091 (.064)	.057 (.089)	
Republic (premerger)	.091 (.082)	.017 (.049)	.298 (.088)	
Republic (postmerger)	.163 (.086)	.035 (.049)	.336 (.093)	
Southern	−.155 (.081)	−.119 (.070)	.043 (.093)	
Texas International	−.195 (.083)	−.164 (.071)	.013 (.097)	
U.S. Air	−.057 (.055)	−.009 (.041)	.115 (.064)	

* Materials price for the variable cost function.

References

BAILEY, E.E. "Contestability and the Design of Regulatory and Antitrust Policy." *American Economic Review Papers and Proceedings,* Vol. 71 (May 1981), pp. 178–183.

——— AND BAUMOL, W.J. "Deregulation and the Theory of Contestable Markets." *Yale Journal on Regulation,* Vol. 1 (1984), pp. 111–137.

——— AND PANZAR, J.C. "The Contestability of Airline Markets during the Transition to Deregulation." *Law and Contemporary Problems* (Winter 1981), pp. 125–145.

BAUMOL, W.J. AND WILLIG, R.D., "Fixed Costs, Sunk Costs, Entry Barriers, and Sustainability of Monopoly." *Quarterly Journal of Economics,* Vol. 95 (August 1981), pp. 405–431.

———, PANZAR, J.C., AND WILLIG, R.D. *Contestable Markets and the Theory of Industry Structure.* New York: Harcourt Brace Jovanovich, 1982.

BROWN, R.S. AND CHRISTENSEN, L.R. "Estimating Elasticities of Substitution in a Model of Partial Static Equilibrium: An Application to U.S. Agriculture, 1947–1974" in E.R. Berndt and B.C. Field, eds., *Measuring and Modelling Natural Resources Substitution,* Cambridge: MIT Press, 1982.

CAVES, D.W. AND CHRISTENSEN, L.R. "Global Properties of Flexible Functional Forms." *American Economic Review,* Vol. 70 (June 1980), pp. 422–432.

———, ———, AND DIEWERT, W.E. "The Economic Theory of Index Numbers and the Measurement of Input, Output and Productivity." *Econometrica,* Vol. 50 (November 1982), pp. 1393–1414.

———, ———, AND SWANSON, J.A. "Productivity Growth, Scale Economies and Capacity Utilization in U.S. Railroads, 1955–1974." *American Economic Review,* Vol. 71 (December 1981), pp. 994–1002.

———, ———, AND TRETHEWAY, M.W. "U.S. Trunk Air Carriers, 1972–1977: A Multilateral Comparison of Total Factor Productivity" in T. Cowing and R. Stevenson, eds., *Productivity Measurement in Regulated Industries,* New York: Academic Press, 1981.

———, ———, AND ———. "Productivity Performance of U.S. Trunk and Local Service Airlines in the Era of Deregulation." *Economic Inquiry,* Vol. 21 (July 1983), pp. 312–324.

———, ———, ———, AND WINDLE, R.J. "Network Effects and the Measurement of Returns to Scale and Density for U.S. Railroads" in A.F. Daughety, ed., *Analytical Studies in Transport Economics,* Cambridge: Cambridge University Press, 1984.

CAVES, R.E. *Air Transport and Its Regulators.* Cambridge; Cambridge: Harvard University Press, 1962.

CHRISTENSEN, L.R. AND GREENE, W.H. "Economies of Scale in U.S. Electric Power Generation." *Journal of Political Economy,* Vol. 84 (August 1976), pp. 655–676.

———, JORGENSON, D.W., AND LAU, L.J. "Transcendental Logarithmic Production Frontiers." *Review of Economics and Statistics,* Vol. 55 (February 1973), pp. 28–45.

DOUGLAS, G.W. AND MILLER, J.C., III. *Economic Regulation of Domestic Air Transport: Theory and Policy.* Washington, D.C.: Brookings Institution, 1974.

EADS, G.C. *The Local Service Airline Experiment.* Washington, D.C.: Brookings Institution, 1972.

———, NERLOVE, M., AND RADUCHEL, W. "A Long-Run Cost Function for the Local Service Airline Industry." *Review of Economics and Statistics,* Vol. 51 (August 1969), pp. 258–270.

GRAHAM, D.R. AND KAPLAN, D.P. *Competition and the Airlines: An Evaluation of Deregulation.* Washington, D.C.: Office of Economic Analysis, Civil Aeronautics Board, December 1982.

HAUSMAN, J.A. AND TAYLOR, W.E. "Panel Data and Unobservable Individual Effects." *Econometrica,* Vol. 49 (November 1981), pp. 1377–1398.

KEELER, T.E. "Domestic Trunk Airline Regulation: An Economic Evaluation." *Study on Federal Regulation.* Washington, D.C.: U.S. Government Printing Office, 1978.

MUNDLAK, Y. "Empirical Production Functions Free of Management Bias." *Journal of Farm Economics,* Vol. 43 (February 1961), pp. 44–56.

———. "On the Pooling of Time Series and Cross Section Data." *Econometrica,* Vol. 46 (January 1978), pp. 69–85.

SCHERER, F.M. *Industrial Market Studies and Economic Performance.* Chicago: Rand McNally, 1980.

SHEPHARD, R.W. *Cost and Production Functions.* Princeton: Princeton University Press, 1953.

TORNQVIST, L. "The Bank of Finland's Consumption Price Index." *Banks of Finland Monthly Bulletin,* No. 10 (1936), pp. 1–8.

WALES, T.J. "On the Flexibility of Flexible Functional Forms: An Empirical Approach." *Journal of Econometrics,* Vol. 5 (1977). pp. 183–193.

WHITE, L.J. "Economies of Scale and the Question of "Natural Monopoly' in the Airline Industry." *Journal of Air Law and Commerce,* Vol. 44 (1979), pp. 545–573.

ZELLNER, A. "An Efficient Method of Estimating Seemingly Unrelated Regressions and Tests for Aggregation Bias." *Journal of the American Statistical Association,* Vol. 58 (December 1962), pp. 977–992.