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MERGERS, COMPETITION, AND MONOPOLY
IN THE REGULATED TRUCKING INDUSTRY*

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Mergers, Competition, and Monopoly

in the Regulated Trucking Industry

1. Introduction and Overview

The natural extent of competition in the regulated trucking industry has been a long-standing topic of debate. Economists generally believe that there is nothing inherent in the structure of the industry that would preclude competition in the absence of regulation.[1] Although the less-than-truckload (LTL) regulated common carriers of general commodities have relatively large investments in terminals and equipment, this capital is readily transferable and should not therefore pose a basic barrier to entry. Given this relative ease of entry (in the absence of regulatory constraints), trucking markets should be highly contestable: even if specific city-pair markets can only support a few carriers, the potential ease of entry should keep prices and service levels at their competitive levels. Thus in the absence of regulation, economists feel that the regulated trucking industry should be characterized by workable competition. The recent Trucking Regulatory Reform Act of July 1980 cautiously endorsed this position in making entry and price competition somewhat easier than it had previously been. However, it stopped short of being a basic deregulationist measure.

Opposing this, is a view widely held by practitioners in the trucking industry, regulatory authorities, and systems analysts of the industry.[2] According to them, the trucking industry is subject to significant economies of scale that would, in the absence of regulatory constraint, lead to a highly concentrated and monopolistic industry. Pointing to the large number of mergers that have taken place in the trucking industry during the past decades and the high concentration ratios that exist in many city-pair markets,[3/] they argue that continued regulation is needed to preserve the public interest. Thus, according to them, in the absence of regulation, concentration and rates would continue to rise, while service levels would fall. Concern is particularly great for rural shippers on low-density corridors who might not have access to a wide range of alternative carriers.

Although there has been an enormous amount of econometric analysis of the trucking industry in recent years,[4/] the evidence with regard to the existence of scale economies is rather mixed. While Friedlaender and Spady (1981) have found no evidence of economies of scale for local or regional carriers, they, Chow (1980), and Lawrence (1976) have found some evidence of increasing returns to scale for large, interregional carriers. Since these carriers already dominate the industry,[5/] there is concern that these carriers would continue to grow in the absence of regulation.

In evaluating the econometric evidence, however, it is important to note that due to data limitations, existing estimates of cost functions for the trucking industry suffer from two possible specification errors: first, output has generally been defined in terms of a single aggregate ton-mile measure and thus has not fully incorporated the effects of shipment characteristics upon costs;[6/] and second, network effects have been ignored in the analyses. Although various attempts have been made to adjust for shipment and operating characteristics by using hedonic or related aggregators (see, for example, Friedlaender and Spady (1981), Koenker (1978), Harmatuck (1981)), they have all utilized ton-miles or shipments as a proxy for the basic unit of output, which is generally recognized as a specific shipment between a city pair.[7/] While data limitations have forced such an aggregation upon the analysis, they have also caused output measures to fail to reflect the corridor-specific nature of trucking traffic. Similarly, the essence of LTL trucking traffic is that it takes place over a network of terminals and specified routes. Since the way in which firms utilize their networks can have a significant impact upon costs, the omission of network characteristics in the cost function can cause serious specification error. For example, two firms with identical loads and underlying shipment characteristics could still have very different costs if one utilized a very dispersed network that required much consolidation and the other had a very concentrated network that required relatively little consolidation.

Fortunately, data have recently become available to permit output disaggregation and the introduction of network characteristics into an analysis of trucking costs.[8/] This should provide a richer analytical framework and permit an analysis of the effects upon costs of the interactions among size per se, the composition of output, and the way in which trucking firms utilize the network. In general, this analysis will provide evidence that conventional measures and estimates of economies of scale fail to provide an accurate characterization of the structure of costs and technology of the regulated trucking industry: economies of network configuration and of utilization and economies of scope play an equally important role in characterizing carrier costs and provide important insights into an understanding of the observed merger movement in the trucking industry.

This paper takes the following form. Section 2 presents the multiproduct joint cost function that will be used to analyze trucking costs and a description of the data used in the analysis. Section 3 discusses the empirical results and their implications for the structure of technology among regulated common carriers of general commodities. Section 4 considers the implications of these findings for competition and regulatory policy.

2. A Multiproduct Joint Cost Function for the Regulated Trucking Industry

2.1 Specification

If full disaggregation of outputs were possible, it would be desirable to define the following joint cost function for the regulated common carriers of general commodities:

$$C = C(y,w,t) \tag{1}$$

where $y = y(y^k_{OD})$ represents a vector of commodity-specific shipments (y^k) between given city pairs (O-D); w represents a vector of factor prices; and t represents a vector of technological conditions of production.[9/] Since, however, the typical large general commodity carrier may have thousands of distinct shipping points, such a degree of disaggregation is impossible within the context of an econometric analysis. Thus, as an alternative, it seems reasonable to aggregate city pair outputs into outputs defined over generic corridor types, each of which is hedonically adjusted to reflect the characteristics of the shipments comprising this aggregate.[10/] Hence we rewrite the general cost function as:[11/]

$$C = C(\psi,w,t) \tag{2}$$

$$\psi_i = \psi_i(y_i,D_i,\tau_i) \tag{2a}$$

where ψ_i represents the hedonically adjusted output along a generic corridor i; y_i represents the physical output along corridor type i; D_i and t_i respectively represent a vector of corridor-specific network characteristics and of operating characteristics, and the other variables have their previously defined meanings. The technological conditions of production, t, is defined as a vector of global measures of network characteristics (N) and operating characteristics (Q).

By conventional aggregation theory, the hedonic function, $\psi_i = \psi_i(y_i, D_i, t_i)$, should be homogeneous of degree one in physical output y_i. In other words, doubling the level of y_i will double the level of effective ouptut ψ_i. A natural functional form for Eq. (2a) would then be

$$\psi_i = y_i \cdot \phi_i(D_i, t_i) \tag{2b}$$

Therefore, as indicated by Baumol, Panzar and Willig (1981), the hedonically adjusted effective output can be interpreted as an aggregate output along a ray in the output space defined by the function ϕ_i. Thus, in theory, if enough hedonic variables were included, the multiproduct cost function with hedonic adjustments would in fact be identical to a multiproduct cost function at the completely disaggregate level.

Under current ICC regulations, output levels, operating characteristics, and network characteristics can all be assumed to be exogenous and beyond the control of the firm, at least in the short run. However, one can argue that some of these variables could still be endogenous, e.g., load per vehicle, since a general-freight carrier has the ability to manipulate load size by dispatching LTL traffic over the network. Nevertheless, average load per vehicle is still very much influenced by market demands which are determined in turn by operating rights and the rate structure. Thus it seems reasonable to treat all of the variables in the cost function as exogenous.

Empirical estimation of a cost function requires an explicit functional form. Extensive research has recently been directed toward deriving flexible functional forms which place no a priori restrictions on the structure of the underlying technology and that are suitable for an analysis of the economies of joint production, e.g., Caves, Christensen, and Treatheway (1980).

In this analysis, we use the following translog functional form to specify the general multiproduct cost function and its associated hedonic output functions:[12/]

$$\begin{aligned}
\ell n C(\Psi, W; N, Q) = {} & \alpha_0 + \sum_i \alpha_i \ell n \psi_i + \sum_j \beta_j \ell n w_j + \sum_k \gamma_k \ell n N_k + \sum_h \delta_h \ell n Q_h \\
& + \frac{1}{2}\Big(\sum_i \sum_s A_{is} \ell n \psi_i \ell n \psi_s + \sum_j \sum_\ell B_{j\ell} \ell n w_j \ell n w_\ell \\
& + \sum_k \sum_q C_{kq} \ell n N_k \ell n N_q + \sum_h \sum_p D_{hp} \ell n Q_h \ell n Q_p\Big) \\
& + \sum_i \sum_j E_{ij} \ell n \psi_i \ell n w_j + \sum_i \sum_k F_{ik} \ell n \psi_i \ell n N_k \\
& + \sum_i \sum_h G_{ih} \ell n \psi_i \ell n Q_h + \sum_j \sum_k H_{jk} \ell n w_j \ell n N_k \\
& + \sum_j \sum_h I_{jh} \ell n w_j \ell n Q_h + \sum_k \sum_h J_{kh} \ell n N_k \ell n Q_h + \varepsilon \qquad (3)
\end{aligned}$$

$$\begin{aligned}
\ell n \psi_i = {} & \ell n y_i + \sum_k a_{ik} \ell n t_{ik} + \sum_h b_{ih} \ell n d_{ih} \\
& + \frac{1}{2}\Big(\sum_k \sum_\ell c_{ik\ell} \ell n t_{ik} \ell n t_{i\ell} + \sum_h \sum_j e_{ihj} \ell n d_{ih} \ell n d_{ij}\Big) \\
& + \sum_k \sum_h f_{ikh} \ell n t_{ik} \ell n d_{ih} \qquad (3a)
\end{aligned}$$

where ε is a disturbance. Eq. (3a) is treated as an identity equation. All variables are measured as deviations from their points of approximation, which are taken as the sample means.

To increase the efficiency of the estimates, the cost function and hedonic ouptut function, Eqs. (3) and (3a), are estimated jointly with the factor share equations implied by Shephard's lemma:

$$SR_j = \frac{\partial \ln C}{\partial \ln w_j} = \beta_j + \sum_{\ell} B_{j\ell} \ln w_{\ell} + \sum_{i} E_{ji} \ln \psi_i$$

$$+ \sum_{k} H_{jk} \ln N_k + \sum_{h} I_{jh} \ln Q_h + \eta_j \qquad (3b)$$

where SR_j is the share of factor j and η_j is the associated disturbance.

In estimating the cost function and its associated factor share equations, the usual coefficient restrictions are imposed to ensure symmetry and homogeneity of the cost function with respect to factor prices.[13/] In addition, the hedonic output function was assumed to take a Cobb-Douglas functional form.[14/] Finally, since the disturbances among the cost function and the factor share equations are typically correlated, we assume that the disturbances are jointly distributed as multivariate normal and estimate eqs. (3), (3a), and (3b) using full information maximum likelihood (FIML) procedures.[15/] To get consistent estimates all but one of the factor share equations are included in the system of equations, and we omit the purchased transportation factor share equation. There are thus a total number of 98 parameters to be estimated.[16/]

2.2. Variables

Table 1 presents the variables used in the cost function and their definitions. Most of these are self-explanatory, but a few comments about the output and the network measures are useful.[17/]

Table 1

Variables Used in Cost Function

C = Total annual costs in dollars, i.e., the sum of (1) labor costs, (2) fuel expenditures and fuel taxes, (3) capital costs for revenue shipment, (4) "other" expenditures, and (5) purchased transportation expenditures.

w_1 = Labor price index in dollars per employee, including all fringes and benefits.

w_2 = Fuel price in dollars per gallon of gasoline, including fuel taxes

w_3 = Factor price of capital for revenue equipment

w_4 = Factor price of other expenditures not elsewhere classified

w_5 = Price index for purchased transportation equipment and services

SR_1 = Factor share of labor, defined as total labor costs divided by total costs

SR_2 = Factor share of fuel, defined as total fuel costs (including fuel taxes) divided by total costs

SR_3 = Factor share of equipment capital, defined as total capital costs on equipment divided by total costs

SR_4 = Factor share of "other" costs, defined as other expenditures divided by total costs

SR_5 = Factor share of purchased transportation, defined as total costs of purchased transportation divided by total costs

y_1 = Type 1 output, defined as total LTL ton-miles with length of haul less than 250 miles

y_2 = Type 2 output, defined as total LTL ton-miles with length of haul of 250 - 500 miles

y_3 = Type 3 output, defined as total LTL ton-miles with length of haul over 500 miles

y_4 = Type 4 output, defined as total TL ton-miles

Table 1, continued

ψ_1 = Hedonically adjusted y_1

ψ_2 = Hedonically adjusted y_2

ψ_3 = Hedonically adjusted y_3

ψ_4 = Hedonically adjusted y_4

t_{11} = Standard deviation of ton-miles for LTL shipments with length of haul less than 250 miles

t_{12} = Standard deviation of length of haul for LTL shipments with length of haul less than 250 miles

t_{21} = Average shipment size for LTL shipments with length of haul between 250 and 500 miles

$$t_{31} = \left(1 - \frac{\text{LTL ton-miles with length of haul 1000 - 1500 miles}}{\text{LTL ton-miles with length of haul over 500 miles}}\right)$$

$$t_{32} = \left(1 - \frac{\text{LTL ton-miles with length of haul greater than 1500 miles}}{\text{LTL ton-miles with length of haul over 500 miles}}\right)$$

(Both t_{31} and t_{32} are used to reflect further differences in y_3 in terms of traffic distribution by distance.)

t_{41} = Standard deviation of ton-miles for TL shipments

t_{42} = Standard deviation of length of haul for TL shipments

N_1 = Global network connectivity measure, defined as (1-Gamma index)

N_2 = Global network density measure, defined as (1-Chi index)

N_3 = Indirect routing index

N_4 = Terminal density measure, defined as ton-miles per terminal

In defining output, the following aggregate measures were used:

- LTL traffic with length of haul under 250 miles
- LTL traffic with length of haul of 250 - 500 miles
- LTL traffic with length of haul over 500 miles
- TL traffic.

Two factors enter into this choice of stratification: length of haul and type of service — truckload (TL) or less-than-truckload (LTL). These two attributes capture most of the characteristics in trucking output that have significant impacts upon technology and thus upon costs. The technology of moving TL traffic is very different from that of moving LTL traffic. Compared to LTL service, TL service typically involves larger shipment sizes, larger vehicle loads, and faster service times, since it requires no terminal consolidation. Furthermore, commodities handled by TL service are also typically different from commodities handled by LTL service. TL shipments usually consist of freight classified by the ICC as specialized — e.g., heavy machinery or liquid petroleum products — which typically require special equipment and handling, while LTL shipments usually consist of general freight. Moreover, the classification of TL/LTL captures the inherent differences in transit time and reliability between these two types of services.[18/] Thus this stratification reflects most of the useful commodity, quantity, and level-of-service attributes that characterize trucking output.

The stratification of LTL traffic into three categories based on length of haul — less than 250 miles, between 250 and 500 miles, over 500 miles — is based on technological considerations. LTL shipments must be consolidated into large lots at terminals for intercity movements. However, the objectives and procedures of terminal operations for short-haul and long-haul traffic are in fact very different from each other.

Since LTL shipments involve extensive handling, labor costs typically represent a high percentage of total costs. Statistics show that approximately 45 percent of LTL freight revenue is spent in pickup, delivery and terminal operations. This percentage increases dramatically as the length of haul rises. For short-haul operations, carriers attempt to utilize direct service for competitive reasons, typically using the standard of next-day delivery. Thus for short-haul movements, shipments are usually dispatched to adjacent terminals for consolidation with other shipments bound for the same destinations and linehaul vehicles are often dispatched without being fully loaded. By contrast, the objective of long-haul LTL operations is to utilize fully the advantages of routing strategy and terminal operations to minimize overall shipping costs. Direct service and speed are, in general, not of principal concern. Freight may be consolidated more than once, at local as well as breakbulk terminals, and trailers are expected to be fully loaded. Thus the terminal and handling costs associated with long-haul traffic are proportionately higher than those associated with short-haul traffic.

There is no clear line to divide a market between the short haul and the long haul. However, 250 miles could well be the limit of direct-service LTL operations. Similarly, lengths of haul over 500 miles are typically too far to allow direct service. By contrast, 500 miles could well be the minimum distance for breakbulk terminal consolidation. Thus it seems reasonable to regard shipments under 250 miles as short-haul movements, with those whose length of haul lies between 250 and 500 miles as being intermediate movements.

Because these output variables reflect the aggregation of many specific corridor movements, it is useful to utilize a hedonic adjustment to reflect the distribution of traffic within each type of corridor.

To this end we utilized variables that reflected the variability of traffic flows, the size of shipments, and the lengths of haul within the different corridor types to adjust the physical output measures in accordance with eq. (3a).

Since location-specific output definitions are not feasible to use in most empirical applications, it is useful to introduce global network measures in the cost function to reflect the role of network effects upon costs. In this regard, two aspects of trucking network are particularly important: network configuration and network utilization. Network configuration basically reflects the operating rights granted by the ICC over which a carrier operates. A large network with many terminals and routes has higher potential to: 1) provide direct service between any points of origin and destination; and 2) perform terminal consolidations to achieve economies of traffic density. Thus network configuration can be measured from at least two points of view: the degree to which the network is fully connected and the size of the coverage of the network.

Network connectivity has been studied extensively in graph theory, and various measurable indices have been suggested.[19/] For our purposes, a useful measure is the Gamma index, which, for a given network of n nodes, gives the ratio of total number of connected links over the possible maximum number of links:

$$\gamma = \frac{\ell}{n(n-1)/2} \qquad (4)$$

where: γ = Gamma index, $0 \leq \gamma \leq 1$

ℓ = number of connected links

n = number of nodes

$n(n-1)/2$ = the possible maximum number of links.

Thus a value of Gamma index close to one indicates that the network is highly connected. A highly connected network would enable a firm to utilize its equipment more efficiently, and thus lead to reduced costs.

There are many ways to describe the size of a network, e.g., number of terminals, number of routes, number of route-miles, number of areas served by the network, number of cities serviced by the network, etc. However, these variables only measure the physical size or the extensiveness of the network and do not reflect the effects that a large network may have on network operation. A better measure, known as the indirect routing index (IDRI) is thus suggested. The IDRI for a network is defined as

$$\text{IDRI} = \frac{\Sigma \text{ tons}_{ij} \cdot \text{dist}^{1}_{ij}}{\Sigma \text{ tons}_{ij} \cdot \text{dist}^{0}_{ij}} \qquad (5)$$

where: tons_{ij} = tons moving from point i to point j

dist^{0}_{ij} = direct distance bewteen i and j

dist^{1}_{ij} = routing distance from i to j

Thus a value of IDRI close to one suggests a large network with many routes and terminals such that direct routing becomes efficient. As such, it provides a measure of the intensiveness of operations between markets.

Network operation is conditional on network configuration. Given a network configuration, operating strategies are performed to route vehicles through the network to minimize costs and maximize profits. Thus a global description of both network operation and network configuration is network density which measures network connectivity as well as the flows over the specific links. A useful measure of network density is the Chi index, which can be expressed as follows:[20/]

$$\chi = (\Sigma\sqrt{f_j})^2/(\Sigma f_j)n(n-1) \tag{6}$$

where: χ = Chi index, $0 \leq \chi \leq 1$

f_j = flow in link j, defined as tons, ton-miles, or vehicle-miles

n = number of nodes

n(n-1) = the possible maximum number of two-way links.

The term $(\Sigma\sqrt{f_j})^2/(\Sigma f_j)$ will reach its maximum value and equal the number of links when flows are equally distributed, i.e., $f_1 = f_2 = ,\ldots,$ $= f_n$. Thus a higher value of Chi implies a network where the system spreads the traffic relatively evenly over the whole network; a lower value of Chi implies a network where the system concentrates flows on a relatively few links and thus has a high degree of traffic consolidation.

An additional global measure of network characteristics is terminal density, which we define as terminals per ton-mile. The effects of terminal density on trucking costs are positive as well as negative. A high density of terminals per ton-mile may indicate a large number of terminal consolidations and thus possible lower pickup and delivery costs. On the other hand, it could also indicate a poor network configuration and inefficient traffic routings. Thus the net effect of terminal density upon costs will depend on which force is dominant and cannot be determined a priori.

3. Empirical Results and Size-Related Economies

The multiproduct joint cost function was estimated using a sample of 105 large general commodity carriers for 1976. This sample included all of the very large carriers whose output exceeds 1 billion ton-miles on down to relatively small carriers with output under 100 million ton-miles.[21/] Because of the concern with possible predatory behavior by the large carriers in a deregulated environment, the sample was skewed toward large carriers. Nevertheless, in order to obtain a representation of the industry, a number of smaller carriers were also included in the sample. The year 1976 was used because this is the year for which disaggregate shipment data are available.[22/]

Tables 2 and 3 present the estimated coefficients and their standard errors for the translog cost function and the hedonic output functions.[23/] Using these estimated coefficients it is possible to analyze a number of important issues dealing with size-related economies and network effects.[24/]

3.1. The Impact of Network Effects upon Costs

Since the estimated cost function suggests that trucking technology is nonhomothetic,[25/] the relationship between costs and network characteristics cannot be globally characterized. Thus changes in costs with respect to network characteristics will usually differ depending upon the levels of factor prices, outputs and other variables. The elasticity of cost with respect to network characteristics can be given by the following equation:

$$\frac{\partial \ln C}{\partial \ln N_i} = \gamma_i + \sum_j C_{ij} \ln N_j + \sum_j F_{ij} \ln \psi_j + \sum_j H_{ij} \ln w_j \qquad (7)$$

At mean factor prices and output levels, this reduces to

$$\frac{\partial \ln C}{\partial \ln N_i} = \gamma_i + \sum_j C_{ij} \ln N_j \qquad (7a)$$

Thus γ_i reflects the elasticity of cost with respect to global network measure i for a "typical" firm operating at the sample mean, and the term $\sum_j C_{ij} \ln N_j$ measures the additional effects of network characteristics upon costs as they diverge from mean values.

COEFFICIENT	VARIABLE*	VALUE	STANDARD ERROR
α_0	Constant	19.1176	0.0620
α_1	ψ_1	0.1022	0.0453
α_2	ψ_2	0.0856	0.0771
α_3	ψ_3	0.3349	0.0466
α_4	ψ_4	0.4789	0.0671
β_1	w_1	0.6357	0.0098
β_2	w_2	0.0681	0.0024
β_3	w_3	0.0187	0.0011
β_4	w_4	0.2141	0.0042
β_5	w_5	0.0634	0.0114
γ_1	N_1	2.6929	2.8253
γ_2	N_2	-6.6476	4.9723
γ_3	N_3	1.0230	0.7171
γ_4	N_4	-0.0290	0.8157
A_{11}	ψ_1^2	-0.0278	0.0386
A_{12}	$\psi_1\psi_2$	-0.0481	0.0458
A_{13}	$\psi_1\psi_3$	-0.0890	0.0190
A_{14}	$\psi_1\psi_4$	0.0852	0.0433
A_{22}	ψ_2^2	0.1460	0.0927
A_{23}	$\psi_2\psi_3$	0.0296	0.0329
A_{24}	$\psi_2\psi_4$	-0.1496	0.0921
A_{33}	ψ_3^2	0.0336	0.0129

COEFFICIENT	VARIABLE*	VALUE	STANDARD ERROR
A_{34}	$\psi_3\psi_4$	0.0099	0.0276
A_{44}	ψ_4^2	0.2670	0.0891
B_{11}	w_1	0.0774	0.0084
B_{12}	w_1w_2	-0.0443	0.0049
B_{13}	w_1w_3	-0.0097	0.0029
B_{14}	w_1w_4	-0.0114	0.0040
B_{15}	w_1w_5	-0.0120	0.0050
B_{22}	w_2^2	0.0499	0.0054
B_{23}	w_2w_3	-0.0040	0.0026
B_{24}	w_2w_4	-0.0017	0.0011
B_{25}	w_2w_5	0.0001	0.0012
B_{33}	w_3^2	0.0161	0.0022
B_{34}	w_3w_4	-0.0015	0.0007
B_{35}	w_3w_5	-0.0009	0.0006
B_{44}	w_4^2	0.0050	0.0034
B_{45}	w_4w_5	0.0097	0.0026
B_{55}	w_5^2	0.0031	0.0059
C_{33}	N_3^2	11.4786	6.8264
C_{34}	N_3N_4	-2.4903	0.8781
C_{44}	N_4^2	0.1957	0.1342
E_{11}	ψ_1w_1	0.0026	0.0064
E_{12}	ψ_1w_2	-0.0024	0.0016
E_{13}	ψ_1w_3	-0.0002	0.0007
E_{15}	ψ_1W_5	-0.0001	0.0078

Table 2. Coefficient Estimates for the Translog Cost Function

Table 2, continued

COEFFICIENT	VARIABLE*	VALUE	STANDARD ERROR
E_{21}	$\psi_2 w_1$	0.0544	0.0105
E_{22}	$\psi_2 w_2$	0.0074	0.0027
E_{23}	$\psi_2 w_3$	0.0015	0.0012
E_{25}	$\psi_2 w_5$	-0.0633	0.0128
E_{31}	$\psi_3 w_1$	-0.0019	0.0040
E_{32}	$\psi_3 w_2$	0.0010	0.0009
E_{33}	$\psi_3 w_3$	-0.0004	0.0004
E_{34}	$\psi_3 w_4$	0.0015	0.0016
E_{35}	$\psi_3 w_5$	-0.0002	0.0048
E_{41}	$\psi_4 w_1$	-0.0326	0.0104
E_{42}	$\psi_4 w_2$	-0.0056	0.0025
E_{43}	$\psi_4 w_3$	-0.0007	0.0010
E_{44}	$\psi_4 w_4$	-0.0071	0.0043
E_{45}	$\psi_4 w_5$	0.0460	0.0120
F_{13}	$\psi_1 N_3$	1.0386	0.4037
F_{14}	$\psi_1 N_4$	-0.0402	0.0735
F_{23}	$\psi_2 N_3$	-2.1168	0.8286
F_{24}	$\psi_2 N_4$	-0.1084	0.1377
F_{33}	$\psi_3 N_3$	0.4782	0.2421
F_{34}	$\psi_3 N_4$	0.0555	0.0317
F_{43}	$\psi_4 N_3$	0.8263	0.8773
F_{44}	$\psi_4 N_4$	-0.2108	0.1196
H_{13}	$w_1 N_3$	0.1576	0.0985
H_{14}	$w_1 N_4$	0.0112	0.0138
H_{23}	$w_2 N_3$	0.0103	0.0232
H_{24}	$w_2 N_4$	0.0086	0.0032
H_{33}	$w_3 N_3$	-0.0061	0.0108
H_{43}	$w_4 N_3$	0.0851	0.0478
H_{44}	$w_4 N_4$	0.0025	0.0065
H_{53}	$w_5 N_3$	-0.2469	0.1106
H_{54}	$w_5 N_4$	-0.0222	0.0153

FINAL LOG OF LIKELIHOOD FUNCTION = 1148.214

NUMBER OF OBSERVATIONS = 105

R^2:	COST FUNCTION	= 0.976
	LABOR EQUATION	= 0.354
	FUEL EQUATION	= 0.144
	EQUIP. CAPITAL EQUATION	= 0.389
	"OTHER" EQUATION	= 0.015
	PURCHASED TRANS. EQUATION	= 0.322
RMSE:	COST FUNCTION	= 0.2188
	LABOR EQUATION	= 0.0621
	FUEL EQUATION	= 0.0144
	EQUIP. CAPITAL EQUATION	= 0.0063
	"OTHER" EQUATION	= 0.0296
	PURCHASED TRANS. EQUATION	= 0.0704

*We have omitted "ℓn" for convenience.

Table 3. Coefficient Estimates and Statistics for the Hedonic Output Functions

COEFFICIENT	VARIABLE*	VALUE	STANDARD ERROR
a_{11}	t_{11}	0.0534	0.1174
a_{12}	t_{12}	1.9327	0.4448
a_{21}	t_{21}	0.1455	0.3084
a_{31}	t_{31}	-0.5236	0.4368
a_{32}	t_{32}	-0.4327	0.3256
a_{41}	t_{41}	0.0084	0.0978
a_{42}	t_{42}	-0.8720	0.2367

*We have omitted "ℓn" for convenience.

In general we would expect that firms using networks that were highly connected (a high γ) and with concentrated traffic flows (a low χ) would have lower costs. Thus the elasticity of costs should be positive with respect to N_1 $(1-\gamma)$ and negative with respect to N_2 $(1-\chi)$. Similarly, since a low value of the indirect routing index (N_3) implies a large network that permits direct routing, the elasticity of costs with respect to N_3 should be positive. Finally, if the cost savings associated with pickup and delivery operations outweigh the costs associated with terminal operations, the elasticity of costs with respect to terminal density (N_4) should be negative.

Table 4 presents the estimated γ_i and C_{ij} coefficients and their standard errors for firms operating at mean output levels with mean factor prices.

Table 4. Elasticity of Costs with Respect to Network Characteristics at Mean Factor Prices and Output Levels

COEFFICIENT	VARIABLE	N_1 NETWORK CONNECTIVITY	N_2 NETWORK DENSITY	N_3 INDIRECT ROUTING INDEX	N_4 TERMINAL DENSITY
γ_i	Constant	2.6929 (2.8253)	-6.6476 (4.9723)	1.0230 (0.7171)	-0.0290 (0.8157)
C_{i3}	ℓnN_3	—	—	11.4786 (6.8264)	-2.4903 (0.8781)
C_{i4}	ℓnN_4	—	—	-2.4903 (0.8781)	0.1957 (0.1342)

These show that costs are quite sensitive to network connectivity, network density, and the ability to perform direct service. Thus economies of network configuration (as shown by N_1) and of network operation (as shown by N_2 and N_3) appear to be quite strong. Moreover, the positive C_{33}

coefficient implies that as the indierect routing index increases from its mean, the economies of direct routing markedly increase. Taken together, these economies of network configuration and of network operation explain why large carriers enjoy a natural advantage over small carriers, since they are able to exploit fully the economies of equipment utilization and traffic flows over the network. In addition, since surveys show that shippers prefer to deal with as few carriers as possible to reduce the chance of loss, delay, or damage from additional handling, a large carrier that operates nationwide with its own fleet has a significant advantage over a smaller competitor, which must interline with others to offer service on a national level.

3.2. Natural Monopoly and Subadditivity

Since the estimated network economies indicate that large carriers with broad network coverage may have a natural competitive advantage over small carriers, this suggests that the observed mergers and increasing concentration in the industry may reflect tendencies toward natural monopoly. In analyzing the existence of natural monopoly in a multiproduct industry the concept of subadditivity is relevant. A cost function is said to be strictly and globally subadditive if for any N output vectors $(\psi^1,\ldots,\psi^N)$ the following holds:

$$C(\psi^1 + \cdots + \psi^N,w,t) < C(\psi^1,w,t) + \cdots + C(\psi^N,w,t) \qquad (8)$$

Thus global subadditivity is a necessary and sufficient condition for natural monopoly for it implies that one firm can produce any given output bundle more cheaply than a subset of firms. Unfortunately, there is no single measure of global subadditivity. However, Baumol, Panzar, and Willig (1981) have shown that the existence of subadditivity along a given output ray and across output rays is sufficient for the existence of natural monopoly. This, in turn, can be demonstrated by the existence of multiproduct scale economies and the existence of transray convexity.

As we have indicated above, nonhomotheticities in production make generalizations about operating economies difficult. This is particularly true with respect to measures of size-related economies in view of the large variation in output among the carriers in the sample. Hence it is useful to analyze the size-related economies from three generic types of firms: "small" carriers which represent the twenty smallest firms in the sample; "large" carriers, which represent the twenty largest firms in the sample; and a "typical" carrier which represents the sample mean.[26]

Following Panzar and Willig (1977a) we define a local measure of the degrees of multiproduct scale economies as

$$S = \frac{C(\psi,w,t)}{\sum_j \psi_j C_j(\psi,w,t)} = 1 \Big/ \sum_j \frac{\partial \ln C(\psi,w,t)}{\partial \ln \psi_j} \tag{9}$$

where C_j represents the marginal cost with respect to the j^{th} output. Thus $S \gtreqless 1$ as there are increasing, constant, or diminishing returns to scale.

Within the context of the cost function used in this analysis, S is measured by

$$S = 1 \Big/ \sum_i^4 (\alpha_i + \sum_j A_{ij} \ln \psi_j + \sum_j E_{ij} \ln w_j + \sum_j F_{ij} \ln N_j) \tag{9a}$$

At the grand sample mean and at the sample mean of the large and small carriers the multiproduct scale economies are given as follows (the standard errors are in parentheses):

"small" firms	1.3188 (n.a.)
"typical" firm	0.9984 (.0679)
"large" firms	0.9293 (n.a.)

Thus there is clear evidence of diminishing returns to scale as the size of the firm grows, with small firms exhibiting rather marked economies of scale and the very large firms exhibiting modest diseconomies of scale. Nevertheless, considering the wide range in output among the carriers in the sample, the difference in scale economies is rather modest, which suggests that neither class of firms necessarily enjoys a cost advantage due to its overall scale of operation.

Since multiproduct economies of scale are a sufficient condition for subadditivity along a ray and the latter is a necessary condition for a natural monopoly, the empirical finding of constant or diminishing returns to scale for most of the firms in the sample casts doubt on the possibility that the trucking industry (as examplified by our sample) would behave as a natural monopoly in the absence of regulation. Nevertheless, as indicated above, natural monopoly also implies the existence of transray subadditivity. Thus before rejecting the hypotehsis of natural monopoly, we should also explore the existence of transray convexity.

Roughly speaking, transray convexity exists if there are economies associated with joint production rather than specialization and if the cost savings from joint production outweigh the cost savings associated with product-specific economies of scale. As indicated by Baumol (1977), a cost function exhibits transray convexity along a hyperplane $\sum_i u_i \psi_i = v$, $\forall u_i > 0$ if for any vectors of output ψ^A and ψ^B on that hyperplane, the following conditions hold:

$$C[\lambda\psi^A + (1-\lambda)\psi^B,w,t] \leq \lambda C[\psi^A,w,t] + (1-\lambda)C[\psi^B,w,t] \qquad (10)$$

$$0 < \lambda < 1$$

Baumol, Panzar, and Willig (1981) have shown that cost convexity and weak cost complementarity are sufficient conditions for transray convexity. Cost convexity exists if the Hessian matrix of the cost function $[C_{ij}]$ is positive-definite, and weak cost complementarity requires that each $C_{ij}(= \partial C/\partial\psi_i\partial\psi_j)$ be nonpositive for $i \neq j$. Thus by examining the Hessian matrix of the cost function, we can tell whether transray convexity exists.

Table 5 gives the Hessian matrices for each type of carrier. We can see that in no case is the Hessian matrix positive-definite; moreover, weak cost complementarity does not exist for each of the product pairs since many of the C_{ij}'s are positive. Thus we can infer that the cost function is not globally transray convex for any type of carrier in the sample.

However, since cost convexity and weak cost complementarity everywhere are merely <u>sufficient</u> conditions for transray convexity, the failure of both tests does not mean that cross sectional cost advantages do not exist, since transray convexity may still exist among output pairs. The existence of pairwise transray convexity requires that one of the following conditions is satisfied (Baumol, Panzar and Willig (1981)).

$$C_{ii} \geq 0,\ C_{jj} \geq 0\ ,\ C_{ij} = C_{ji} \leq 0\ ,\ \text{or} \qquad (11)$$

$$C_{ii} \leq 0,\ C_{jj} \leq 0,\ C_{ij} = C_{ji} \leq 0,\ C_{ij} \leq -\sqrt{C_{ii}C_{jj}}$$

Using the Hessian matrices in Table 5, we can therefore see whether the conditions in Eq. (11) are satisfied for any given product pair for each type of carrier. However, evaluation of these matrices indicated that with a few isolated exceptions (e.g., outputs 2 and 4 for the "typical" firm), pairwise transray convexity does not exist.

Although "small" firms exhibit some evidence of global scale economies, both the "typical" firm and the "large" firms exhibited evidence of constant

Table 5. Hessian Matrices Evaluated at the Sample Mean, by Carrier Type

	Output[a]			
	y_1 (LTL < 250)	y_2 (LTL 250-500)	y_3 (LTL > 500)	y_4 (TL)
"Small" Carriers				
y_1	-0.1654	0.0003	-0.0471	0.0348
y_2	0.0003	0.0079	0.0694	-0.0251
y_3	-0.0471	0.0694	-0.2849	0.0208
y_4	0.0348	-0.0251	0.0208	0.0082
"Typical" Carrier				
y_1	-0.1310	-0.0157	-0.0041	0.0064
y_2	-0.0158	0.0099	0.0016	-0.0019
y_3	-0.0041	0.0016	-0.0010	0.0006
y_4	0.0064	-0.0019	0.0006	0.0004
"Large" Carriers				
y_1	-2.3233	-0.1265	-0.0093	0.0159
y_2	-0.1265	0.0320	0.0006	-0.0018
y_3	-0.0093	0.0006	-0.0018	0.0002
y_4	0.0159	-0.0018	0.0002	0.0001

[a] C_{ij} measured in 10^{-6}.

or decreasing returns to scale. Moreover, no type of firm exhibited transray convexity. Thus this analysis does not support the hypothesis that firms in the trucking industry have characteristics of a natural monopoly.

Taken at their face value, these results imply that the firms in the sample incur no advantages from increased size through mergers and may, in fact, incur cost disadvantages. Thus these estimates concerning ray and transray subadditivity are at odds with the observed behavior of the firms typified by this sample, which are generally the most active in mergers and acquisitions. Nevertheless, it is important to note that the absence of global subadditivity does not necessarily imply that there are no ecomies associated with the production of a given type of output or that there are no economies associated with specific output combinations. Thus to understand fully the nature of size-related economies in the trucking industry, it is useful to consider the nature of product-specific scale economies and the nature of economies of scope or of joint production.

3.3. Product-Specific Economies of Scale

In analyzing product-specific scale economies it is reasonable to assume that trucking production involves common fixed costs rather than product-specific fixed costs for two reasons: vehicles, labor and fuel are common inputs and can easily be transferred among markets; and fixed facilities like terminals and platforms are used for all types of output. In fact, trucking operations involve a dynamic routing of vehicles over a network to handle different types of freight, and thus the costs of terminals, administration, equipment, etc., are common to all outputs and cannot be allocated to specific shipments. The problem, therefore, is to estimate the amount of the common fixed costs. In principle the common fixed cost element can be estimated as the costs that are incurred when all output levels are zero. However, in a translog or other log-linear cost formulation this approach does not work since $C(0) = 0$. One solution to this problem is to estimate the costs at an arbitrarily small level of output, ψ^*, and calculate $C^* = C(\psi^*)$. Then C^* would primarily represent common fixed costs. Experimental analysis suggests defining ψ^* as 10 percent of ψ at the sample mean to arrive at the common fixed costs.

The product-specific scale economy of output i (S_i) is defined by Baumol, Panzar and Willig (1981) as

$$S_i(\psi,w,t) = \frac{AIC_i(\psi,w,t)}{C_i(\psi,w,t)} \tag{12}$$

where C_i and AIC_i respectively represent the marginal cost and average incremental cost of output i.[27/] Again $S_i \gtrless 1$ as there are increasing, constant, or diminishing returns to the production of output i.

Table 6 indicates that all types of firms in the sample exhibit increasing returns with respect to output 1 (LTL shipments in corridors under 250 miles), with these economies increasing with the size of the firm. Thus from the perspective of costs alone, the "typical" firm operating at the sample mean and the very large firms appear to have considerable incentive to expand their operations in relatively short-haul markets.

In considering the policy implications of this finding, it is useful to distinguish between the very short-haul markets which are served by short-haul regional carriers who typically have an average length of haul under 150 miles, and intermediate-haul regional carriers whose average length of haul is around 200 miles. Since very short-haul operations utilize a different technology from long- and intermediate-haul operations,[28/] these findings suggest that in the absence of regulatory constraints, the LTL market could well be divided into two types of carriers — regional carriers which handle very short, local shipments, and interregional carriers which handle other LTL shipments. The current intermediate-haul regional carriers could have difficulty remaining in this market because of their inability

Table 6. Scale Economies at Sample Means

	Output			
	y_1 (LTL < 250)	y_2 (LTL 250-500)	y_3 (LTL > 500)	y_4 (TL)
"Small" Carriers				
Marginal Cost ($/ton)	3.55	1.65	3.87	0.69
Product-Specific Scale Economy	1.55	-5.86	-4.32	-21.07
Scope Economy	10.05	5.17	4.19	8.25
"Typical" Carriers				
Marginal Cost ($/ton)	1.75	0.54	0.39	0.35
Product-Specific Scale Economy	2.43	-7.76	1.01	-0.55
Scope Economy	0.43	1.31	0.47	0.75
"Large" Carriers				
Marginal Cost ($/ton)	8.25	0.31	0.39	0.36
Product-Specific Scale Economy	2.61	-21.51	1.27	0.46
Scope Economy	-0.07	1.06	-0.20	-0.10

to compete with interregional carriers who are likely to have cost advantages due to economies of network configuration and network operation. Also, shippers are most likely to choose carriers with large network coverage. Thus the economies associated with short-haul traffic in conjunction with shipper preferences for dealing with a single carrier do much to help explain the recent movement toward mergers.

3.4. Economies of Scope

Economies of scope measure whether there are cost savings associated with the simultaneous production of many products. In the four-output case analyzed here, economies of scope exist with respect to the production of outputs ψ_1, ψ_2, ψ_3, and ψ_4 if

$$C(\psi_1,\psi_2,\psi_3,\psi_4) < C(\psi_1,0,0,0) + C(0,\psi_2,0,0) + C(0,0,\psi_3,0) + C(0,0,0,\psi_4) \tag{13}$$

and the degree of economies of scope, SC, is measured as

$$SC = \frac{C(\psi_1,0,0,0) + C(0,\psi_2,0,0) + C(0,0,\psi_3,0) + C(0,0,0,\psi_4) - C(\psi_1,\psi_2,\psi_3,\psi_4)}{C(\psi_1,\psi_2,\psi_3,\psi_4)} \tag{14}$$

Thus SC > 0 if joint production is more efficient than nonjoint production. For the firms in the sample SC is estimated as follows: small firms 18.421; "typcial" firm, 1.576; and large firms 0.104. Thus all of the firms in the sample appear to have an incentive to operate with combinations of different types of corridors instead of specializing in any given type of shipment. However, it is clear that the smaller carriers exhibit much stronger scope economies than the larger carriers.

In addition to analyzing the global scope economies, it is also useful to analyze the specific economies of scope associated with any given output type, which indicates whether it would be cheaper to produce otuput type i independently and the remaining output types in combination than to produce all output types together. The measure of the product-specific economies of scope associated with output type i is given by:

$$SC_i = \frac{C(\psi_i,0) + C(0,\psi_{N-i}) - C(\psi_i,\psi_{N-i})}{C(\psi_i,\psi_{N-i})} \tag{19}$$

where ψ_i represents output type i and ψ_{N-i} represents the set of output other than i. Table 6 also presents the product-specific economies of scope for each output type and each type of carrier. It is interesting to see that while the small carriers in the sample have marked economies of scope associated with the production of each type of output, the large carriers appear to have virtually exhausted these economies. For these carriers there do not seem to be particular cost advantages from producing one type of output jointly with another output type. Nevertheless, the economies of scope with respect to output y_2, exhibited by all carrier size groups, suggest that trucking operations within this range involve less specialized equipment and technology than those dealing with the other output types. Firms with facilities and technologies devoted to short- or long-haul LTL operations or to TL operations, have the potential to produce intermediate-haul LTL service more cheaply than firms whose facilities and technology are devoted exclusively to intermediate-haul LTL operations.

4. Policy Implications

For policy purposes, the ultimate concern is to determine whether the relatively high and increasing levels of concentration that are observed in the regulated trucking industry are due to natural economic forces or whether they are induced by specific regulatory practice and restrictions. If the former is true, there may be reasons for continued regulation to maintain competitive behavior, while if the latter is true, there should be a strong case for deregulation and the establishment of "workable competition" in the trucking industry.

If the firms in the trucking industry exhibited tendencies toward natural monopoly, this would largely explain the tendency towards mergers, acquisition, and concentration. However, the empirical evidence does not indicate the existence of either multiproduct scale economies or of transray convexity and thus does not support the hypothesis that the regulated trucking industry would behave as a natural monopoly in a deregulated environment.

This raises the question of what economic motivation lies behind the current merger movement in this industry. We thus look more closely into trucking technology and examine the nature of specific scale economies and economies of scope. We find that although there are no global economies of scale, there are economies of scale associated with specific output types; moreoever, there are economies of scope associated with joint production. These economies of scope arise from economies of network configuration and of network operation, as well as of shared inputs. Thus the empirical evidence of this study indicates the following: 1) There are cost advantages associated with a high degree of network connectivity which brings about efficiencies through direct routing strategies. 2) These cost advantages increase with firm size since larger firms are better able to provide direct service.

3) Conditional on network configuration, there are marked economies associated with network operation and traffic density, resulting from better routing and terminal consolidation practices. Thus both economies of network configuration and economies of network operation justify the current merger and acquisition movement on a cost basis.

While these economies of operation exist for all types of carriers, it is interesting to note that the nature of the observed economies differs by type of firm. In particular, the largest firms in the sample face slightly decreasing returns to scale, and very modest economies of scope. Indeed, carriers with annual ton-miles of over one billion have virtually exhausted their scope economies. The findings of weak economies of scope and decreasing returns to scale for these giant, transcontinental carriers suggest that these firms have reached their optimal size. Thus there should be no advantages to these firms to increases in their size of output or geographical coverage, from the perspective of costs alone. In contrast, the smaller interregional carriers exhibit very strong economies of scope and marked economies of scale. Thus these firms have incentive not only to produce all outputs jointly — short-, intermediate- and long-haul LTL as well as TL services — but also to expand the level of these outputs. This explains why these carriers are heavily involved in the current merger movement in the trucking industry.

Since the operations of long-haul interregional carriers require a large network with a considerable number of terminals in order to be able to perform vehicle routings and terminal consolidations to achieve lower costs, the existing giant, nationwide interregional carriers should continue to dominate the long-haul trucking market. Because these carriers exhibit decreasing returns to scale, however, they should have little incentive to expand further in size. Moreover, because they appear to have exhausted most of their economies of scope, they would only have limited incentive to expand their operating rights to take advantage of economies of network configuration and of network operation. Thus in the absence of regulation, we would expect to see their spatial expansion saturated very quickly and the character of their operations to remain relatively stable. They would continue to provide service primarily to the long-haul LTL and TL markets, with a considerable amount of short- and intermediate-haul interregional operations as byproducts resulting from the nature of network operations. They would compete among themselves with a certain degree of inherent monopoly power due to the spatial location of networks.

It is less clear how the other sectors of the trucking industry would behave in the absence of regulation. Naturally, without regulatory constraints on operating rights, regional and interregional carriers would become more competitive. The terms "regional" and "interregional" would be irrelevant and only length of haul would be an important measure. The markets currently dominated by intermediate-haul regional carriers would face competition from interregional carriers. Similarly, short-haul and possibly some intermediate-haul interregional markets would be shared by existing regional carriers. Because of the existence of economies of network configuration and of network operation, we would expect larger carriers (currently regional or interregional) to have cost advantages over smaller carriers. Therefore, we would predict that these carriers would expand their networks geographically through mergers and acquisitions as well as through internal growth. Furthermore, in the absence of regulation, large carriers could use rate deductions to push small carriers out of markets since large carriers are better able to cross-subsidize among markets. Thus the number of carriers handling intermediate-haul LTL traffic would be considerably reduced. After the markets stabilized, a new competitive environment would result. Under the new market equilibrium, the number of carriers operating at each origin-desination market would depend on the level of demand in that market. Again, carriers providing service for this sector of the trucking industry would gain a certain degree of monopoly power due to the existence of economies of spatial scope. Nevertheless, the extent of this monopoly power is sufficiently small that workable competition would prevail in these markets.

In conclusion, the most important finding of this research for policy purposes is that general-freight common-commodity carriers have no perceptible tendency to behave as natural monopolists in a deregulated environment. Thus although the number of carriers in certain markets would probably fall and the tendency toward mergers should increase, the efficient size of firms appears to be sufficiently small that monopolization would not exist. Competition, while perhaps not perfect, would surely be workable.

Notes

1. See, for example, Meyer et al. (1959), Moore (1975), and Friedlaender and Spady (1981).
2. See, for example, Roberts (1977), and Lawrence (1976).
3. However, in a recent document, the Senate Judiciary Committee (1980) argued that these high concentration ratios were caused by regulatory constraint on entry.
4. See Spady and Friedlaender (1978), Friedlaender, Spady and Wang Chiang (1981), Koenker (1978), and Harmatuck (1981) in addition to the references cited above.
5. For example, in 1980, one percent of the common carriers of general freight earned 52 percent of the industry revenues and six percent of the carriers earned 75 percent of the industry revenues. See Senate Judiciary Committee (1980).
6. However, Harmatuck (1981) has recently tried to incorporate the effects of less-than-truckload (LTL) and truckload (TL) traffic upon costs.
7. For an interesting discussion of the biases inherent in using the ton-miles aggregation see Jara-Diaz (1981).
8. These data were initially provided to the Senate Judiciary Committee by the trucking industry and are now controlled by the Interstate Commerce Commission. Since their access is constrained, interested researchers should contact the ICC concerning their dissemination.
9. See McFadden (1978) for a full discussion of the use of technological variables in the cost function.
10. See Spady (1979) for a full discussion of hedonic aggregation of output.
11. Note that this is defined to be a long-run cost function. In view of the ready transferability of trucking capital, this seems to be a reasonable assumption.

12. Although use of the translog function makes an analysis of economies of scope difficult because it is not defined for zero outputs, it was felt that the translog function presented sufficient advantages with regard to hypothesis testing concerning separability, joint production, and scale economies to warrant its use.

13. In the context of this cost function, the symmetry conditions are:

$A_{is} = A_{si}\ \forall i,s;\quad B_{j\ell} = B_{\ell j}\ \forall \ell,j;\quad C_{kq} = C_{qk}\ \forall k,q;\quad D_{hp} = D_{ph}\ \forall h,p.$

To ensure homogeneity in factor prices, the following conditions are needed:

$\sum_i B_{j\ell} = 0\ \forall \ell;\quad \sum_j E_{ij} = 0\ \forall i;\quad \sum_i H_{jk} = 0\ \forall k;\quad \sum_j I_{jh} = 0\ \forall h.$

14. This can be viewed as a restricted form of a general technology specification since it implies the following coefficient restrictions: $C_{ij} = 0\ \forall i,j$; $e_{ihj} = 0\ \forall i,hj$; $f_{ikh} = 0\ \forall i,h,k$. For a full discussion of the relationship between the hedonic specification and the technology specification see Friedlaender and Spady (1981).

15. Since the factor share equations must sum to one, they must satisfy the following restrictions in the parameter and disturbances: $\Sigma B_j = 1$; $\Sigma \eta_j = 0$. For a full discussion of the estimation procedure see Berndt et al. (1974).

16. The program used to estimate this cost function is based upon the translog estimation package written by Spady and Snow (1978). Some modifications have been made. This program can be made available upon request.

17. For a full discussion of the variables used and their construction see Wang Chiang (1981).

18. While there are clearly other dimensions to level of service than truckload and LTL traffic, they are probably endogenously determined. Thus to include them in the cost function would require the simultaneous formulation of both supply and demand functions.

19. See Kansky (1963), Garrison and Marble (1965), Gordon and de Neufville (1977). Other connectivity measures such as the Alpha index are defined in ways that are quite similar to the Gamma index but do not seem to provide much additional information while providing greater computational complexity.

20. See Gordon (1974) and Gordon and de Neufville (1977) for a full description of the Chi index.

21. A list of these carriers will be made available upon request.

22. Although the trucking industry has collected these data for other years, 1976 is currently the only year for which the ICC processed the data.

23. In the final estimation, parameters were omitted that were shown to be consistently statistically insignificant (as determined by t-tests and likelihood ratio tests).

24. In addition, the estimated cost function yields important information on separability and factor demands. For a full discussion of these issues see Wang Chiang (1981).

25. Within a translog framework, homotheticity is indicated by a lack of interaction terms between inputs, outputs, and characteristics. For this cost function, input-output separability would exist if $F_{ij} = 0 \; \forall i,j$, while separability between inputs and operating characteristics exist if $H_{jk} = 0 \; \forall j,k$ and $I_{jh} = 0 \; \forall j,h$. From Table 2 one can see that the estimates of the E_{ij}'s, the H_{jk}'s, and the I_{jh}'s are generally significantly different from zero, indicating that production is nonhomothetic.

26. In comparing the characteristics of these carriers, it is important to note that they all represent relatively large carriers: the average output of the twenty smallest firms is 87.4 million ton-miles; the output of the mean firm is 745.9 million ton-miles; and the average output of the twenty largest firms is 2.138 billion ton-miles. Thus the scale of operation of the 20 largest firms is almost 25 times larger than the scale of the 20 smallest firms.

27. The incremental cost of output i represents the additional costs incurred by the firm to produce the given level of output i, while the quantities of other outputs are held constant. Mathematically, this is given by

$$IC_i(\psi,w,t) = C(\psi,w,t) - C(\psi_{-i},w,t)$$

where IC_i represents the incremental cost of ψ_i at ψ and ψ_{-i} represents the output vector in which $\psi_i = \psi_i^*$, a minimum scale of output. Then average incremental costs are naturally defined as

$$AIC_i(\psi,w,t) = IC_i(\psi,w,t)/\psi_i$$

Note that incremental and average incremental costs can be negative if there are economies associated with the production of a specific product type for its given level of output.

28. See Friedlaender, Spady, and Wang Chiang (1981) for a full discussion of this point.

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