A MOTOR CARRIER JOINT COST FUNCTION

A Flexible Functional Form with Activity Prices

By Donald J. Harmatuck*

The Motor Carrier Act of 1980 was intended to reduce unnecessary regulation of the motor carrier industry; to provide the Interstate Commerce Commission (ICC) with explicit direction for regulating it; and to provide more opportunity for entry. The ICC still maintains considerable discretion in developing its entry policy. Several proposals now before it for reforming entry policy would distinguish between the truckload and less-than-truckload traffic segments of the industry. ¹ Under one proposal there would be immediate deregulation of truckload entry and route restrictions for truckload carriers, followed by gradual relaxation of route and entry restrictions on less-than-truckload traffic. The differential treatment is rationalised on the ground that:

"slower conversion to deregulation for LTL carriers might be appropriate because of the more extensive capital investment for LTL operations and the longer time needed to adjust their business to altered market conditions".²

However, the main motive for the differential treatment appears to be political expediency.

A number of objections can be raised to this proposal. Two of the more serious objections are that (1) the loss of TL traffic by LTL carriers may raise their cost of providing LTL service, especially to smaller communities, and (2) TL carriers without access to LTL traffic may be at a cost disadvantage vis-à-vis LTL carriers.³

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¹ Truckload (TL) shipments are shipments of sufficient size to be individually transported; less-than-truckload (LTL) shipments need to be consolidated for efficient transport. Typically, a TL shipment is picked up and delivered in the vehicle. An LTL shipment is often picked up in a straight truck or trailer along with other shipments, sorted on to line haul trailers, and transported to its destination city where this terminal process is reversed. While these extensive LTL mixing practices better utilise both drivers and equipment, higher investment in terminal facilities is often required. Arguments for limiting entry have often focused on the economies of utilising such facilities.

² This statement was made by the U.S. Department of Transportation to support their legislative proposals to Congress. See Traffic World, 18 December 1978, p. 14.

³ One trucking official believes that there are scale economies in the LTL segment of the industry and constant returns in the TL segment. See "Waiting for D Day", Forbes, Vol. 122, 25 December 1978, pp. 41–42. As shown below, the differential impact of the various types of traffic and complementarity of these outputs suggest that a joint cost specification should be used to examine motor carrier costs.
Unfortunately, there are several aspects of motor carrier technology about which little is known: one of these is the relationship between motor carrier costs and the composition of a carrier's traffic. Transport literature has not shown whether economies of scope for firms producing specific combinations of outputs are greater or smaller than for firms specialising or producing other combinations of outputs. Till we increase our understanding of motor carrier technology, public policy will continue to be guided by political considerations which disregard economic import.

In this study, a joint cost function is specified and estimated from a sample of large Class I motor common carriers of general commodities (listed in Appendix A). In this cost function specification, less-than-truckload traffic and truckload traffic are treated as separate outputs, each of which is described by the carrier's annual number of shipments, average shipment size and average length of haul. Factor inputs are aggregated into line haul, pickup and delivery, platform handling, and billing and collecting activities; and activity prices are then used in the cost function specification.

The results of this study suggest that (1) the marginal cost functions for TL and LTL traffic are distinctly different and, therefore, require a multiple output specification; (2) the amount of TL traffic has an important effect upon a carrier's cost of providing LTL services; and (3) a generalised flexible functional form of the cost function is necessary to capture the complex nature of motor carrier costs.

In the next section, a methodological introduction to motor carrier costs is followed by a brief review of empirical motor carrier cost functions. Next, a flexible form joint cost function is specified. The parameter estimates of that function are presented. Finally, the conclusions and policy implications are given.

**MOTOR CARRIER COST FUNCTION METHODOLOGY**

Nearly all the numerous estimates of motor carrier cost functions contain one or more of the following methodological problems: (1) use of highly restrictive functional forms, (2) improper characterisation of output, (3) omitted or improperly measured factor prices, and (4) a heterogeneous sample of motor carriers. This section discusses these problems, along with some basic elements of cost theory. The discussion leads to the cost function specification described in the next section.

**Restrictive functional forms**

Neoclassical economic theory characterises a firm's technology by scale, distribution and substitution effects. For multiproduct firms, additional effects are incorporated to reflect the marginal rates of transformation of outputs. These technological effects can be estimated through either a production function or a cost function of the firm. The choice between the production function and the cost function in estimating technological effects depends upon stochastic components in the technology, measurement errors, aggregation errors, etc. (Fuss et al., 1978). For regulated industries, where output levels can be assumed to be exogenously determined, estimation by cost function is felt to be preferable (Brown et al., 1976).

The choice of a particular functional form for estimating the cost function requires
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A balancing of the simplicity of a functional form which is easy to estimate against one which better reflects the complex nature of a technology. In transport cost studies, for example, Cobb-Douglas and linear forms of cost functions have often been used because of their ease of estimation. Unfortunately, these functional forms carry with them nonestable maintained hypotheses. For example, substitution elasticities between factor inputs for the linear and Cobb-Douglas cost functions are assumed to be zero and unity, respectively. Input prices are often assumed to be the same for every firm in the sample. Returns to scale or other estimated characteristics of production are unfortunately difficult to assess under these restrictive assumptions.4

Flexible functional forms are those forms which do not restrict a scale, distribution, or substitution effect of a technology to dependence upon another scale, distribution, or substitution effect. Parsimonious flexible forms contain a minimum number of parameters to characterise independently all the neoclassical technological effects. An example is the translog cost function which can be expressed as:

\[
\ln C(y; w) = \alpha_0 + \alpha_1 \ln y + 1/2 \sigma_2 (\ln y)^2 + \sum_{j=1}^{n} \beta_j \ln y \ln w_j
\]

\[
+ \sum_{i=1}^{n} \gamma_i \ln w_i + 1/2 \sum_{i=1}^{n} \sum_{j=1}^{n} \delta_{ij} \ln w_i \ln w_j
\]

where \( \sum \gamma_i = 1, \ \sum \beta_j = 0, \ \delta_{ij} = \delta_{ji}, \ \sum \delta_{ij} = \sum \delta_{ij} = 0 \), and where

- \( C(y; w) \) = total cost,
- \( y \) = output, and
- \( w_i \) = price of factor input \( i \).

The translog cost function, like other parsimonious flexible forms, offers a second-degree approximation to the true cost function at a point such as the average output level and average factor prices. However, to obtain a good approximation over the entire range of output and factor price levels, additional parameters may be necessary.

Output specification

The specification of output in motor carrier cost functions has taken one of two forms: (1) reducing multiple outputs to a single dimension, using a common measure such as ton-miles, or (2) preserving the multiple dimensions of output. Most previous motor carrier cost studies have reduced multiple outputs to a single dimension such as ton-miles, using output characteristics such as the number of shipments, shipment sizes, and lengths of haul to qualify this output index. Other characteristics, such as the percentage of LTL to total traffic, insurance cost per ton-mile, average load per

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4 Fuss, McFadden and Mundlak (1978) point out the problem as follows: “The outcome of a specific test of hypothesis depends in general on both the validity of the hypothesis under consideration and the validity of the maintained hypothesis . . . This suggests the general principle that one should not attempt to test a hypothesis in the presence of maintained hypotheses that have less commonly accepted validity . . . An implication of this is the need for general flexible functional forms, embodying few maintained hypotheses, to be used in tests of the fundamental tests of production theory.”
trailer, and terminal costs per ton-mile, have been used to reduce the heterogeneity of output (Friedlaender et al., 1979).

Unfortunately, a single output index may cause bias in estimates of the structure of technology in the motor carrier industry. Since the marginal cost functions for LTL and TL traffic are likely to be significantly different, combining diverse outputs into a single index may lead to biased estimates of returns to scale. Not only do TL and LTL operations involve different personnel and equipment, such as LTL platform labour and pickup and delivery straight trucks; labour constraints often prohibit personnel affiliated with one activity from working in another activity. Line haul drivers, for example, are often prohibited under union contract rules from making local deliveries of freight. As a result, there is no necessary correspondence between input prices and productivity of different activities or between the marginal costs of the services produced from different activities.

Single output motor carrier cost specifications often define labour prices in terms of average annual compensation per employee (for example, Friedlaender et al., 1979, and Keaton, 1978). These specifications confound the influences of output and factor prices. In general, LTL operations are more costly per ton-mile and involve more labour-intensive terminal activity than TL operations. Since average annual compensation of terminal employees is low, firms with higher costs and more LTL traffic have lower measured prices of labour. Thus, the effect of annual compensation on cost reflects the output composition of a carrier’s traffic as well as the effect of real labour prices.

A preferred approach to handling multiple outputs is to specify a joint cost function which preserves individual output dimensions. Specification of such a function is often developed using a second-order Taylor’s series approximation. For a case involving \( m \) outputs and \( n \) inputs, there would be \( [(m+1)(m/2) + (n+1)(n/2) + mn] \) parameters. The assumption of cost minimisation reduces the number by \( m + n + 1 \). The large number of remaining parameters to be estimated suggests a specification with relatively few outputs.

Previous motor carrier cost studies have not used a flexible form joint cost approach. Chow (1978), Klem (1978) and Koenker (1977) use restrictive single output Cobb-Douglas specifications with second-order output terms. Factor prices.

\[ C(x^*) \approx f(x^*) + \sum_{i=1}^{n} \frac{\partial f(x^*)}{\partial x_i} (x_i - x_i^*) + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{\partial^2 f(x^*)}{\partial x_i \partial x_j} (x_i - x_i^*)(x_j - x_j^*) \]

where \( f \) is the approximate functional form and \( x = (x_1, x_2, \ldots, x_n) \) is a vector of independent variables. The translog joint cost function can be obtained by (1) letting \( \mathbf{x} \) be a vector of the logarithms of outputs and factor prices and (2) defining

\[ a_0 = f(x^*) \]
\[ a_i = \frac{\partial f(x^*)}{\partial x_i} \quad i = 1, 2, \ldots, n \]
\[ a_{ij} = \frac{\partial^2 f(x^*)}{\partial x_i \partial x_j} \quad i, j = 1, 2, \ldots, n. \]
are omitted from these specifications. Friedlaender, Spady and Chiang (1979), Cherry (1978) and Keaton (1978) adopt a translog cost function but place arbitrary restrictions on the nature of output. Aggregate output indices are specified as translog functions of output qualities. Cherry (1978) adopts a multiple output translog formulation, but his approach maintains that factor prices and output qualities are separable.6 Finally, all previous translog motor carrier cost studies employ rather weak estimates of factor prices.

**Factor prices**

Omitting factor prices from motor carrier cost function specifications, or inappropriately including factor prices, leads to bias in the parameter estimates. For convenience cost specifications often omit factor prices, assuming that all firms face the same set of prices. While a national labour contract, current equipment financing methods, and a high salvage value on transport equipment suggest similar factor prices for large general commodity common carriers, it may be inappropriate to generalise across segments of the motor carrier industry. Furthermore, interesting and important structural characteristics, such as separability of inputs and outputs, can be assessed if factor prices are included in the specification.

Labour prices based on an average annual compensation per employee often leads to the erroneous conclusion that there are diseconomies of scale in the motor carrier industry.7 The reason is that traffic composition (TL/LTL mix) determines the average annual compensation per employee. Firms producing LTL services have a lower average compensation because they use more terminal employees, who are paid less on an annual basis than their line haul counterparts. In previous studies of motor carrier scale economies, average compensation and other factor prices have been held constant when the influence of output on cost was examined. This procedure assumes that factor prices are determined independently of the composition of output. However, size is correlated with composition; that is, LTL carriers are generally larger. Ignoring this relationship gives the incorrect impression that firms which have high costs per ton or per ton-mile have high costs because of their large size rather than because of their traffic composition.

Precise parameter estimation of the translog cost function required the use in the estimation process of additional information in the form of factor share equations. Factor share equations, linear in the same parameters found in the translog cost function, are derived from the application of Shephard's Lemma under the assumption that firms choose inputs based on the factor prices that they face. Without firm specific prices reflecting the costs of the resources actually employed, Shephard's Lemma cannot be used (Lau, 1974). Many previous studies of motor carrier costs

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6 Separability implies that the average length of haul, for example, has no influence upon the marginal rates of substitution of labour for capital or fuel, so that it is as easy to substitute labour for fuel or labour for capital in the short haul as it is in the long haul. The imposition of this "maintained hypothesis" casts doubt on Cherry's conclusions.

7 This conclusion was found in Friedlaender (1978), Friedlaender, Spady, and Chiang (1979), Keaton (1978) and Spady and Friedlaender (1978).
have used regional or national fuel and other factor prices. Unless there is a remarkable amount of homogeneity within regions, these prices provide little information that is useful in estimating cost function parameters.

Furthermore, previous cost studies have employed measures of firm-specific prices which bear little resemblance to the underlying price. For instance, in measuring the cost of capital Spady and Friedlaender (1978) do not use only expenditures other than labour, fuel, and purchased transport divided by net carrier operating property. They use also many other items of expenditure, such as telephone expenses, salesmen’s commissions, insurance expenses, etc., which bear little resemblance to the cost of capital services.

The fit of Spady and Friedlaender’s factor share equations illustrates the inappropriateness of using poorly defined or nonspecific factor prices. In Spady and Friedlaender (1978), the $R^2$ values for the cost, labour, fuel, and capital share equations are 0.94, 0.05, 0.04, 0.05, respectively. An overall lack of fit to the share and cost equations may indicate a particular technological structure; but the close fit to the cost function and the poor fit to the share equations are more likely to indicate that the levels of factor inputs employed and the measures of factor prices are independent of each other. Rather than indicating a particular production structure, the lack of fit probably indicates that the price measures used are inappropriate. Unfortunately, factor share equations limit the cost function parameter estimates to values which are consistent with the share equation but which are not likely to be consistent with the underlying technology. As is shown below, consistent cost and input share equations are obtained by aggregating inputs into activities and developing activity prices rather than so-called natural factor prices.

Other problems

There are three further difficulties in estimating a motor carrier cost function. First, motor carriers may operate off their cost curves because of backhaul restrictions, common carrier obligations, gateway restrictions, etc. If carriers suffer from these so-called X-inefficiencies, it is doubtful whether duality principles and estimation techniques can be validly used. Second, data problems lead to substantial reporting errors in output estimates, and these can cause serious bias in cost function parameter estimates. Finally, bias also arises if carriers do not adapt to unplanned output changes. In this study the large established carriers in the sample have been selected with a view to minimising these problems.

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8 The maximum likelihood estimation techniques employed here and in the estimation of other translog cost functions are described in E. K. Berndt et al. (1974). For an introductory discussion of the constraints employed in these joint estimation procedures, see Theil (1971), chapter 7.

9 X-inefficiency is the difference between a firm’s actual cost of output and the theoretical minimum cost of that output. Circuitous route and restricted commodity authorisations, for example, may lead to X-inefficiency.

10 Output data of smaller firms are often estimated periodically using crude estimation techniques. Errors in such output estimates can lead to bias in the parameter estimates of the cost function.

11 Koenker (1977), for example, has labelled the costs of operating in the face of unplanned output as short run costs. However, short run costs are associated with planned outputs but a limited planning horizon. Unplanned outputs give rise to the regression fallacy. See Borts (1960).
The joint cost model

A generalisation of the translog joint cost function is used here to relate costs to multiple dimensions of outputs and factor prices. The joint cost specification permits an examination of scale economies in the truckload and less-than-truckload segments of the industry. This section presents the specification of the translog joint cost function, together with extensions which add flexibility to this functional form. The output and input price measures are also described.

The translog joint cost function

The translog joint cost function can be expressed as:

$$\ln C(y; w) = \alpha_0 + \sum_{i=1}^{m} \alpha_i \ln Y_i + 1/2 \sum_{i=1}^{m} \sum_{j=1}^{m} \beta_{ij} \ln Y_i \ln Y_j$$
$$+ \sum_{i=1}^{n} \gamma_i \ln w_i + 1/2 \sum_{i=1}^{n} \sum_{j=1}^{n} \delta_{ij} \ln w_i \ln w_j + \sum_{i=1}^{m} \sum_{i=1}^{n} \epsilon_{ij} \ln Y_i \ln w_j$$

(1)

where the restrictions are imposed on parameters

$$\sum_{i} \gamma_i = 1 \quad (1a) \quad \beta_{ij} = \beta_{ji} \quad (1b)$$
$$\delta_{ij} = \delta_{ji} \quad (1c) \quad \sum_{i} \delta_{ij} = 0 \quad (1d) \quad \sum_{j} \epsilon_{ij} = 0 \quad (1e)$$

and where $C(y; w)$ is total cost, $Y_i$ is the $i$-th output, and $w_j$ is the $j$-th factor price. These added restrictions impose linear homogeneity in factor prices [((1a), (1d), and (1e)] and symmetry [((1b) and (1c)]. The restrictions reduce the number of free parameters to [(m + n + 1)(m + n)/2].

Even with only a few inputs and outputs, unless additional information is provided direct estimation of equation (1) is likely to yield poor results, as multicollinearity is likely to reduce the precision of the individual parameter estimates. However, the assumption that firms minimise cost yields additional information, which greatly facilitates the estimation of parameters.

Using Shephard's Lemma, the partial derivative of the cost function (1) with respect to the price of factor input $i$, $w_i$, if it exists, equals the unique cost minimising input demand for factor $i$:

$$x_i(y, w) = \frac{\partial C(y; w)}{\partial w_i}$$

where $x_i$ is the quantity of factor $i$ demanded. Similarly, a relationship can be developed between $\ln C(y; w)$ and $\ln w$, the variables of the translog joint cost function. The share of factor $i$ expenditures $[S_i(w, y)]$ can be expressed as the partial derivative of $\ln C(y; w)$ with respect to $\ln w$:

$$S_i(w, y) = \frac{\partial \ln C(y; w)}{\partial \ln w_i} = \gamma_i + \sum_{j=1}^{n} \delta_{ij} \ln w_j + \sum_{i=1}^{m} \epsilon_{ij} \ln Y_r$$

(2)
The share equations for the translog cost function are shown to be linear in the same parameters found in the cost function. Given an error structure for the cost and share equations which is additive joint normal with nonzero correlations permitted for a firm and zero correlation across firms, the parameter estimates can be efficiently estimated using maximum likelihood multivariate regression techniques (Berndt et al., 1974).

Additional restrictions placed on the translog joint cost function yield simpler representations of motor carrier technology, such as the Cobb-Douglas production structure. The simplicity of the Cobb-Douglas production structure may be tested by imposing the following restrictions on the translog cost function:

$$\beta_{i} = 0 \quad (3a) \quad \delta_{i} = 0 \quad (3b) \quad \varepsilon_{i} = 0 \quad (3c)$$

The appropriateness of the representation can be tested by using likelihood ratio tests of the composite hypotheses (Berndt et al., 1974, p. 659).

An extension of the translog joint cost function developed by Caves, Christensen and Tretheway (1978), based on the Box-Cox transformation, is used here.\(^{12}\) In equation (1), each output variable is transformed to the following:

$$Y_i^{(\lambda)} = \begin{cases} \frac{Y_i^\lambda - 1}{\lambda_i} & \lambda_i \neq 0 \\ \ln Y_i & \lambda_i = 0 \end{cases}$$

where $\lambda_1, \lambda_2, \ldots, \lambda_m$ are empirically determined parameters which yield the flexible forms from a class known as general quadratic forms. Box and Tidwell (1962) have shown how to estimate these parameters. A further set of transformations might be applied to the cost variable and the factor price variables; but, unfortunately, these transformations would lead to complicated representations of the input demand or factor share equations. Therefore, only output variables are transformed.

**Output measures**

Less-than-truckload and truckload outputs are assumed to be distinct. Each output is described by (a) its number of shipments, (b) its average weight of shipments, and (c) the overall average length of haul. Since average length of haul is not reported separately, five dimensions of output are used:

- $y_1 = \text{number of shipments - TL}$
- $y_2 = \text{average weight of shipment - TL}$
- $y_3 = \text{number of shipments - LTL}$
- $y_4 = \text{average weight of shipment - LTL}$
- $y_5 = \text{average length of haul}$

This specification avoids the assumption that the effects of factor prices and output

\(^{12}\) The Box-Cox transformation applies to transformations on the dependent variable so as to make the disturbance term additive and normally distributed with a constant variance. See Box and Cox (1964). This transformation is used here to apply only to the independent variables.
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characteristics upon total costs are the same for all outputs.\textsuperscript{13} It permits the TL and LTL marginal cost functions to differ from each other.

\textit{Factor input prices}

Rather than dealing with aggregations of labour and capital, factor inputs are aggregated into the following activity sets:

- line haul
- pickup and delivery
- billing and collecting
- platform handling
- all other factors

and “activity prices” are determined for each activity. Assignment and allocation of costs into these categories is consistent with the Interstate Commerce Commission’s Chart of Accounts (ICC, 1976).

Activities can be considered as individual production centres producing services which are measured as follows:

- line haul: vehicle miles
- pickup and delivery: tons
- platform handling: LTL tons
- billing and collecting: shipments.

These intermediate services are then combined to produce motor carrier service. Activity prices are estimated by dividing total activity expenditures by the output measure of the activity. This procedure implicitly assumes that the production process of each activity is itself homothetic.\textsuperscript{14}

To reduce the dimensionality of the cost function, inputs can be aggregated into either activity categories or natural factor categories. The appropriate choice depends upon the production structure. In aggregating inputs by activities, it is assumed that each factor within an activity (e.g., line haul labour or line haul capital) has the same elasticity of substitution with any factor outside that activity (e.g., pickup and delivery labour). This method of aggregating inputs is preferable to aggregating inputs by natural factors. Under that approach, it would be necessary to assume that line haul labour and pickup and delivery labour, for example, are equally substitutable for line haul capital.

On more practical grounds, activity prices are preferred to natural factor prices because of the difficulties of properly defining natural factor input prices.

\textsuperscript{13} This flexibility is particularly important in view of the way in which input factors are aggregated in this study. For example, it is expected that platform handling activity’s share of total cost would be positively associated with the number of LTL shipments and negatively associated with the number of TL shipments. Furthermore, the effect of LTL shipment size on the amount of platform handling activity and total carrier cost is likely to differ significantly from TL shipment size.

\textsuperscript{14} Shephard (1976, p. 124) states that the practice of price deflating dollar values to convert to physical quantities is justified if and only if the production structure is homothetic. It follows that quantity deflating to estimate prices also requires homotheticity or, equivalently, a multiplicatively separable cost function and constant return: $C(y; w) = y^T(w)$. Most cost finding techniques in transport have used accounting approaches which implicitly make these assumptions.
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<td>Y_2 ln w_1</td>
<td>-0.123-03</td>
<td>-5.23</td>
</tr>
<tr>
<td>Y_16</td>
<td>-0.711-03</td>
<td>-0.37</td>
<td>Y_1 ln w_1</td>
<td>0.031</td>
<td>13.20</td>
<td>Y_2 ln w_1</td>
<td>0.130</td>
<td>4.68</td>
</tr>
<tr>
<td>Y_17</td>
<td>0.379-04</td>
<td>1.02</td>
<td>Y_2 ln w_1</td>
<td>-0.016</td>
<td>-11.95</td>
<td>Y_2 ln w_1</td>
<td>-0.016</td>
<td>-11.95</td>
</tr>
<tr>
<td>Y_18</td>
<td>0.587</td>
<td>4.29</td>
<td>Y_3 ln w_1</td>
<td>0.013</td>
<td>4.68</td>
<td>Y_3 ln w_1</td>
<td>-0.016</td>
<td>-11.95</td>
</tr>
<tr>
<td>Y_19</td>
<td>-0.623-02</td>
<td>-1.55</td>
<td>Y_3 ln w_1</td>
<td>0.013</td>
<td>4.68</td>
<td>Y_3 ln w_1</td>
<td>-0.016</td>
<td>-11.95</td>
</tr>
<tr>
<td>Y_20</td>
<td>-0.456</td>
<td>-0.56</td>
<td>Y_3 ln w_1</td>
<td>0.013</td>
<td>4.68</td>
<td>Y_3 ln w_1</td>
<td>-0.016</td>
<td>-11.95</td>
</tr>
</tbody>
</table>
A MOTOR CARRIER JOINT COST FUNCTION

DATA

Cost, output and activity prices are derived from data in the Trinc’s Blue Book of the Trucking Industry, 1977 edition. The sample of carriers used in this analysis consists of the top 100 general commodity common carriers with a complete data set. The cost term includes only total operating expenses, and therefore excludes interest expenses. Activity expenses and output measures are taken directly from Trinc’s.

RESULTS

The following transformations of output variables were used in the cost function:

\[ Y_1 = \frac{y_1^{0.13} - 1}{0.13}, \quad y_1 = \text{number of TL shipments} \]
\[ Y_2 = \frac{y_2^{2.27} - 1}{2.27}, \quad y_2 = \text{TL shipment size} \]
\[ Y_3 = \frac{y_3^{0.06} - 1}{0.06}, \quad y_3 = \text{number of LTL shipments} \]
\[ Y_4 = \frac{y_4^{1.51} - 1}{1.51}, \quad y_4 = \text{LTL shipment size} \]
\[ Y_5 = \frac{y_5^{0.13} - 1}{0.13}, \quad y_5 = \text{average length of haul.} \]

These output variables were combined with the logarithms of factor prices, ln \( w_P \), into a quadratic form generalisation of the translog cost function. All output and price variables are defined as deviations from their mean levels. The parameters of the cost function and the factor share equations were jointly estimated and the results are shown in Table 1 (see Appendix B).

The results are highly significant. Forty-nine of the 55 parameter estimates have \(|t|\) values greater than 2.0. All activity price and output variables are highly significant. The cost function is clearly nonseparable, as interaction terms of outputs and activity prices are all highly significant. As Table 2 shows, the model explains variations in activity shares nearly as well as it explains variations in costs.

The results suggest that there are approximately constant returns to scale for the average firm in the sample, with significant scale economies for smaller firms and diseconomies for larger firms. In order to measure scale economies for the multiple

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15 Interest expense is not available from Trinc’s, and therefore needs to be estimated from other sources. A capital recovery approach might be used. See, for example, Harmatuck (1979). However, in the motor carrier industry interest expenses account for a very small percentage of total expenses or total revenues. For example, in 1977 among the 30 publicly held motor carriers, interest expense accounted for 0.7% of total revenues. Therefore, omitting such expenses has little impact on the overall results presented here. See Kohler (1978), p. 46.

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### Table 2

*Fit of Cost Function and Share Equations*

<table>
<thead>
<tr>
<th>Equation</th>
<th>$R^2$</th>
<th>Standard Error of the Regression</th>
<th>Mean Value of Dependent Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost function</td>
<td>0.9903</td>
<td>0.1100</td>
<td>10.9096</td>
</tr>
<tr>
<td>Line haul share</td>
<td>0.9325</td>
<td>0.0374</td>
<td>0.3866</td>
</tr>
<tr>
<td>Pickup and delivery share</td>
<td>0.8964</td>
<td>0.0344</td>
<td>0.2644</td>
</tr>
<tr>
<td>Billing and collecting share</td>
<td>0.8810</td>
<td>0.0056</td>
<td>0.0306</td>
</tr>
<tr>
<td>Platform handling share</td>
<td>0.9056</td>
<td>0.0230</td>
<td>0.1264</td>
</tr>
</tbody>
</table>

### Table 3

*Cost Elasticities of TL and LTL Service by the Number of TL and LTL Shipments*

<table>
<thead>
<tr>
<th>Elasticity</th>
<th>LTL Shipments (000)</th>
<th>TL Shipments (000)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>TL</td>
<td>500</td>
<td>0.46</td>
</tr>
<tr>
<td>LTL</td>
<td>0.37</td>
<td>0.37</td>
</tr>
<tr>
<td>Total</td>
<td>0.96</td>
<td>1.04</td>
</tr>
<tr>
<td>TL</td>
<td>1,000</td>
<td>0.33</td>
</tr>
<tr>
<td>LTL</td>
<td>0.63</td>
<td>0.49</td>
</tr>
<tr>
<td>Total</td>
<td>0.96</td>
<td>1.08</td>
</tr>
<tr>
<td>TL</td>
<td>1,500</td>
<td>0.26</td>
</tr>
<tr>
<td>LTL</td>
<td>0.72</td>
<td>0.58</td>
</tr>
<tr>
<td>Total</td>
<td>0.97</td>
<td>1.01</td>
</tr>
<tr>
<td>TL</td>
<td>2,000</td>
<td>0.20</td>
</tr>
<tr>
<td>LTL</td>
<td>0.78</td>
<td>0.64</td>
</tr>
<tr>
<td>Total</td>
<td>0.98</td>
<td>1.05</td>
</tr>
<tr>
<td>TL</td>
<td>5,000</td>
<td>0.02</td>
</tr>
<tr>
<td>LTL</td>
<td>1.00</td>
<td>0.85</td>
</tr>
<tr>
<td>Total</td>
<td>1.02</td>
<td>1.00</td>
</tr>
<tr>
<td>TL</td>
<td>10,000</td>
<td>—</td>
</tr>
<tr>
<td>LTL</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Total</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

*Rounding errors cause several discrepancies. Negative cost elasticities were omitted.*

Output firm, we adopt procedures of Brown, Caves and Christensen (1976) of summing the individual output cost elasticity. First, outputs are measured by the number of TL shipments and the number of LTL shipments, given approximately the sample average TL shipment size of 15.0 tons, the sample average LTL shipment size of 0.376 tons, and an average length of haul of 417 miles. The sample average length of haul is actually 494 miles. Table 3 shows that the sum of the TL and LTL cost elasticities for the average size of 52,640 TL shipments and 1,330,250 LTL
shipments is approximately unity and it is near unity over a broad range of outputs. There are decreasing returns to scale for firms producing almost exclusively truckload service.

Given a sample average number of shipments and shipment sizes, the cost elasticity of increasing the average length of haul is less than unity. For the sample average length of haul, a 10 percent increase in average length of haul increases cost by only 3.8 percent. The cost elasticity with respect to average length of haul remains substantially below unity for all carriers in the sample. The greatest average length of haul in the sample is less than 1,750 miles, for which the cost elasticity is 0.71. Finally, it is mildly surprising that the composition of truckload and less-than-truckload traffic has relatively little impact on the cost elasticity of average length of haul.

Another important question in motor carrier technology is whether or not there are "economies of scope". In other words, there may be economies for a single firm in producing both TL and LTL service rather than specialising in one service or the other. The existence of such economies is consistent with isocost contours in output space being concave to the origin. For an isocost contour,

\[ dC = \frac{\partial C}{\partial y_1} dy_1 + \frac{\partial C}{\partial y_3} dy_3 = 0 \]

its slope is

\[ \frac{dy_1}{dy_3} = -\frac{(\partial C/\partial y_3)}{(\partial C/\partial y_1)}. \]

Allen (1964, pp. 338 and 466) has shown that the rate of change in the slope of the isocost contours can be expressed as:

\[ \frac{d^2 y_1}{dy_3^2} = -\frac{1}{(\frac{\partial C}{\partial y_1})^3} \left( \left( \frac{\partial^2 C}{\partial y_3^2} \right) \left( \frac{\partial C}{\partial y_3} \right)^2 - 2 \left( \frac{\partial^2 C}{\partial y_1 \partial y_3} \right) \left( \frac{\partial C}{\partial y_1} \right) \left( \frac{\partial C}{\partial y_3} \right) \right) + \left( \frac{\partial^3 C}{\partial y_1^2 \partial y_3} \right) \left( \frac{\partial C}{\partial y_3} \right) \]

A negative value of \( d^2 y_1/dy_3^2 \) indicates concavity and economies of scope, whereas a positive value indicates economies of specialisation.

The second derivative of the isocost contours for various output levels is shown in Table 4. For firms with smaller than average TL and LTL shipments, there are economies of specialisation. For large firms which specialise in TL movements or LTL movements, there are economies of scope. These firms could enjoy economies by diversifying. For large firms which have diversified, there is a wide range of TL and LTL output levels over which the ratio of the marginal cost of TL shipments to the marginal costs of LTL shipments is approximately constant.

The activity demand elasticities and the elasticities of substitution among activities, shown in Table 5, suggest that motor carrier technology does not result in fixed activity proportions, as assumed in many ICC and industry costing procedures. Furthermore, the Cobb-Douglas type of specification assumed in previous analyses of
the motor carrier industry is clearly inappropriate, since the elasticities of substitution differ substantially from unity. This analysis suggests that line haul and platform handling activities show some sensitivity to activity prices. Furthermore, line haul and platform handling activities are quite interchangeable for the carriers in this sample. On the other hand, platform handling and pickup and delivery activities are rather weak substitutes.

POLICY IMPLICATIONS AND CONCLUSIONS

The methodology developed here for estimating motor carrier costs has been remarkably successful by comparison with previous attempts to estimate the motor carrier cost function. The significance of the results is extraordinary. The development of the joint cost function specification in terms of distinct truckload and less-than-truckload outputs avoids biases found in single output cost specifications as well as in those multiple output specifications which treat multiple outputs as qualitative variations of a single output index rather than as separate and distinct. Results have been improved by the use of general flexible functional forms rather than the translog function. The use of activity prices rather than prices of inappropriately aggregated natural factors also leads to more reasonable results. Confining the analysis to a homogeneous set of carriers produces more consistent results than previous cost studies, as it avoids the introduction of rather artificial measures to account for heterogeneity among carriers. Confining this analysis to larger carriers has reduced reporting errors.

The results have a number of important implications for policy. For firms below $50 million in operating costs, there are scale economies. For example, for firms producing less than 25,000 truckload shipments and 1,000,000 less-than-truckload shipments, cost elasticities are less than 0.96. Twenty-three firms in the sample fell into this category. This finding is in contrast to that of studies such as Spady and
Friedlaender (1978), which suggest that there are slight diseconomies of scale for firms with operating costs as low as $8 million. Above this minimum efficient size, there are constant returns to scale. Unlike previous cost studies, this analysis suggests that smaller carriers cannot compete on equal terms with larger regular route common carriers. Whether this large minimum efficient size stems from technological characteristics of the industry or from institutional characteristics cannot be determined solely from the results presented here. However, to the extent that technological characteristics are the source of scale economies, placing restrictions on the ability of firms to grow may not be in the public interest.

Easing entry restrictions into the truckload segment of the industry while maintaining entry restrictions for the less-than-truckload segment may be incompatible with the finding of scope economies for firms specialising in either truckload or less-than-truckload traffic. The results suggest that on operational grounds adding LTL traffic to truckload traffic is an economically sound practice. Being denied access to less-than-truckload traffic is uneconomical, especially for larger carriers.

The results of this analysis suggest that there is some degree of instability in a motor carrier industry in which entry into less-than-truckload markets is restricted. All small firms, regardless of traffic composition, have incentives to become larger on grounds of scale elasticity. Larger specialised firms, especially TL firms, have an additional incentive to diversify. Artificially restricting a firm’s ability to diversify raises the cost of providing motor carrier service. Thus, on efficiency grounds, there should be some less-than-truckload traffic available to truckload carriers wishing to engage in regular route operations.

APPENDIX A

Motor Carriers in the Analysis

1. B & P Motor Exp
2. Commercial Mtr Frt
3. Cooper-Jarrett
4. Dohrn Transfer
5. Eastern Express
6. Eazor Express
| 7. Gateway Trptn | 54. Interstate Motor Frt Sys |
| 8. Halls Mtr Transit | 55. Werner Continental |
| 10. Motor Frt Express | 57. Great Lakes Exp |
| 11. Preston Trkg | 58. Overnite Trptn |
| 12. Smiths Transfer | 59. Adleys Express |
| 13. Spector Frt Sysm | 60. Akers Motor Lines |
| 14. Transport Mtr Exp | 61. Bowman Trptn |
| 16. A A A Trucking | 63. Carolina Frt Carriers |
| 17. A-P-A Transport | 64. ET & WNC Trptn |
| 18. Burgmeyer Bros | 65. Hemingway Trpt |
| 19. Holmes Trptn | 66. Johnson Mtr Lns |
| 23. Schuster Express | 70. Pilot Frt Carriers |
| 24. Consolidated Frtways—Del | 71. Ryder Truck Lines |
| 25. East Tex Mtr Frt Lns | 72. Admiral-Mrchts Mtr Frt |
| 26. I M L Freight | 73. All-American |
| 27. Illinois-Calif Exp | 74. Briggs Trptn |
| 28. Lee Way Motor Frt | 75. Churchill Trk Lns |
| 29. Navajo Frt Lns | 76. Crouch Frt Systems |
| 30. Pacific Intermtn Exp | 77. Glendenning Mtrwys |
| 31. Sante Fe Trail Trptn | 78. Graves Truck Line |
| 32. T I M E—D C | 79. Mid-American Lines |
| 33. Transcon Lines | 80. Murphy Mtr Frt Lns |
| 34. Western Gillette | 81. Estes Express Lines |
| 35. Yellow Freight Sysm | 82. Georgia Highway Exp |
| 36. Arkansas-Best Frt System | 83. M R & R Trucking |
| 37. Campbell Sixty-Six Exp | 84. Old Dominion Frt Ln |
| 38. Gordons Trpts | 85. Southeastern Frt Lns |
| 39. Jones Trk Lns | 86. Thurston Mtr Lns |
| 40. Transamerican Frt Lines | 87. Clairmont Transfer |
| 41. Delta Line | 88. Duff Truck Line |
| 42. Garrett Frt Lns | 89. Jones Transfer |
| 43. Milne Trk Lns | 90. A & H Truck Line |
| 44. O N C Freight Systems | 91. Associated Trk Lns |
| 45. System 99 | 92. Cleveland Cols & Cin Hwy |
| 46. Whitfield Trptn | 93. Commercial Mtr Frt—Inc |
| 47. Central Frt Lns | 94. Holland Mtr Exp |
| 48. Merchants Fast Mtr Lns | 95. Lovelace Truck Svc |
| 49. Red Arrow Frt Lns | 96. O K Trucking |
| 50. Red Ball Mtr Frt | 97. Shippers Dispatch |
| 51. Roadway Exp | 98. Suburban Mtr Frt |
| 52. Strickland Trptn | 99. Tucker Frt Lns |
| 53. C W Transport | 100. United Trucking Svc |
APPENDIX B

Procedures for Estimation of Parameters

The maximum likelihood multivariate regression techniques used here are described in *TSP-WISC Manual, Update No. 4* (November 1977) distributed by the University of Wisconsin, Madison Academic Computing Center. The system of \( L \) equations, each having \( T \) observations, are of the type

\[
Y_t = X\beta_t + \varepsilon_t
\]

These equations are “stacked” to give \( Y = XB + E \) where

\[
Y = [y_1, y_2, \ldots, y_L]^	ext{r}
\]

\[
B = [\beta_1, \beta_2, \ldots, \beta_L]^	ext{r}
\]

\[
E = [\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_L]^	ext{r}
\]

and

\[
X = \begin{bmatrix}
X_1 & 0 & \cdots & 0 \\
0 & X_2 & \cdots & 0 \\
\vdots & \ddots & \ddots & \vdots \\
\vdots & & \ddots & \vdots \\
0 & 0 & \cdots & X_L
\end{bmatrix}
\]

In this paper the number of equations is 5, the number of observations per equation is 100, and the total number of system parameters is 55.

The ordinary least squares estimates, \( B = (X'X)^{-1}X'Y \) yield residuals, \( U = [u_1, u_2, \ldots, u_L] \), and the estimated variance-covariance matrix, \( \hat{\Sigma} = (1/T)U'U. \) New parameter estimates,

\[
B = [X'(\hat{\Sigma}^{-1} \otimes I) X]^{-1} X'(\hat{\Sigma}^{-1} \otimes I) Y,
\]

untransformed residuals, \( U \), and the variance-covariance matrix, \( \hat{\Sigma} \), are then estimated where \( I \) is an identity matrix of order \( T \). The new estimates of \( \Sigma \) are used to re-estimate \( B \). This iterative procedure yields maximum likelihood estimates when

\[
E'E = U'(\hat{\Sigma}^{-1} \otimes I) U
\]

forms an identity matrix. \( E \) is the matrix of transformed residuals.

The variance-covariance matrix of the \( k \) parameter estimates of the system is given by

\[
V = \frac{L}{LT - k} [X'(\hat{\Sigma}^{-1} \otimes I) X]^{-1}.
\]

The \( t \) statistics in Table 1 equal the parameter estimates divided by the square roots of the diagonal elements of \( V \), the asymptotic standard errors of the parameter estimates.
REFERENCES


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Donald J. Harmatuck


