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# Railroad Cost Structure—Revisited

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## ABSTRACT

Dating back to the landmark work of Meyer, Peck, Stenason and Zwick (1959), economists such as Borts (1960), Healy (1962), Griliches (1972), Keeler (1974), and Harris (1977), Harmatuck (1979), Spady and Friedlaender (1981), Breautigam, Daughety, and Turnquist (1982) and Caves, Christensen, Tretheway and Windle (1985) have attemped to estimate railroad cost structure. However, there are a number of data limitations common to most of these studies. First, accounting data is often used which does not correspond to economic reality. For example, betterment accounting techniques historically treated maintenance expenses as current expenses rather than additions to capital stock. Thus, the economic value of capital is not accurately reflected, and this may well result in biased estimates of economies of density. Second, these studies have relied on older data (no more recent than 1975). Consequently, potential impacts on cost structure from regulatory reform have not been previously estimated.

This paper presents new estimates of railroad structure, improving upon previous estimates by using more recent data and superior estimates of capital costs. A data set consisting of Class I railroads for the years 1979 through 1983 is used. Major findings are strong economies of density and length of haul, but no economies of firm size. Implications for both public policy and management strategy are discussed.

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## I. INTRODUCTION

The cost structure of the railroad industry has long been of interest to transportation economists and railroad managers. An important question, both for regulatory policy and strategic management, is whether railroads can lower their average costs by expanding their operations. This question is complicated by the fact that railroads can expand their operations (i.e., increase their ton-miles of output) in three distinct ways. First, firms can seek to achieve **economies of density** by adding more traffic to an existing route structure. Average costs are reduced by spreading the fixed cost per mile of route over more units of output, and by using more efficient methods of production as increasing volume warrants correspondingly higher capital invest ment on the route. Economies of density can also be derived from reduced operating costs, such as lower classification and switch ing charges, as traffic density on an existing route is increased.

Second, firms can boost output by increasing their length of haul. **Economies of length of haul** imply that unit costs decrease as length of haul increases. These economies are achieved mainly by spreading origination and termination costs over more output.

Third, firms can expand output by merging with other firms or purchasing additional lines. The cost advantages of size apart from economies of density or length of haul are referred to in the railroad literature as **economies of scale.** To estimate scale economies one must measure average costs associated with various firm sizes while holding traffic density and average length of haul constant. Economies of scale are more likely to be associated with the administrative rather than operating functions of the firm, although there may be opportunities for more efficient utilization of plant, equipment and crews with respect to total firm size.

Theoretically, any or all of these economies could exist in the rail industry. However, it is crucial to distinguish between these three types of economies when formulating business or public policy. The existence of economies of density may provide rationale for natural monopoly regulation of railroads, for differential pricing of rail services, and for parallel mergers to increase traffic density. The presence of economies of length of haul may support a policy of end-to-end mergers and the focus of marketing efforts on longer haul traffic. Economies of scale, on the other hand, may provide a rationale for mergers of unrelated rail lines.

Dating back to the landmark work of Meyer, Peck, Stenason and Zwick (1959), economists have attempted to estimate the railroad industry's cost structure. The state-of-the-art was advanced by other economists, such as Borts (1960), Healy (1962), Griliches (1972), Keeler (1974), and Harris (1977), who offered alternative equation specifications and new insights into the applicable economic theory.

More recently, Friedlaender and Spady (1981), Harmatuck (1979), Braeutigam, Daughety, and Turnquist (1982) and Caves, Christensen, Tretheway and Windle (1985) have employed a translog functional form. This equation specification is more flexible than the simpler ones used in earlier studies. More recent studies have also included factor prices as independent variables.

In spite of the differences in econometric techniques and data, these studies have shown strong and somewhat consistent evidence of economies of density, virtually no evidence of economies of scale, and mixed results on economies of length of haul. The overall results are summarized in more detail in Jara-Diaz (1982), Keeler (1983), Winston (1985), and Daughety (1985).

There are, however, a number of limitations or weaknesses in the studies cited above. First, previous research has relied on older data—none more recent than 1975. Consequently, potential impacts on cost structure from regulatory reform brought about by the 4R Act of 1976 and the Staggers Act of 1980 have not been previously estimated. Furthermore, although this pre-1975 data was audited by both the railroads and the ICC, it has been shown to be inconsistent over time and between carriers. In recent years, however, the ICC has perfected its automatic data processing audits of railroad data. Thus, recent data, particularly post-Staggers, is measurably better than the data previously used to estimate railroad cost functions.

In addition, most of the capital data in previous studies were derived from annual reports filed with the ICC and reflect accounting expenses rather than economic costs. Because of the accounting conventions employed, the reported expenses may not correspond to the underlying economic costs. Most importantly, until 1983, the railroads utilized a special railroad accounting technique for roadway property, known as Retirement Replacement Betterment Accounting (RRB). Under this accounting convention programed roadway maintenance expenses are treated as current expenses rather than as additions to capital stock. Under conventional accounting systems such programed maintenance expenditures are capitalized and depreciated. It is generally agreed that depreciation accounting more closely links expenditures to the physical consumption of the assets. Since major capital expenditures are treated as expenses under RRB accounting, the economic value of roadway consumption is not accurately reflected.

The purpose of this paper is to improve and update estimates of railroad cost structure, utilizing more recent and refined data vis-a-vis previous studies. Data is drawn from the years 1979-1983. Moreover, recent ICC studies are utilized to more accurately assess capital costs on a rational economic basis.

This paper is organized as follows. Section II provides details on the methodology and data used in the study, while section III provides the results of a translog cost function estimation. Revisiting railroad cost structure is warranted by the ever greater importance for both public and business policy in the post-Staggers Act environment. Section IV explores the implications of the findings for regulators and rail managers.

## II. METHODOLOGY AND DATA

The methodology used to estimate railroad cost structure is the translog cost function. Details of the procedure are provided in the Technical Appendix.

The data used in this study were developed for Class I railroads for the years 1979 through 1983. Table 1 lists all of the variables used to construct the data set along with the sources from which they are abstracted. This data can be divided into four broad classes: size variables, operating expenses, capital costs and factor data.

### A. Size variables

Operating statistics quantify the physical characteristics of the rail system, including the size of the system and the level of output. The operating statistics used in this study are taken from the Annual Report of Class 1 Railroads (R-1) to the Interstate Commerce Commission (ICC). These data items include: net ton-miles (NTM), net freight tons (NFT), and miles of road (MR).

### B. Operating costs

The dependent variable in the translog regression is the total costs for each railroad, obtained from summing operating and capital costs. Operating expenses reflect the reported expenditures for variable inputs. This data, derived from the annual reports, include: maintenance-of-way and structures (MWS), maintenance of equipment (ME), transportation expense (TE) and traffic expense and general expense (TFEGE).

### C. Capital costs

Capital costs are defined to include the return to physical capital and the amortization of the investment over its expected life. The computation of capital costs is more complex than that for operating expenses because the lives of capital assets in the railroad industry are extremely long. A major improvement of our study over most previous estimates of rail costs is an assessment of capital costs based on current economic value in lieu of accounting valuation. Accordingly, the derivation of capital expenditures used in the study will be explained in detail.

Current capital costs (CURKC) measures the market value of capital assets in the current year, i.e., the current net book value of road property and equipment. This figure is computed by the Depreciation Branch (DB) of the ICC and is derived using the following procedure. The historic (book) value of each asset or group of assets is brought to current levels using a price index peculiar to that category of assets. This process yields an estimate of gross current value. The DB also has developed estimates of current depreciation (CURDP), reflecting consumed life and/or economic obsolescence of the assets. By deducting the accumulated depreciation from the current gross investment, CURKC is computed. Current land values (LAN63) were calculated by using a DB study conducted in 1963, which estimated land values, and indexing them to a current level using asset specific indices developed by the Department of Agriculture.

The return to capital is computed by applying the real pre-tax cost of capital to the railroad net investment base. A nominal cost of capital is first computed and then converted to a real value. The nominal cost of capital used in this study differs from that used in prior studies in that differences in the cost of equity capital are recognized for the major rail systems. Virtually all prior studies employ a uniform weighted cost of capital. Differences in the cost of capital, however, may affect investment levels and therefore should be explicitly recognized. Since the

**TABLE 1**
Sources of Underlying Data

| **Variable** | **Description** | **Source** |
|---|---|---|
| **Size Variables** | | |
| NTM | Net ton-miles | R-1 Sch 755 L 128 Col. B (78-82), L 114 (83) |
| NFT | Net freight tons | R-1 Sch 755 L 121 Col. B (78-82), L 107 (83) |
| MR | Miles of road | R-1 Sch 700 L 57 Col. D |
| **Operating Costs** | | |
| MWS | Maintenance of ways and structures | R-1 Sch 410 L 151 Col. F |
| ME | Maintenance of equipment | R-1 Sch 410 L 324 Col. F |
| TE | Transportation expense R-1 | R-1 Sch 410 L 528 Col. F |
| TFEGE | Traffic and general expense | R-1 Sch 410 L 619 Col. F |
| **Capital Costs** | | |
| REAL | Real cost of capital | ICC Financial Analysis |
| CURKC | Current value of track, road property & equipment, under depreciation accounting | ICC Depreciation Branch |
| CURDP | Accumulated depreciation on current valuation of track, road property and equipment | ICC Depreciation Branch |
| LAN63 | Current value of land | Indexed 1963 special study |
| **Factor Prices and Shares** | | |
| FG | Fuel gallons | R-1 Sch 750 L 4 Col. B |
| FE | Fuel expense | R-1 Sch 750 L 5 Col. B |
| FP | Fuel price per gallon | Calculated |
| LH | Labor Hours | ICC Wage Statistics Form A L 909 Col 7 |
| LE | Labor expense | Form A L 909 Col 11 |
| LP | Labor price | Calculated |
| RIMS | Regional Index | AAR's Railroad Materials-Supplies Cost Recovery Index |
| RIPS | Regional Index | AAR's Railroad Purchased Services Cost Recovery Index |

cost of equity is more likely to reflect carrier differences, this study utilizes individually computed equity costs for thirteen major rail carriers. These carriers are: Burlington Northern, CSX, MoPAC, Norfolk Western, Denver and Rio Grande Western, Atchison Topeka and Santa Fe, Southern, Soo, Kansas City Southern, Southern Pacific, Seaboard Coastline, Illinois Central Gulf and Union Pacific. The cost of equity for each of the above carriers was also extended to its subsidiaries.

The cost of equity capital for the carriers listed above was based on the discounted cash flow (DCF) methodology adopted by the ICC for use in its annual revenue adequacy determinations for the Class I railroads. Under the DCF methodology the cost of equity is computed by solving the following equation:

$$K = \{(Do/Po)\ (1+G/2)\} + G$$

WHERE;

$K$ = pre-tax nominal cost of equity
$Do/Po$ = dividend yield per share
$G$ = projected growth rate in earnings

The DCF methodology has been applied in Commission revenue adequacy proceedings for a number of Class I railroads. The cost of equity for these observation was taken directly from the record in the individual Interstate Commerce Commission proceedings. For those carriers not covered by the record and for years in which a record did not exist, the equation was estimated using year end data from Moody's Stock Guide. The growth rate "G" was estimated using the earnings per share for the prior six years. The weighted nominal cost of capital was then computed using the appropriate debt/equity capital structure for each year and the industry average current cost of debt. The cost of capital for other than the thirteen carriers identified was based on the annual weighted system average cost of capital.

The nominal cost of capital was restated to a real level using the following formula:

$$r = [(1+n)/(1+i)]-1$$

Where;

$r$ = real cost of debt or equity or debt
$n$ = nominal cost of equity or debt
$i$ = inflation as measured by the GNP deflator

### D. Factor prices and shares

Four factors were used in the study: capital, fuel, labor, and materials/purchased services. Gallons of fuel purchased (FG) and fuel expenses (FE) are derived from the R-1 annual reports. Statistics relating to labor input levels (LH) and wage compensation (LE) are derived from the year ending Report of Employees, Service and Compensation, I.C.C. Wage Statistics, Form A. Several factor price variables are calculated from data abstracted from ICC sources. These are price per gallon of fuel (FP) and hourly labor wage (LW) for each of the catagories captured. Finally, the Association of American Railroads' (AAR) "Railroad Cost Recovery Index" is used to obtain regional indices on materials and supplies (RIMS) and purchased services (RIPS). The factor share for materials and supplies/purchased services is calculated by subtracting labor and fuel expenses from total operating costs.

## III. RESULTS

Parameter estimates for the translog cost function are provided in Table 2. The R-square of the equation (.96) indicates a very strong fit. All first order terms are of the expected sign and statistically significant. The elasticities of substitution for all pairs of inputs are provided in Table 3, with details of elasticity derivation given in the Technical Appendix.

The normalization of data employed in the study allows the first order terms to be interpreted as the mean elasticity of cost with respect to the ith coefficient, as detailed in the Technical Appendix. The coefficient on net ton-miles provides evidence on economies of length of haul. Given that net freight tons is also included in the equation, the parameter measures the impact of changing ton-miles while holding tons constant, thereby also altering length of haul. Specifically, the first order coefficient on net ton-miles indicates that a one percent increase in the

**TABLE 2**
Regression Coefficients
(Standard Errors in Parentheses)

| First Order Terms | Coefficient | T-Statistic |
|---|---|---|
| Constant | -.364<br>(.057) | -6.417 |
| NTM | .416<br>(.077) | 5.399 |
| NFT | .224<br>(.068) | 3.303 |
| MR | .390<br>(.075) | 5.216 |
| Energy Price | .072<br>(.002) | 46.226 |
| Labor Price | .320<br>(.007) | 46.059 |
| Capital Price | .177<br>(.008) | 23.372 |
| Materials Price | .431<br>(.006) | 76.634 |
| **Interaction terms** | | |
| NTM x NTM | .495<br>(.195) | 2.535 |
| NFT x NFT | .088<br>(.144) | .607 |
| MR x MR | -.011<br>(.099) | -0.114 |
| NTM x NFT | -.385<br>(.154) | -2.492 |
| NTM x MR | -.187<br>(.129) | -1.449 |
| NFT x MR | .348<br>(.103) | 3.368 |
| Energy x Energy | .063<br>(.006) | 9.832 |
| Energy x Labor | -.001<br>(.004) | -0.280 |
| Energy x Capital | -.029<br>(.003) | -11.602 |
| Energy x Materials | -.033<br>(.008) | -4.268 |
| Labor x Labor | .037<br>(.018) | 2.005 |
| Labor x Capital | -.094<br>(.010) | -9.553 |
| Labor x Materials | .058<br>(.018) | 3.175 |
| Capital x Capital | .222<br>(.010) | 22.277 |
| Capital x Materials | -.099<br>(.011) | -8.758 |
| Materials x Materials | .074<br>(.023) | 3.275 |
| NTM x Energy | .047<br>(.003) | 13.949 |
| NTM x Labor | -.049<br>(.015) | -3.249 |
| NTM x Capital | -.059<br>(.011) | -4.921 |
| NTM x Materials | .061<br>(.016) | 3.730 |
| NFT x Energy | -.027<br>(.003) | -9.090 |
| NFT x Labor | .060<br>(.014) | 4.433 |
| NFT x Capital | .042<br>(.010) | 3.977 |
| NFT x Materials | -.075<br>(.015) | -5.159 |
| MR x Energy | -.025<br>(.003) | -9.558 |
| MR x Labor | .012<br>(.011) | 0.964 |
| MR x Capital | .026<br>(.009) | 2.800 |
| MR x Materials | -.013<br>(.013) | -0.990 |
| Time Trend | .070<br>(.013) | 5.597 |

**TABLE 3**
Elasticities of Substitution Between Factors

| | Energy | Materials | Labor | Capital |
|---|---|---|---|---|
| Energy | -0.94 | -1.74 | 0.95 | 2.05 |
| Materials | | -0.95 | 1.95 | -0.33 |
| Labor | | | -1.76 | -1.67 |
| Capital | | | | -0.13 |

average length of haul increases total costs by only .416 percent. Thus, evidence of economies of length of haul is provided.

The attributes of rail cost structure of paramount interest are returns to density and scale. Following the procedure outlined by Caves, Christensen, Tretheway and Windle (1985) to calculate returns to scale and density, the present results show strong economies of density but no economies (or diseconomies) of scale. The Technical Appendix reviews the methodology employed, while Table 4 summarizes the empirical evidence on returns to density and scale from the present and previous studies of rail cost structure. As discussed earlier, previous studies have relied on data no more recent than 1975 and have employed a wide range of specifications, econometric techniques and data. It is then noteworthy that the key results regarding economies of scale and density are largely consistent with the previous work. More specifically, the current study confirms the lack of scale economies found across all of the previous studies. Note that the coefficient capturing returns to scale varies between a narrow range of 0.93 - 1.03 across the seven studies, where a value less than 1 denotes decreasing returns to scale while a value greater than 1 denotes increasing returns. In no case is the value significantly different from 1, so that this study in concurrence with all of the previous ones points to constant returns to scale. This implies that there is no cost advantage from size independent from the effects of density and length of haul.

However, evidence regarding returns to density is perhaps more indicative of railroad cost structure in that these economies influence the optimal number of carriers in a given market. Increasing returns to density up to and beyond the level of demand in a given market would imply that a natural monopoly exists. Referring again to Table 4, the earlier studies of Keeler, Harris and Harmatuck all revealed strong evidence of returns to density. However, the next two studies, by Caves, Christensen and Swanson, and Friedlaender and Spady, found little evidence of

**TABLE 4**
Returns to Scale and Density: Present and Previous Studies

| | Returns to Density | Returns to Scale |
|---|---|---|
| Keeler (1974) | 1.79 | 1.01 |
| Harris (1977) | 1.72 | 1.03 |
| Harmatuck (1979) | 1.92 | 0.93 |
| Caves, Christensen and Swanson (1981) | 1.00 | 1.01 |
| Friedlaender & Spady (1981) | 1.16 | 1.02 |
| Caves, Christensen, Tretheway and Windle (1985) | 1.76 | 0.98 |

[Source: Caves, Christensen, Tretheway and Windle (1985)]

| | | |
|---|---|---|
| Present Study | 1.59 | 0.98 |

Returns to Density = 1/(.416 + .224) = 1.59

Test if returns are significantly different from 1: T-Statistic = 4.749 - Reject null hypothesis of constant returns in favor of increasing returns to density.

Returns to Scale = 1/(.416 + .224 + .390) = 0.98

Test if returns are significantly different from 1: T-Statistic = 1.047 - Cannot reject null hypothesis of constant returns to scale.

returns to density1. A later study by Caves, Christensen, Tretheway and Windle, again found strong economies of density. It is then significant that the present study finds strong evidence of returns to density, confirming the result found in the majority of earlier studies.2

In summary, it is notable that technological and regulatory changes in the rail industry since 1975 (the last data point of previous rail cost studies) have not substantially affected railroad cost structure. To clarify, while railroads have reduced costs through measures such as abandonments, the fundamental relationship between average costs, density and scale of operation has not been measurably altered. To confirm this, specifically with regard to the impacts of the Staggers Act of 1980, a dummy variable was employed to obtain separate estimates of scale and density economies for the periods 1979-1980 and 1981-1983. The results over the two periods were not significantly different.

## IV. POLICY IMPLICATIONS

The results of this study have important policy implications for both regulators and railroad management. The presence of economies of density and length of haul are particularly meaningful because of the recent changes in regulation brought about by the Staggers Rail Act of 1980. These changes resulted in new rules and guidelines which are intended to permit greater ratemaking freedom in today's competitive environment. With this increased pricing latitude, a solid understanding of the railroad industry's cost structure is necessary.

Clearly regulators have relied on prior research in formulating merger policies and maximum rate rules. However, as was recognized in the introduction to this paper, all prior research of industry cost structures was based on pre-Staggers data. The findings in the present study indicate that, from a technological perspective, the cost structure for the industry has not changed materially as a result of regulatory reform. Thus, it appears that the ICC's assessment of the cost structure of the railroads, based on prior research, is consistent with current technology.

Because of the increased reliance on the marketplace to set rates, the results of this study have perhaps their most important implications for railroad management. Managers must be fully cognizant of the impact density and length of haul have on their companies' cost structures. The presence of economies of density and length of haul influence decision making in the areas of operations, rate making, abandonments and mergers. From an operations perspective, the presence of significant economies of density suggest that management should attempt to maximize line segment densities wherever possible. Economies of length of haul further suggest that carriers should focus on longer haul movements. From a ratemaking perspective, the study results indicate that the railroads should price traffic so as to maximize the volume of compensatory traffic using its lines. Contract rates aid the railroads in this area, since they permit carriers to adjust operations for maximum efficiency.

Finally, railroad managers should conduct further cost studies such as this one, utilizing where possible line or corridor specific expense and output data not publicly available. Results from studies of this type would provide managers with greater insight into their infrastructure, i.e., the cost of providing service over specific lines, profitability of current traffic and the cost impact of soliciting additional traffic. Cost and density data on a line specific basis would thus permit greater precision in pricing competitive traffic and allow managers to determine the optimal mix of inputs for the most cost efficient system. Given that prices for the majority of rail services are set in the competitive marketplace, information on optimal operational networks and attendant cost structures is of the utmost importance to railroad executives.

## ENDNOTES

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[1] Keeler (1983) argues that, properly interpreted, the studies are consistent with the earlier work.

[2] Work in progress by Tenpao Lee and C. Philip Baumel finds significant returns to density weaker than the present study and constant returns to scale.

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## TECHNICAL APPENDIX

The measures of returns to scale, returns to density and elasticities of substitution presented in the paper were computed with the parameter estimates of a four input, three output translog cost function (TLC) with Hicks neutral technical change. If we define Q, as the ith normalized output and $P_i$ as the ith normalized input price where the normalizing factors are the sample means, then the cost function which was estimated for this paper is written as follows:

$$(1) \quad \ln C = \alpha_0 + \sum_{i}^{4} \alpha_i \ln P_i + \sum_{i}^{3} \beta_i \ln Q_i + \alpha_t t + \sum_{i}^{4} \sum_{j}^{4} \theta_{ij} \ln P_i \ln P_j + \sum_{i}^{3} \sum_{j}^{3} \delta_{ij} \ln Q_i \ln Q_j + \sum_{i}^{4} \sum_{j}^{3} \phi_{ij} \ln P_i \ln Q_j$$

where ln is the natural log and C is normalized total factor cost.

The appeal of (1) to many researchers is that it has potentially very desirable theoretical properties while at the same time it provides a functional form which may be relatively easily estimated. Theory tells us that (1) can be viewed as derivable from a concave, twice differentiable, continuous, multi-output transformation function under cost minimizing behavior if certain restrictions hold. Specifically, the cost function itself must be linearly homogenous in prices and must itself be concave. Linear homogeneity was imposed parameterically wtih the linear restrictions:

$$(2a) \quad \sum_{i} \alpha_i = 1$$

$$(2b) \quad \sum_{i} \theta_{ij} = \sum_{j} \theta_{ij} = 0$$

$$(2c) \quad \sum_{i} \phi_{ij} = 0 \text{ for } j=1..3.$$

Concavity must be checked once the parameter estimates have been derived. A necessary condition for concavity is that the own price elasticities must be nonpositive. As the estimates of the own price elasticities of must be nonpositive. As the estimates of the own price elasticities of substitution in the paper illustrate, this condition is satisfied.

For estimation purposes, we augment (1) and (2) with cost share equations. Taking the partial derivative of (1) with respect to the (log of) the ith input price and applying Shepard's Lemma gives

$$(3) \quad S_i = \alpha_i + \sum_{j} \theta_{ij} \ln P_j + \sum_{j} \phi_{ij} \ln Q_j \qquad i=1...4$$

where $S_i$ is the ith cost share. Thus, we are able to introduce more degrees of freedom by estimating the cost function (1) jointly with the share equations (3) subject to the restrictions in (2). Note that the share equations involve no new parameters.

To estimate the model, we must eliminate one of the share equations for, otherwise, the error matrix would be singular. We then use an iterative version of Zellner's seemingly unrelated regression technique, Zellner (1982), which produces maximum likelihood estimates and assures that the parameter estimates will be invariant with respect to the share equation which is excluded from the system.

The most useful theoretical property of TLC is that the elasticities of substitution are estimated directly and may be different for different pairs of inputs. In contrast, the Cobb Douglas production/cost function (CD) requires that the elasticity of substitution must be unity for all pairs of inputs while the Constant Elasticity of Substitution production/cost function (CES) requires that the elasticity of substitution must be constant and identical among all pairs of inputs (although it may differ from unity). Thus, while the CES is a generalization of the CD, the TLC is more general than both and provides a far richer set of potential technology estimates.

The elasticities of substitution which are presented in the paper where derived from the following formulas:

$$(4a) \quad \sigma_{ij} = (\theta_{ij} + S_i S_j)/S_i S_j \qquad i \neq j,$$

$$(4b) \quad \sigma_{ii} = (\theta_{ii} + S_i^2 - S_i)/ S_i^2.$$

Following Caves et al (1984), returns to density is given by

$$RTD = 1 / (E_{c1} + E_{c2})$$

where $E_{c1}$ and $E_{c2}$ are the elasticities of cost with respect to $Q_1$ and $Q_2$. In the paper, $Q_1$ is net freight tons (NFT), $Q_2$ is net ton miles (NTM) and $Q_3$ is miles of road (MR). Returns to scale is then given by

$$RTS = 1 / (E_{c1} + E_{c2} + E_{c3}).$$

Therefore, RTS and RTD depend upon the estimated output elasticities.

Taking the partial derivative of (1) with respect to the (log of) the ith output gives

$$(5) \quad E_{ci} = \beta_i + \sum_{j} \phi_{ij} \ln P_j + \sum_{j} \delta_{ij} \ln Q_j.$$

In the paper, we present the mean output elasticities which are derived by simply inserting mean price and output into (5). Since all prices and outputs are normalized by their sample means, all terms in (5) vanish except for $\beta_1$. By estimating the model with normalized data, therefore, the first order term, $\beta_1$, is the direct estimate of the mean elasticity of cost with respect to the ith output.