UC Irvine
Working Paper Series

Title

Analysis of Costs, Economies of Scale, and Factor Demand in Bus Transport

Permalink

https://escholarship.org/uc/item/0rm1h3k2

Author

Berechman, Joseph

Publication Date

1982-06-01

Analysis of Costs, Economies of Scale and Factor Demand in Bus Transport

Joseph Berechman [1]

[1] Visiting Associate Professor, School of Social Sciences and Institute of Transportation Studies
University of California, Irvine. On leave from Tel-Aviv University.

June 1982

ANALYSIS OF COSTS, ECONOMIES OF SCALE

AND FACTOR DEMAND IN BUS TRANSPORT

Joseph Berechman

ABSTRACT

A review of the literature on the issue of the cost structure of bus
transport shows that most studies use simplistic analytical constructs
which do not allow for analysis of relationships between production cost
on the one hand and output and input factor prices on the other. In
particular, the demand for factors of production, factor substitution and
price elasticities are not investigated. This study uses a two factors
translog cost function model, which is subject to very few a priori
economic restrictions, to investigate these issues. By using a data base
which represents the Israeli bus sector, the empirical results provide a
comprehensive description of the cost structure of the sector. These
results include scale economies, fixed factor proportions-type production
technology; non-linear separability of factors in cost function, and
small own price elasticity of demand for labor relative to capital.

1. <u>Introduction</u>

Increasing attention is being paid to the economic underpinnings of bus transport services. Questions pertaining to service production conditions, the operators' cost structure and the impacts of regulatory pricing and subsidy policies on performance, are increasingly raised by students of the industry and by decision makers. This surge in interest relates to the fact that mass transit, and in particular bus transport, is regarded by some as the best option for alleviating many current problems such as energy shortages, traffic congestion, air pollution and urban decline; yet, public transport services are in general of poor quality, are produced inefficiently and require increasing subsidies. Moreover, regulatory and pricing policies which are introduced to enhance efficiency and quality, by and large fail to do so and, in fact, are viewed as having a destructive effect on service provision. It is, therefore, of major importance to understand the economic structure of bus transport service production so that the effects of public policies on production can be evaluated. This paper proposes a cost function approach to empirically estimate production conditions and the cost structure of bus transport operations.

Much of the published research done to date on these and related issues tends to be narrow in focus, using an outdated methodological framework for analysis. The single most frequently examined issue is the existence (or non-existence) of scale economies in bus transport (e.g., Lee and Steedman, 1970; Koshal, 1970, 1972; Wabe and Coles, 1975; Button, 1977; Fravel, 1978). Relatively few studies take a broader view and

analyze other production and cost factors (Nelson, 1972; Mohring, 1972; Veatch, 1973; Foster, 1973).

In part this narrow focus on scale economies is the result of very simple analytical constructs which, in most cases, amount to the estimation of a single equation average cost function (e.g., Lee and Steedman, 1970; Koshal, 1970, 1972; Wabe and Coles, 1975), or several single equations, each containing a different set of explanatory variables (e.g., Foster, 1973; Veatch, 1973). A very few studies attempt to estimate a system of equations and relate the specification of these cost functions to the production process of the transit services (Nelson, 1972; Fravel, 1978; Berechman, 1980). None of the above studies directly estimate the industry demand function for factors of production, nor do they attempt to analyze factor substitution and price elasticities, which are of major importance for the design of efficient transit policies.[1]

The general form of the estimated single cost function used in the studies mentioned above is: average cost = f (scale or size of producer, factor prices, demand setting), where demand setting refers to some urban factors, like population density, auto availability or income. Thus, the principal differences among the various studies cited above are the specification of the cost function, the set of independent variables used

---

[1]Interestingly enough, rail freight and passenger transport as well as trucking freight have received much more rigorous analytical treatment in the literature (see, for example, Harris, 1977; Spady and Friendlaender 1978; Caves et al, 1980). There are, however, major differences in the market and production conditions between bus transportation and rail and trucking services.

and the specific measure used to represent the scale of a producer.[2]
For example, Koshel (1970, 1972), Foster (1973) and Wabe and Coles (1975)
use a linear cost model. Fravel (1978) and Lee and Steedman (1970) use
an exponential model transformed into a log-linear model for regression
estimation. Nelson (1972) uses a system of three nonlinear equations (of
transit demand and supply) which, for estimation purposes, are also
transformed into log-linear simultaneous equations. The principal
problem with these models (with the exception of Nelson) is that they
lack a solid economic and transportation analytic foundation. Therefore,
the interpretation which can be given to their results is limited in
scope and value.

An important common feature of these studies is their almost
exclusive use of cross-sectional data, where each data point (i.e., an
observation), represents a particular bus operator. This practice
appears to be the source of a number of computational problems. First,
if all bus operators are treated as equal in the sample (i.e., receive
the same weight as is the case in the Wabe and Cole study, for example),
the analysis will produce average cost parameters which do not reflect
the average cost on a per unit output basis. The use of a deflating
factor for eliminating the impact of size involves making some assump-
tions on the demand environment which, if incorrect, will generate

---

[2]Griliches (1972) and Harris (1977) differentiate between scale of
an operator and its level of output as, in many instances, output level
is used to characterize size. I return to this point below.

further estimation difficulties (Griliches, 1972).[3] Second, there are

likely to be major differences in the composition and quality of services

offered by different operators. In general, operating conditions across

bus firms differ with regard to form of ownership, fare structure, type

of regulation imposed, and the distribution of demand over time and

space. Using observations on services produced in diverse environments

in one sample, may amount to combining apples with pears. Finally,

factor prices may vary little among transit firms, and the resulting lack

of variation may make accurate estimation difficult.

A major finding common to all the previously mentioned studies is the

almost total lack of economies of scale (Oram, 1979). All of the studies

have concluded that economies of scale in bus transit are insignificant

and that service provision is characterized by constant returns over a

broad range of sizes. For large systems, the industry is sometimes

characterized by decreasing returns to scale. In contrast, the results

of the empirical analysis carried out in this paper indicate the

existence of conditions of economies of scale in the Israeli bus sector.

This contradiction in findings can be attributed to differences in the

data, the particular organizational structure of the industry and the

methodology used. It may also be attributed to the fact that the above

studies examined primarily the cost differences associated with increase

---

[3]Combining observations of very small and very large operators in a
cross section analysis leads to statistical problems if error is related
to size. The larger the observation the larger is the error associated
with it (Johnston, 1972, p. 217).

in the size of bus operators rather than with increases in their level of output which is demand related.[4]

As mentioned, the main objective of this paper is to analyze the cost structure of passenger bus operation, and in particular cost elasticities, the demand for factors of production, factor substitution and scale economies. The model used for estimating these elements is a derivative of the generalized translog multiproduct cost function, and it is described in the following section. The data base consists of time series observations describing the inputs, outputs and other characteristics of the passenger bus sector in Israel. Section 3 provides a detailed description of the data base, with an emphasis on the specific characteristics of the Israeli bus sertor. Major results of the empirical analysis are presented and discussed in section 4 of the paper. The final section will summarize the major findings and conclusions. A major shortcoming of the empirical analysis is that, for lack of data, only two factors of production, labor and capital, can be considered. Needless to say, to fully analyze the bus sector operations a further disaggregation of inputs is necessary. The methodology used here would also be appropriate for analysis of such data.

2. Methodology

This section presents the analytical framework used for the empirical estimation of the cost structure of bus services provision. It is largely

---

[4]An important exception to these studies is the approach advocated by Mohring (1972) and Vickrey (1980), which regard passengers' time as a factor of production. Mohring's empirical study, while showing the existence of scale economies, does not explicitly explore demand for input factors and their substitution.

based on econometric developments in the area of production theory and
duality. (See Fuss and McFadden, 1979, for further discussion.)

Let,

$$T = \Phi(\underline{Q},\underline{X}) = 0 \qquad (1)$$

represent an efficient transformation of a vector of inputs $\underline{X}$ into a
vector of outputs $\underline{Q}$, where Φ is an implicit function. The duality
theory states that if Φ is strictly convex with regard to $\underline{X}$, then
there exists a unique cost function which is dual to Φ. It can be
written as

$$C = \theta(\underline{P},\underline{Q}) \qquad (2)$$

where $\underline{P}$ is a vector of factor prices and C is total cost. It is
explicitly assumed that equation (2) represents cost-minimization
behavior by the bus system management. That is, given the level of
output and the prices of the factors of production, the transit operators
will select that combination of inputs which will minimize their total
costs of producing that output.[5]

For the purpose of analyzing scale economies, factor substitution,
and demand, an explicit estimateable functional form of equation (2) is
required. Assuming first an homothetic cost function, homogeneous in
factor prices, equation (2) can be factored into:[6]

---

[5] It is also assumed that the transport companies face competitive
factor markets. See below, for a discussion of these assumptions in the
context of the Israeli bus industry.

[6] Shephard (1970) has shown that an homothetic cost function (2) can
be written as $C = g(P)h(Q)$, where $h(Q) > 0$ for all $Q > 0$.

$$\theta(\underline{P},\underline{Q}) = \Psi(Q)\,\theta(\underline{P}) \qquad (3)$$

where $\theta(P)$ is homogeneous of degree 1, nondecreasing and concave with respect to $\underline{P}$. A simple representative case of (3) would be

$$C(w,r,Q) = A_0 Q^\alpha w^{\beta_1} r^{\beta_2} \qquad (4)$$

where w and r are, respectively, labor and capital unit prices and A_0, α, β_1, β_2 are parameters. For estimation purposes, (4) can be written

$$Ln\ C(w,r,Q) = A + \alpha\ Ln\ Q + \beta_1\ Ln\ w + \beta_2\ Ln\ r + \varepsilon \qquad (5)$$

where $A = Ln\ A_0$ and ε is the error term. Notice that homogeneity in prices requires that $\beta_1 + \beta_2 = 1.0$. For $\alpha < 1$, the average cost decreases as Q increases, implying scale economies.

A major problem with (4) is that if $C(w,r,Q)$ is an homothetic cost function, which meets the conditions of being nondecreasing and concave (with respect to prices), then, from the duality theorem, its ex ante production function is also homothetic.[7] An homothetic production function implies that scale economies can be defined independently of factor proportions, a property which may not exist in transit service production.[8] Another theoretical problem is that of (non)linear factor separability in the cost function. A priori, there is no reason for cost to change in direct proportion to a given change in factor prices as implied by equation (5). A change in factor price may affect the demand for other factors which, in turn, will affect the total cost.

---

[7] See Varian, 1978, Ch. 1, for mathematical exposition.

[8] On the other hand it is plausible to assume independence between level of output and all unexplained factors represented by ε because output is determined exogenously, by demand conditions.

In the empirical section of the paper, model (5) will be estimated mainly for comparison purposes. However, the implications of these problems are that a cost function like (5), places a number of a priori restrictions on some important economic elements. For example, it assumes constant factor elasticity of substitution, constant price elasticity of factor demand, and marginal cost. For these reasons we wish to specify a cost function which does not assume such a priori restrictions on the underlying production structure. There is a number of such functions in the literature (for a review, see Fuss et al., 1978). In this study I use the translog cost function which is quite well used and has known analytical properties (Christensen et al., 1973).[9] Specifically, the following model is estimated[10]

---

[9]The general form of this function is:

$$\text{Ln } C\ (\underline{P},\underline{Q}) = A_0 + \sum_i^m \alpha_i \text{ Ln } Q_i + \sum_i^n \beta_i \text{ Ln } P_i + \frac{1}{2} \sum_i^m \sum_j^m \delta_{ij} \text{ Ln } Q_i \text{ Ln } Q_j$$

$$+ \frac{1}{2} \sum_i^n \sum_j^n \gamma_{ij} \text{ Ln } P_i \text{ Ln } P_j + \sum_i^m \sum_j^n \rho_{ij} \text{ Ln } Q_i \text{ Ln } P_j$$

with the symmetry conditions: $\delta_{ij} = \delta_{ji}$; $\gamma_{ij} = \gamma_{ji}$. Sufficient conditions for C to be homogeneous of degree one in $\underline{P}$ are $\sum_i^n \beta_i = 1.0$, $\sum_j^n \gamma_{ij} = 0$ $(i = 1,\ldots,n)$, $\sum_j^n \rho_{ij} = 0$ $(i = 1,\ldots,m)$.

Notice that if $\rho_{ij} = 0$ for all ij, the function is homothetic-homogeneous cost function.

[10]This translog model is assumed to be an exact representation of the minimum cost function. As an alternative, it is possible to use it as a second order approximation at a point, to an arbitrary twice-differentiable cost function. The major disadvantage of the latter approach is that test results hold only at point of approximation and not globally. For a discussion of these alternative approaches see Spady and Friendlaender, 1978.

$$\text{Ln } C = A + \alpha \text{ Ln } Q + \beta_1 \text{ Ln } w + \beta_2 \text{ Ln } r + \frac{1}{2}\delta(\text{Ln } Q)^2 + \gamma_1 \text{ Ln } w \text{ Ln } r$$

$$+ \frac{1}{2} \gamma_2 (\text{Ln } w)^2 + \frac{1}{2} \gamma_3 (\text{Ln } r)^2 + \rho_1 \text{ Ln } Q \text{ Ln } w + \rho_2 \text{ Ln } Q \text{ Ln } r \quad (6)$$

with the linear homogeneity conditions, $\beta_1 + \beta_2 = 1.0$; $\rho_1 + \rho_2 = 0$; $\gamma_1 + \gamma_2 + \gamma_3 = 0$, and the symmetry conditions (see Footnote 9).

Differentiating (6) with respect to factor prices and rearranging we get

$$\frac{w}{C} \frac{\partial C}{\partial w} = \beta_1 + \gamma_1 \text{ Ln } r + \gamma_2 \text{ Ln } w + \rho_1 \text{ Ln } Q \quad (7)$$

Similarly,

$$\frac{r}{C} \frac{\partial C}{\partial r} = \beta_2 + \gamma_1 \text{ Ln } w + \gamma_3 \text{ Ln } r + \rho_2 \text{ Ln } Q \quad (8)$$

From Shephard's Lemma it is known that the first partial derivatives of the cost function (with respect to factor prices) are equal to the cost minimizing factor quantities necessary to produce Q units of output i.e.,

$$\frac{\partial C(w,r,Q)}{\partial w} = L(w,r,Q) \qquad \frac{\partial C(w,r,Q)}{\partial r} = K(w,r,Q)$$

where L and K are quantitites of labor and capital used, respectively. Thus, from (7) and (8)

$$S_L = \frac{wL}{C} = \beta_1 + \gamma_1 \text{ Ln } r + \gamma_2 \text{ Ln } w + \rho_1 \text{ Ln } Q \quad (9)$$

and

$$S_K = \frac{rK}{C} = \beta_2 + \gamma_1 \text{ Ln } w + \gamma_3 \text{ Ln } r + \rho_2 \text{ Ln } Q \quad (10)$$

where S_L and S_K, are the shares of total labor costs and total capital costs in the total cost. Equations (6), (9) and (10) form the system of equations to be estimated below.[11] They provide information regarding scale economies, factor demand, substitution and price elasticities. Before we turn to the data base, estimation procedure, and results, two more points should be made with respect to the above model.

The data base used in the present analysis contains time series data on costs, factor prices and output of the Israeli bus transit-operation for the period 1972-1979. Consequently, the problem of possible technological changes over time, has to be considered. To test the hypothesis that no technological changes occur during the period considered, two more parameters ν_1 and ν_2, have been added to the cost function (6). Thus, the cost function to be estimated is augmented by

$$\text{Ln } C = [\text{eq. (6)}] + \nu_1 \text{ Ln } T + \nu_2 \text{ Ln } T^2 \qquad (11)$$

where T denotes time and the constraints $\nu_1 = \nu_2 = 0$ are imposed for testing the null hypothesis of no technological change. Using the Israeli bus transit data base, it was found that the parameters ν_1 and ν_2 are statistically insignificantly different from zero, implying that the null hypothesis of no technological change during the sampled period, cannot be rejected.

---

[11]The cost share equations introduce no additional parameters into the cost system. By estimating them together with the cost function (6), the number of degrees of freedom is increased, without increasing the number of parameters to be estimated.

The second point is that estimating the parameters of the cost function (6) can provide an estimate for the bus sector's marginal cost, given its average cost. In general, $\partial LnC/\partial LnQ = MC/AC$. Thus from (6),

$$MC = \frac{C}{Q} \; (\alpha + \rho_1 \; Ln \; w + \rho_2 \; Ln \; r + \delta \; Ln \; Q) \; . \qquad (12)$$

The term $\partial LnC/\partial LnQ$, which is the elasticity of total cost with respect to output, is also used below to provide an estimate of the degree of scale economies in the production of the services.

An important aspect of the production process which underlies the cost function model is the elasticity of substitution between the input factors. This element, denoted by σ, measures the percent change in the ratio of two factors (e.g., capital and labor), caused by a one percent change in the relative prices of these factors, i.e.,

$$\sigma = \frac{d(K/L)/(K/L)}{d(P_L/P_K)/(P_L/P_K)}$$

where K, L, P_K, P_L are quantities and prices of capital and labor respectively. The importance of this measure lies in the fact that if $\sigma > 0$, the two factors are substitutes while $\sigma < 0$, indicates complementary inputs. ($\sigma = 0$ indicates a fixed input proportion production process.) Given these results, our objective is to empirically estimate σ and, as a consequence, the technological relationships between the input factors in the production of bus transit services.

In general, there are various possible empirical definitions for the elasticity of substitution, σ_{ij}, between any two factors i and

j. The most commonly used one is the Allen partial elasticity of substitution (Allen, 1938), which is

$$\sigma_{ij} = \frac{C^* \frac{x_i}{p_j}}{x_i \, x_j} \qquad\qquad i,j = 1,\ldots,n$$

where, C^* is the (estimated) cost function, x_i, x_j are quantities of factors i and j, and p_j is the price of factor j.

In the present two-factor model, the Allen partial elasticities of substitution, equal the following:[12]

$$\sigma_{LL} = \frac{\gamma_2 + S_L^2 - S_L}{S_L^2} \qquad\qquad (13)$$

$$\sigma_{KK} = \frac{\gamma_3 + S_K^2 - S_K}{S_K^2}$$

$$\sigma_{LK} = \sigma_{KL} = \frac{\gamma_1 + S_K S_L}{S_L S_K}$$

where S_L and S_K are the factor shares, defined above.

---

[12]Uzawa (1962) had shown that the σ_{ij} are defined as $\sigma_{ij} = C^* \left(\frac{\partial^2 C^*}{\partial P_i \partial P_j}\right) \Big/ \left(\frac{\partial C^*}{\partial P_i} \cdot \frac{\partial C^*}{\partial P_j}\right)$, where C^* is the cost function, P_i, P_j are factor prices and $\sigma_{ij} = \sigma_{ji}$ $(i,j = 1,2,\ldots,n)$. For the translog cost function, $\sigma_{ii} = (\gamma_{ii} + S_i^2 - S_i)/S_i^2$ and $\sigma_{ij} = (\gamma_{ij} + S_i S_j)/(S_i S_j)$, where γ_{ij} are parameters (see footnote 9), and S_i, S_j are factor shares.

From the above, the direct and cross price elasticities of demand for factors of productions, ε_{ij}, are[13]

$$\varepsilon_{ww} = \frac{\gamma_2 + S_L^2 - S_L}{S_L} \tag{14}$$

$$\varepsilon_{rr} = \frac{\gamma_3 + S_K^2 - S_K}{S_K}$$

$$\varepsilon_{wr} = \frac{\gamma_1 + S_L S_K}{S_K}$$

$$\varepsilon_{rw} = \frac{\gamma_1 + S_L S_K}{S_L}$$

These major components of the cost model will be estimated in section 4.

3. The Data Base

The data used for the analysis in this study describe the Israeli bus transport sector. Relative to other countries, the Israeli sector is unique in a number of ways, of which the most important are mentioned below. A detailed review of the sector can be found in Berechman, 1980.

---

[13]The price elasticity parameters, ε_{ij}, are defined as $\varepsilon_{ij} = \partial \ln x_i / \partial \ln p_j$ $(i,j = 1,\ldots,n)$, where x_i, is quantity of factor i, and when quantity and prices of all others factors are held constant. Allen (1938) had shown that $\varepsilon_{ij} = \sigma_{ij} \cdot S_j$. Note that $\sigma_{ij} = \sigma_{ji}$, but $\varepsilon_{ij} \neq \varepsilon_{ji}$.

Buses are the principal public mode of transport in Israel in terms of patronage, number of daily trips performed, and geographical coverage. Other modes such as trains, taxis and vans provide very limited services. About 85 percent of the total daily bus trips for all purposes are offered by two bus companies.[14] The remaining 15 percent are provided by a number of relatively very small bus firms most of which operate locally and are privately owned.

Institutionally the two major bus companies are cooperative societies where each member works for the company and owns one voting share. The value of the shares changes over time to reflect appreciation in the value of the cooperative assets and changes in the number of members. Nonmembers employees are also used by the bus companies to augment their short and long run needs for labor. In 1979 about 40 percent of the total labor force of the two major companies were nonmembers whose terms of employment mainly reflect market conditions. These terms are formally determined through collective bargaining and individual contracts.

This organizational form suggests that like private enterprise the bus firms in Israel wish to minimize their cost and indeed the evidence suggest that to be the case (Berechman, 1980). Accordingly in this analysis we consider the firms as selecting their factor inputs so as to minimize long-run total cost, given factor prices and the level of output.

Because of the small size of the country and the dense concentration of the population along a narrow and short stretch of the coastal line,

---

[14]These are Dan, which operates only in the Tel-Aviv metropolitan area, and Egged, which provides intraurban and interurban services elsewhere. See also below.

the majority of daily trips performed (about 80 percent) are intraurban type trips including innercity, metropolitan and suburban trips. Moreover many of the interurban trips are of short duration, in many cases, serving also population located at the periphery of urban centers and thus having similar demand characteristics (e.g., peak off/peak ratio) as intraurban trips. The major implication of these facts for the present analysis is that, with respect to demand and supply characteristics, interurban and intraurban trips in Israel are largely indistinguishable in any systematic and meaningful way. On practical grounds, the accounting reports of the Egged bus company, which operates both interurban and intraurban services, do not differentiate between these trip types, in particular, with regard to the use of input factors and their associated costs items. For these reasons the data used in these analyses are not disaggregated by trip type.[15]

Government control of public transport includes the issuing of permits for operation on specific lines; setting the minimum level of services on regular lines; setting the bus fares; and providing lump sum subsidies to the bus operators (see Berechman 1980, for an analysis of the subsidy policy).

The major results of this control are that the fare structure of bus trips in Israel is quite uniform and that intercity, metropolitan and many interurban fares are almost completely independent of trip length. Given the scope of this paper no attempt is made here to examine the

---

[15]Notice that none of the studies mentioned above estimated costs on the basis of trip type--probably for reasons similar to those given here.

motives and consequences of this policy except to notice below its implications for the selected output measure.

The data base used here is composed of quarterly observations for the years 1972-1979 for the bus industry as a whole. A major advantage of using quarterly data is that this period seems to be sufficient for the operators to adjust their supply of services in order to meet fluctuations in demand and, as a consequence, minimize costs. The principal sources of data are the Quarterly Transport Statistics (QTS), 1972-1979, the Statistical Abstract of Israel (SAI), 1979, and the Quarterly Prices Statistics (QPS), 1972-1979. Other complementary sources of data are publications and reports published by the bus companies and the Ministry of Transportation.

A problematic variable in cost studies is the selection of output variables which reflect the scale of operation of the sector (or the individual bus operator). Yet, for the purpose of analyzing long-run production decisions a measure of the amount of actual services produced, rather than the size of the producing units, seems appropriate. Following Harris (1977), the variable "revenue per passenger-kilometer" was proposed for this study. The data on bus passenger-kilometers, however, was, in general, unavailable. Consequently, gross revenue in fixed prices (1969 = 100), was used as the output variable.[16] Data on

---

[16]It was mentioned above that the bus fares in Israel are very uniform and, by and large, are not distance-related, including the interurban fares. Given this and the fact that gross revenue actually measure the number of passenger-trips times the unit fare, then the measure: "price deflated gross revenue," approximates the actual number of passenger-trips performed during the studied period.

revenue in current prices and the revenue-price index were obtained from the QTS publications.

Data for the other real variables, labor (L) and capital (K), were also obtained from the QTS and were measured, respectively, as actual man-days worked and the number of buses in operation. The reasons for selecting the latter variable were that bus purchases constitute the principal capital outlay for the bus companies and because changes in the supply of services are, in the long-run, carried out through changes in the size of the bus fleet.

The cost of labor (w) and the cost of capital (r) were measured as follows: Total labor cost (including wages, taxes and social benefits) per actual man-days worked were obtained from QTS, for each quarter (1972-1979). These figures were then deflated by the industrial inputs (not the transport industry) price index, which is reported in the QPS (using 1969 = 100). The results--labor costs in fixed prices--were converted for the analysis into an index vector.

Quarterly data on total expenditure on buses (including maintenance but excluding capital expenditures), are reported in the QTS. Dividing by K and deflating these costs by the above price index (1969 = 100), produced a vector of cost of capital in fixed prices. This vector was then converted into an index vector.

Data on total cost (C) were obtained by using the accounting relationships $C = wL + rK$. Having the quarterly figures for w, L, r and K, the quarterly nominal figures for C were produced. This vector was then deflated by the above vector of industrial input prices

(1969 = 100). The resultant vector, in index form was used as the C
variable for the analysis.[17]

Table 1 contain these data, including factor share data. Of
particular interest is the effect of inflation which has increased the
nominal prices of labor and capital during the sampled period 19.4- and
20.4 fold, respectively. However in fixed prices, these changes were a
much less dramatic 0.33 and 0.10, respectively. Some of the fluctua-
tions in the real cost of labor especially at the fourth quarter can be
attributable to some institutional peculiarities of the Israeli economy
(e.g., a sharp rise, in the fourth quarter of each year, in the indices
used for deflating current prices of labor and capital).

In section 2 a question was raised regarding the validity of the
hypothesis of exogenous factor prices, i.e., the degree to which the
prices of labor and capital are determined within the transit sector or
external to it. When comparing labor prices as reported in Table 1, with
labor prices elsewhere in the transportation sector (as defined by Bureau
of Statistics), it is evident that there are almost no significant
differences. Similar comparisons of capital costs are more difficult,
but one has to remember that buses and parts and materials, are imported

---

[17]To validate these figures, I have compared them with the
estimated annual cost figures for the entire sector, which were computed
as follows. From available accounting reports by the largest bus
company, Egged (59 to 63 percent of the market, in terms of gross revenue
and number of buses, 1972-1979), the firm's annual total cost were
derived. These costs were then discounted by Egged's annual share of the
market to produce an estimate of the industry total annual cost. For all
the years but one (1973), the two sets of figures compared quite
reasonably (5-10% deviations). For the year 1973 the above computed
quarterly data were adjusted so that their sum would equal the sector's
estimated total cost figure.

Table 1.

Factor Quantity and Price and Cost Data of

The Israeli Bus Industry, 1972-1979 (Quarterly)*

Year	Quarter	K	L	Q	w	r	C	S_L
1972	1	4139	1026.4	80.5	60.0	67.6	75.3	0.69
	2	4181	1047.5	85.4	62.0	68.5	78.2	0.70
	3	4102	1029.9	92.5	68.0	71.9	81.3	0.70
	4	4196	1076.4	88.3	58.0	69.6	76.5	0.69
1973	1	4235	1065.8	81.2	62.0	68.4	78.0	0.70
	2	4278	1107.9	85.8	62.0	68.0	78.2	0.70
	3	4371	1070.2	92.6	66.0	67.4	78.8	0.71
	4	4437	767.2	69.7	61.0	67.7	61.4	0.61
1974	1	4504	871.4	80.5	66.0	63.0	70.7	0.66
	2	4555	920.5	78.3	68.0	63.7	73.9	0.67
	3	4587	952.9	83.9	77.0	64.4	75.8	0.69
	4	4667	980.9	82.7	60.0	61.5	70.4	0.65
1975	1	4705	942.4	77.6	69.0	62.3	70.9	0.67
	2	4729	952.9	79.8	67.0	63.7	69.0	0.66
	3	4755	967.8	84.1	79.0	64.0	76.1	0.70
	4	4784	997.5	84.1	66.0	65.3	69.2	0.66
1976	1	4851	962.5	80.7	66.0	62.4	70.2	0.66
	2	4892	984.2	74.8	66.0	61.9	69.5	0.67
	3	4977	1001.0	94.1	65.0	57.7	71.8	0.67
	4	5090	1023.6	86.6	61.0	56.0	70.5	0.67
1977	1	5142	1010.8	84.9	81.0	58.0	85.3	0.71
	2	5176	1141.0	101.9	75.0	56.7	83.6	0.73
	3	5252	894.4	103.0	79.0	57.9	80.1	0.70
	4	5334	1035.0	98.8	66.0	56.8	73.9	0.67
1978	1	5390	1047.4	94.6	81.0	54.5	87.3	0.73
	2	5413	1048.4	95.3	86.0	53.9	83.6	0.73
	3	5473	1082.5	102.4	85.0	53.0	85.5	0.74
	4	5475	1023.6	97.2	85.0	50.4	83.5	0.74
1979	1	5510	1087.5	91.2	79.0	74.0	96.3	0.65
	2	5539	1062.9	100.0	83.0	75.5	93.8	0.65
	3	5568	1091.4	99.8	74.0	75.8	99.2	0.63
	4	5597	1118.1	92.5	71.0	73.8	113.5	0.63

K = number of buses

L = actual man-days worked (in thousands)

Q = revenue in fixed prices (in millions)

w = cost of labor, in fixed prices (x 100)

r = cost of capital, in fixed prices

C = Total cost in fixed prices (in millions)

S_L = Share of labor in total cost

*See text for explanation on the computation of variables. Costs are in IL.

into the country and, consequently, there is little the bus companies can do to affect their prices. In general, therefore, cost shares depicted in Table 1, provide satisfactory estimates of cost-elasticities with respect to factor prices. (See also Berechman, 1980.)

4. Estimation and Results

Two different cost functions were estimated below. These are equation (5) and equations (6), (9) and (10). Hereafter these will be labeled as model 1 and model 2, respectively.

While the estimation of model 1 required the use of ordinary least squares analysis, the estimation of model 2 required a more complicated statistical procedure. The relatively large number of parameters to be estimated (equation 6) calls for the simultaneous estimation of the cost function and the share equations to increase the degrees of freedom without adding more parameters. However, since the cost-share equations sum to unity, their associated error terms are not mutually independent. Therefore, one equation is deleted for the joint estimation to avoid a singular variance-covariance structure.

A sound estimation approach under these circumstances is a modification of Zellner's (1962) procedure which is a two-stage nonlinear iterative estimation process.[18] In addition to providing efficient

---

[18]The first stage of this process provides estimates of the variance-covariance matrix without the symmetry constraints. In the second stage the V-C matrix is held constant and the parameters are estimated with the symmetry constraints imposed. These estimates are iterated until the estimated V-C matrix is diagonal and the parameters estimates converge. For a description see Christensen and Greene, 1976.

estimates of the parameters it is invariant to which share equation is deleted. The estimates obtained at convergence are unbiased maximum likelihood estimates.

Table 2 presents the results of the joint estimates of the translog cost function and the labor share equation (model 2). For purpose of comparison the estimates of model 1 are also presented.[19] The adjusted R^2, the Durbin-Watson statistic, the log likelihood function and the t-values associated with the parameters, are all reported in Table 2.

A well-behaved cost function should meet two principal regularity conditions. Input price-coefficients should be non-negative to insure concavity in prices (a sufficient condition for concavity) and each factor demand function should be strictly positive. Not all the price estimates, indicated in Table 2 (i.e., γ_1), are non-negative and one has to verify that the Hessian matrix is negative semi-definite for concavity of the cost function (at least within a reasonable neighborhood of observed prices). Using the above coefficient-estimates, the Hessian matrix is negtive semi definite (i.e., $\partial^2 C/\partial p_i \partial p_j \leq 0$) for each sample observation, thus satisfying the concavity condition.

To test for positivity, the cost share equations (9) and (10), were fitted with the quarterly price data using the above estimates. They were found to be positive for each quarter. (Note that ρ_1 and ρ_2 are statistically not different from zero.)

_____

[19]Notice that Model 1 essentially presents the cost function estimates corresponding to Cobb-Douglas production function technology. By assuming for Equation (6) that $\beta_1 + \beta_2 = 1.0$, $\alpha \neq 0$, and all other substitution parameters are zero, we obtain Model 1.

Table 2.
Parameter Estimates of Cost Models*

Parameter	Model 1	Model 2
A (const.)	6.2935 (5.112)	-26.590 (-1.9)
α	0.4380 (5.055)	0.8590 (4.531)
β_1	0.6345 (13.882)	0.6160 (9.431)
β_2	0.3654 (7.953)	0.3910 (8.245)
δ		-0.0551 (-2.371)
γ_1		-0.235 (-3.785)
γ_2		0.2001 (4.369)
γ_3		0.0751 (3.210)
ρ_1		-0.1290 (-0.356)
ρ_2		-0.652 (-0.637)
R^2 (adj.)	0.91	0.711
D.W.	1.48	1.32
log likelihood function		1.05

*The figures in parentheses are "t" values.

The questions of homotheticity of the production function in output and the separability of inputs were mentioned above as major motives for using the translog cost model. To test for these properties of the production function (which is dual to equation (6)), a likelihood ratio test is used. In this test the translog cost function is restricted such that $\rho_1 = \rho_2 = 0$, and ratio of the maximum value of the restricted likelihood function to that of the unrestricted function is computed.[20] The test statistic value was 5.98 which, at 0.05 level, is on the border of the critical value. Thus, we cannot reject the null hypothesis that production is homothetic in output.

To test for separability, the restrictions $\gamma_1 = \gamma_2 = \gamma_3 = 0$, are imposed. The test statistic was 16.32 which is greater than the χ^2 critical value at level 0.05, thus implying that the hypothesis of linear separability of labor and capital cannot be accepted. If the above separability and homotheticity restrictions are jointly imposed on (6) (thus deriving model 1), the test statistic is: 21.73, which is greater than the critical value at 0.05 level. Consequently, the hypothesis that the dual to model 2 production function is of the Cobb-Douglas type cannot be accepted.

I turn now to the measurement of factor substitution in the production of bus transportation services. Using equations (13) and (14), the Allen partial elasticities of substitution (σ_{ij}) and the factor

_____

[20]Under the null hypothesis $(-2 \log R)$ is assymptotically distributed $\chi^2(n)$ where R is the above ratio and n is the number of restrictions.

demand price elasticities (ϵ_{ij}) are computed for each year of the sampled period. Table 3 provides these estimates.

Several conclusions can be stated. The negative and small elasticity of substitution parameters between labor and capital suggest that these inputs are weakly complementary in the production of the services. This conclusion should be qualified, however, since a two factors model like the above precludes factors complementarity. An alternative explanation is that of fixed factors proportion technology.[21] This result is of no surprise given the technology of the bus sector where each bus is operated by one driver. The factors cross price elasticities, which are also small, indicate that increase in the price of labor will tend to reduce the demand for capital in the long run.

As could be expected the demand for labor and capital in the bus industry are responsive to changes in their own prices as indicated by their negative own price elasticities. It should be noticed, however, that the variable used in the analysis as the labor input factor was actual man-days worked and not number of employees. Thus, it is impossible to directly infer from the estimated values of ϵ_{ww}, the actual impact on the size of the labor force, of changes in labor prices. On the other hand, the derived values of ϵ_{rr} in part reflect the fact that the reported data on expenditures on buses, which were used for the compution of capital cost, include also elements of maintenance costs.

_____

[21]Another possible econometric explanation is that of a missing variable. That is, if another factor of production (e.g. maintenance) was explicitly included in model 2, labor and capital could indeed be regarded as complementary while being substitutes to that third factor.

Table 3.

Estimated Allen partial elasticities of substitution

and price elasticities of demand, 1972-1979

Year	σ_{LK}	ε_{ww}	ε_{rr}	ε_{wr}	ε_{rw}
1972	-0.116	-0.015	-0.449	-0.080	-0.035
1973	-0.104	-0.019	-0.448	-0.071	-0.032
1974	-0.069	-0.020	-0.442	-0.046	-0.022
1975	-0.081	-0.025	-0.445	-0.054	-0.025
1976	-0.071	-0.019	-0.443	-0.047	-0.023
1977	-0.136	-0.009	-0.450	-0.096	-0.039
1978	-0.214	-0.007	-0.451	-0.157	-0.056
1979	-0.024	-0.046	-0.432	-0.015	-0.008

The cost elasticity of output $\partial \ln C / \partial \ln Q$, can be derived from equation (6),

$$\frac{\partial \ln C}{\partial \ln Q} = \alpha + \delta \ln Q + \rho_1 \ln w + \rho_2 \ln r \tag{15}$$

As the coefficients ρ_1 and ρ_2 were statistically not different from zero, the following simplified equation is computed:

$$\frac{\partial \ln C}{\partial \ln Q} = \alpha + \delta \ln Q \tag{16}$$

Similarly, the marginal cost equation (12) can be written for computational purposes as:

$$MC = \frac{C}{Q} \left[\alpha + \delta \ln Q \right] . \tag{17}$$

The annual estimates of the cost elasticities and marginal cost appear in Table 4.

Several important points should be observed about the results of Table 4. For each year, the cost elasticities are less than unity, thus indicating scale economies in the production of bus transportation services. Following the conventional approach (e.g., Caves et al., 1980), the degree of scale economies is measured as unity minus the cost elasticity. These results are given in column 2 of Table 4, and indicate that, in contrast with findings of previous studies significant economies of scale were found in the Israeli bus sector. It is important to emphasize here that what was measured are economies of passenger-trips related output, or trip density, and not economies of size of bus operators (e.g. size of rolling stock or vehicle-miles).

Table 4.

Cost elasticities, marginal cost and economies

of scale Israeli bus sector, 1972-1979

Year	cost elasticity[a]	scale economies[b]	MC[c]	AC[c]
1972	0.53	0.47	0.53	1.00
1973	0.54	0.46	0.58	1.09
1974	0.54	0.46	0.64	1.18
1975	0.54	0.46	0.66	1.22
1976	0.54	0.46	0.63	1.17
1977	0.53	0.47	0.65	1.22
1978	0.53	0.47	0.76	1.45
1979	0.53	0.47	0.84	1.59

a. $\dfrac{\partial \text{Ln } C}{\partial \text{Ln } Q}$

b. scale economies $= 1 - \dfrac{\partial \text{Ln } C}{\partial \text{Ln } Q}$

c. in current prices (IL) per passenger trip

Since factor prices were statistically insignificant in the MC function (12), it seems that output alone determines the level of marginal cost (given AC, α and δ). It is evident from Table 4 that MC values are below the average cost values for all Q which, of course, is expected under conditions of scale economies. The difference between AC and MC for a given level of output reflects the cost per unit output which would not be covered under a marginal cost pricing policy. The range of these differences is between 0.47 and 0.75 in current price and between 0.27 and 0.04 in fixed prices.

5. Conclusions

Various studies have been conducted in recent years on the issue of the cost function of bus transport. A review of these studies shows that most of them use simplistic analytical constructs which, in addition to being theoretically deficient, do not allow for analysis of the relationships between production cost on the one hand and output and input factor prices on the other. In particular, the demand for factors of production, factor substitution and price elasticities are not investigated. Also, it is impossible to deduce from these studies the analytical properties of the underlying production technology.

By using a general translog cost function under conventional restrictions from neoclassical theory, these issues have been investigated in this study. The data base represents the Israeli bus sector which, in contrast to many other countries, is composed of privately owned bus firms. A number of conclusions from the analysis can be stated. The

first conclusion is that the production of bus services probably cannot be accurately described by a Cobb-Douglas type technology. While the statistical analysis did not reject the hypothesis of homothetic production in output, it showed that the factors of production are not linearly separable.

Another conclusion from the analysis is that the technology of bus services production is that of fixed factors proportions (labor to capital). The own price elasticities, which have the correct sign, are much larger for capital than for labor, the latter being measured in units of actual man-days worked and not number of employees.

The analysis also revealed that economies of scale in the provision of bus service in Israel do prevail. This finding stands in direct contrast to many of the studies reviewed above and partly it can be attributed to the use of gross revenue in fixed prices as output measure rather than variables like bus-miles or bus-hours. The use of time series data and not cross-section data may be another reason for this finding, since time series data do not require standardization of observations by operator size and demand environment. The specific structure of the Israeli bus sector described above, in particular, its high degree of concentration and private ownership of the bus firms, when coupled with the densely distributed demand for transport travel, may provide another plausible explanation. The latter argument thus suggest that this finding of economies of scale in the production of bus services cannot be easily generalized.

Obvious limitations of the above analysis are the use of only two factors of production. The inclusion of fuel and repairs and maintenance

as specific factors may provide more insight into the production process in particular with regard to factors substitution and demand. Bus companies produce a variety of services such as center-city, metropolitan, suburban and express trips, which may have different production and cost characteristics. It is suggested, therefore, that a separate analysis for each service type be conducted, given data availability.

Finally, it is desirable to compare the production of services by profit maximizing (or cost minimizing) bus transport systems with services produced by completely regulated and publicly owned companies. The principal question to be explored is whether type of ownership does affect bus services production technology and cost structure.

References

Allen, R.G.D. (1938), <u>Mathematical Analysis for Economists</u>, 2nd ed., MacMillan, London.

Berechman, J. (1980), "Transit Subsidies and Regulation: Lessons from the Israeli Experience," <u>Transportation</u>, 9(4), pp. 369-388.

Button, K. J. (1977), <u>The Economics of Urban Transit</u>, Saxon House, Ch. 5.

Caves, D. W., Christensen, L. R., and Swanson, J. A. (1980), "Productivity in U.S. Railroads, 1951-1974," <u>The Bell Journal of Economics</u>, 11(1), pp. 166-181.

Christensen, L., Jorgenson, D. W. and Lau, L. J. (1973), "Transcendental Logarithmic Production Frontiers," <u>Review of Economics and Statistics</u>, 55(1), pp. 28-45.

Christensen, L., and Greene, W. (1976), "Economies of Scale in the U.S. Electric Power Generation," <u>Journal of Political Economy</u>, 84(4), 655-676.

Foster, J. R. (1973), "The Determinants of Costs and the Cost Function of Urban Bus Transit 1960-1970," unpublished Ph.D. dissertation, Syracuse University.

Fravel, D. F. (1978), "Returns to Scale in the U.S. Intercity Bus Industry," <u>Transportation Research Forum Proceedings</u>, pp. 551-600.

Fuss, M., McFadden, D. and Mundlak, Y. A. (1978), "A Survey of Functional Forms in the Economic Analysis of Production," in M. Fuss and D. McFadden (eds.), <u>Production Economics: A Duel Approach to Theory and Application</u>. North-Holland, pp. 219-268.

Griliches, Z. (1972), "Cost Allocation in Railroad Regulation," <u>The Bell Journal of Economics</u>, 3(1), pp. 26-51.

Harris, R. G. (1977), "Economies of Traffic Density in the Rail Freight Industry," <u>The Bell Journal of Economics</u>, 8(2), pp. 550-564.

Johnston, J. (1972), <u>Econometrics Methods</u>, McGraw Hill Book Co.

Koshal, R. K. (1970), "Economics of Scale in Bus Transport: Some Indian Experiences," <u>Journal of Transport Economics and Policy</u>, 4, pp. 29-36.

Koshal, R. K. (1972), "Economics of Scale in Bus Transport: Some United States Experience," <u>Journal of Transport Economics and Policy</u>, 6, pp. 151-153.

Lee, N. and Steedman, I. (1970), "Economies of Scale in Bus Transport," Journal of Transport Economic and Policy, 4, pp. 15-28.

Mohring, H. (1972), "Optimization and Scale Economies in Bus Transportation," American Economic Review, 62, pp. 591-604.

Nelson, G. R. (1972), "An Econometric Model of Urban Bus Transit Operations," in Economic Characteristics of the Urban Public Transportation Industry, Institute of Defense Analyses, Washington, D.C.

Oram, R. L. (1979), "Peak-Period Supplements: The Contemporary Economics of urban Bus Transport in the U.K. and U.S.A.," Progress in Planning, 12, pp. 81-154.

Shephard, R. (1970), Theory of Cost and Production Functions. Princeton University Press, Princeton, New Jersey.

Spady, R. H. and Friendlaender, A. F. (1978), "Hedonic Cost Functions for the Regulated Trucking Industry," Bell Journal of Economics, pp. 159-179.

Uzawa, H. (1962), "Production Functions with Constant Elasticities of Substitution," Review of Economic Studies, pp. 291-299.

Varian, H. R. (1978), Microeconomic Analysis, Norton and Company, Inc.

Veatch, J. F. (1973), "Cost and Demand For Urban Bus Transit," unpublished Ph.D. dissertation, University of Illinois at Urbana-Champaign.

Vickrey, W. (1980), "Optimal Transit Subsidy Policy," Transportation, 9(4), pp. 389-410.

Wabe, S. J. and Coles, O. B. (1975), "The short and Long Run Cost of Bus Transport in Urban Areas," Journal of Transport Economics and Policy, 1, pp. 127-140.

Zellner, A. (1962), "An Efficient Method of Estimating Seemingly Unrelated Regressions Under Tests for Aggregation Bias," Journal of American Statistical Association, 53, pp. 977-992.