Cost of Urban Bus Transit Operations and Geography of Service Territory

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Abstract

Bus transit cost studies have been limited in their spatial scope. Service territory variables characterizing differences among the physical settings where busses are operating have been largely neglected. The purpose of this paper is to expand empirical research on bus transit operation costs and test the hypothesis that physical and geographical characteristics are plausible explanatory cost factors. A translog cost function has been estimated, using a panel dataset of 1,061 observations over 1996-2002 for a cross-section of 264 transit agencies operating only diesel-powered busses in the U.S., combined with geographical and physical data processed with GIS technology. The results show that the total cost decreases with the population density, the average street segment length, and the percentage of flat land in the service territory. The elasticity of cost with respect to output, ε_Q, varies between 0.459 and 1.205, with a mean of 0.806. ε_Q is <1 for 928 observations, indicating that economies of scale are experienced in 87.5% of the observations.

Keywords: Bus transit, cost function, geographical factors, GIS, translog.

1. Introduction

The Urban Mass Transportation Act of 1964 enabled mayors and managers, in collaboration with organized labor, to receive more funding for transit planning, capital investment, operating subsidies and personnel development. Many small and medium-sized private transit systems were transferred to public ownership through federal assistance (Fielding 1995). The cost structure of the bus industry has vital importance in forming the expansion decisions of these transit agencies and in shaping the pricing policies of governmental agencies, because information on scale economies, marginal costs and cost elasticities can be derived from this cost structure. Thus, the estimation of cost functions has become the preferred approach in the analysis of the transit industry (Jara-Diaz and Cortes 1996).

Miller (1970) states that the costs of urban bus transit operations "vary across the cities in ways that cannot be entirely accounted for by factor price or output differences" (p. 22). He states that "the city setting ought to be considered in estimating the costs of urban bus transportation" (p.31). Lee and Steedman (1970) claim that "variations between geographical areas in terrain and traffic conditions are plausible explanatory factors in transport cost differences between undertakings" (p. 20). However, site-specific variables approximating the differences among the physical settings where the busses are operating have been largely neglected, and bus transit cost studies have been limited in their spatial scope. The aim of this paper is to test the hypothesis proposed by Miller (1970) and Lee and Steedman (1970), using current data and expanding earlier empirical research on bus transit operation costs, while accounting for the site-specific characteristics of the service area. A total cost function is estimated using a panel dataset covering bus agencies operating in the U.S. The effects of the site-specific factors on scale economies are further assessed to achieve a better understanding of the economic characteristics of bus transit operations.

The remainder of the paper is organized as follows. Section 2 consists in a review of the literature, and Section 3 presents the modeling approach. Data sources and processing are described in Section 4, and the estimation procedure is discussed in Section 5. The results of the empirical analyses are presented in Section 6. Section 7 concludes the research.

2. Literature Review

In his extensive review of the transportation literature, Winston (1985) notes that there has been much statistical cost analysis of all modes of transportation since Alan Walters' (1963) survey of production and cost functions. The economics of bus transit operations have drawn particular attention for two reasons: (1) Bus transit is the most efficient form of urban transportation in terms of cost per passenger trips (Keeler et al. 1975), and (2) it is the only mode with the ability to generate enough revenues to cover both capital and variable costs (Viton 1981). Studies on bus transit operations are highly empirical, and focus on the estimation of cost functions to answer questions regarding cost elasticities, factor substitution, efficiency, and economies of scale.

Earlier studies make use of linear functions. Koshal (1970) estimates 5 disaggregate cost functions for personnel, material, overhead, capital, and depreciation costs for three groups of bus agencies operating in (1) urban routes, (2) long-distance routes and (3) mountainous routes. A total of 15 linear cost functions, where the output is measured in seat-kilometers, are estimated using 1963-1964 data for 26 state agencies in India. Similarly, Lee and Steedman (1970) estimate disaggregate cost functions for power, repair and maintenance, traffic operation and management, and general costs per bus-mile. A total cost function is also estimated. They use 1967 data for 44 municipal bus agencies in Britain. The explanatory variables include the output (total bus mileage, fleet size, size change in fleet size, average bus-mile), input prices (labor, fuel), and a number of physical and traffic environment variables, including average bus speed, population density, and percentage of annual bus mileage on two-man operation.

Since the early 1980s, cost functions for the bus transit industry have been conventionally modeled as functions of output and input prices with a translog specification. While agency cross-sectional data are used in most studies, some authors employ aggregate data. Berechman (1983), estimates a single-output (total revenue) and two-input (labor and capital) translog cost model, using aggregate time-series quarterly data for the Israeli bus industry for the years 1972-1979. De Borger (1984) estimates a single-output (seat-kilometers) and three-input (capital, labor and fuel) translog cost function to calculate productivity growth for regional bus transportation in Belgium. The fleet size is used as a measure of the capital stock, and a time variable is included in the model.

At the agency level, Viton (1981) estimates a single-output (vehicle-miles) and three-input (capital, labor, and fuel) translog cost model to analyze the short and long-term cost behavior of the sector. The sample consists of 54 large and small bus transit agencies operating in the U.S. in 1975. Total fleet size for each agency is used for the fixed rolling stock, replacing the capital price variable. Similarly, Williams and Dalal (1981) estimate a single-output (bus-miles) and four-input (capital, labor, fuel and equipment) translog cost function to investigate factor substitution possibilities. They use 1979 data for 20 publicly-owned bus agencies in Illinois. Tauchen et al. (1983) propose a multi-product cost function to derive the marginal costs of regular-route, charter, local and school bus services, which are regarded as different products. They use data for 950 privately-owned intercity bus agencies in the U.S. for the year 1975. The estimated modified translog cost functions include total bus-miles as output, shares of different products and prices for three inputs (capital, labor and fuel). Obeng (1985) tests the hypothesis that low total productivity of inputs and low levels of factor substitution are the cause of variation in bus operating costs. Fleet size is used as the measure of fixed capital, as in Viton (1981) and De Borger (1984), in this single-output (vehicle-miles) and three-input (capital, labor and fuel) translog model. The sample consists of 62 bus agencies operating between 25 and 600 vehicles in the U.S. in 1982.

Several authors include additional exogenous variables to explain variations in operating costs across bus agencies. Miller (1970) includes schedule speed, city age, average age of fleet and a variable to measure the compactness of the city, in addition to the output (bus-miles) and input price (labor) variables. The dependent variable is the total cost per vehicle-mile. A linear model is estimated using 1963 data for bus agencies operating in 33 cities in the U.S. Jorgensen et al. (1995) estimate a modified Cobb-Douglas cost function to explain the variations in total cost per vehicle-kilometer in Norway. The output variable is in vehicle-kilometers. The additional exogenous variables include average bus size, number of counties served, number of passengers per kilometer, and dummy variables to capture working conditions (coastal or inner service area), ownership structure, and subsidy conditions. They use 1991 data for 174 bus operators. Matas and Raymond (1998) include total route length as a network characteristics variable in their single-output (bus-kilometers) and single-input (labor) translog model. They use panel data for medium-size and large-size cities in Spain to analyze the degree of efficiency. Karlaftiz and McCarthy (2002) also include route length to approximate network characteristics. They use a panel dataset covering U.S. bus transit agencies for the years 1986-1994. Transit agencies in the dataset are first classified into groups using cluster analysis. Single-output (bus-miles) and three-input (labor, material and capital) total operating cost functions, in translog form, are estimated separately for 6 groups. Fleet size is used as the measure of fixed capital, and dummy variables are included to capture time effects. Filippini and Prioni (2003) estimate two single-output (bus-kilometers and seat-kilometers, respectively) and three-input (capital, labor, and fuel) translog cost function using 1991-1995 data for 34 bus agencies in Switzerland. Their models include a time variable to capture technology effects, network variables (route length, number of stops), and a dummy variable to test the effect of private ownership.

The cost elasticities derived from the above cost function estimations display much variability. Williams and Dalal (1981) report diseconomies of scale for smaller agencies with less than 253,000 annual vehicle-miles, and economies of scale for agencies with larger fleets. Tauchen et al. (1983) show that economies of scale in the production of intercity bus-miles are exhausted at low levels of output. Thus, an increase in output provides cost advantages only for the smallest bus agencies. Viton (1981) concludes that smaller firms experience short-run economies of density and long-run economies of scale, while larger firms experience short-run economies of density and long-run diseconomies of scale. Filippini and Prioni (2003) report slight economies of scale for medium-sized bus agencies in Switzerland. Koshal (1970) and Lee and Steedman (1970) conclude that the bus industry operates under constant returns to scale. Likewise, Matas and Raymond (1998) indicate near constant returns to scale and economies of density. De Borger (1984) reports unstable values for short-run economies of scale, ranging between -0.44 and 1.92 for the years 1951-1979. Berechman (1983) reports significant economies of scale for the Israeli bus industry, which may be attributed to the use of aggregate time-series data and total revenue in fixed prices as the output variable.

De Borger (1984) claims that literature results on scale economies vary because the samples include agencies operating in different environments, and the studies disregard differences in these environments. Miller (1970) states: “If all cities had identical distributions of population, economic activity and identical geography, the outputs of bus firms in different cities could be meaningfully compared by use of the single output variable used in most previous studies: the vehicle-mile” (p. 24). Clearly, most of the previous cost studies are of little help to understand the role of site-specific geographical and physical cost factors. Only a few studies consider site-specific variables. Lee and Steedman (1970) suggest that traffic and terrain conditions are cost factors. They use population density as a proxy for traffic conditions, but terrain conditions are ignored because of difficulty in measuring them. Lee and Steedman's (1970) findings indicate higher power, traffic operation, and total costs (per bus-mile) for higher levels of population density; and lower traffic operation costs for lower average bus speeds. Koshal (1970) reports higher marginal costs for agencies operating in mountainous routes. Jorgensen et al. (1995) show that bus agencies operating in the coastal areas of Norway have higher costs than the ones operating in the inner regions. Total route length is used to approximate network characteristics in Matas and Raymond (1998) and Karlaftiz and McCarthy (2002).

3. Methodology

Shephard (1970) has demonstrated that the cost and production functions are dual to each other under certain regularity conditions, and that the cost function summarizes all the economically relevant information provided by the production function. The estimation of the cost function is more attractive when the level of output can be considered exogenous (Christensen and Greene 1976). This is the case of transit bus companies. The total output is defined exogenously, since these agencies are required to meet user demand through the regulatory process. Routes and fares are determined by state or local authorities (Winston and Shirley 1998). Also, none of the transit bus agencies have a significant effect on market input prices. They are price takers in the factor market. In brief, each company may be viewed as a cost-minimizer, and the decision variables are the quantities of inputs necessary to supply the exogenous demand. The cost function provides a more direct approach to the estimation of scale economies as well (Christensen et al. 1983). The general cost function is

$$C = f(\boldsymbol{Q}, \boldsymbol{P}, \boldsymbol{H}), \tag{1}$$

where C is the total cost, $\boldsymbol{Q}$ the output vector, and $\boldsymbol{P}$ the input prices vector. A site-specific characteristics vector, $\boldsymbol{H}$, is included to test the hypothesis that physical and geographical characteristics are plausible explanatory cost factors.

Flexible functional forms, such as the translog, are generally used in the estimation of transportation cost functions, because they impose fewer restrictions on the underlying production structure. The translog specification is used here to estimate the total cost function. Originally developed by Kmenta (1967), the translog function was introduced formally by Berndt and Christensen (1973), and Christensen, Jorgenson and Lau (1975). It has remained the most popular form, despite the development of other forms (Greene 2000), and has become the standard in applied transport cost studies (Jara-Diaz and Cortes 1996). There are a number of advantages in using the translog cost function: (1) It imposes no a-priori restrictions on the substitution of production factors; (2) it allows for variations in economies of scale with the levels of inputs, which enables the unit cost curve to attain the classical U-shape (Christensen and Greene 1976); and (3) it is convenient for tests of econometric hypotheses (Guldmann 1990).

The translog cost function is a second-order Taylor series approximation of the unknown function. It is assumed that each transit bus company produces a single output, measured by passenger-miles, by means of three inputs: capital, labor and fuel. Service area population density, slope conditions, and a street pattern variable, the average street segment length, are included in the site-specific vector. In order to measure the effects of the site-specific factors on output elasticity, their interaction terms with the output (*ln H.ln Q*) are included in the equation. Initially, stand-alone terms were also considered, together with the interaction terms, but turned out to be insignificant and were dropped from the equation. The selected specification for the cost function is:

$$
\begin{aligned}
\ln C = \ & \alpha + \beta_Q \ln Q + \beta_L \ln P_L + \beta_K \ln P_K + \beta_F \ln P_F \\
& + \tfrac{1}{2} \beta_{QQ} (\ln Q)^2 + \beta_{LL} \tfrac{1}{2} (\ln P_L)^2 + \tfrac{1}{2} \beta_{KK} (\ln P_K)^2 + \tfrac{1}{2} \beta_{FF} (\ln P_F)^2 \\
& + \beta_{LK} (\ln P_L)(\ln P_K) + \beta_{LF} (\ln P_L)(\ln P_F) + \beta_{KF} (\ln P_K)(\ln P_F) \\
& + \beta_{QL} (\ln Q)(\ln P_L) + \beta_{QK} (\ln Q)(\ln P_K) + \beta_{QF} (\ln Q)(\ln P_F) \\
& + \xi_{QDENSITY} (\ln Q)(\ln H_{DENSITY}) + \xi_{QSTREET} (\ln Q)(\ln H_{STREET}) \\
& + \xi_{QSLOPE} (\ln Q)(\ln H_{SLOPE}),
\end{aligned} \tag{2}
$$

where C is the total cost, Q is the output measured in passenger-miles, P_K is the unit capital price measured in dollars per operated bus, P_L is the unit labor price measured in dollars per hour, and P_F is the unit fuel price measured in dollars per gallon. $H_{DENSITY}$ is the population density in people per sq. mile, H_{STREET} is the average street segment length in mile, and H_{SLOPE} is the percentage of land with 0% slope (flat land).

Factor share equations are derived from the translog cost function from Shephard's (1970) lemma:

$$S_L = \partial \ln C / \partial \ln PL = \beta_L + \beta_{LL} \ln P_L + \beta_{KL} \ln P_K + \beta_{LF} \ln P_F + \beta_{QL} \ln Q \,, \tag{3}$$

$$S_K = \partial \ln C / \partial \ln PL = \beta_K + \beta_{KK} \ln P_K + \beta_{KL} \ln P_K + \beta_{KF} \ln P_F + \beta_{QK} \ln Q \,, \tag{4}$$

$$S_F = \partial \ln C / \partial \ln PL = \beta_F + \beta_{FF} \ln P_F + \beta_{KF} \ln P_K + \beta_{FL} \ln P_L + \beta_{QF} \ln Q \,. \tag{5}$$

4. Data

The American Public Transportation Association (APTA) defines a *transit agency* as “a public or private entity responsible for administering and managing transit activities and services. Transit agencies can directly operate transit service or contract out for all or part of the total transit service provider” (FTA 1997). Here, only directly-operated transit bus services are considered.

The panel dataset includes 1,061 observations pertaining to 1996-2002, for a cross-section of 264 transits agencies operating in the U.S. The total cost, input prices and output data are drawn from The National Transit Database (NTD) Annual Reports published by The Federal Transit Administration (FTA), formerly known as Section 15 data. The service territory area and population data are drawn from the Bureau of the Census. The street data is derived from an Environmental Systems Research Institute, Inc. (ESRI) street map containing locational and hierarchical information on all highways, major roads and local streets in the U.S. This map was originally derived from the 1997 TIGER files of the Bureau of the Census. The slope data is derived from digital elevation model (DEM) files, available from the U.S. Geological Survey, using raster GIS functions. Finally, the indices to recalculate the cost data for the base year 2000 are obtained from the Bureau of Labor Statistics.

The total cost variable, C, is the sum of the annual operating and capital costs, in thousands of dollars. The operating cost includes all the labor costs, expenses for fuel, lubricants, tires and other materials and supplies. The capital cost includes the expenses related to purchasing capital equipment and financing capital projects including rolling stock for replacement or for fleet expansion, funds expended on the rehabilitation of operating vehicles, acquisition of major components for inventory, and expenses on stations, facilities and fare collection equipment. Expenditure on utilities and services, and casualty and liability costs are excluded from the total cost.

The output variable, Q, is passenger-miles. The labor input price, P_L, is measured by the average hourly cost of labor in dollars, derived by dividing total labor cost by total work hours. Total labor cost includes salaries and wages, fringe benefits, expenses, depreciation, interest charges, taxes and return on equity. The fuel input price, P_F, is measured by the average cost per gallon of diesel fuel, dividing the total expenditure on fuel and lube by total fuel usage. The NTD Annual Reports include fuel usage data disaggregated by fuel type, and total fuel and total lube expenditure data for each agency. The calculation of an average fuel price per gallon is only possible for these agencies that use only a single type of fuel. Thus, only agencies operating diesel-powered busses are included in the study. The unit price of fuel includes the price of lube. However, this is a negligible problem, because the cost of lube is a constant share of the cost of every gallon of fuel used. The capital input price, P_K, is derived by dividing total capital cost by the total number of busses in service.

The labor, fuel and capital cost data are recalculated for the base year 2000 using the Employment Cost Index for the labor cost data; the Consumer Price Index for All Types of Fuel[1] for the fuel cost data; and the Producer Price Index Industry Data for Heavy Duty Truck Manufacturing (including buses) for the capital cost data.

[1] For the tire and tube cost data *Consumer Price Index for Tire Manufacturing* is used.

An Urbanized Area (UZA) is a statistical geographic entity defined by the Census Bureau, consisting of a central core and adjacent densely settled territory that together contain at least 50,000 people. The NTD Annual Reports include a primary UZA that every bus transit agency serves. The geographical data used to approximate service territory characteristics are collected at the national level and assigned to corresponding UZAs for each transit agency using GIS tools. The population density variable, $H_{DENSITY}$, is the resident population per sq. mile. The average street segment length per intersection is used as the street pattern variable, H_{STREET}. It is derived by dividing the total street length by the total number of intersection points. Finally, the slope conditions variable, H_{SLOPE}, measures the percentage of flat land (with 0% slope) in the primary UZA of each agency. Descriptive statistics on all the above variables are presented in Table 1.

Table 1: Descriptive statistics for the sample (n = 1,061)

Variable	Mean	St. Dev.	Minimum	Maximum
Total Cost C (1000 \$)	39,281	106,975	365	1,424,894
Labor Cost Share S_L	0.614	0.142	0.133	0.848
Capital Cost Share S_K	0.276	0.161	0.066	0.845
Fuel Cost Share S_F	0.111	0.045	0.014	0.461
Passenger-Miles Q (mile)	52,442	130,908	133	1,376,040
Price of Labor P_L (\$)	22.285	6.045	8.970	48.162
Price of Capital P_K (\$)	66,898	73,571	10,063	906,722
Price of Fuel P_K (\$)	0.951	0.208	0.238	2.470
Population density $H_{DENSITY}$ (people/sq. mile)	2,547	1,324	980	7,429
Average street segment length H_{STREET} (mile)	0.186	0.021	0.122	0.295
% of Land with 0% slope H_{SLOPE}	21.378	21.472	0.400	87.500

5. Estimation

The optimal procedure is to estimate the cost function and the cost share equations jointly as a multivariate regression system. This method adds additional degrees of freedom without adding new regression coefficients, and results in more efficient parameter estimates, as compared to the ones obtained by OLS (Christensen and Greene 1976). It is assumed that (1) the error terms have a joint normal distribution (Christensen and Greene 1976), (2) there are no correlations across firms, and (3) non-zero correlations for a particular firm are allowed (Zellner 1962).The iterative Feasible Generalized Least Squares procedure (FGLS) is applied under these assumptions, and the procedure is iterated to convergence. However, as the share equations sum up to 1, one of the share equations, S_F, is deleted from the system so that the covariance structure remains non-singular.

Table 2 presents the joint estimates of the translog cost function, C, and labor cost share equation, S_K, under five cases. All five models correspond to a well-behaved cost function, which imposes the minimum requirement that it be positive and homogenous of degree one in prices, with the following restrictions:

$$\sum_i \beta_i = 1, \tag{6}$$

$$\sum_i \beta_{Q\,i} = 0, \tag{7}$$

$$\sum_i \beta_{ij} = \sum_j \beta_{ij} = \sum_i \sum_j \beta_{ij} = 0. \tag{8}$$

The symmetry restrictions imply:

$$\beta_{ij} = \beta_{ji}\,, \tag{9}$$

where i and j are the inputs K, L, and F, and Q is the output.

Table 2: Cost function estimates (t-statistics in parentheses)

	Models			
Coefficient	1	2	3 [a]	4
α	-3.2019 (-40.510)	6.3774 (24.979)	5.3623 (20.637)	5.1697 (19.492)
β_Q	1.1947 (13.138)	0.5699 (6.195)	0.6923 (7.523)	0.2224 (4.206)
β_L	0.6206 (151.182)	1.6474 (101.193)	1.5345 (89.658)	1.5341 (89.657)
β_K	0.2674 (57.883)	-1.1820 (-67.341)	-1.0546 (-60.351)	-1.0544 (-60.310)
β_F	0.1120 (83.178)	0.5346 (38.870)	0.5201 (39.494)	0.5203 (39.521)
β_{QQ}	-	0.0418 (15.358)	0.0418 (15.419)	0.0370 (13.657)
β_{LL}	-	0.0972 (63.975)	0.0985 (56.677)	0.0984 (56.693)
β_{KK}	-	0.0895 (89.016)	0.0891 (99.149)	0.0890 (99.105)
β_{FF}	-	0.0346 (26.676)	0.0383 (24.869)	0.0383 (24.885)
β_{LK}	-	-0.1521 (-85.122)	-0.1493 (-87.155)	-0.1492 (-87.166)
β_{LF}	-	-0.0424 (-16.613)	-0.0477 (-15.671)	-0.0477 (-15.674)
β_{KF}	-	-0.0269 (-22.727)	-0.0289 (-25.659)	-0.0289 (-25.674)
β_{QL}	-	-	0.0081 (9.000)	0.0081 (9.008)
β_{QK}	-	-	-0.0137 (-16.023)	-0.0137 (-16.013)
β_{QF}	-	-	0.0057 (8.763)	0.0056 (8.746)
$\xi_{QDENSITY}$	-0.0141 (-3.720)	-0.0260 (-7.429)	-0.0260 (-7.451)	-
$\xi_{QSTREET}$	-0.0515 (-3.950)	-0.0633 (-5.382)	-0.0645 (-5.503)	-
ξ_{QSLOPE}	-0.0039 (-3.731)	-0.0035 (-3.698)	-0.0036 (-3.774)	-
R^2 – cost equation	0.9475	0.9567	0.9565	0.9531
R^2 – labor share equation	-0.0025	0.8762	0.8876	0.8876
R^2 – capital share equation	-0.0026	0.8805	0.9036	0.9036
Log-likelihood	1,972.19	3,458.80	3,575.41	3,534.73

[a] Selected model.

Model 1 corresponds a Cobb-Douglas cost function, which implies output and input separability, or homotheticity ($\beta_{QL} = \beta_{QK} = \beta_{QF} = 0$), and excludes second-order terms for input prices and output ($\beta_{KK} = \beta_{PLL} = \beta_{FF} = \beta_{QQ} = 0$). Model 2 corresponds to a homothetic production function: It imposes input and output separability restrictions, but includes second-order terms for output and input prices. Model 3 is the full model with the site-specific variables and does not assume input and output separability and constant elasticity of factor substitution, and includes second order terms for input prices and output. Model 4, like Model 3, is the full model without any site-specific characteristics.

The likelihood ratio test is used to test the validity of the imposed restrictions. This test is based on the ratio of the likelihood function valued at the unconstrained estimates to the one valued at the restricted estimates (Greene 2000). Comparing Model 1 and Model 2 shows that the Cobb-Douglas form can be rejected ($-2ln\lambda$=2,973.21, 5% critical χ^2=14.07). The input and output separability (homotheticity) restriction is rejected, based on the comparison of Model 2 and Model 3 ($-2ln\lambda$=233.22, 5% critical χ^2=7.81). Models 3 and 4 are compared to test the validity of including the site-specific variables. This inclusion is supported by the test ($-2ln\lambda$=81.36, 5% critical χ^2=7.81). The remainder of the analyses is thus based on Model 3, the full model with the site-specific characteristics.

In addition to the constraint of linear homogeneity in factor prices, there are two regularity conditions that Model 3 must satisfy to correspond to a well-behaved cost function: monotonicity and concavity in factor prices (Diewert 1974; Christensen and Greene 1976; Greene 2000). Monotonicity requires that all estimated cost shares must be non-negative at every data point. The labor cost share varies between 0.303 and 0.488, thus

Model 3 satisfies the monotonicity condition. Concavity in factor prices requires that the Hessian matrix H be negative semi-definite, which it is when $\beta_{QQ}<0$ and det $H\geq0$. The condition $\beta_{QQ}<0$, which is satisfied by Model 3, guarantees that the cost function is never convex. Det H is positive at all points, satisfying the concavity condition.

Following Kennedy (1998), the correlation coefficients for all pairs of independent variables are derived to detect the existence of collinearity. All coefficients are smaller than 0.4, indicating at most moderate correlations. As all the signs in the estimated model are as expected and statistically significant, no further multicollinearity detection methods are applied.

6. Results and Analyses

The signs of Model 3 regression coefficients are all as expected and significant at the 1% level. The elasticities of cost with respect to output, ε_Q, price of labor, ε_L, price of capital, ε_K, and price of fuel, ε_F, are all positive for all the observations in the sample. ε_Q varies between 0.459 and 1.205, with a mean of 0.806; ε_L varies between 0.168 and 0.877, with a mean of 0.614; ε_K varies between 0.002 and 0.775, with a mean of 0.275; and ε_F varies between 0.016 and 0.217, with a mean of 0.111. C decreases with population density, $H_{DENSITY}$, the average street segment length, H_{STREET}, and the percentage of flat land, H_{SLOPE}. The effects of the site-specific factors are further assessed below.

Bus operating costs are lower when the agency operates in denser areas. A 1% increase in population density, for example, produces a 0.28% decrease in total costs when the output is at its sample mean (Q=52,442 passenger-miles). This elasticity varies between

-0.13 and -0.37 across the sample (Q_{min}=133, Q_{max}= 1,376,040). This result supports claims in the literature. Le Corbusier (1929) asserts that higher densities are needed for a frequent and viable mass transportation system. Hall (1975) states that high-density population concentrations in urban areas tends to favor public transportation. Jacobs (1961) calls busses the important manifestation of city intensity and concentration. Density provides more potential transit riders per square mile and makes waiting at transit stops and walking to the stops more pleasant (Gildea 2004) and safer. For example, Miller and Shalaby (2003) explain the high per capita transit usage in Toronto, Canada, by the high density throughout the city. Thus, the same level of service is obtained with fewer busses with the help of shortened distances and increased ridership, decreasing the total costs. Note also that, when ridership, increases in transit transport, congestion levels decrease, allowing for additional cost savings in bus operations. This finding is also consistent with Miller's (1970) result indicating lower costs with higher intensity of service, as the level of service is higher in denser areas.

The results point to lower bus transit costs with longer street segments in the street pattern. The cost elasticity for the average street segment is -0.70 when output is at its sample mean, and varies between -0.32 and -0.91 across the sample. This finding is as expected. Jacobs (1961) states that less interface and more speed is essential for efficient bus transport. The shorter the street segment, the larger the number of road intersections. As Le Corbusier (1929) stated "cross-roads are an enemy to traffic" (p.169). Fuel consumption is significantly influenced by inner-city traffic conditions (Mayer and Davies 2004) and a larger number of intersections affect bus operations in two ways: (1) more stops and idling and (2) lower and unstable speeds. Idling wastes two liters of diesel fuel per hour on average (PCRA 2005). A study conducted by the Petroleum Conservation Research Association (PCRA) and the Central Road Research Institute of India reveals that the amount of diesel wasted by vehicles every day at traffic intersections in Delhi alone is over one hundred thousand liters. As Miller (1970) empirically shows, slower operating speeds require more busses to achieve the same level of service, thus increasing operating costs.

Bus operating costs are lower when the agency operates on flat land. A 1% increase in percentage of flat land in the service territory yields a 0.04% decrease in cost when the output level is at the sample mean. This elasticity varies between -0.02 and -0.05 across the sample. This result is also consistent with findings in the literature. Koshal (1970) reports significantly higher marginal costs for agencies operating in mountainous routes. Wunch (1996) shows that the impact of speed on operating costs is much higher for busses than for other modes of public transportation. Hensher (2003) concludes that terrain has a significant influence on fuel consumption, cost of tires and overall time to complete trips in non-urban bus operations. This paper confirms that this is also the case in urban bus operations. Lynch (1971) points out that flat lands are more suitable for intense movement activity. The vehicles operating on steeper slopes are susceptible to failure, which results in higher operating costs (Marsh 1983). The reason is simple: maintaining a steady speed while driving is much easier on flat land, and sudden breaks and accelerations are less likely. Sudden acceleration injects more diesel than necessary (PCRA 2005), and frequent and sudden breaks wear out the break pads, increasing fuel and material costs.

The elasticity of cost with respect to output, ε_Q, is:

$$\varepsilon_Q = \frac{\partial C}{\partial Q} \cdot \frac{Q}{C} = \frac{\partial \ln C}{\partial \ln Q} = 0.6923 + 0.0418 (\ln Q) + 0.0081 (\ln P_L) - 0.0137 (\ln P_K) + 0.0056 (\ln P_F) - 0.0260 (\ln H_{DENSITY}) - 0.0645 (\ln H_{STREET}) - 0.0036 (\ln H_{SLOPE}) \,. \tag{10}$$

ε_Q, is <1 for 928 observations, indicating that economies of scale are experienced in 87.5% of the sample transit operations. When all the variables, except Q, are kept at their sample means, solving the equation ε_Q=1 indicates that economies of scale are exhausted at 117,502 passenger-miles. That is, whenever the output level is less than 117,502 passenger-miles, agencies experience economies of scale. Whenever the value of any variable in ε_Q is changed, the ε_Q=1 curve shifts. Figure 1 presents this curve for three different sample values of the population density variable, $H_{DENSITY}$: minimum, mean, and maximum. Higher values of $H_{DENSITY}$ shift the curve downwards, and lower values upward. An upward-shifted ε_Q curve means that economies of density are exhausted at lower levels of output. For instance, a transit agency starts experiencing diseconomies of scale over 85,381 and 166, 771 passenger-miles when $H_{DENSITY}$ is at its minimum and maximum, respectively. Likewise, higher values of H_{STREET} shift the curve downwards. The threshold output levels for experiencing diseconomies of scale are 87,429 and 162,114 passenger-miles when H_{STREET} is at its minimum and maximum respectively (Figure 2). Figure 3 presents this curve for three different values of the slope variable, H_{SLOPE}, with the rest of the variables at their sample means. The threshold output levels are 99,819 and 124,870 for the sample minimum and maximum values of H_{SLOPE}. Finally, Figure 4 presents the ε_Q=1 curve for three hypothetical transit agencies with sample minimum, mean and maximum values for all the site-specific variables simultaneously. The threshold output level drops to 53,436 passenger-miles for a transit agency with the minimum values, causing an increase in cost. However, a transit agency operating in an environment with the maximum values enjoys a reduced cost. The threshold output level jumps to 248,478 passenger-miles.

Figure 1: Economies of scale, ε_Q, versus output at different levels of population density ($H_{DENSITY}$).

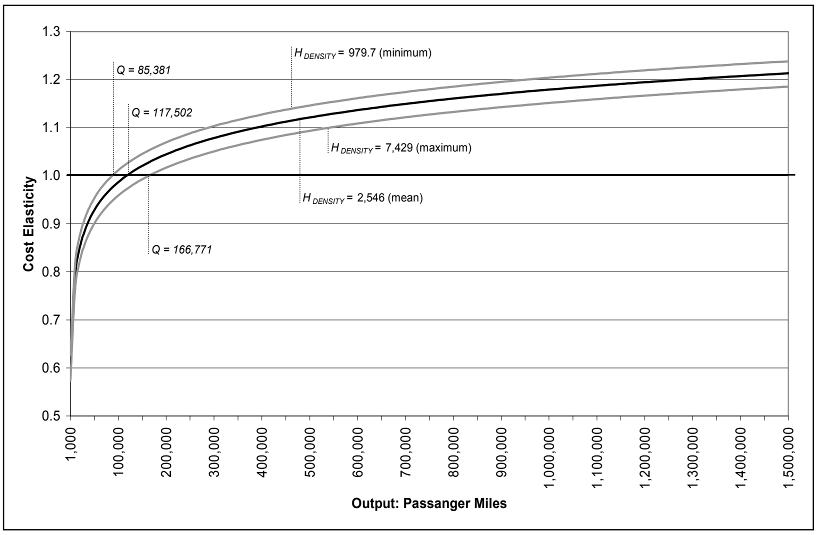


Figure 2: Economies of scale, ε_Q, versus output at different levels of average street segment length (H_{STREET}).

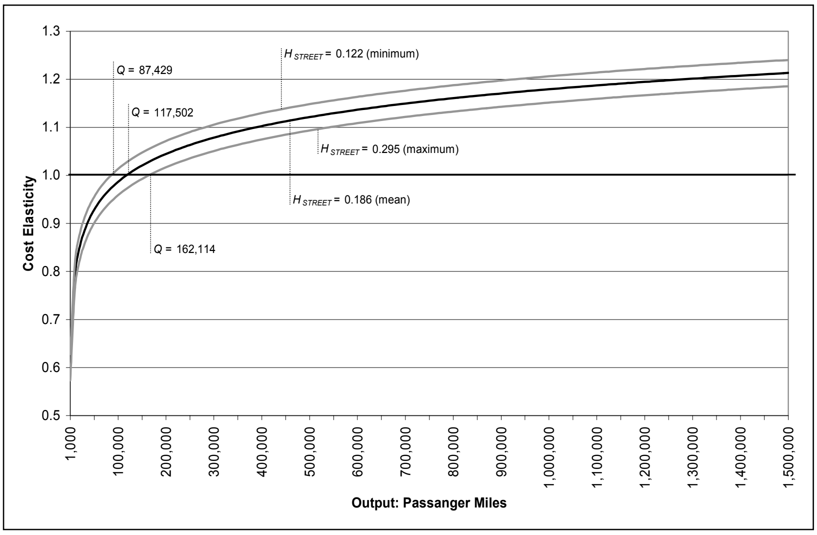


Figure 3: Economies of scale, ε_Q, versus output at different land percentages with slope of 0% (H_{SLOPE}).

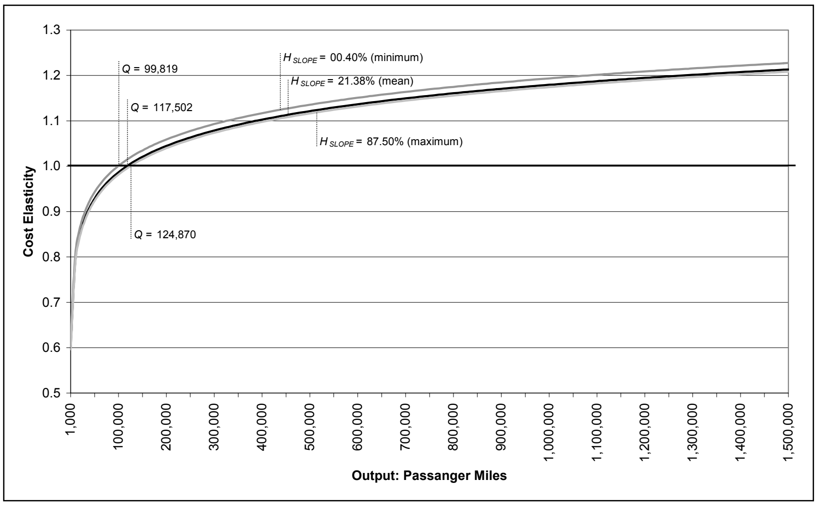
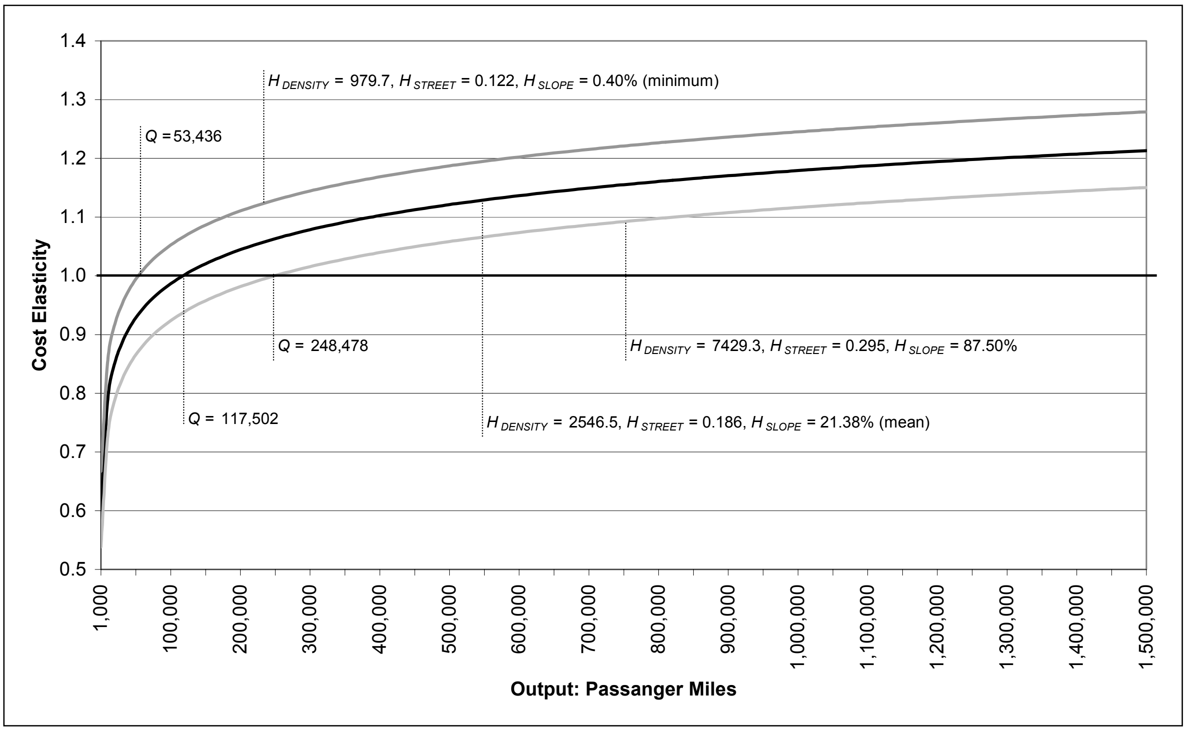


Figure 4: Economies of scale, ε_Q, versus output at sample minimum, mean and maximum values for all the site-specific variables simultaneously.



7. Conclusions

The purpose of this paper was to test the hypothesis that physical and geographical characteristics are plausible explanatory factors for bus transit operation costs. A translog cost function has been estimated, using a panel dataset of 1,061 observations pertaining to the period 1996-2002, for a cross-section of 264 transits agencies operating only diesel-powered buses in the U.S., combined with geographical and physical data, processed with GIS technology. The results show that site-specific factors are significant cost determinants in the bus transit industry. Total cost decreases with population density, average street segment length, and the percentage of flat land. When these site-specific factors are set at their sample mean values, economies of scale are exhausted for an output of 117,502 passenger-miles. This threshold level varies with the values of the site-specific cost factors. It is as low as 53,436 passenger-miles for a hypothetical transit agency with all the site-specific variables are at their sample minimums. This output level is 248,478 passenger-miles when all the site-specific variables are at their sample maximums. Economies of scale are experienced in 87.5% of the sample transit operations.

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