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Depicting the Cost Structure of an Urban Bus Transit Firm

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Working Paper No. 50

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ABSTRACT

Unearthing the behaviour of costs is crucial for examining `economic characteristics' of transportation industries. Cost functions that depict the relationship between costs and factors affecting costs can be empirically estimated to throw light on various economic facets of these industries such as the extent of scale economies, substitution possibilities between factors of production, the elasticity of demand for these factors, possibilities of reaping economies of density and scope as well as productivity growth over time.

This paper presents the results of an exercise to empirically estimate a `cost function' for the transport wing of 'Bombay Electricity Supply and Transport Undertaking' (B.E.S.T., Bombay). A host of `economic effects' have been derived and interpreted for the purpose of providing overall directions for the efficient operation of bus services. The need for technology upgradation, the significance of a rigorous maintenance policy, the necessity of designing, implementing and enforcing innovative `bus priority measures' are some of the important implications that emerge from our analysis. Presence of different kinds of `economies' within the existing set-up was also detected. Considerable cost savings would accrue by exploiting these economies judiciously.

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1. Introduction

The most significant feature of the transportation scenario within the city of Bombay, is the excessive dependence of the travelling public on the mass transit system. As per the modal share of total passenger trips, the share of mass transit trips (consisting of both, bus and rail transit trips) is around 80%. This phenomenon can be largely explained by the locational separation of functions in the urban area- the separation of home and the place of work. While 'metropolitan dispersion' has been mainly in terms of residential development within the 'Bombay Metropolitan Region', employment continues to be concentrated in the 'Greater Bombay Area' (appendix 1). Consequently, a large fraction of the commuting public is forced to depend on the mass transport system for its travel needs. People commute 'inwards' on their way to work in the mornings. A reverse flow of humanity occurs at the end of the working day. An efficient and cheap public transport system can mitigate this spatial disadvantage of separation and at the same time aid in strengthening the spatial interdependence of functions across the urban fabric.

The B.E.S.T. (Bombay Electricity Supply and Transport Undertaking) plays an important role catering to a considerable proportion of trips, especially for movement to and from work, within the 'Greater Bombay Area'.[1] Over the years, the B.E.S.T. has grown significantly in terms of 'effective-kilometers' as well as 'route-kilometers' provided by an expanding fleet of buses and a large number of employees. However, in financial terms the record has not been so satisfactory. This is evident from the trends with respect to the 'operating ratio' which indicates an adverse cost-revenue relationship (appendix 1). As a result, services have also deteriorated. Given the critical role played by the B.E.S.T in catering to the ever rising demands of urban commuters, the principal purpose of this paper is, therefore, to make an analytical assessment of these deficiencies in bus transit operations by scrutinising the

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[1] Bus service within the 'Bombay Metropolitan Region' as a whole, are provided by two urban level and one state level bus transport corporation. B.E.S.T.'s service provision is mainly restricted to the 'Greater Bombay Area'. 95% of its routes are concentrated in this area. Few services are also provided to 'New Bombay' across the Thane creek (app.1). The 'Thane Municipal Transport Undertaking' provides services within the jurisdiction of the Thane municipality. Rest of the 'Bombay Metropolitan Region' is served by the state level 'Maharashtra State Road Transport Corporation'. The suburban rail network caters to the entire 'Bombay Metropolitan Region' and comes under the jurisdiction of the 'Western Railways' (2 corridors) and the 'Central Railways' (3 corridors). The B.E.S.T. clearly supplements mass transport services provided by the railways since majority of B.E.S.T.'s routes are 'feeder routes' providing feeder links to the rail network.

behaviour of costs. Towards this end attempts have been made to empirically estimate a 'cost function' for the B.E.S.T., on the basis of monthly time-series data relating to the period: 1986-87 to 1993-94. A sound theoretical and quantitative base has been embedded to ensure reliability of results. A host of 'economic effects' has been subsequently derived and interpreted for the purpose of providing overall directions for efficient operation of bus services.

2. Literature: Cost Functions for Transportation Modes.

'Cost functions' as applicable to the transportation industries have evolved from simple analytical constructs to fairly complex structures. Simple transport cost studies can be grouped under three major categories: 'accounting cost studies', 'engineering cost studies' and 'simple statistical cost studies'. The basic methodological framework embodying these models is fairly straightforward. Potential influences on costs are identified and expressed in terms of 'linear' and 'log-linear' models which are amenable to statistical estimation by standard least square regression techniques. Due to these advantages of procedural simplicity, simple bus cost studies have been widely used and under practical circumstances do provide quick but somewhat crude estimates of costs pertaining to bus operations. A serious limitation of these cost studies is that the cost models are theoretically deficient making it almost impossible to impart any kind of economic meaning to the results obtained. The 'linear' and 'log-linear' structure of these cost models impose apriori restrictions on the substitution possibilities between input factors as well as 'economies of scale' making any investigation into these aspects futile.

Due to these lacunae, considerable research efforts have been invested in reinforcing the theoretical base of cost function specifications relating to transportation industries, since the late seventies. Further, salient features of the transport industry such as the pervasive presence of the government, the spatial nature of the transport product, the importance of service quality and problems related to the temporal nature of demand (Winston, 1985, pp.60) have been gradually incorporated considerably influencing these analytical developments. The cost structure has been depicted by resorting to flexible functional forms which place few apriori restrictions on the underlying production technology. These advances have made the interpretation of results more meaningful in relation to the economic characteristics of transportation industries, providing better tools for efficient formulation of policies towards these industries.

Another major area of research relates to the definition of 'output' of a transport firm. This output is actually a bundle of services[2] provided, which may vary spatially or temporally across the network. Therefore, units of transport service are not homogenous. Inability to account for this heterogeneous nature[3] of transport output in the cost function analysis would amount to overlooking important variables that may significantly affect costs. 'The analysis of costs in transportation has therefore gradually come to grips with the heterogeneous nature of transport product by recognising that the foundations of the subject lie in the theory of the multiproduct firm as opposed to the traditional theory of the single output producer' (Winston, 1985, pp.60)

As will be seen, attempts have been made to incorporate some of these more recent developments while trying to specify the cost function for the B.E.S.T., Bombay.

3. Methodological Framework.

3.1 Theoretical base:

In this study, the analytical approach used for empirical estimation of the cost structure of bus services is based on developments in duality theory which unravels the relationship between neo-classical production and cost functions.[4] Given a 'well-behaved'[5] production function, duality principles establish the existence of a unique cost function which is the minimum cost of producing a given output level during a given time period, expressed as a

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2 These may be thought of as routes of a network with varying service characteristics like frequency, speed, hours of operation

3 Ideally, the extent of disaggregation would depend on the ability to view the transport output as a vector 'Y' such that, $Y=[Y_{ij}^{kt}]$ where, 'Y_{ij}^{kt}' is the flow of commodity (freight or passenger) 'k' between origin 'i' and destination 'j' at time period 't' (Jara-Diaz, 1982, pp.268). This approach may be applicable for firms with very small networks. But for larger transport firms some degree of aggregation is inevitable, since otherwise a large number of parameters would have to be estimated 'exacerbating problems of multicollinearity' (Mcfadden et al., 1978, pp.224). In any case this sort of analysis calls for an extremely disaggregate data base.

4 Chambers, (1988).

5 Satisfies regularity conditions such as 'monotonicity', 'concavity' and 'essentiality'.

function of input prices and output. The neo-classical cost function is specifically applicable to regulated transport industries as it depicts the optimising behaviour of decision units fairly well. Under the regulated framework, these industries are required to supply all the services demanded at the predetermined rate structure, implying that 'output' can be treated as an exogenous variable. Exogeniety of 'factor prices' is justified on grounds that the transport firm is a price taker in the factor market. Given output level and factor prices, entrepreneurial decisions are aimed at minimising costs by selecting the optimum combination and levels of factor inputs.

However, the theoretical assumption of 'cost minimisation' may be somewhat stringent, discounting problems of 'x-inefficiency' (Leibenstein, 1966).[6] In situations where competitive pressures are light, as in the case of the B.E.S.T. which has a virtual monopoly in the provision of bus services, firms may be simply lethargic or otherwise not motivated to control costs. Hence input costs are not minimised. Inability to quantify and account for these qualitative factors that constitute 'x-efficiency' parameters directly in this cost function analysis is no doubt a limitation of the exercise. We therefore proceed with the 'cost minimisation' assumption given the continuous pressure on public firms to hold down costs (Williams et al., 1981), attempting to ascertain whether the phenomenon of 'x-inefficiency' gets reflected indirectly in terms of violations of theoretical consistency conditions.

3.2 Cost function variables:

Both 'producer-related' and 'user-related' variables have been experimented with while specifying the 'output' variable in the cost function. Producer-related measures of output such as 'effective-kilometers' or 'seat-kilometers'[7] reflect the output capacity of the bus transit firm.

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[6] 'There is more to the determination of output than the obviously observable inputs. The nature of management, the environment in which it operates and the incentives employed are significant' (Leibenstein, 1966, pp.401). The concept of 'x-efficiency' encompasses all these qualitative factors which termed as "non-input output growth factors" may well contribute to the enhancement of output. Unit costs would then depend on 'x-efficiency' which would vary in consonance with the degree of competitive pressures as well as other motivational factors. The response to such pressures in the nature of effort, search or the utilisation of new information can be quite significant.

[7] 'Effective-kilometers' reflects kilometers operated for the purpose of earning revenue. It therefore, excludes 'dead-kilometers' which arise due to movement of buses from depot to terminus, movement of buses for testing or movement of buses sent as relief in case of accidents and breakdowns. This measure of output has been widely used in a number of studies conducted for analysing the cost structure of the urban bus transit industry. 'Seat-kilometers', which is the product of effective-kilometers and the seating capacity of the bus, has been used in some studies to capture variations in costs associated with the size of the vehicle. This may be of significance in cross-section analysis where the sample may consist of bus companies operating vehicles of different sizes.

The advantage of using these output measures is that data is easily available and less susceptible to measurement errors. What is more, major cost items like 'labor' and 'fuel' may tend to be more correlated with these measures of output, enhancing the possibility of good statistical results while estimating the cost function. However, these technical measures of output may not adequately reflect the basic economic motive of providing bus services namely, carrying passengers. 'User-related' measures of output such as 'passenger-kilometers', 'passengers carried' or 'passenger-revenue' have been used in more recent studies on urban bus transit costs to overcome this problem. The limitation surrounding 'user-related' output variables is that inputs may not vary systematically with these output variables. Further, data pertaining to these output magnitudes may not be as accurate as 'producer-related' output measures.[8] In this study, two cost models have been estimated, one based on the producer-related measure of output 'effective-kilometers' and the other based on the 'user-related' measure 'deflated passenger-revenue'.[9] The rationale for estimating two models is that each would have different implications from the point of view of interpretation of results. Basic data on these variable was obtained from the bus transit firm's internal departmental records.

Four factors, 'labor', 'energy', 'capital' and 'maintenance' have been identified as the main inputs in the bus transit industry. Accordingly, four factor prices enter the cost function specification. Due to lack of requisite data, construction of factor prices implicitly assumes the need for homogenisation of heterogeneous inputs especially different types of 'labor' and 'capital' or the whole array of maintenance inputs that exist. Further, as will be evident, 'stock variables' have been used in place of 'flow variables' for the same reason. Fixity of certain inputs was ruled out and it was assumed that all inputs adjust instantaneously to their long run equilibrium values.[10]

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8 For instance, data on 'passengers carried' or 'passenger-revenue' is primarily obtained from data on sale of tickets. However fare-evasion or misappropriation of fare-box revenue, which may not be an uncommon phenomena in public bus corporations in developing countries (Armstrong et al., 1987), might lead to an underestimate of 'passengers-carried' or 'passenger-revenue' hampering accuracy of results.

9 Conceptually, the passenger-kilometers measure comes closest to representing the output of a transit firm. Passenger-kilometers for a certain distance category is given by the product of passengers travelling this distance and the distance travelled. Aggregating over all such distance categories we get the total 'passenger-kilometers' for a transport firm. But very often, it may be difficult to obtain data on distance travelled by each passenger. If the requisite data is not available, then proxies for 'passenger-kilometers' may have to be used. For instance, in some studies, 'deflated passenger-revenue' has been used, the logic being that, since fares are related to distance, passenger revenue can be perceived of as being a crude multiple of passenger-kilometers.

10 Rather than assuming that all inputs adjust instantaneously to their full equilibrium levels, researchers

$$P_m' = \alpha P_{M1} + \beta P_{M2} + [1-(\alpha+\beta)].P_{M3}$$

where, P_{M1}, P_{M2} *and* P_{M3}, denote prices of maintenance inputs 'M_1', 'M_2' and 'M_3', respectively, and α, β, denote share of specific maintenance input in the total maintenance expenditure. We identified 'tyres', 'tubes' and 'lubricants' for which time series data on price index was available for developing the above composite price index. However, as proportion of total maintenance expenses, these items account for only about 40% of the expenditure. If we based our maintenance price on these items alone, it would be erroneous as important maintenance inputs accounting for about 60% of the total maintenance expenses would be left out.[13] To circumvent this problem, the total number of 'maintenance' department employees was used as a proxy for the total quantity of maintenance inputs used and the unit price of maintenance entering the cost function was given as:

P_m = *Total expenses on tyres, tubes, spares and materials / Total maintenance employees.*

In addition to the 'output' and 'input price' variables, a time trend variable *'t'* was also incorporated into the cost function to assess the nature of technical change over time. Econometric necessity and the fact that technical advances usually requires the passage of time led to the widespread identification of technical change with a time term in the production function (Chambers, 1988, pp.203)

The dependent variable 'total costs' was computed using the accounting relationship:

$$C = P_k.K + P_l.L + P_e.E + P_m.M$$

where, C=total costs; P_i(i=K,L,E,M)= price of inputs and K,L,E,M are total quantities of inputs 'capital', 'labor', 'energy' and 'maintenance'. The dependent variable in the share equations was derived as:

$$S_i = (P_i.X_i)/C$$

13 The records showed that this 60% was presented under the heading 'spares and materials' in the expenditure' statements. Our discussions with the maintenance department officials indicated that a large number of maintenance materials are clubbed together in this category.

where, S_i= share of input 'i' in total costs and P_iX_i= the total expenditure on input 'i'
Data pertaining to these variables was obtained from the 'accounts section'.

The cost function analysis in this study is based on disaggregated monthly time series data. Monthly data was resorted to so that there was sufficient degrees of freedom. The aim was also to have as large a data set as possible in order to ensure feasibility and accuracy of the econometric analysis. The data trends indicate that the study period (April'86 to March'94) appeared to be an expansionary period marked by an increase in 'output' as well as 'input' usage. This expansion was especially significant after January'90, except for a period of sudden decline, between December'92 and January'93, caused by civic disturbances in the city of Bombay. There has been a modest increase in input usage, increase being the highest in the case of 'energy' input followed by the 'labor' input. This is probably reflected in the almost stagnant fuel efficiency rate of 2.84 kilometers per litre of fuel consumed and a high staff ratio of 12.03 persons per bus held. The prices of inputs, especially that of 'labor' increased substantially leading to a staggering increase in total costs during the study period (362%). The share of 'labor' costs as fraction of total costs increased from 43% to 56% during the same period This may no doubt indicate the 'labor-intensive' nature of the bus industry, but it may also call for considerable restructuring in order to enhance 'labor' productivity if costs are to be curtailed. This point needs to be stressed particularly in the case of public undertakings, like the B.E.S.T., wherein, stringent work contracts may not permit the possibility of outright expulsions.

3.3 The hedonic framework:[14]

The 'hedonic framework' is an advancement over the 'single-output' framework where the thrust of research work has been to expand the 'output vector' to include qualitative variables that depict 'service' characteristics, in addition to the generic measure of output such as 'effective-kilometers or 'passenger-kilometers'.[15] Empirical studies conducted elsewhere (Spady

[14] A multiproduct framework was also experimented with by disaggregating the output vector into two types of services namely, 'limited services' and 'ordinary services'. However, only a restrictive 'homogenous' version of the cost function could be estimated to depict the cost structure. Further, the problem of autocorrelation could not be rectified in this case. This alternative was therefore abandoned in favour of the 'hedonic framework'.

[15] Hedonic functions are often used because of aggregation problems (Gillen, D. et al., 1990, pp.13). Given varying conditions across the network, each origin-destination pair should be treated as a separate output. Since it is impossible to estimate a cost function with innumerable outputs especially when the network is large, some kind of 'aggregation' is inevitable. Output attribute variables are introduced to control for some

et al., 1978) have shown that costs can be quite sensitive to these service characteristics, and therefore exclusion of these qualitative variables can be a serious mis-specification, introducing significant bias. The cost function including the service attribute variables would look like:

$$C = c(\mathbf{P}, y, t, \mathbf{z})$$

where, C= total costs; $\mathbf{P}$= vector of input prices; y= output; z= vector of service attributes and t= time trend variable.

In this study attempts were made to include three service attribute variables namely the 'speed of service',[16] the 'frequency of service'[17] and the 'load factor'.[18] Out of these three variables only the 'frequency of service' variable could be effectively incorporated. Due to lack of data on 'hours of operation' the 'vehicle utilisation' ratio had to be used as a proxy for 'speed'. Probably, this was not an accurate way of representing the 'speed of service' because, when incorporated into the cost function problems of multicollinearity were detected and the variable had to be dropped. Inability to include the 'speed of service' variable is no doubt a limitation of the study. As a result the interrelationship between 'speed', which captures an important aspect of the external operating environment and 'costs' could not be analysed.

3.4 Functional form and estimation procedure:

A flexible 'translog' cost function was selected for econometric estimation of the neo-classical cost function. The translog cost function can be envisaged as a second-order Taylor's series approximation in logarithms to an arbitrary cost function. The translog functional form is advantageous as it places no apriori restrictions on substitution possibilities, allows scale economies to vary with the level of output and permits a multiproduct framework of analysis. Further, parametric restrictions can always be imposed to confirm the superiority of the unrestricted translog cost function (non-homothetic) over other more restricted form such as 'homothetic', 'homogenous'. 'constant returns to scale' or the 'Cobb-Douglas' form.[19]

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of the aggregation bias.

16 Speed of service=Effective-kilometers operated daily/Average number of buses on road daily. This is the vehicle utilisation ratio. Ideally, 'speed' should have been measured as :
Effective-kilometers operated daily / Hours of operation daily.

17 Frequency of service=Effective-kilometers operated daily/ Total route-kilometers.

18 Load factor=Passengers carried daily/ Total carrying capacity offered daily.

The cost function is estimated along with the share equations,[20] which only increases the degrees of freedom without adding to the number of parameters to be estimated. The share equation system possesses a special property in that for each observation, the sum of the dependent variables (cost shares) over all the equations always equals unity. Or,

$$\Sigma_i S_i (= p_i x_i / C) = 1$$

Therefore, the sum of disturbances across equations must always equal 'zero'. This means that the errors associated with the cost share equations cannot be mutually independent and the disturbance covariance matrix of the share equations is 'singular', $[E(\mathbf{u}_i \mathbf{u}_j)]=0$. The procedure adopted to overcome this problem is that, prior to estimation, one of the share equations is dropped and the remaining set of equations estimated in order to reduce the system to a 'non-singular' one.[21] If we impose the constraint that the cost function must be homogenous of degree one in prices, which is a theoretical necessity,[22] the system is reduced to a non-singular one. Imposing the linear homogeneity in input prices[23] and dropping the 'energy' share equation the final system of equations to be estimated may be given as:

$$\ln(C/p_e) = \alpha_o + \alpha_y \ln y + \Sigma_i \alpha_i \ln(p_i/p_e) + \alpha_t t + \alpha_{er} \ln er + \tfrac{1}{2}\alpha_{yy}[\ln y]^2 + \tfrac{1}{2}\Sigma_i \Sigma_j \alpha_{ij}[\ln(p_i/p_e)\ln(p_j/p_e)] + \tfrac{1}{2}\alpha_{tt} t^2 + \tfrac{1}{2}\alpha_{erer}[\ln er]^2 + \Sigma_i \alpha_{iy} \ln(p_i/p_e)\ln y + \Sigma_i \alpha_{it} \ln(p_i/p_e).t + \Sigma_i \alpha_{ier} \ln(p_i/p_e)\ln er + \alpha_{yt} \ln y.t + \alpha_{yer} \ln y \ln er + \alpha_{ert} \ln er.t$$

$$S_i = \alpha_i + \alpha_{ii}\ln(p_i/p_e) + \Sigma_j \alpha_{ij}\ln(p_j/p_e) + \alpha_{it} t + \alpha_{ier}\ln er$$

where, $\alpha_{ij}=\alpha_{ji}$ and

C=total cost; *y*=generic measure of output (Model 1: y=effective-kilometers; Model 2: y= passenger-revenue); $p(p_k, p_l, p_e, p_m)$=vector of input prices where p_k=price of capital, p_l=price of labor, p_e=price of energy, p_m=price of maintenance; *t*=time trend variable where t=1,2,.....n;

19 'The literature has produced something of a competition in the development of exotic functional forms. However, the translog function has remained the most popular and by one account, (Guilky et al., 1983) is the most reliable of several available alternatives' (Green, 1990, FN.25)

20 Share equation for input 'i' may be given as 'S_i' where $S_i = \delta \ln C/\delta \ln p_i$, wherein $\delta c/\delta p_i = x_i$ by 'Shephard's lemma' (x_i= quantity of input i).

21 It has been shown (Barten, 1969) that maximum-likelihood estimates of a system of share equations with one equation deleted is invariant to which equation is dropped.

22 This means that only relative prices matter, or, *C(tP,y)= t.C(P,y)*

23 To impose linear homogeneity in input prices the following constraints have to be imposed: $\Sigma_i\alpha_i=1$; $\Sigma_i\alpha_{ki}=0$; $\Sigma_i\alpha_{li}=0$; $\Sigma_i\alpha_{ei}=0$; $\Sigma_i\alpha_{mi}=0$; $\Sigma_i\alpha_{yi}=0$; $\Sigma_i\alpha_{ti}=0$; $\Sigma_i\alpha_{eri}=0$ where, i=k,l,e,m; y=output, t=time trend and er=frequency of service.

er=frequency of service and S_i(=$p_i x_i$/C)=share of 'i' th input in total costs where x_i=input usage with respect to the 'i'th input.

Given the special property that the sum of cost shares always equals unity, the system of share equations provides a 'seemingly unrelated regression model' that can be used to estimate the parameters of the system of equations. For efficient estimation one must take into account the correlation between error terms across equations. This is achieved through a systems method of estimation. Zellner(1962), devised a method which takes these factors into account when there is a system of equations ('Zellner's Seeminly Unrelated Estimator). The parameter estimates which emerge are numerically equivalent to those of the 'maximum likelihood estimator'. This method was therefore used to estimate the system of equations consisting of the cost function and the share equations.[24] After parameter estimates have been obtained the cost function has to be tested for theoretical consistency or 'well-behavedness'. Two main aspects to be checked are 'monotonicity' and 'concavity'.[25]

4. Empirical Results

4.1 Some preliminaries:

Prior to the actual estimation exercise it was essential to look into the question of 'stationarity' and 'cointegratedness' of the variables since we have specified a regression model in time-series. Testing for cointegratedness can be quite complex in the case of multivariate regression analysis encompassing a system of equations as in this study.[26] Further, these tests could not be attempted since the time period of this analysis covers only 9 years. This may be considered as a limitation of the present analysis.

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24 This method uses equation by equation 'OLS' to obtain an estimate of the disturbance covariance matrix and then does 'generalised least squares' given this initial estimate on an appropriately 'stacked' set of equations. Further, one can update the estimates of the disturbance covariance matrix and iterate the Zellner procedure until changes from one iteration to the next in the estimated parameters and the estimated disturbance variance-covariance matrix becomes arbitarily small.

25 'Monotonicity' implies that the cost function should be monotonically increasing in input prices. This can be detected by observing whether the fitted 'shares' are positive or not at all observations. 'Concavity' indicates that the cost function should be strictly 'quasi-concave' in input prices. This calls for 'negative semi-definiteness' of the bordered 'Hessian' of the cost function or, alternatively the 'nxn' matrix of substitution elasticities must be negative semi-definite at each observation.

26 See Harris, R. (1995).

Another consideration that had to be assessed before presentation of the final results was to ascertain the 'structure of the cost function' which best depicts the underlying technology. The procedure involved was to check the validity of the parameter restrictions imposed on the 'non-homothetic' translog cost function by resorting to the 'likelihood ratio test' (Christensen et al., 1976). For B.E.S.T. (Bombay), the non-homothetic version of the cost function could not be estimated at all due to problems of multicollinearity between the 'output' term and the second-order 'output' terms in the cost function. Consequently, these second order 'output' terms had to be dropped from the more general non-homothetic cost function. In the case of the alternative with 'effective-kilometers' as the measure of output, the resultant cost structure turned out to be 'homothetic'.[27] For the alternative with 'passenger revenue' as the measure of output only a 'homogenous' version of the more general translog cost function could be estimated.

The main problem encountered while trying to estimate the system of equations was that of 'autocorrelation'. The system was therefore corrected for autocorrelation of the first order. More specifically, the procedure involved was to estimate each alternative before correcting for autocorrelation and noting the value of the 'Durbin-Watson' statistics. In the next step, correction for autocorrelation was undertaken, the 'Durbin-Watson' statistics noted and the presence or absence of the problem of 'autocorrelation' reconfirmed by the 'Box-Pierce' test based on the 'Q-statistics'.

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27 Berechman (1983, pp.19) found evidence of a homothetic production structure while developing a translog cost function for two bus co-operatives in Israel. Similarly, De Borger (1984, pp.46) confirmed that the hypothesis of homotheticity could not be rejected while trying to estimating a translog cost function for a regional bus transport company in Belgium. A homothetic production structure was also reported by Williams et al.(1981) while estimating a translog cost function for twenty publicly owned municipal bus operators in the State of Illinois, the U.S.

4.2 Empirical results:

Estimates of the Translog Cost Function:
B.E.S.T. (Bombay)

	Y=Effective-kilometers. (Model: 1)	Y=Passenger-revenue (Model: 2)
Coefficient	*Homothetic*	*Homogenous*
α_o	1.160*	9.266
α_y (OUTPUT)	1.070*	0.016
α_k (CAPITAL)	-0.056*	-0.041*
α_l (LABOR)	0.648	0.668
α_m (MAINTENANCE)	-0.242	-0.250
α_e (ENERGY)	0.650	0.623
α_t (TIME)	0.009*	0.014
α_{cr} (FREQUENCY)	0.584*	1.057*
α_{yy}	-0.055*	-
α_{kk}	0.200	0.197
α_{ll}	0.226	0.226
α_{mm}	0.037	0.040
α_{ee}	0.127	0.125
α_{tt}	1.968E-06*	1.027E-05*
α_{crcr}	0.041	-0.023
α_{kl}	-0.135	-0.134
α_{km}	-0.008	-0.009
α_{lm}	-0.025	-0.026
α_{ke}	-0.057	-0.054
α_{le}	-0.068	-0.066
α_{me}	-0.004	-0.005
α_{ky}	-	-
α_{ly}	-	-
α_{my}	-	-
α_{ey}	-	-
α_{tk}	-0.001	-0.001
α_{tl}	0.0007	0.0005
α_{tm}	0.0007	0.0008
α_{te}	-0.0004	-0.0003
α_{ty}	-	-
α_{crk}	-0.062	-0.062
α_{crl}	-0.078	-0.079
α_{crm}	0.049	0.050
α_{cre}	0.091	0.091
α_{cry}	-	-
α_{crt}	-0.0006*	-0.001*

* *Indicates not significant at the 5% level of significance.*

Table 1 (continued): Important Statistics.

	Y=Effective-kilometers (Model: 1)	Y=Passenger revenue. (Model: 2)
	Homothetic	*Homogenous*
COST FUNCTION		
R^2	0.986	0.986
R^2	0.982	0.981
SER	0.020	0.020
DURBIN-WATSON	2.650	2.653
Q-STATISTICS	17.447	17.349
SUM OF SQUARED RESIDUAL	0.028	0.030
F-STATISTICS	230.74	227.37
SHARE EQUATION		
CAPITAL		
R^2	0.953	0.955
DURBIN-WATSON	2.572	2.581
LABOR		
R^2	0.968	0.969
DURBIN-WATSON	2.690	2.688
MAINTENANCE		
R^2	0.696	0.713
DURBIN-WATSON	2.663	2.663

Critical values of the 'Q-statistics': 5% level of significance ($\chi_{0.05}^2$)=21; 1% level of significance ($\chi_{0.01}^2$)=26.2
H_0: There is no autocorrelation

The final results of the empirical estimation exercise for the B.E.S.T. (Bombay) are presented in Table 1. The coefficient estimates seem to alter depending on 'output' measure used. Coefficients associated with the price of maintenance variable were significant. This assessment is required since, due to data constraints, a proxy measure has been formulated for depicting this variable. Similarly coefficients linked to the only output attribute variable, 'frequency of service' were also mostly significant. Small magnitude of coefficients associated with the time trend variable 't' may be due to the monthly time-series data base used in this analysis. Under these circumstances, major shifts are unlikely.

Further economic interpretation of the parameter estimates can be provided by analysing the derived 'economic effects' such as patterns of factor substitution, economies of scale and economies of density as well as the nature of technical change over time. These are considered in the sections that follow.

5. Derived Economic Effects.

5.1 Elasticities of factor substitution and demand:

A major advantage of the translog functional form is that it places no apriori restrictions on economic effects such as the elasticities of factor substitution and demand. The 'Allen partial elasticity of factor substitution' which has been widely used in many studies, was resorted to for the purpose of computing these elasticities (Chambers, 1988, pp.93). This formulation is given as:

$$\sigma_{ij} = C.C_{ij}/C_iC_j$$

where, C= *total* costs; C_{ij}= $[\delta^2 C/\delta p_i . \delta p_j]$; C_i= $[\delta C/\delta p_i]$; C_j= $[\delta C/\delta p_j]$ and 'σ_{ij}' is the elasticity of factor substitution between factor *'i'* and factor *'j'*. If 'σ_{ij}' is greater than zero then it indicates that factors *'i'* and *'j'* are substitutes, while if 'σ_{ij}' is less than zero then factors *'i'* and *'j'* are complements. Partial elasticities of substitution in terms of the parameters of the translog cost function are expressed as (Binswanger, 1974, pp. 379) :

$$\sigma_{ij} = (\alpha_{ij} + S_iS_j)/(S_iS_j) \quad i \neq j \quad \text{and} \quad \sigma_{ii} = [\alpha_{ii} + S_i(S_i - 1)]/S_i^2$$

where 'S_i' indicates cost share of the '*ith*' factor and 'S_j' the cost share of the '*jth*' factor.[28] The own price elasticities of factor demand were also computed as (Chambers, 1988, pp.95):

$$\varepsilon_{ii} = \sigma_{ii}S_i$$

Estimates of these elasticities related to B.E.S.T. (Bombay) are given in Table 2.

28 The 'σ_{ii}' are meaningless conceptually. But 'σ_{ii}' should be negative for regularity conditions to be satisfied or else the own price elasticities of factor demand will not be negative, which is a theoretical necessity for a downward sloping factor demand curve.

Table 2. Estimates of the elasticity of factor substitution and own price elasticity of factor demand.*

Estimate	Effective-kilometers *(Model: 1)*	Passenger-revenue. *(Model: 2)*
σ_{kl}	0.0148	0.0224
σ_{ke}	-0.3536	-0.2861
σ_{km}	0.6334	0.5870
σ_{le}	0.1023	0.0997
σ_{lm}	0.3563	0.3329
σ_{em}	0.6882	0.6440
σ_{kk}	-0.0175	-0.0536
σ_{ll}	-0.0980	-0.0976
σ_{ee}	-0.0379	-0.1351
σ_{mm}	-5.6784	-5.3008
ε_{kk}	-0.0049	-0.0150
ε_{ll}	-0.0480	-0.0478
ε_{ee}	-0.0057	-0.0203
ε_{mm}	-0.4542	-0.4241

* *These have been computed at mean values of the cost shares.*

Firstly, Table 2 indicates that there is a fair amount of consistency in the magnitudes and signs of the elasticities irrespective of the output measure used. The own elasticity of factor demand have the theoretically correct negative sign. The values of 'σ_{kl}' indicates weak substitutability between 'labor' and 'capital' implying that there is not much scope of adjusting the way in which these inputs are combined.[29] Complementarity between 'capital' and 'energy', as reflected by the estimates of 'σ_{ke}' denotes that buses are not fuel efficient. In this connection, it may be noted that in the Indian context, bus chassis are actually truck chassis unsuitable for intra-city driving conditions, reflecting out-moded and obsolete technology. However, the fuel inefficiency depicted via this complementarity relationship may also be a result of the adverse operating environment in the city of Bombay, where rising levels of congestion mainly due to the spectacular growth of vehicular population over limited and constricted road space can hamper the efficiency of operations in terms of slower speeds and consequent deteriorating fuel consumption levels. Substitution possibilities exist between 'maintenance' and all other

[29] Button (1985) refers to this as the 'technologically unprogressive' nature of the bus transit industry characterised by 'one bus one driver' technology.

inputs in the production process. The coefficients 'σ_{km}', 'σ_{lm}' and 'σ_{em}' are greater than zero. This is a significant result. Better maintenance of buses would ensure better day to day performance and go a long way in prolonging the service life of a bus, reducing the need for costly fleet replacement. A strong maintenance drive would enhance energy efficiency in terms of kilometers run per litre of fuel consumed, resulting in higher vehicle-utilisation, greater fleet-utilisation and through better scheduling raise productivity of labor as well. Thus, the entire system could be effectively revamped, in a bid towards achieving better performance levels of all inputs in the production process. Needless to say, a determined maintenance drive would have wider ramifications in terms of reducing 'negative externalities' of bus operations such as pollution levels since emission levels of diesel driven vehicles such as passenger buses are very sensitive to proper tuning and maintenance. The estimates of the own price elasticity of factor demand are small indicating weak response to factor price changes.

An important by-product of the cost model we have estimated is the possibility of getting an insight into the degree of scale economies in the provision of bus services. This aspect is scrutinised in the following section:

5.2 Economies of scale:

What should be the optimum scale of operations for a bus transit firm in order to be cost-effective is a matter of serious debate everywhere. Analysis of scale economies attempts to provide some kind of quantitative basis to resolve this issue. Scale economies are defined as unity minus the elasticity of 'cost' with respect to 'output'. Symbolically, this may be given as:

$$\eta_c = 1 - (\delta \ln C / \delta \ln y)$$

The interpretation of results with respect to scale economies would depend on which of the two models is being considered for calculating the values. If the model based on 'effective-kilometers' is being used (model 1), then scale economies would denote variation in costs due to changes in capacity. We denote this type of scale economies as 'economies of scale with respect to service provision'. Whereas, if the model incorporating 'passenger revenue' as the measure of output (model 2) is being resorted to for computing the values then scale economies would depict the behaviour of costs with respect to capacity utilisation.[30]

30 It may be noted that Windle (1988), in his analysis of urban bus transit firms in the U.S., formulates a

We designate this type of scale economies as 'economies of scale with respect to service use'. To begin with Table 3 presents estimates pertaining to 'economies of scale with respect to service provision' for the B.E.S.T. (Bombay).

Table 3. Economies of scale with respect to service provision
Model 1 (y=Effective-kilometers):

YEAR	$\eta_c^{@}$
1986-87	0.8399
1987-88	0.8405
1988-89	0.8392
1989-90	0.8352
1990-91	0.8393
1991-92	0.8466
1992-93	0.8548
1993-94	0.8587

** Economies of scale were computed at all points in the sample given monthly time-series data. The results presented in the above table are means of these estimates for a particular year*
@ Given a 'homothetic cost structure in this case, $\eta_c = 1 - [\alpha_y + \alpha_{yy} \ln y]$.

If we observe the trends in the above table we find that there is sufficient scope for exploiting scale economies within the existing set-up in the case of B.E.S.T. (Bombay). The apparent geographical vastness as regards area of operation may be put forth as an explanation for this phenomena. Thus in relation to the size of the bus transit corporation the market being served is very large in terms of geographical coverage, conferring sufficient cost advantages which accrue from increasing scale of operations. What this result also seems to hint at is the futility of introducing other new entrants into the market for provision of bus services.

Economies of scale with respect to 'service use' derived from model 2, provides an insight into the behaviour of costs with respect to capacity utilisation. Since the cost structure was found to be 'homogenous' in this case, 'η_c' =0.984 for the entire study period.[31] Therefore considerable economies exist with respect to service use, for B.E.S.T. (Bombay). This means that cost savings would accrue by tapping areas of high patronage and times of the day when demand for service peaks. Thus, the routing and scheduling patterns could be redesigned taking this factor into account.[32]

similar measure termed as 'returns to passenger density' which shows the effect on costs of increasing passenger-miles and load factor.

31 More specifically, η_c=[1-δlnC/δlny]=α_y in this case.

Since high patronage will be assured along prime catchment areas such as busy traffic corridors and during peak-hours, this may call for innovative traffic management schemes such as 'exclusive bus lanes' so that users can have ready access to transit services and buses can move smoothly to cater to the commuters effectively. This result also emphasises the high social cost of the policy of operating a large number of uneconomic routes mainly characterised by low passenger density.

Another measure which is significant in industries where output is provided over a network is the 'economies of density'. The following section highlights this measure specially relevant in the case of transportation industries.

5.3 Economies of Density:

Output produced by the bus corporation has to be distributed over a network. The manner in which output is provided across the network in terms of the routing pattern or the scheduling of services could affect costs. 'Economies of density' attempt to capture some of these relationships. If route-kilometers broadly reflects the network configuration then, a measure of network density can be computed as :

Frequency of service (er)= Effective-kilometers / Route-kilometers.

Since we have already incorporated this variable into our cost function, the degree of 'economies of density' can be derived by computing the following elasticity:

$$\eta_{er} = \delta \ln C / \delta \ln er$$

The estimates of 'economies of density' for B.E.S.T. (Bombay) have been presented in Table 4.

[32] Evans (1991, pp.137) while analysing Britain's local bus service provides evidence to support the greater profitability of high passenger density routes. It is rationalised that cost per passenger are lower on high density routes because the same bus operating costs are spread over more passengers. Similarly, Windle (1988, pp.130) detected substantial 'returns to passenger density' in his analysis of urban bus transit firms in the U.S.

Table 4. Economies of Density.*@

YEAR	η_{er}
1986-87	0.106
1987-88	0.092
1988-89	0.063
1989-90	0.041
1990-91	0.037
1991-92	0.021
1992-93	0.036
1993-94	0.035

**For computing 'economies of density' we resorted to the cost model:1 which incorporates producer-related output measure, 'effective-kilometers'. This approach was adopted since it was felt that the 'frequency of service' on which this scale economies measure is based is an attribute which the producer can partly influence while designing service provision. @The estimates are mean values based on monthly data for a particular year.*

The overall implication that emerges from Table 4 is that considerable cost advantages can be gained by enhancing the frequency of service.

Having analysed a host of 'economic characteristics' relating to the three urban bus transit corporations under study, such as elasticities of factor substitution and own price elasticities of factor demand, different kinds of scale economies such as 'economies of scale with respect to service provision', 'economies of scale with respect to service use' and 'economies of density', we now proceed to scrutinise the nature of technical change over time in an attempt to throw light on the overall performance of the B.E.S.T. (Bombay) during the study period.

5.4 The nature of technical change

The time trend variable was incorporated into the cost function to diagnose the nature of technical change over time. This would aid in ascertaining whether productivity levels had improved or deteriorated during the study period. Technical change can be deciphered from the cost function as the downward proportionate shift in the cost function over time. Symbolically, this is given as:

$$\rho_t = -[\delta \ln C/\delta t]$$

If 'ρ_t' is greater than zero it implies technical progress, if 'ρ_t' is less than zero it means that there is technical decline and if 'ρ_t' is equal to zero, it implies that there is no technical change. Although technical change is usually measured in terms of the production function, Winston (1985, pp. 69) stresses that it is more appropriate to estimate cost changes over time rather than output changes (as depicted by shifts in the production function) since in the case of regulated industries, service obligations are often specified and productivity measures focusing solely on output changes may yield potentially misleading results. Since the B.E.S.T. is a regulated concern with specified service obligations to cater to, we also adhered to this contention.[33]

The results depicting the nature of technical change over time for the B.E.S.T. (Bombay) is given in Table 5.

Table 5. Technical change over time.*

YEAR	ρ_t
1986-87	-6.56
1987-88	-7.11
1988-89	-7.42
1989-90	-7.77
1990-91	-7.98
1991-92	-8.15
1992-93	-8.73
1993-94	-9.43
Mean (Study period)	**-7.90 per annum**

** For deriving measures of technical change the alternative based on producer-related measure of output, 'effective-kilometers' (model: 1) was used. It was reasoned that since productivity is supposed to reflect performance form the producers side, this was the correct approach.*

Table 5 indicates that the entire study period is characterised by increasing rate of technical decline. This clearly supports our preliminary notion that performance and services have deteriorated in the case of B.E.S.T. (Bombay).

33 Before analysing our results regarding the nature of technical change it may be noted:
(a) We are assuming that 'time' is continuous and therefore measures of technical progress (or regress) can be expressed in terms of the differentials of the cost function. (b) We assumed 'disembodied' technical change, which implies that the underlying production function does not change in shape or form but merely shifts up or down over time. (c) Since our data is based on monthly observations, we had to convert the 'per month' shifts in the cost function to 'per annum' shifts since, conventionally, productivity changes are expressed in terms of annual changes.

6. Summary and Conclusions:

The B.E.S.T performs a crucial role in providing commuter services within the city of Bombay, carrying over 55 lakh passengers daily. And, with a fleet size of nearly 4000 buses along with a staff strength of nearly 40,000 employees, is easily one of the largest city level bus transit corporations in the world. Given these facts, an in-depth look into the 'economic characteristics' of this urban bus transit firm seemed inevitable to assess various economic facets from the point of view of efficient operation of bus services. For this purpose, an attempt was made to empirically estimate a 'cost function' for the B.E.S.T. on the basis of monthly time-series data related to the period 1986-87 to 1993-94 and to derive some 'economic effects.' A sound theoretical and quantitative base that characterises this cost function was embedded to ensure authenticity of the results. This paper presents an overview of this exercise.

The interpretation of the empirical results revealed vital aspects which could be extremely significant for monitoring bus transit services. First and foremost, it appears that productivity has declined during the study period. The rate of technical decline is around 8% per annum, which, is a high figure. There seems to be an ardent need for corrective action in this respect. The most important conclusion, based on the 'elasticities of factor substitution', clearly suggests that it is advantageous to pursue an effective maintenance culture if costs are to be curtailed. This would prevent the need for costly fleet replacement, ensure better energy utilisation rates and through better use of these inputs, enable better utilisation of labor as well. This can be a critical issue since, given long term contractual agreements, labor appears to be a 'quasi-fixed factor' This is particularly true in the case of the B.E.S.T., where the 'staff-ratio' has remained almost static at 'twelve' per bus on road. Given this constraint, it only seems fair to introduce such measures that will lead to optimum use of the 'labor' resource. Complementarity diagnosed between 'capital' and 'energy' signals the need for fuel-efficient technology specifically suited to city driving conditions. Lastly, there is considerable scope for exploiting economies by expanding services in general, by tapping areas of high patronage, and by enhancing the frequency of service within the existing set-up of a single large firm such as the B.E.S.T. Innovative bus priority measures such as 'exclusive bus lanes' are inevitable under these conditions so that the bus transit system can provide high levels of accessibility and achieve their maximum potential. This result also probably hints at the futility of introducing other new entrants into the market for providing bus services.

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Appendix 1

Figure 1. The Bombay Metropolitan Region.

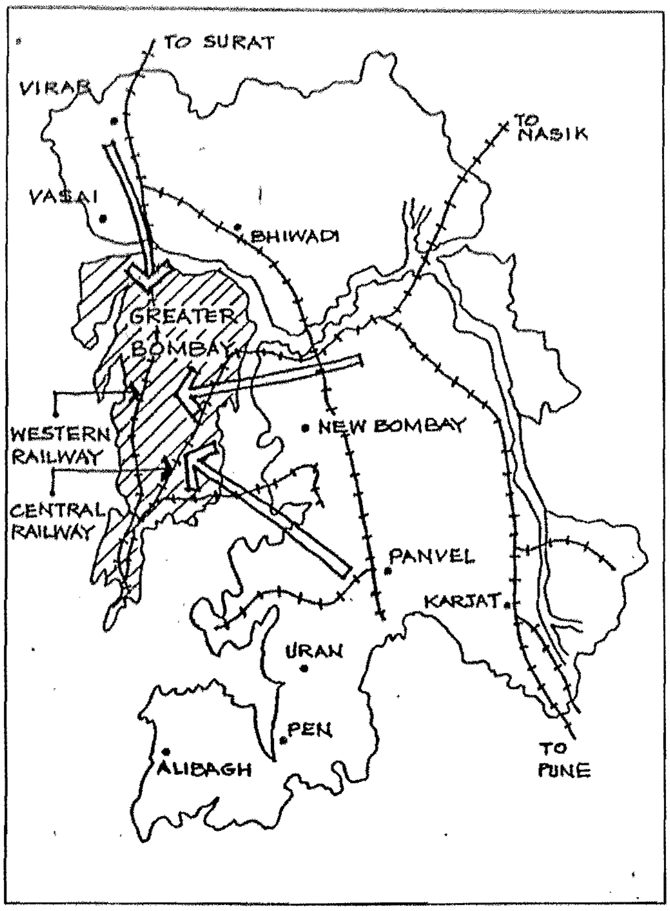
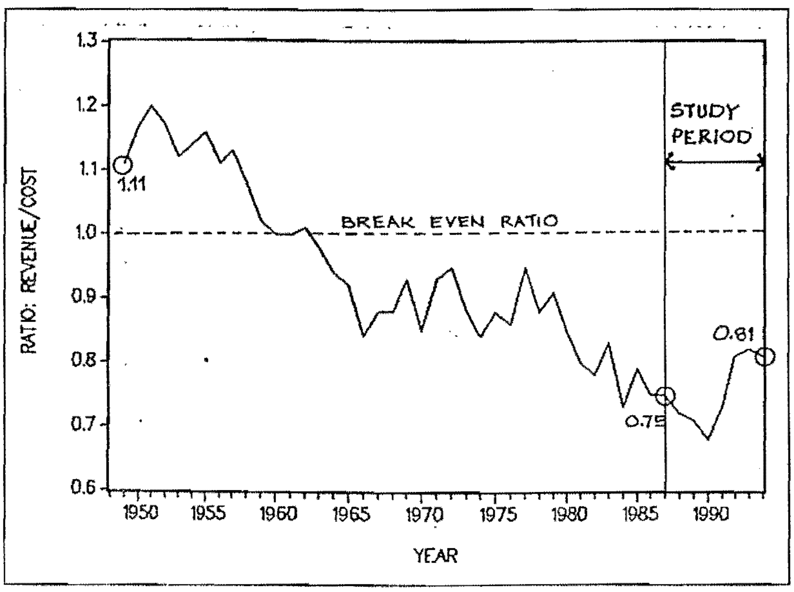


Figure 2. Operating Ratio: B.E.S.T. (Bombay)



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