EVALUATION OF BUS ROUTES PERFORMANCE IN ADDIS ABABA CITY USING STOCHASTIC FRONTIER MODEL *

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1. INTRODUCTION

The efficiency of bus routes is an important performance measure for bus service providers. Route efficiency can be regarded as a production process in which a variety of individual route inputs is used to determine its output. From the viewpoint of the bus companies, the way in which resources are used to transform routes into an efficient route is important. This study has an objective of analyzing the input factors influencing the efficiency of bus routes using stochastic frontier regression. Thus, based on the result, strategic recommendations would be drawn to improve the bus route performance. Bus routes provided by a bus company in the city of Addis Ababa (the capital of Ethiopia) is taken as a case study. Bus transportation is an important element of day-to-day activities in Addis Ababa because it is a relatively affordable means of transportation. Among many factors affecting the overall bus transportation performance, bus route design in such a way that it generates revenue is important. The attributes related with the individual bus route affects the economic productivity of the bus company. According to TCRP synthesis of transit practice 10, 1995[1], Economic and productivity standards of bus routes depend on some criteria such as passengers per hour, cost per passenger, passengers per km, passenger per trip, revenue per passenger per route etc. Stochastic frontier analysis assumes that there is a parametric function between the inputs and outputs (K. Cullinane et al, 2006)[2]. To apply the logarithmic frontier model, dependent variables (outputs) are taken as the revenue and/or the number of passengers per route. The efficiency of each route was calculated and based on the result, strategic measures were recommended.

2. METHODOLOGY

The research approach implemented in this study involved analysis of bus company data and modeling the bus route efficiency using stochastic frontier analysis to assess the functional performance of the bus routes.

Stochastic frontier model

The stochastic frontier regression model is a classical linear regression model with a non-normal, asymmetric disturbance. It has been used variously in studies of production and cost. (W. Green, 2000)[3] Stochastic Frontier Model (SFM) is introduced simultaneously by Aigner et al., 1977[4] and Meeusen and van den Broeck, 1977[5]. SFM analyses the parametric and functional relationship between the input factors and the output. What differs SFM from the Data Envelopment Analysis (DEA) is that SFM is not only allows for technical inefficiency, but also acknowledges the fact that random shocks outside the control of producers can affect output (K. Cullinane et al. 2006)[2]. SFM can be stated as a frontier production function as follows:

$$\log Y_i = \alpha + \sum \beta_i \log x_i + \varepsilon_i \qquad (1)$$

Where Y_i donates the production (output) for the *i*th producer (i = 1,2,…, N); xi is a vector of appropriate functions of the input factors; α and β are estimated coefficients. ε_i is the error term made up of two independent components.

$$\varepsilon_i = v_i - u_i \qquad (2)$$

wher $v_i \sim N(0,\delta^2_v)$ is the error term representing the usual statistical noise found in any relationship and $u_i \geq 0$ is the error term representing the *technical inefficiency.* Note that u_i measures the technical inefficiency in the sense that it measures the shortfall of output (Y_i) from its maximal possible value given by the stochastic frontier ($\alpha + \sum\beta_i \log x_i + v_i$) (J. Jondrow et.al. 1982). The inefficiency term u_i is the center of attention of this study. When the method of this form is estimated, one readily obtains residuals $\varepsilon_i = \alpha + \sum\beta_i \log x_i - \log Y_i$, which can be regarded as the estimate of the error term. The problem of decomposing these estimates in to separate estimates of components v_i and u_i for each producer has remained unsolved for several times even though it was possible to calculate the average technical efficiency of N producers (G.E. Battese and T.J. Coelli, 1988)[6]. J. Jondrow et al. 1982[7], however, have derived a useful approximation that now the standard measure of technical efficiency for the half-normal model is given in equation 3. λ and δ can be estimated and/or calculated with the relationship $\lambda = \delta_u / \delta_v$, $\delta = (\delta_u^2 + \delta_v^2)^{1/2}$. ε is readily considered as a residual. ϕ (.) is a standard normal distribution and Φ(.) is its cumulative standard distribution.

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$$E[u_i \mid \varepsilon_i] = \frac{\delta\lambda}{1+\lambda^2}\left[\frac{\phi(Z)}{1-\Phi(Z)} - Z\right], \qquad Z = \frac{\varepsilon\lambda}{\delta} \tag{3}$$

Once u_i is estimated, the technical efficiency can be calculated as;

$$TE_i = \exp(-U_i) \tag{4}$$

Among the application of SFM to the transportation researches, Sanjay and Anand (2002)[8] made an attempt to quantify the technical efficiency (productive efficiency) of twenty three major Indian state transport undertakings mainly providing rural and inter-city passenger transport services for the year 2000-2001. This is done by the estimation of stochastic frontier production using the method of maximum likelihood. Anna and Raymond (1998)[9] implemented the stochastic frontier cost functions to analyze the degree of efficiency of urban bus companies and to quantify the reason for this efficiency. Farsi et al. (2006)[10] applied a number of stochastic cost frontier models to a panel of 94 regional bus companies over 12 years period to distinguish the ability of those models to estimate the inefficiency and the unobserved firm-specific heterogeneity in network industry. Gagnepain and Ivaldi (2005)[11] applied stochastic production and cost frontiers to measure inefficiencies in France transport system and European airline. Cullinane et al. (2005)[2] applied Data Envelopment Analysis and Stochastic Frontier Analysis to measure technical efficiency of the world's largest container ports and compared the results obtained. In this study, the half-normal stochastic frontier model is chosen for the analysis. There are no objective criteria for choosing between the half-normal and exponential specifications apart from the judgment of the individual researcher. Nevertheless, the half-normal is suggested by some literatures to be the most useful formulation (Battese and Coelli, 1998)[6]

3. EMPIRICAL ANALYSIS

(1) Data

The data implemented in this study is collected from the bus company and the characteristics of each route are analyzed. The dependent variable is taken to be the revenue collected per route for the year 2004, because revenue is a very good measure of route output. The independent variables are selected to be the number of buses allocated for the specific route, the distance covered by the route in the year, number of trips per route, government subsidy per route, the fare of the route (in the city of Addis Ababa the fixed price is implemented, with each route has different price). Trip length, number of bus stops, employed population and the population density at the origin station are also taken as independent variables. The entire dependent and the independent variables are given in the logarithm of the original value for application of the proposed model. When the number of passengers served by individual routes per year is concerned, the majority (27 out of 93 routes) served the passenger between 2 million to 3 million per year. Only three bus routes have 7 million and above passengers per year. 14 bus routes have passengers of less than 500,000 per year. The revenue generated by individual routes is also analyzed having in mind that it has high correlation with the number of passengers. 46 bus routes have a revenue of 500,000 to 1 million Ethiopian Birr [ETB] per year (1US = 8.8ETB). Only 2 bus routes exhibit a revenue of 2 million and above and 2 bus routes have the revenue of less that 10,000 ETB per year. The above outputs have a direct relation with the number of buses allocated to individual routes, which ranges from one to ten. The minimum route length is less than 5km (only 1 bus route) and the maximum one is greater than 40km (4 bus routes). Concerning the bus frequency/waiting time of individual routes, the majority (34 bus routes) have the waiting time of 10-20 minutes. The minimum one is the waiting time of less than 10 minutes and there observed 70 minutes and above waiting time (5 routes). The waiting time is calculated as headway of consecutive buses.

(2) Overview of bus transportation in Addis Ababa city

In the city, there is only one bus company called Anbessa City Bus Enterprise. It operates a fleet of 524 conventional buses and provides scheduled services along 93 routes as well as non-stop rapid (express) services. Although there is a system of flat fares, there is a range varying according to distance. There are about 1400 bus stops, 16 checkpoints and 3 main bus terminals. The Anbessa City Bus Enterprise, a reliant on and subsidized by the city council, moves around 40%of all public transport passengers. The absence of an up-to-date structure in the enterprise, shortage of finance, and the reduction of subsidy from government are the biggest challenge for the service improvement. Absence of well-defined performance parameters to evaluate the operational efficiency of the bus company is also a constraint for development. The spatial analysis on the bus network coverage shows that only the centre of the city, where commercial activities are abundant, shows high bus network availability. The areas with low or no bus network availability are in localities where the city is exhibiting trends of urban expansion, and residential developments are underway (Mintesnot G. and S. Takano, 2006)[12]. According to the recent structural synthesis map, prepared by the Addis Ababa Master Plan Revision Office, those areas are strategic areas for city expansion development (ORAAMP, 2002)[13]

(3) Bus route efficiency

The result of the maximum likelihood estimates of stochastic frontier model is presented in table 1. The least squares and the half-normal SFM approaches have similar tendency on the results. The least square model has R^2=0.894; which shows the highly interdependent input and output factors. According to the analysis result, an increase in the number of trips increase the revenue generated by the routes. Subsidy and fare has also a direct relationship with the route performance. One of the identified factors that reduce route performance is the number of bus stops. The higher the number of bus stops the route has, the lower the revenue generated. Employee population at the route origin also reduce route performance because of the very fact that employee population as a tendency of choosing taxi. The other factor that has a negative influence on the route performance is waiting time and linkage. Evidently, high waiting time reduces revenue generation. That higher the route is connected with others routes, the less the revenue is because of high income/passenger sharing among routes. The results on the efficiency estimates of individual route are calculated using equation 3 & 4, and given in figure 1. The efficiency estimate of the half-normal estimate shows that the efficiency concentrated within the range of 50 to 80%.

Table 1. Stochastic frontier estimations

	Least squares		Half-normal SFM	
Variable	**β**	**t-ratio**	**Variable**	**β**
Constant	1.847	1.527	2.835	1.782
Number of trips	1.072	1.327	1.895	1.556
Subsidy	2.080	1.635	2.899	1.851
Fare	0.247	5.435	0.265	5.472
Trip distance	0.770	8.874	0.737	6.669
Number bus stops	-0.017	-1.244	0.005	1.049
Employee population at route origin	-0.016	-1.380	-0.017	-1.339
Population density at route origin	0.017	1.050	0.014	1.871
Waiting time	-0.059	-0.795	-0.058	-0.720
Number of buses	0.023	1.259	0.042	1.459
Trip length	0.177	1.549	0.142	1.067
Linkage	-0.081	-3.072	-0.080	-2.878
Bus frequency	1.431	0.438	2.216	0.650
Bus capacity	1.522	1.467	2.325	1.683
λ	-	-	1.475	1.266
δ	-	-	0.058	4.703
δ_u	-	-	0.048	-
δ_v	-	-	0.033	-
R^2	0.894		-	
Log likelihood	159.837		160.303	

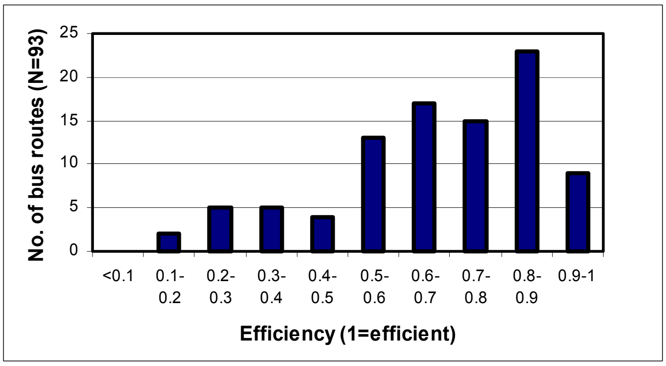

Figure 1. Efficiency estimates of bus route

4. POLICY RECOMMENDATIONS

In order to improve the existing bus service in to an efficient system, a competitive bus industry should be created in the city. In addition to this, the existing bus company has to make strategic efforts. There are four policy and strategic interventions recommended in this study:

(1) Service coverage

The results on the population density and the employed population shows that there are strategic areas the bus service should be diversified. According to the study on transit availability indices, it is clearly seen that the areas with low or no bus transit availability are in localities where the city is exhibiting trends of urban expansion and residential developments are underway. According to the recent structural synthesis map prepared by the Addis Ababa Master Plan

Revision Office, those areas are strategic areas for city expansion development. Therefore, it is recommended that the bus company use the opportunity of this attractive area for its service expansion.

(2) Subsidy

The Addis Ababa city bus service is believed to be provided for the urban poor. Government has its own economic as well as political interest on it. Therefore, subsidizing the existing bus service will help the company to secure its financial capability. Currently, the government is decreasing the subsidy so that the bus fare is increasing and the burden is coming upon the urban poor. As a strategic measure, the government may issue a policy to *subsidies the productive rout*e. This will stimulate to company to improve route productivity

(3) Bus and drivers scheduling

The number of buses and the demand are not compatible. Adding the number of buses and allocating to the under served areas is important. An efficient public transport is characterized by the optimal allocation of available resources. Bus scheduling and dispatching system should be prepared carefully so that a number of buses in one route will not affect the efficiency of the overall system.

(4) Bus pricing

Currently the fixed and flat fare system is implemented in the network system even though different routes have different prices. Implementing the fares differentiated by distance and time-of-day could improve the company's financial position. Since the government subsidy is decreasing year by year, the company has to look for cost recovery mechanism. The fare differentiated by distance and peak-hour high fare is applicable because there exists a very low demand elasticity. However, political acceptability is an issue as the city bus is an interest of the government as a public service for the urban poor.

5. CONCLUSION

The objective of this research was to analyze factors affecting the bus route performance and to quantify the efficiencies of each bus routes. The half-normal stochastic frontier model was implemented and it gives a fine result in estimating the technical efficiencies of bus routes. The input conditions that affect the efficiency of each route are diagnosed. The mean efficiency of the bus routes was found out to be 67.14%. The first and the third quartile result showed that the efficiency values are concentrated between 50% and 80%. Bus routes destined to the periphery (expansion areas) have higher efficiency that inner and intermediate city routes. This research signifies the importance of measuring bus route inefficiencies as an input for service improvement endeavors considering the individual bus route as a firm attempting to get a better output by transforming inputs.

REFERENCE

[1] Howard P. Benn. Bus Route Evaluation Standards, TCRP, synthesis of transit practice 10, Transport Research Board, National Academy Press, Washington DC, 1995

[2] Kevin Cullinane, Teng-Fei Wang, Dong-wook Song, Ping Ji. The Technical Efficiency of Container Ports: Comparing Data Envelopment Analysis and Stochastic Frontier Analysis, Transportation research part A, 40, pp. 354-374, 2006

[3] William H. Green. Econometric Analysis-4ed, Prentice-Hall, inc., New Jersey, 2000

[4] Aingner D.J., C.A.K. Lovell and P. Schmidt. Formulation and Estimation of Stochastic Frontier Production Function Models, Journal of Econometrics, 6, pp. 21-37, 1977

[5] Meeusen W. and van den Broeck. Efficiency Estimation from Cobb-Douglas Production Function with Composed Error, International Economic Review 18, 435-444, 1977

[6] George E. Battese and Tim J.Coelli. Prediction of Firm-Level Technical efficiencies with a Generalized Frontier Production Function and Panel Data, Journal of Econometrics, 38, pp. 387-399, 1988

[7] J. Jondrow, C.A.K. Lovell, I.S. Materov and P. Schmidt. On the Estimation of Technical Inefficiency in the Stochastic Frontier Production Function Model, Journal of econometrics, 19, pp. 233-238, 1982

[8] Sanjay K. Singh and Anand Venkatesh. Comparing Efficiency across State Transport Undertakings: a Production Frontier Approach , Indian Journal of Transport Management 27(3): 374-391

[9] A. Matas and Jose-Luis Raymond. Technical Characteristics and Efficiency of Urban Bus Companies: the case of Spain, Transportation, 25, pp. 243-263, 1998

[10] M. Farsi, M. Filippini and M. Kuenzle. Cost Efficiency in Regional Bus Companies: an Application of Alternative Stochastic Frontier Models, Journal of Transport Economics and Policy, 40 (1), January 2006

[11] P. Gagnepain and M. Ivaldi. Measuring Inefficiencies in Transport Systems: between Technology and Incentives, IDEI working Paper No. 377, September 2005

[12] Mintesnot G. and S. Takano. Application of Logical Planning Model for Public Transport Improvement Programs in the City of Addis Ababa, JSRSAI, Studies in Regional Science Vol. 36, 2006

[13] Office of the Revision of Addis Ababa Master Plan (ORAAMP). Project Proposal for Addis Ababa Transport Sector, Addis Ababa, Ethiopia, 2002.