PUBLIC TRANSIT PRODUCTIVITY

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Abstract

This paper analyzes total factor productivity (TFP) in public transit systems using panel data for 24 US transit systems and 13 years of data. It estimates a production function and input demand equations jointly to obtain the coefficients needed to decompose TFP among its sources. It finds that the factors that contribute to TFP growth are network expansion, fleet age, reductions in operating subsidies, increases in capital subsidies and technical change. Additionally, it finds that decreases in average bus speed reduce TFP, and private sector involvement in providing transit services does not affect total factor productivity in these systems.

KEYWORDS: total factor productivity, production function, input demand equations, decomposition, efficiency.

1. Introduction

Over the past two decades many productivity studies have been conducted with the purpose of identifying the best and worst performing transit systems and the sources of their performance. In the early years these studies compared simple productivity and efficiency measures and established relationships between them and policy variables. Lately, the analysis has assumed a level of sophistication hitherto unforeseen. This has been made possible by the development of alternative indexes of efficiency and productivity in other fields particularly economics and management science that have seen applications in public transit systems. These indexes include efficiency measures based on data envelopment analysis, stochastic frontier estimation of cost and production functions, and non-parametric distance functions (Fare and Grosskopf, 1990) of which the Malmquist index is the most popular. Not to be left out in this list is parametric total factor productivity defined as the rate of change in output less the sum of the share weighted rates of changes of inputs.

While all these approaches have their merits, the one which seems most favored in the productivity literature is total factor productivity. This is because it can be used to decompose the rate of change of output among various sources including most of those listed by Ray and Mukherjee (1996) in their decomposition of the Fisher productivity index. Additionally, it can be combined with second-stage regression to relate it to policy and background variables. Except the Fisher index decomposition offered by Ray and Mukherjee the other non-parametric measures of efficiency and productivity must be combined with second stage regression analysis to decompose efficiency among its sources. This is especially so with regard to DEA measures of efficiency; the Malmquist index can be used to decompose efficiency into technical change and catching-up effect.

Because of its widespread acceptance total factor productivity is used in this paper to identify the sources of productivity changes in selected US public transit systems. In doing so the paper makes a modest contribution to the public transit economics literature through its findings that changes in network size, fleet age, pure technical change, and operating and capital subsidies are some of the sources of total factor productivity growth. Additionally, the paper finds that decreases in average bus travel speed have reduced total factor productivity.

The rest of the paper is organized into five sections. The section following deals with empirical framework, and it is followed by data. Next, estimation and results, total factor productivity decomposition and conclusions are presented respectively.

2. Empirical Framework

Assume that a transit system uses a set of inputs $x_1, x_2 \dots, x_n$ which consists of capital, labor and fuel whose prices are represented by the vector w to produce output Q. The transit system's technology is represented by a set of $z = 1,2,3, \dots, k$ variables including operating and capital subsidies, time (*t*), fleet age, purchased transportation, and network size in terms of route miles that influence output. Its total cost (C) is given by $C = \sum_n w_n x_n$. Assume also that the firm's objective is to maximize output subject to this cost and let the underlying production function be a Cobb-Douglas type of the form,

$$(1) \quad Q = \beta_0 x_1^{\beta_1} x_2^{\beta_2} x_3^{\beta_n} z \quad where \quad z = \exp\left(\sum_k \ln z_k\right)$$

From this equation the first order condition for constrained output maximization is the equation below:

$$(2) \qquad \frac{\partial \ln Q / \partial \ln x_i}{\partial \ln Q / \partial \ln x_n} = \frac{w_i x_i}{w_n x_n}$$

Using this equation and the production function the demand for each input is given by (3).

$$(3) \qquad x_1 = \left(Q^{\theta}\right)\left(z^{-\theta}\right)\left(\frac{w_2}{w_1}\right)^{\beta_2\theta}\left(\frac{w_3}{w_1}\right)^{\beta_3\theta}\left[\beta_0 \prod_n \left(\frac{\beta_n}{\beta_1}\right)^{\beta_n}\right]^{-\theta}$$

$$for \quad \theta = 1/\left(\beta_1 + \beta_2 + \beta_3\right)$$

Similar demand equations can be derived for the other inputs.

Given the production function, the growth of output will be in terms of the growths in inputs and all the variables in the production function including the technology variables. This output growth is the partial derivative of the production function with respect to time. Taking this derivative and solving gives (4).

$$(4) \quad -\sum_n S_n\left(\partial \ln x_n / \partial t\right) = -\theta \frac{\partial \ln Q}{\partial T} + \theta \frac{\partial \ln z}{\partial t}$$

$S_n = w_n x_n / \sum_n w_n x_n$ is the cost share of an input. Adding the rate of change of output to both sides of (4) the rate of change of total factor productivity $\partial \ln TFP / \partial t = \partial \ln Q / \partial t - \sum_i S_i \partial \ln x_i / \partial t$, is,

$$(5) \quad \partial \ln TFP / \partial t = (1-\theta)\frac{\partial \ln Q}{\partial T} + \theta \frac{\partial \ln z}{\partial t}$$

Equation (5) is a decomposition of the rate of change of total factor productivity among its sources. Its first term is the scale-adjusted rate of change in output. Under constant returns to scale this term is zero, whereas under economies (diseconomies) of scale it is positive (negative) and increases in output increase (reduce) total factor productivity. The second term is the effect of the set of technology variables on total factor productivity. If a technology variable has a positive coefficient increases in it would increase output growth and total factor productivity.

To apply (5) requires it is rewritten in discrete form, and second, knowing the values of its coefficients. With regard to the first requirement, the instantaneous changes in the logarithms of inputs during any two successive periods are approximated by the differences in the logarithms of the variables in those two periods. With this change the rate of change of total factor productivity can now be rewritten as,

$$(6) \quad \ln TFP_1 - \ln TFP_0 = [1-\theta][\ln Q_1 - \ln Q_0] + \theta(\ln z_1 - \ln z_0)$$

Traditionally, the coefficients of the total factor productivity equation have been obtained in one of two ways. First, as in Bergstrom (2000), (6) can be estimated directly as a first difference equation. Second, if it is assumed that the underlying production function is Cobb-Douglas, and if technology and other variables are included in this function the resulting equation can be estimated to obtain the relevant coefficients to decompose total factor productivity among its sources. This approach can be found in Harris and Trainor (2005). The main criticism of these approaches is that they do not use all the information about the production characteristics of the firms including the first order conditions for cost minimization. Absent this condition it is uncertain if the resulting coefficients from the estimation are consistent with those of cost minimization. In this paper the coefficients are obtained by estimating input demand equations jointly with the production function.

3. Data

The data consist of 312 observations of a balanced panel of 24 U.S. public transit systems covering the period 1985 to 1997. All costs are constant 1984 dollars, the measure of output is vehicle miles and the sample consists of public transit systems providing own account transit services and those that purchase their services from private sector providers. The inputs are gallons of fuel, total labor hours employed, and capital is total revenue vehicles operated. The technology variables are fleet age, capital subsidies and purchased transportation, network size, time in years, speed and fleet age. A lower fleet age captures new developments that make newer vehicles more reliable and able to provide high quality service, i.e., vintage effect. Purchasing transportation from private sector companies allows a transit system access to new technology without directly purchasing it. Additionally, to be competitive a private provider of transit services is expected to use new vehicles and equipment that enable it to cut cost and return profit. Network size captures the use of larger and longer buses in large urban areas. It also captures market size which Bergstrom (2000) argues makes firms become more productive than others. For example, in small transit markets, incentives are not present to operate different vehicles, provide different types of services and try new technologies. In the U.S. if a transit system purchases transportation from a private provider, it is required to submit that private provider’s data to the Federal Transit Administration (FTA) as a part of the annual Section 15 reporting system. In its early years this reporting system required all transit systems to submit their annual data to FTA, then the Urban Mass Transportation Administration. The data was audited and used to allocate federal formula grants to transit systems. Although the data collection continues today, for some transit systems annual data submission to FTA is no longer compulsory. Moreover the level of detail and the amounts of data submitted have been reduced substantially compared to what existed years ago.

The data include transit systems that do or do not receive capital subsidies from local, state and federal governments. They also include operating cost from which the prices of labor and fuel are determined. Fuel is a proxy for all inputs that are not capital or labor, and all non-labor operating cost is assigned to it. Capital cost is calculated based upon the approach in Obeng and Sakano (2002) which uses fleet size, fleet age and composition, and new bus prices from awarded bus purchase contracts each year to calculate the user price of a vehicle for each transit system. The approach assumes a bus useful life of 20 years.

Table 1 provides summary statistics about the systems in the sample. The average transit system provided 9.14 million miles of service using 399 vehicles, 2.2 million hours of labor, 4.12 million gallons of fuel, and a network of 1003.3 route miles. This system operated relatively old vehicles whose average age was 8.08 years.

Table 1 Descriptive Statistics

Variable	Mean
Dedicated tax share of operating revenue (%0	6.10
Federal share of operating revenue (%)	7.18
State share of operating revenue (%)	13.57
Local share of operating revenue (%)	25.49
Operating subsidy ($)	29853341
Capital Subsidy ($)	9962085
Vehicle miles	9.12
Fleet age	8.08
Speed (mph)	15.17
Labor hours	2181351
Gallons of fuel	4117836
Revenue buses	398.37
Right-of-way miles	1003.53
Proportion private/purchased transportation	0.62

In terms of quality of service the average transit system maintained a system-wide average speed of 15.17 miles per hour, and incurred a cost of $53.49 million. Its revenues did not cover all its costs; local, state and federal government support to cover operating losses amounted to $29.85 million. The sources of these funds were local dedicated taxes (6.10%), local governments (25.49%), state government (13.57%), and federal government (7.18%). Adding the percentages for dedicated tax sources and local governments' share in revenue gives 31.59% as the total percentage of operating funds the average transit system received from local governments. In addition the average transit system received $9.96 million in capital subsidies to cover the costs of vehicle replacement, new facilities and equipment. Finally, the services of 62% of the transit systems are purchased from private providers of transit services. Although we had expected that private providers would operate relatively new buses, it is not the case. The data show that on the average these firms operate buses that were 8.17 years old compared to 7.92 years for other firms.

4. Estimation and Results

The equation below is that used to characterize technology in the production function.

$$\ln(z) = \alpha_o \ln(A_o) + \alpha_N \log(N) + \alpha_F \ln(F) + \alpha_M \ln(M) + \alpha_H H + \alpha_A \ln(A_K) + \alpha_t t$$

N is network size in terms of right-of-way, *F* is fleet age, *M* is quality of service in terms of average bus travel speed, *H* is purchased transportation, *t* is time, A_k is the amount of capital subsidy received, and A_o is operating subsidy. Substituting this equation into (1) table 2 shows the results of jointly estimating the production function and the input demand equations. The models used all the observations and the variables explain 95.45%, 79.28%, 89.30% and 89.24% of the variation in output, capital, labor and fuel demand respectively. Also, almost all the coefficients are highly significant statistically at the commonly accepted probability level of 0.01. The exception is the coefficient of purchased transportation which is statistically insignificant.

Table 2: Estimate of Production Function and Input Demand

Variable	Estimate	Std Err	t –Value	Pr > |t|
Constant	0.9837	0.0022	448.78	<0.0001
Labor	0.2359	0.0028	83.60	<0.0001
Fuel	0.2600	0.0018	143.08	<0.0001
Capital	0.2599	0.0014	182.94	<0.0001
Operating subsidy	-0.0045	0.0005	-9.87	<0.0001
Route miles	0.2207	0.0044	50.06	<0.0001
Fleet age	0.0650	0.0059	11.01	<0.0001
Speed	0.4683	0.0096	48.99	<0.0001
Purchased transportation	-0.0009	0.0038	-0.23	0.8174
Capital subsidy	0.0027	0.0003	7.85	<0.0001
Time	0.0010	0.0004	2.26	<0.0244
Model	**R-square**	**RMSE**		**MSE**
Production function	0.9545	0.1892		0.0358
Capital	0.7928	0.3923		0.1539
Fuel (logarithm)	0.8924	0.3460		0.1197
Labor (logarithm)	0.8930	0.3200		0.1024
	Model	**Statistics**		**System**
Number of observations used	312	Objective		1.6832
Number of missing observations	0	Objective *N		525.1451

From the coefficients of fuel, capital and labor in the production function there are decreasing returns to scale in the transit systems analyzed because their sum is 0.7558. Except the coefficient of operating subsidies which is negative, all the statistically significant technology variables have positive coefficients showing that increases in them increase output. Using the coefficient of time, there is a statistically significant pure technical growth of 0.10%. Furthermore, a 1% increase in operating subsidies reduces output by 0.45% according to the results.

These results suggest that possible policy actions to increase output could include improving speed, expanding network size and offering capital subsidies. Fleet age is also positively related to output but it may be capturing private sector involvement in providing transit services because as noted this sector operates relatively old buses. It could also be capturing how reliable older buses are because maintenance employees are more familiar with them than the newer more sophisticated buses.

Table 3: Technology Variables

Technology Variables	**Partial Derivatives**	**Discrete Approximation**
Effect of operating subsidies	$\theta\alpha_o \frac{\partial \ln A_o}{\partial t}$	$\theta\alpha_o\left(\ln A_{o1} - \ln A_{o0}\right)$
Effect of fleet age	$\theta\alpha_f \frac{\partial \ln F}{\partial t}$	$\theta\alpha_f\left(\ln F_1 - \ln F_0\right)$
Effect of network size	$\theta\left(\alpha_N \frac{\partial \ln N}{\partial t}\right)$	$\theta\alpha_N (\ln[N_1] - \ln[N_0])$
Effect of purchased transportation	$\theta\alpha_H \frac{\partial H}{\partial t}$	$\theta\alpha_H\left(H_1 - H_0\right)$
Effect of speed	$\theta\alpha_M \frac{\partial \ln M}{\partial t}$	$\theta\alpha_M\left(\ln M_1 - \ln M_0\right)$
Effect of capital subsidy	$\theta\alpha_A \frac{\partial \ln A}{\partial t}$	$\theta\alpha_A\left(\ln A_1 - \ln A_0\right)$
Effect of time	α_t	α_t

The subscripts 1 and 0 refer to time.

5. Total Factor Productivity

Given the results above especially the impacts of the technology variables on production, the question is how do they affect total factor productivity? In table 3 are the formulae used to calculate the effects of each technology variable on total factor productivity and table 4 shows changes in total factor productivity using the estimated coefficients. Column 2 of table 4 shows that throughout the years studied the trend is a decrease in total factor productivity by scale-adjusted output one year followed by an increase in another year. This is especially so from 1985 to 1993. Despite this trend, from 1994 onwards there were two years when consistent growth in output increased total factor productivity. These years are 1994-95 and 1995-96. From the data in this column changes in output reduced total factor productivity by 0.13% per year.

Column 3 shows the effect of network size on total factor productivity and reveals a pattern different from that of scale-adjusted output. From 1985 to 1992, increases in network size increased total factor productivity every year, except in 1988-1989. This trend reversed from 1992 to 1995 to show decreases in total factor productivity, and from 1995 to 1997 to show increases in total factor productivity. Overall, increases in network size increased total factor productivity by 0.26% per year.

While network size was increasing total factor productivity, decreases in quality of service in terms of average bus travel speed were reducing it. In column 4 reductions in average bus travel speed reduced total factor productivity by 0.15% per year especially in the initial and end periods of the years studied. Except in 1991-92, 1992-93 and 1996-97, changes in speed increased total factor productivity from 1989 to 1997. These increases were, however, not enough to avert the overall decline in total factor productivity due to changes in bus travel speed.

Column 5 shows that fleet age decreased total factor productivity from 1986 to 1991. Because the coefficient of fleet age in the production function is positive this decrease is from operating newer buses. After 1991, changes in fleet age increased total factor

Table 4: Sources of Total Factor Productivity

Years	Output effect	Network effect	Speed effect	Fleet age effect	Capital subsidy effect	Operating subsidy effect	Purchased	Tech. change	TFP
1985-86	0.0058	0.0067	0.0056	0.0022	-0.0005	-0.0011	0.0000	0.0010	0.0191
1986-87	-0.0418	0.0221	-0.0009	-0.0017	-0.0006	-0.0026	-0.0002	0.0010	-0.0246
1987-88	0.0354	0.0056	-0.0159	-0.0006	0.0005	0.0010	0.0002	0.0010	0.0272
1988-89	-0.0032	-0.0055	-0.0028	-0.0058	0.0007	0.0004	0.0000	0.0010	-0.0152
1989-90	0.0011	0.0034	0.0030	-0.0025	-0.0004	0.0007	-0.0001	0.0010	0.0062
1990-91	-0.0066	0.0007	0.0037	-0.0049	-0.0004	-0.0007	0.0000	0.0010	-0.0073
1991-92	0.0063	0.0027	-0.0250	0.0111	-0.0012	0.0097	0.0000	0.0010	0.0047
1992-93	-0.0018	-0.0070	0.0180	0.0039	0.0013	0.0032	-0.0001	0.0010	0.0184
1993-94	-0.0073	-0.0027	-0.0067	0.0025	-0.0009	0.0001	0.0000	0.0010	-0.0140
1994-95	0.0002	-0.0034	0.0038	-0.0004	0.0004	0.0000	0.0000	0.0010	0.0014
1995-96	0.0060	0.0039	0.0016	0.0058	0.0012	0.0031	0.0000	0.0010	0.0221
1996-97	-0.0101	0.0043	-0.0021	-0.0062	0.0025	0.0001	-0.0001	0.0010	-0.0106
Average	-0.0013	0.0026	-0.0015	0.0003	0.0002	0.0012	0.0000	0.0010	0.0023

Notes: PUR – Purchased transportation. Prob. –Probability productivity until 1994 showing that transit systems were operating older buses, and decreased in 1994-95 and 1996-97. The combined effect of changes in fleet age is an increase in total factor productivity of 0.03% per year which is attributable to transit systems operating relatively old buses. From the data the firms that operate relatively old buses are private sector companies from whom public transit systems purchased some of their services. Since past studies show that private providers of public transit services are more efficient than public providers, this efficiency in producing output even with older vehicles is the reason for the productivity growth.

This positive contribution of fleet age to total factor productivity is similar in size to how much increases in capital subsidies affected total factor productivity. In column 6 increases in capital subsidies increased total factor productivity very little by 0.02% per year. Comparatively, because the coefficient of operating subsidies is negative in the production function, the results in column 7 show that reductions in these subsidies increased total factor productivity by 0.12%. This increase is six times the increase that results from capital subsidies. The pattern revealed in column 7 is that of consistent increase (except in 1990-91) in total factor productivity from reductions in operating subsidies since 1987. Since the period studied corresponds to when the federal government reduced its operating subsidies to transit systems, we surmise that as it became increasingly difficult for transit systems to receive operating subsidies total factor productivity increased as firms became more efficient in combining their inputs to produce output and reduce cost. This suggests that the unavailability of “easy” money compelled transit systems to be productive and use their inputs efficiently. Combining the results in both these columns increases in capital subsidies and decreases in operating subsidies increased total factor productivity in the period studied.

In columns 8 and 9 are the changes in purchased transportation and technical change and their effects on total factor productivity. Here, it is observed that purchased transportation did not have any effect on total factor productivity. This is not surprising, because its coefficient is statistically non-significant. On the other hand technical improvements increased total factor productivity by 0.10% per year.

Adding the row-wise entries for each year, column 10 gives the changes in total factor productivity from 1985 to 1997. This column shows alternating increases and decreases in total factor productivity especially from 1985 to 1991. Further, it shows that the period 1991 to 1997 was characterized mostly by growth in total factor productivity except in 1993-94 and 1996-97. When these changes are combined total factor productivity increased by 0.23% per year. From the entries in the last row the sources of this growth are increases in network size, fleet age, capital subsidies and technical change, and reductions in operating subsidies. Changes in output and average bus travel speed reduced total factor productivity this period.

6. Conclusion

This paper studied total factor productivity in selected US transit systems for the period 1985 to 1997. It estimated a production function and input demand equations jointly and used their coefficients in a decomposition equation to calculate total factor productivity. The evidence is that the sources of growth in total factor productivity in the transit systems studied are increases in network size, fleet age, capital subsidies and pure technical change, and decreases in operating subsidies. Reductions in average bus travel speed reduced total factor productivity by 0.15% per year. This finding suggests that reductions in bus travel speed add to total factor productivity decline and must be addressed especially where congestion levels are increasing. Some possible approaches to increase bus travel speed include network redesign and application of traffic management principles in transit corridors to reduce congestion. Speed improvement too can be achieved through joint planning efforts between transit systems and the cities where these systems are located to reduce congestion along bus routes and speed traffic flow.

Further, this paper supports the conclusion that increases in network size, and decreases in operating subsidies reinforce total factor productivity growth the most. While capital subsidies are important they do not increase total factor productivity as much as an increase in network size does according to the results. Nor do changes in capital subsidies increase total factor productivity by as much as do changes in operating subsidies. In fact changes in operating subsidies increase total factor productivity more than do changes in capital subsidies according to the results. This may be because these changes especially at the federal level compelled transit systems to be efficient. In sum it is concluded that the transit systems analyzed enjoyed productivity growth in the period analyzed.

These results are limited by sample size, and by the treatment of subsidies as lump-sum. It is possible that when the input substitution and lump-sum effects of these subsidies are considered simultaneously overall decline in total factor productivity would be observed.

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