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"Short Term Productivity Changes in U.S. Bus Transit Systems"

by

Prof. Kofi Obeng

Department of Economics and the Transportation Institute
North Carolina A&T State University
Greensboro, North Carolina 27411
U.S.A.

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Kofi Obeng

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Affiliation: Department of Economics and the Transportation Institute
North Carolina A&T State University
Merrick Hall, Room 301-C
Greensboro, NC 27411
(919) 334-7744

Abstract

The literature on productivity measurement in bus transit systems has generally focused on two areas: i) the development of acceptable measures of productivity (Tomazinis 1974, Fielding 1977) and ii) establishing relations between these measures and background variables. Recently, lines of inquiry apply economic theory, especially the duality between production and cost functions, to determine total factor productivity in transit systems (Meyer and Gomez-Ibanez 1980, Obeng et. al 1986, Obeng 1985, Kim 1985). This new approach attempts to overcome the problems in earlier studies such as the inability of performance measures to account for input interaction and productive efficiency reflected in the presence or the absence of economies of scale. This paper continues the on-going search for a better measure of transit performance. It presents the total factor productivity method, extends it by developing a method to determine the rate of change of input productivity and applies the method to data pertaining to 74 transit systems for the period from 1979 to 1985. It is shown that the rate of change of input productivity depends directly on the rate of change of total-factor-productivity.

The application shows that vehicle-mile total factor productivity has been declining at a rate of 0.4% per year while passenger-mile total factor productivity has been decreasing at a rate of 0.2% per year. Labor productivity has declined at a yearly rate of 0.8% based on vehicle-mile of output, and at a rate of 0.7% per year based on passenger-mile output. The rates of the yearly changes of vehicle mile

and passenger mile capital productivity are respectively an increase of 0.1% and a decrease of 0.3%. With passenger mile and vehicle-mile as output, fuel productivity declined at the respective rates of 1.45% and 1.72%. Overall, it is found that relatively large changes in productivity have occurred in the transit systems studied when vehicle mile is the output. Although fuel and labor have contributed substantially to the decline in total factor productivity, on the average, the effect of capital is neutral. Negative and positive contributions of vehicle miles and passenger miles respectively to the changes in total factor productivity have also been observed.

Associations developed between the changes in policy and background variables and the changes in total factor productivity as well as the productivities of the various inputs reveal that the changes in the daily hours that each vehicle is operated, the peak-base ratio, the labor-vehicle ratio, the proportion of executives, professionals and supervisors, and fleet age are the sources of productivity changes. The results presented in this paper have been found to be consistent with those of previous work.

Short Term Productivity Changes in U. S. Bus Transit Systems

1. INTRODUCTION

In the past decade and a half, many studies including those of Tomazinis (1974), Fielding (1977), Fielding et. al. (1978) have been conducted on the performance of United States bus transit systems. These initial studies focused on developing acceptable measures of efficiency, productivity and effectiveness. Recently, many authors have used some of these measures in their studies and have developed associations between the measures and selected policy and background variables (Obeng 1985a, 1985b, 1987; Anderson 1980; Barbour and Zerillo 1980). Among the findings of these studies are: labor productivity is positively associated with the daily hours that each vehicle is operated (Obeng 1987); transit performance is weakly associated with organizational structure (Fielding et. al. 1978); government ownership and influence through subsidies affect transit cost (Anderson 1983); and labor productivity is high in small private or public bus operations (Barbour and Zerillo 1980). These associations provide insight into and an understanding of those factors that contribute to the observed differences in transit performance.

There are, however, problems when system-wide policies are based on associations between the background variables and a performance measure such as labor or capital productivity or any of the fourteen performance measures suggested by Fielding et. al. (1977). Because there are many performance measures, policies become dependent upon which one is used in a study. If an inappropriate measure is chosen, its association with a policy variable could result in erroneous policies. Additionally, the absence of well defined procedures for selecting the correct measure of performance makes the choices that are made sometimes arbitrary. Finally, in the choice of performance measures there does not appear to be any consideration given to the interactions between the various inputs used in producing transit output. Thus, the transit performance measures currently in use, such as vehicle-mile or passenger mile per labor or per gallon of fuel, assume that these inputs are mutually exclusive; an assumption that cannot be supported in practice.

Given these shortcomings, it is not surprising that many authors are currently devoting their efforts to developing a superior measure of total performance for transit systems. Notably, Kirby and Green (Talley and Becker 1982) developed a set of criteria for selecting the best measure of transit performance. Talley and Becker (1982) too have suggested that if the objective function is to maximize passenger miles subject to a deficit constraint then subsidy per rider is the superior measure of transit total performance. Based on Talley and Becker's approach the selection of the superior measure depends on the objective of the analysis. In another paper, Talley (1986) proposes the inclusion of service-characteristics in a transit firm's operating objective and argues that the optimal values of these variables in maximizing the objective function will be the performance standards.

Borrowing from developments in economics a number of authors including Meyer and Gomez-Ibanez (1980), Obeng (1985a), Kim (1985), Obeng et. al. (1986), Caves and Christensen (1988) and Hensher (1987) have suggested and applied total factor productivity as the single best measure of the overall transit performance though Stokes (1979) contends that no measure of overall performance is available. Simply defined, total factor productivity is output per all inputs. Its advantage is that it accounts for all or most of the problems discussed.

Despite this advantage, the total factor productivity method has not received widespread use in the transit industry. This is partly due to the difficulty of obtaining information on the price of capital required as an argument in the cost equation from which the cost elasticity with respect to output is determined. Second, many transit systems do not have the personnel to apply the method on a large scale. The first reason also explains why, even in the scholarly literature, little has been done to determine total factor productivity in transit systems until recently. Yet, the usefulness of the method in policy analysis, its flexibility that allows the analyst to decompose the changes in transit total performance into the changes in output, inputs, and even factor ratios, makes a compelling case for its continued use in the transit industry. It is only when more research using the method is conducted will its usefulness be fully demonstrated.

To expand present knowledge, about the usefulness of the total factor productivity method in the transit industry, the method is applied to data covering the period from 1979 to 1985 and pertaining to seventy-four United States bus transit systems. This paper formally derives the total factor productivity method, extends it to develop a method to determine the rate of change of the productivity of each input and applies these methods to data pertaining to seventy-four transit systems. It is shown that the rate of change of input productivity is directly related to the rate of change of total factor productivity. The new method of determining the rate of growth of input productivity is shown to give the same result as the traditional definition of productivity as output per an input.

Using regression analysis, associations between the changes in total factor productivity, input productivity, and important policy and background variables are determined. The results of the analysis show that from 1979 to 1985 vehicle-mile total factor productivity declined at a yearly rate of 0.5% and passenger-mile total factor productivity decreased at a rate of 0.24% per year. Large variation in total factor productivity change is observed when the results are compared system by system. That comparison gives the range of total factor productivity change per year as - 13.3% to 12.2% when vehicle mile is the output. With passenger mile as output the range of total factor productivity change is a 7.8% yearly decline to a yearly increase of 13.3%. Similar results have been obtained for the rate of change of input productivity. The results of the analysis also show that the peak base ratio, the average daily hours that each vehicle is operated, fleet age, the labor-vehicle ratio, and the proportion of executives, supervisors and professionals are the significant sources of total factor and input productivity changes.

2. METHODOLOGY

To determine total factor productivity in bus transit systems assume that three inputs, labor (X_1), capital (X_2), and fuel (X_3) are used to produce either passenger-mile or vehicle-mile of output(Q). The production function relating these inputs and the output is

$$Q(t) = g(X_1(t), X_2(t), X_3(t)) + \varepsilon \qquad (1)$$

where t represents a variable such as productivity or time that shifts the production function. Further, assume that underlying equation 1 is a dual cost function which is homogeneous of degree one in input prices and represent this cost function by $C = F(P_1, P_2, P_3, Q)$ where P_1, P_2, P_3 are the respective prices of labor, capital and fuel. This cost function is also equal to $C = \sum^{i} P_i \cdot X_i$. Thus, the total cost is the sum of the products of the input prices and their respective quantities. The first order partial derivative of the cost function with respect to the price of an input gives the demand for that input. This important property is Shephard's Lemma and applies to cost functions that are homogeneous of degree one in input prices. From Shephard's Lemma, $d\ln C/d\ln P_i$ is the cost share of input i.

Changes in productivity cause the cost function and the production function to shift. A downward shift in the cost function represents improvement in productivity which reduces the cost per unit of output. But, for technologies that exhibit economies of scale, productivity growth may be due to a movement along the cost function and not to a downward shift in cost (Baltagi and Griffin 1988). On the other hand an upward shift in the production function implies an increase in productivity or technical change brought about by innovations or inventions. The rate of change in either the production or cost function represents the rate of change in total factor productivity. This rate of change of the production function is obtained by totally differentiating the natural logarithm of equation 1 with respect to t and solving for dlng/dt. This approach yields:

$$\mathrm{dlng/dt} = (\mathrm{dlnQ(t)/dt}) - \sum_{i=1}^{3} (\mathrm{dlng/dlnX_i(t)}) \cdot (\mathrm{dlnX_i(t)/dt}) \qquad (2)$$

Equation 2 is the measure of the rate of change of total factor productivity. The various inputs are combined in this equation by weighting them by their respective elasticities $(\mathrm{dlng/dlnX_i(t)})$.

A major problem associated with equations 1 and 2 which limits their application is that in selecting labor, capital and fuel to produce transit output, management may consider their qualities and, even, variations in technology. These considered variables are not included in the equation; they are not directly observable, and yet are correlated with the error term. As a result, an input elasticity based on equation 1 will be biased.

A solution to this problem is to estimate the cost function that is the dual of equation 1 and use it to derive the output elasticities. The dual cost function is homogeneous of degree one in input prices. It assumes that the input prices are exogeneously determined in competitive market situations so that the prices of the inputs reflect their quality attributes. To derive the input elasticities from a cost function, let the elasticity of output with respect to each input be denoted as $A_i(t)$. Further let the production function equation be homogeneous of degree $h(t)$ in input quantities. Then, it follows that $h(t) = \sum^{i} A_{i(t)} = 1/(\mathrm{dlnF(t)/dlnQ(t)})$. It can be shown that solving this expression for $A_j(t)$ gives the elasticity of each input j:

$$A_j(t) = h(t) \cdot S_{jt} = S_{jt}/(\mathrm{dlnF(t)/dlnQ(t)}) \qquad (3)$$

where S_{jt} is the cost share of input j in period t (Obeng 1987, Intriligator 1978, p. 283). Substituting equation 3 into equation 2, the rate of change of total factor productivity based on shifts in the production function is:

$$d\ln g/dt = (d\ln Q(t)/dt) - (1/(d\ln F(t)/d\ln Q(t))) \cdot \Sigma S_i (d\ln X_i(t)/dt) \quad (4)$$

Equation 4 can be used to determine the rate of change of total factor productivity. In the alternative, multiplying both sides of this equation by dlnF(t)/dlnQ(t) gives the rate of change of the cost function which is also a measure of the rate of change of total factor productivity. Thus:

$$d\ln F(t)/dt = (d\ln F(t)/d\ln Q(t))\ (d\ln Q(t)/dt) - \sum^{i} S_{it}\ (d\ln X_i(t)/dt) \quad (5)$$

where dlnF(t)/dt is the shift in the cost function due to productivity changes or time. The right-hand side of equation 5 is clearly the same result obtained by Caves et. al. (1979). Thus, the above procedure for deriving the rate of change of total factor productivity is an alternative to the derivation presented by Caves et. al. Note that dlnF(t)/dlnQ(t) is the cost elasticity with respect to output. If this elasticity is equal to one, there are constant returns to scale and equations 2 and 5 are the same. Under increasing (decreasing) returns to scale when the elasticity is less (greater) than one, both equations are not the same.

In this paper, the rate of change of total factor productivity is determined based on equation 5. It is instructive also to note that $d\ln F(t)/dt = (d\ln F(t)/d\ln Q(t)) \cdot d\ln g/dt$. Further, equation 5 can be modified to determine the rate of change of input productivity. Define the rate of change of input productivity as $d\ln(g/X_i(t))/dt$ and subtract $d\ln X_i(t)/dt$ from both sides of equation 4. For clarity of expression, denote the inverse of the cost elasticity with respect to output by h(t) and solve the resulting equation for $d\ln(g/X_i(t))/dt$.

Following this procedure yields:

$$d\ln(g/X_i(t))/dt = h(t) \cdot (d\ln F(t)/dt) - d\ln X_i(t)/dt \qquad (6)$$

Equation 6 gives the rate of change of input productivity and shows that it can be decomposed among the changes in total factor productivity and the rate of change of the utilization level of that input. It further shows that the rate of change of the productivity of any input is directly related to the rate of change of total factor productivity. If total factor productivity is declining, some input productivity must also be declining ceteris paribus. An increase in the quantity of an input is, however, not sufficient to decrease its productivity. A decline in input productivity occurs if the rate of increase in the quantity of that input is greater than the weighted rate of increase in total factor productivity derived from the cost function.

Since equations 5 and 6 are for instantaneous changes they must be modified to account for discrete changes in the inputs, outputs, and the cost elasticity with respect to output. The arithmetic averages of the elasticities and the input cost shares in two successive periods are used to approximate these two variables. For the instantaneous changes in total factor productivity and input productivity, they are approximated by the logarithmic differences of their values in two successive time periods. Thus:

$$\ln F_t - \ln F_{t-1} = \tfrac{1}{2}((d\ln F_t/d\ln Q_t) + (d\ln F_{t-1}/d\ln Q_{t-1}))(\ln Q_t - \ln Q_{t-1}) - \tfrac{1}{2}\Sigma(S_{it} + S_{it-1})(\ln X_{it} - \ln X_{it-1}) \qquad (7)$$

and

$$\ln(g/X_{it}) - \ln(g/X_{it-1}) = \tfrac{1}{2}(h_t + h_{t-1})(\ln F_t - \ln F_{t-1}) - (\ln X_{it} - \ln X_{it-1}) \qquad (8)$$

There are other advantages to using equations 7 and 8 in productivity studies besides accounting for the interactions between all inputs. Both equations account for changes in productive efficiency reflected in either the measure of scale economies or in total factor productivity. Equations 7 and 8 are therefore more refined and are superior measures of the rate of productivity change than the traditional method. The main disadvantage of equation 7 is that it becomes complex as the total number of inputs increases. Furthermore, as previously noted, both equations require a knowledge of the elasticity of cost with respect to output and that can limit their application.

Although a knowledge of productivity change is important, it must be related to policy and background variables. Specifically, the changes that have occurred in total factor and input productivity must be associated with whatever changes that have occurred in the policy and background variables. Suppose growth is observed in both total factor and input productivity in a transit system. That growth could be due to the changes in route miles, the average daily hours that each vehicle is operated and, even, the peak-base ratio. An increase in route miles leads to more vehicle-miles and passenger-miles. If these increases are substantial and are not accompanied by large increases in inputs or cost productivity growth will occur. However, service expansion through increases in route-miles could reduce productivity growth if accompanied by a large cost increase and a small increase in output.

Let Y_{1t}, Y_{2t}, ...Y_{nt} be the relevant set of all the background and policy variables with which productivity can be associated. These variables include fleet age, fleet composition, the average daily hours that each vehicle is operated, and route miles of service and are listed in Table 1. The sum of the yearly rates of change in each variable over the entire analysis period is $\sum^{t} d\ln Y_{nt}/dt$. This is approximated by $\sum_{2}^{t} (\ln y_{nt} - \ln Y_{nt-1})$ which also yields $\ln Y_{nt} - \ln Y_{n1}$. Thus, the sum of the logarithmic differences in each variable for successive time periods or the logarithmic difference between the values of each variable at the ending and beginning periods is used as an independent variable. Similarly, define the sum of the logarithmic difference of total factor productivity indices for successive periods as $\sum_{2}^{t}(\ln F_t - \ln F_{t-1}) = \ln F_t - \ln F_1$. Further, define the sum of the logarithmic difference of the productivity of each input in successive time periods as $\sum_{2}^{t}(\ln(g/X_{it}) - \ln(g/X_{it-1})) = \ln(g/X_{it}) - \ln(g/X_{i1})$. The logarithmic differences approximate the rates of change of each of the dependent and independent variables.

Using the approximations, the following formal relationship between the changes in total factor productivity and the background and policy variables is specified:

$$\ln F_t - \ln F_1 = A\,[(\ln Y_{1t} - \ln Y_{11}), (\ln Y_{2t} - \ln Y_{21}), \ldots, (\ln Y_{nt} - \ln Y_{n1})] \quad (9)$$

All the background variables are hypothesized as affecting total factor productivity. However, only a subset of these variables is specified as affecting the productivity of each input.

Based on equation 9, the policy and background variables that are significantly associated with productivity are determined using multiple regression analysis. The signs of the estimated coefficients give the direction of association while their significance levels test the null

Table 1: Changes in the Background Variables from 1979-1985

Variable	Mean
. Proportion of Benefits Paid by Employees	-0.079
. Peak-base Ratio	-0.045
. Proportion of Supervisors, Executives and Professionals	0.088
. Fleet Age	-0.006
. Speed in miles per hour	0.018
. Route Miles	0.094
. Average Daily Hours Each Vehicle is Operated	-0.006
. Vehicle Capacity Utilization	0.024
. Labor-Vehicle Ratio	-0.032
. Proportion of Public Funds From All Federal Sources	0.448
. Equivalent labor	0.022
. Gallons of Fuel	-0.003
. Fleet size	0.069

hypothesis that each coefficient is not different from zero. Dividing both sides of equation 9 by the logarithmic difference of each variable gives the approximate value of the elasticity of cost with respect to that variable.

3. DATA

Applying the above methodology requires analyzing a large data set on cost, output, input quantities, the policy and background variables. This data has been obtained from the bound National Urban Mass Transportation Statistics (United States Department of Transportation, 1982a, 1982b, 1983, 1984, 1986, 1987). This data source is the most comprehensive of those currently available including the Statistics collected by the American Public Transit Association.

A number of factors contributed to the choice of the study period. First the studies from which the elasticity equations are obtained are based on the 1979-80 data (Obeng, 1985a, 1987). Second, the most recent Section 15 data publicly available is that for the calendar year 1985. Lastly, researchers including Hobieka et. al. (1983) have pointed to inconsistencies, errors and other problems associated with the first year Section 15 data which make its inclusion in the current research inappropriate. This choice of the study period means that only the changes that have occurred in transit systems during the first part of this decade are considered. It also means that the study focuses on a period during which major changes in federal operating subsidies were impacting on transit systems.

Although the earlier studies (Obeng 1985, 1987) analyzed 77 bus transit systems, we focus on 74 of them which reported consistently on the data required. In particular, three transit systems were eliminated from the original set because they did not file Section 15 report from 1980 to 1985. Of the remaining transit systems, not all reported information on each variable every year and this resulted in missing data. No attempt was made to estimate the values for the missing data. As a result, the descriptive statistics in Table 1 are based on each variable's own degrees of freedom. For example the degrees of freedom for the federal share of public funds and the peak-base ratio are respectively 59 and 74.

4. TRENDS IN BACKGROUND VARIABLES

Table 1 summarizes the mean of the total rate of change (the mean of the sum of the logarithmic differences) of each of the relevant variables from 1979 to 1985. The contents of this Table can be interpreted as approximations to the rates of change in all the variables (Caves et. al. 1979). Clearly, the Table shows that a general decline in five background variables occurred during the study period (inputs not counted). The largest decline, 7.9%, is in the proportion of the benefits paid by employees. In many transit systems, employees now contribute less to their benefit programs than they did in 1979. Additionally, better fleet management has reduced the peak-base ratio by 4.5%. This reduction in the peak-base ratio has been accompanied by a small decline of 0.6% in the average daily hours that each vehicle is operated respectively. The decline in the average daily hours of vehicle operation is insignificant and shows a relatively stable service between 1979 and 1985. In fact using route miles of service, one can argue that service expansion indeed occured between 1979 and 1985. This is because route miles increased by 9.4%.

Besides the increase in route miles fuel usage declined by 0.3% in the transit systems analyzed. Also, the labor-vehicle ratio declined by 3.2%. Two factors that partially account for the decline in the labor-vehicle ratio are an increase in fleet size of 6.9% and a small increase in employment of 2.2%. Because the total number of buses operated has increased through acquisition, while service hours remained fairly stable and route miles increased, it follows that in 1985 each bus was operated less intensively than in 1979.

Although these averages appear to suggest that only small changes have occurred in the quantities of the inputs used by the transit systems, the individual system data reveals that reductions in input utilization is widespread. About 50%, 46% and 39% of the transit systems reduced their amounts of labor, fuel, and vehicle use respectively. This reduction is not concentrated in one group but it is found across transit systems of various sizes. Thus, it is found in the very large transit systems such as the Chicago Transit Authority and in small transit systems such as Cedar Rapids Transit.

In contrast to this finding some transit systems increased their use of labor, fuel and vehicles. Large increases of up to 114%, 125% and 133% in labor, fuel and vehicles respectively have been observed. This observation shows that while some transit systems have experienced decline in inputs, others have experienced input growth. But, for the average transit system, service has remained stable or has expanded, more new buses are now operated, the overall labor requirement has changed only marginally and employees now enjoy a better benefit package than they did in 1979. Additionally, in the average transit system, the composition of employment has changed as more supervisors, professionals and executives are now employed. From 1979 to 1985, the average transit system employed an additional 8.8% of supervisors, professionals and executives.

From 1979 to 1985 too, the quality of transit service, as measured by speed, improved by 1.8%. In comparison, vehicle capacity utilization increased by 2.4% and the federal share of public funds increased by 44.8% or 7.45% per year. The increase in the federal share of public funds must be viewed cautiously. The Section 15 data base does not disaggregate federal subsidy by mode, and it is possible that not all the observed increase went to bus operations. This is especially true in multi-modal transit systems. Also, because of aggregation, the overall 44.8% increase does not reflect the decrease in federal operating subsidies during this same period but the on-going emphasis on capital subsidy.

5. PRODUCTIVITY CHANGES

Applying equations 8 and 9 and the data involves a determination of the cost elasticity with respect to output. The elasticities can be obtained from a cost function specifically developed for that purpose. However, for an analysis using data covering a short time period, as in this paper, if an assumption is made that the coefficients of the cost equation remain unchanged in the short run, then a cost function estimated for one period can be used to determine the elasticities in other periods. This is the approach adopted in this paper. Two cost functions reported in Obeng (1985a, 1987) for 77 bus transit systems are used to calculate the elasticity of cost with respect to vehicle-mile (VM) and with respect to passenger-miles (PM).

From the referenced research, the cost elasticity equations are:

$$dlnF/dlnVM = 0.074lnVM - 0.16 \quad (10)$$

$$dlnF/dlnPM = 0.9822 - 0.02281lnPM \quad (11)$$

Using equation 10, it has been shown in Obeng (1985a) that there are economies of scale up to 6 million vehicle-miles, constant returns to scale from 6 million to 12 million vehicle-miles, and thereafter, decreasing returns to scale. Similarly, it has been shown that with passenger-miles as output there are increasing returns to scale in the transit systems studied (Obeng 1987). Comparing the results leads to the conclusion that the presence of economies of scale across the transit systems studied depends upon the selected output measure.

Based on equations 10 and 11, as well as the data, Tables 2, 3, 4 show the averages of the changes in total factor productivity and input productivity from 1979 to 1985.

The total factor productivity Tables give very similar results for the two outputs. In all cases, a majority of the transit systems had a decline in total factor productivity from 1979 to 1985. With passenger-mile as output, approximately 60% of the transit systems had a decline in total factor productivity. The corresponding percentage of transit systems with a decline in vehicle-mile total factor productivity is 55%. However, not all, but 38%, of the transit systems showed a decline in both passenger-mile total factor productivity and

Table 2: Index of Total Factor Productivity and Changes in Productivity in All Transit Systems

	Output = Vechile-miles		Output = Passenger-miles	
	Average Change In TFP for all Systems	Index of TFP	Average Change In TFP for all Systems	Index of TFP
1980		1.033		1.014
1981	-0.019	1.014	0.019	1.033
1982	-0.048	0.965	-0.008	1.025
1983	0.036	1.000	-0.025	1.000
1984	-0.097	0.903	0.020	1.020
1985	0.105	0.998	-0.012	1.008

1983 = 1.00

Table 3: Index of Average Input Productivity (Passenger-mile as Output)

Year	dln(g/l)/dt	Index Of Labor Productivity	dln(g/K)/dt	Index Of Capital Productivity	dln(g/F)/dt	Index Of Fuel Productivity
1980		1.019		1.054		1.025
1981	-0.010	1.009	-0.003	1.051	-0.031	0.994
1982	0.013	1.022	0.033	1.018	0.000	1.994
1983	-0.022	1.000	-0.018	1.000	-0.006	1.000
1984	0.025	1.025	0.068	1.068	0.030	1.030
1985	-0.048	0.977	-0.032	1.036	-0.094	0.938

Note 1. 1983 = 1.00

2. The log differences of successive indices may not equal the change in productivity due to approximation errors.

3. dln(g/L)/dt = change in labor productivity in period t.
dln(g/K)/dt = change in capital productivity in period t.
dln(g/F)/dt = change in fuel productivity in period t.

Table 4: Index of Average Input Productivity
(Vehicle-mile Used as Output)

Year	dln(g/L)/dt	Index Of Labor Productivity	dln(g/K)dt	Index Of Capital Productivity	dln(g/F)/dt	Index Of Fuel Productivity
1980		1.033		1.041		1.040
1881	-0.055	0.977	-0.021	1.019	-0.077	0.963
1982	-0.023	0.955	-0.069	0.951	-0.035	0.929
1983	0.046	1.000	0.05	1.00	0.073	1.00
1984	-0.096	0.908	-0.052	0.949	-0.091	0.913
1985	0.083	0.987	0.099	1.048	0.037	0.947

Note 1. The index for 1983 is 1.00.

2. dln(g/L)/dt = change in labor productivity in period t.
dln(g/K)/dt = change in capital productivity in period t.
dln(g/F)/dt = change in fuel productivity in period t.

vehicle-mile total factor productivity. On the other hand only 12% of the transit systems showed an increase in vehicle-mile and passenger-mile total factor productivity simultaneously.

Converting the yearly rates of change of total factor productivity into indices in Table 2 reveals that except from 1982 to 1983 and from 1984 to 1985, there has been a yearly decline in vehicle-mile total factor productivity. The total decline is 2.5% or 0.4% per year. This rate is quite small and different from the results obtained by Obeng et. al. (1986) which showed no substantial change in total factor productivity in transit systems from 1955 to 1980. The index of passenger-mile total factor productivity gives similar results and shows a small decline of 1.2% (0.2% per year). Although these results show that when all transit systems are combined the change in total factor productivity is not substantial the individual system data reveals otherwise. Comparing the results shows that the decline in vehicle mile total factor productivity is twice the decline in passenger mile total factor productivity.

Additionally, the range of total factor productivity change is from a decline of 80% to an increase of 73% with vehicle-mile as output. These figures translate into a decline of 13.3% per year to an increase of 12.2% per year in vehicle-mile total factor productivity. When passenger-mile is the output, the range is from a yearly decline of 7.8% to a yearly increase of 13.3%. The individual system data, therefore, reveals relatively large changes in total factor productivity.

Besides total factor productivity Tables 3 and 4 show the averages of the rates of change of the productivities of the inputs as well as their corresponding indices. Considering the labor productivity indices, the changes that have occurred are not the same for the two outputs. No definite trend emerges in the changes in labor productivity in Table 3. Similarly, no trend emerges from Table 4 when labor productivity based on vehicle-mile output is considered although some decline occurred before 1983. Overall, with either vehicle-mile or passenger-mile as the output labor productivity declined at the respective rates of 0.8% and 0.7% per year. These results, show similar changes in labor productivity regardless of the output measure.

Irrespective of the output measure, the averages of the yearly changes in capital productivity and in fuel productivity are small. The productivities of fuel and capital have not declined consistently year after year. Periods of productivity decline have generally been followed by periods of productivity growth. The sizes of the rates of growth and of decline are also small and make the sum of the overall change very small. Also with passenger mile as output capital and fuel productivity declined by 1.8% and 8.7% respectively. However, with vehicle mile as output the productivities of capital and fuel declined by 0.7% and 10.3% respectively. Furthermore, Tables 3 and 4 show that the averages of the rates of change of labor productivity and of capital productivity increase or decrease simultaneously.

From the total factor productivity and input productivity analyses, only the system-by-system comparison reveals substantial changes in productivity. Combining all the transit systems, small changes in either total factor productivity or input productivity occurred from 1979 to 1985. These results are true regardless of the output measure used.

6. THE MAJOR SOURCES OF PRODUCTIVITY CHANGE

Table 5 shows the sources of the changes in total factor productivity. The contribution of each input is the sum of the product of its cost share and the changes in that input over the entire period of the analysis. A negative entry for an input in the Table shows that the input reduces total factor productivity. The contribution of output to productivity change is the sum over time of the weighted changes in output, where the weights are the cost elasticities with respect to output. Here too, a negative sign shows that output reduces total factor productivity.

From Table 5, the contribution of passenger mile to total factor productivity is positive. This positive contribution of passenger-mile to total factor productivity is augmented by scale economies (see section 5). On the other hand, the decline in vehicle mile is tertiary behind labor and fuel respectively in accounting for the decline in vehicle mile total factor productivity. Increased employment levels and higher fuel prices (since fuel use declined from 1979 to 1980 in Table 1) have moderated the growth in passenger mile total factor productivity and have contributed substantially to the observed decline in vehicle mile total factor productivity. In fact 56% of the decline in vehicle mile total factor productivity is due to labor with fuel and output accounting for 32% and 12% of the decline respectively. Clearly, none of these results supports Caves and Christensen's (1988) contention that in urban bus transit "much of the industry's productivity decline can be traced to the

Table 5: Sources of Productivity Change

Source	Mean
. Contributions by output (Vehicle miles)	-0.003
. Contributions by output (Passenger-miles)	0.010
. Contributions by labor	-0.014
. Contributions by fuel	-0.008
. Contributions by capital	0.00
. Vehicle mile total factor productivity	-0.025
. Passenger mile total factor productivity	-0.012

effects of declining output on economies of density." Only a small proportion of the productivity decline is due to output.

While the contributions of labor, fuel and output to productivity changes are substantial Table 5 shows that transit capital, as measured by the number of vehicles, does not contribute to the changes in total factor productivity. Its effect on total factor productivity is neutral. Conceivably, there has not been any substantial change in the quality of the buses used by transit systems that will bring about changes in total factor productivity. Transit systems continue to operate relatively old buses as evidenced by the small decline of 0.6% in fleet age from 1979 to 1985. Even when new buses are operated their design features such as lifts for the handicapped and increased length make them slow and reduce vehicle miles.

Comparing the contributions of output and the inputs, specific conclusions regarding vehicle-mile total factor productivity and passenger mile total factor productivity can be drawn. First, with respect to passenger mile total factor productivity, the positive contribution of output to productivity changes is the most important. The positive contribution of output is quite substantial but does not overwhelm the moderating effects of the contributions of labor and fuel. Second, the negative contributions of labor and fuel in that order are the most important factors in understanding the decline in vehicle mile total factor productivity. Finally, because transit capital (the number of buses) has neutral effect on the changes in total factor productivity, it (transit capital) could have been excluded from the total factor productivity analysis in this paper. The exception could be when there is strong evidence to suggest substantial changes in both the quantity and quality of transit capital.

Of course, that transit capital shows a neutral effect on total factor productivity could be due to measurement errors. That is, transit vehicles may not adequately represent transit capital. New and efficient maintenance machinery is not captured by the use of transit vehicles as capital. Similarly, some recent innovations such as the introduction and use of micro computers which add to the capital stock are not considered in the measurement of capital. It is possible that the effect of transit capital on total factor productivity will be different if these components of capital are considered.

7. IDENTIFYING OTHER SOURCES OF IN PRODUCTIVITY CHANGE

Besides labor, fuel, capital and output there are important policy and background variables that can be associated with the changes in total factor productivity and input productivity. These associations can offer further explanations for the changes in productivity. In this section, multiple regression is used to estimate the coefficients of policy and background variables that affect productivity. A correlation matrix was used to determine possible multicollinearity between the independent variables. The matrix showed very weak correlation between each pair of the independent variables. In absolute terms, 70% of the correlations were less than 0.2, 12% were greater than 0.3, 18% were between 0.2 and 0.3 and the largest correlation was 0.4. These low correlation coefficients suggest that any multicollinearity that may exist is weak.

Tables 6 and 7 show the estimation results. The equations show variations in the sizes of the coefficients of determination.

Table 6: Effects of Changes in Background Variables on Changes in Productivity (Passenger-mile as output)

Rate of Change in Independent Variables	Dependent Variable = Total Factor Productivity Coefficients	Dependent = Labor Productivity Coefficients	Dependent = Capital Productivity Coefficients	Dependent = Fuel Productivity Coefficients
Proportion of public funds from federal sources	-0.0079 (0.0239)	-0.0148 (0.0510)	0.0071 (0.2657)	0.0166 (0.0473)
Fleet Age	0.1094 (0.0558)	0.2667* (0.1190)	0.1214 (0.0999)	0.3147* (0.1066)
Average Daily Hours Vehicle	0.1228 (0.1376)	0.3235 (0.2935)	0.8185* (0.2745)	0.0702 (0.2825)
Route Miles	0.0720 (0.0624)	0.0239 (0.1330)	-0.0282 (0.1268)	-0.1775 (0.1270)
Vechile Capacity Utilization	0.4724* (0.0608)	0.5375* (0.1296)	0.5678* (0.1138)	0.6503* (0.1212)
Proportion of Executives, professionals and Supervisors	0.1385* (0.0670)	0.3595 (0.1430)*	n/a	n/a
Peak-Base Ratio	-0.0857 (0.1411)	-0.3602 (0.3001)	-0.4116 (0.2563)	-0.2729 (0.2734)
Speed (mph)	0.1024 (0.1307)	0.2866 (0.2789)	0.5808* (0.2563)	0.0850 (0.2773)
Labor-vehicle Ratio	-0.2783* (0.1266)	-1.238* (0.2701)	-0.7553* (0.2487)	n/a
Proportion of Benefits Paid By Employees	0.0260 (0.1053)	0.1840* (0.2246)	n/a	n/a
Constant	-0.0726* (0.0272)	-0.1511* (0.0580)	-0.0964 (0.0505)	-0.1119* (0.0532)
R-square	0.6588	0.5846	0.5474	0.4917

*Statistically significant

Table 7: Effect of Changes in Background Variables on Changes in Productivity (Vehicle Mile Output)

Rate of Change in the Independent Variables	Dependent = Total Factor Productivity	Dependent Variable Rate of Change of Labor Productivity	Dependent = Capital Productivity	Dependent = Fuel Productivity
	Coefficients	Coefficients	Coefficients	Coefficients
Proportion of Benefit Paid by Employees	-0.0096 (0.0866)	0.1202 (0.1789)	n/a	
Peak-Base Ratio	-0.1392 (0.1494)	-0.3573 (0.2431)	-0.3342 (0.1676)	-0.2092 (0.2033)
Proportion of Executives, Professionals and Supervisors	0.1480* (0.0551)	0.3319 (0.1139)	n/a	
Fleet Age	0.09149* (0.0459)	0.2068* (0.0948)	-0.0266 (0.0654)	0.2393* (0.0793)
Speed in mph	0.1546 (0.1076)	0.3193 (0.2221)	0.5007* (0.1738)	0.1834 (0.2063)
Route-miles	0.0332 (0.0513)	-0.0294 (0.1059)	0.0231 (0.0829)	-0.1629 (0.0944)
Average Daily Hrs. Vehicle is Operated	0.1097 (0.1132)	0.3020 (0.2337)	0.8198* (0.1795)	0.1616 (0.2101)
Vehicle Capacity Utilization	-0.0511 (0.0501)	-0.1467 (0.1059)	-0.5229* (0.1626)	-0.1132 (0.0901)
Labor-Vehicle Ratio	-0.0918 (0.1042)	-0.9330* (0.2151)	-0.7553* (0.2487)	
Proportion of Public Funds From Federal Sources	-0.01456 (0.01968)	-0.0155 (0.0406)	-0.0045) (0.0290)	0.0066 (0.0352)
Constant Term	-0.0650* (0.0224)	-0.1152* (0.0462)	-0.0310 (0.0330)	-0.0860* (0.0396)
Coefficient of Determination	0.3498	0.4488	0.4057	0.2313

*Statistically significant

These coefficients range from 0.2313 to 0.6588.

Considering the passenger mile total factor productivity equation, only three variables, vehicle capacity utilization, the proportion of executives, professionals and supervisors, and the labor-vehicle ratio significantly affect it. Of these variables, the labor-vehicle ratio and the peak-base ratio are the only ones that have a negative association with total factor productivity. Passenger-mile total factor productivity is positively associated with the proportion of supervisors, executives and professionals. It follows that changes in passenger-mile total factor productivity can be traced to these variables. With regards to vehicle mile total factor productivity, only the proportion of executives, professionals and supervisors significantly affect it. The other variables are insignificantly associated with it and cannot be regarded as the major sources of labor productivity change.

Extending the analysis to labor productivity in Column 3 of both tables, the sources of labor productivity changes can, again, be traced to those variables whose coefficients are statistically significant. These variables are fleet age, vehicle capacity utilization, the proportion of benefits paid by employees and the proportion of executives, supervisors and professionals. Except the labor-vehicle ratio, these variables are positively associated with passenger mile labor productivity. Also, except the proportion of benefits paid by employees and vehicle capacity utilization, these same variables significantly affect vehicle-mile labor productivity and have the same signs.

In addition to total factor productivity and labor productivity, Tables 6 and 7 show the associations between the rates of change of capital productivity and the changes in eight of the variables discussed. Two variables, the proportion of benefits paid by employees and the proportion of executives, supervisors and professionals, which are directly related to labor productivity, are excluded from the analysis because it is not conceivable that they affect capital productivity. As Table 6 shows, changes in the labor-vehicle ratio, the average daily hours that each vehicle is operated, speed and vehicle capacity utilization are significantly associated with the changes in passenger mile capital productivity. Similarly vehicle-mile capital productivity is significantly affected by changes in speed, the average daily hours of vehicle operation and the labor-vehicle ratio.

Contrary to expectation, the federal share of public funds is not significantly associated with vehicle productivity regardless of the output. A large portion of these federal funds are used to replace existing capital and to cover operating losses. If vehicle productivity has been declining and if a large federal subsidy is obtained to replace part of the fleet, the decline will continue. This is because the federal subsidy variable will increase vehicle productivity only if it is required as part of an overall service expansion program or if it adds to the existing stock of capital. Using the subsidy for capital replacement does not add to productivity unless the new capital has embodied technical improvements. As it is well known, much of the federal subsidy to bus transit systems, today, is mostly spent on new buses whose performance levels are questionable.

In column 5 of Tables 6 and 7, the sources of the changes in fuel productivity are traced to fleet age and vehicle-capacity utilization. These are the only variables whose coefficients are statistically significant. In both Tables, fuel productivity increases are associated with transit systems which operate older buses. This finding is plausible and is explained by the new requirements, such as lifts, which all new buses must have. These requirements increase the weight of a new bus and make it less fuel efficient. It is, however, evident in both tables that vehicle-capacity utilization is significantly associated with passenger-mile fuel productivity and not vehicle-mile fuel productivity. Thus, financial variables and those variables that describe the level of transit service are not significantly associated with fuel productivity changes and cannot be considered as the sources of these changes.

8. SIMILARITIES AND DIFFERENCES IN THE EFFECTS OF VARIABLES

Reading Tables 6 and 7 row by row reveals differences in the effect that each background variable has on the rate of change of total factor productivity and on the rates of change of the productivities of the inputs. Of course, similarities in these effects are also observed. For example, focussing only on the coefficients that are statistically significant in Table 6, while the vehicle capacity utilization and the proportion of executives, profesisonals ans supervisors and fleet age have consistent positive effects on total factor productivity as well as on input productivity, the labor-vehicle ratio has consistent negative effects on total factor productivity and on input productivity. Very similar results are observed in Table 7 where, again, the statistically significant variables have the same signs on total factor productivity as on input productivity. On the other hand considering the statistically insignificant coefficients some, such as the federal share of public funds and route miles in Table 6, have mixed effects on total factor productivity and on input productivity.

The obvious implication of these results is that systemwide policies must be based on the effect of the changes in a policy or a background variable on the changes in total factor productivity and not on its effect on the changes in the productivity of an input. This is because the overall outcome of using a particular background variable as the basis of policy is measured by its effect on total performance (See Obeng (1987) for a discussion of this subject and for approaches to classify policy and background variables.) Of course, if a policy or a background variable is negatively or positively associated with the rate of change of total factor productivity, as well as with the rate of change of the productivity of each input, then policies can be based on its association with the rate of change of the productivity of any of the inputs.

For each background variable that has a different effect on total factor productivity and on input productivity, its effect on total factor productivity can be interpreted as the outcome of the tradeoff between its effects on the productivities of the various inputs. Using these outcomes, it is clearly evident that the negative effects of the proportion of public funds from federal sources, are dominant. That is, the positive effects of these variables on the productivities of some of the inputs are not of sufficient size to compensate for their negative effects on the productivities of the other inputs. Similarly, the positive effect of route miles is dominant since in both tables its effect on total factor productivity is positive though insignificant. Route mile increases then appears to be a good policy based on total factor productivity. But, increases in the federal share of public funds are not supported by productivity improvement; other non-efficiency objectives will justify those increases.

9. COMPARISON TO PREVIOUS RESEARCH

To generalize the results above, it is necessary to compare them to those of previous research. A major difficulty in comparing the total factor productivity results is that very little work has been done in this area in transit systems except the few referenced in this paper. However, many studies have been conducted on associations between input productivity and background variables. (See the introduction section of this paper for references to some of these research.) A condition for comparing our results to those of previous studies is that they should be based on the same output. Similarly, the same definition of the background variables must be used in the studies compared.

Given these conditions, Table 7 compares the signs of the coefficients in this study to those reported in Obeng (1987) which used virtually the same set of background variables and vehicle mile as the output. Despite the differences in the definition of input productivity (that is the present study used the rate of change of input productivity as the dependent variable whereas the previous study used the ratio of output to input), the Table shows that the background variables, except two, have the same signs in both studies. The proportion of executives, supervisors, and professionals and route miles have different signs in Table 7. The ratio of executives, professionals and supervisors have a

Table 9: Comparison To Previous Research

Variables	Q/L[1]	Rate of Change of Labor Productivity	Q/K[1]	Rate of Change of Capital Productivity	Q/F	Rate of Change of fuel Productivity
Peak-base Ratio	-	-	-	-	-	-
Proportion of Executives, Supervisors and Professionals	-	+	n/a	n/a	n/a	n/a
Fleet age	+	+	-	-	+	+
Speed	+	+	+	+	+	+
Route-miles	n/a	n/a	-	+	-	-
Average Daily hrs. vehicle is operated	+	+	+	+	+	+
Vehicle Capacity Utilization	-	-	n/a	-	n/a	-

Notes [1] The signs of these coefficients are from Obeng, K. (1987), Classification of Bus Transit Policy Variables," Transportation Planning and Technology Vol. 11, pp.257-272.

n/a This means the signs cannot be compared because the variables appeared only in one of the research compared.

negative association with the ratio of output per labor input (labor productivity) and has a positive association with the rate of change of labor productivity. On the other hand route-miles has a negative association with the ratio of output to capital but has a negative association with all other applicable productivities in Table 7. The reasons for these differenes is unclear but it is argued that they are attributable to the definition of productivity used in this paper. That definition is different from the traditional definition of productivity as output per input.

The total factor productivity results can be compared to those obtained in other studies. Meyer and Gomez-Ibanez (1980) in their study found that between 1948 and 1970, total factor productivity declined by 0.11% per year if vehicle-mile is the output and 1.40% per year if passengers are the output. This result indicates a relatively large decline in total factor productivity when passenger-mile is the output. The present research shows a decrease of 0.24% per year in passenger-mile total factor productivity and a decline of 0.5% per year in vehicle-mile total factor productivity. Thus, our results are consistent with the trend depicted by the total factor productivity results reported by Meyer and Gomez-Ibañez. However, the size of the decline in vehicle-mile total factor productivity is larger in this study than that reported above and depicts the short term nature of the current research. Long term industry adjustments are possible in terms of changes in input requirements. In the short term output reduction cannot be immediately followed by input reductions. Hence, short term productivity changes are likely to be larger than long term productivity changes.

In a study of total factor productivity by Benjamin and Obeng (1988) vehicle-mile total factor productivity was found not to be significantly associated with subsidy variables. This result is consistent with the findings in this paper. Hence, this paper confirms most of the results of the earlier total factor productivity research.

10. CONCLUSION

This paper has analyzed the changes that have occurred in seventy-four United States bus transit systems from 1979 to 1985 and how these changes have affected input productivity and total factor productivity. Econometric models have been developed to determine the rates of change of total factor productivity and the rates of change of the productivities of labor, fuel and capital. The results of the analyses show that in a system-by-system comparison, there are substantial differences in the rates of change in both total factor productivity and input productivity. Very little change in these productivities is observed when all transit systems are combined. The results also show that on the average passenger-mile total factor productivity has been decreasing largely due to negative input contributions. On the other hand, output decreases and the negative contributions of labor and fuel have reduced vehicle mile total factor productivity. The effect of capital on total factor productivity is neutral.

Based on the regression results, changes in speed, vehicle capacity utilization, the average daily hours that each vehicle is operated, and the proportion of executives, professionals and supervisors and the labor vehicle ratio are significantly associated with the rate of change of either total factor productivity or input productivity. These variables are the most important in understanding the sources of productivity change. A comparison of the results of this paper to previous work also shows consistency in the effects of most of the background variables on total factor productivity and on input productivity.

To facilitate the widespread use of the total factor productivity method in industry, more research is required to test the results of this paper. Future research should focus on two areas: i) developing simple methods to determine the cost elasticity with respect to output and ii) developing methods to estimate the price of transit capital. These two research are necessary for the correct application of the total factor productivity method.

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