Highway Stock and Private-Sector Productivity

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The availability of a good transportation system is essential to a growing, healthy economy. For this reason, in developing economies transportation improvements are usually among the first projects undertaken to start the path toward economic development and prosperity. Transportation facilities connect markets and facilitate production and trade. Although the relationship between transportation facilities and the well-being of the economy of a country is intuitively obvious, little research has been undertaken to measure this relationship quantitatively. An attempt was made to demonstrate that variations in the existing stock of public highways have, to a large extent, explained variations in the productivity of labor and capital in the private sector of the economy. For this purpose, two econometric regression models were constructed to separately measure the association between the stock of highways and the productivities of (a) private-sector capital and (b) combined labor and capital. The regression models not only support the contention that the highway stock has contributed to improved private-sector productivity, but also that it has had a proportionately greater effect than that of the non-highway infrastructure. A third regression model in which the infrastructure was further disaggregated also supports the same conclusions.

The availability of transportation facilities plays an essential role in the process of a nation's economic development from a state of underdevelopment. Usually, one of the first steps taken in the path of development is to link markets together by creating transportation facilities. Unfortunately, once markets are linked, transportation facilities often are taken for granted—until severe inadequacies begin to emerge. As competing social needs bid for limited resources, nations tend to forget that, although factor supplies determine the initial level of economic output, their growth (or growth in their productivity) determines later economic growth. The stimulation of such growth has been generally neglected in the United States, including California.

The problem stems from the *long-term* nature of providing transportation infrastructure. Facilities are usually planned and constructed with a 20- to 30-year time horizon. The planned excess capacity often creates the illusion of indefinite adequacy. When this capacity is eventually exceeded by demand, realization of the finite nature of capacity occurs, sometimes at the considerable cost of stalled economic growth.

Although the significance of the contribution of transportation facilities (as well as other infrastructure) to the U.S. economy is intuitively obvious, it has neither been easy to quantify nor has there been any urgency for researchers to do so. Until recently, no systematic research had been conducted to quantitatively link transportation facilities to the well-being of the economy. However, with national concern for the competitive position of the nation's economy and productivity, this linkage has become of increasing interest. Aschauer (*1*) has successfully modeled and quantified the contribution of public investment in infrastructure to economic productivity. (Productivity is defined as the value of goods and services, in constant dollars, produced per unit of input—e.g., labor or capital. Total factor productivity refers to output per unit of combined labor and capital.)

Aschauer (*1*) associated the stock of the nation's total infrastructure with private-sector productivity. As a variation of that study, this analysis focused on the highway component of public infrastructure and attempted to isolate the effect of a slowdown in the growth rate of federal, state, and local highway stock on private-sector productivity. Cursory examination of the data between 1950 and 1985 (compiled by the Bureau of Labor Statistics) revealed a striking correlation between the rate of growth in the stock of highway infrastructure and the rate of growth in productivity. After normalizing the data to remove effects of time trends and business cycles, this close association became quite apparent (see Figure 1).

In order to test the hypothesis that productivity in the private sector of the economy is strongly associated with the availability of highway stock, three econometric regression models were constructed. The purpose of the capital productivity regression model was to examine the empirical relationship between private-sector capital productivity and the total stock of state and federal highways. (Highway stock is defined here as the present value of the existing stock of highways, net of depreciation, and measured in constant 1982 dollars.)

The total factor productivity regression model was formulated to analyze the relationship between private-sector total input productivity and the total stock of highways. It was hypothesized that the growth rates in both productivity measures could be explained to a large extent by variations in the existing stock of highways. In other words, the hypothesis contends that the stock of public highways has greatly influenced the growth in productivity of the private sector, which in turn has influenced the growth of the U.S. economy and the competitiveness of U.S. commodities in the international markets.

The third regression model further disaggregated the stock of public infrastructure in order to evaluate the conclusions obtained from the first two models.

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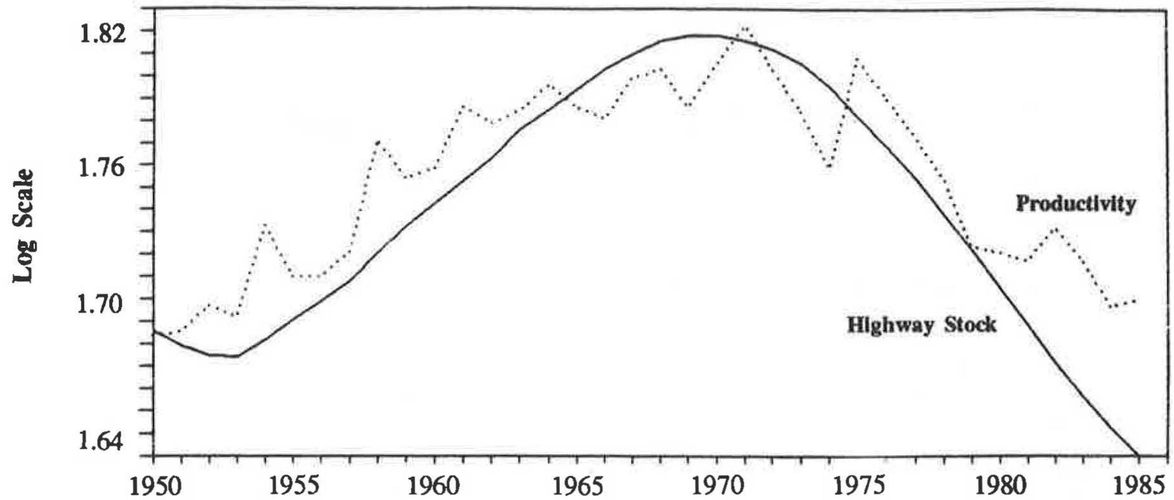

Note: After the effects of technological gains have been removed, the decline in productivity in the private sector (broken line) since the early 1970's has gone hand-in-hand with the decline in the real value (net of depreciation) of the total highway stock. The slope of the two curves (expressed in log form) indicates the percentage change in the two variables over time.

FIGURE 1 Productivity and highway stocks (growth trends).

ECONOMETRIC MODELS

The general form of the economy-wide production function is

$$Y = Y(T, C, K, L, G, \ldots) \quad (1)$$

where

- Y = private-sector output variable,
- T = physical time variable running on a discrete annual basis from 1950 through 1985,
- C = capacity utilization rate,
- K = private-sector capital input variable,
- L = labor input variable, and
- G = total stock of public infrastructure variable.

In Equation 1, all the variables have explicit cumulative time dependence although the independent time variable is omitted for simplicity in terminology.

The discussion that follows is based on several sources (*1–5*).

In order to analyze the relationship between the growth rate in the stock of highway infrastructure and private-sector capital productivity, a Cobb-Douglas production function was used. This functional form precludes explicit modeling of the substitutability or complementarity of the inputs. That is, the elasticity of substitution is assumed to be unity. Future research on this topic will attempt to capture and quantify the interrelationship among all inputs by directly estimating the elasticities of substitution. To this end, more general production functions such as the constant elasticity of substitution production function and the translog production function could be used.

In the analysis, a working hypothesis of constant returns to scale was used, meaning that total private output is generated by labor, private capital, and the total stock of public infrastructure in such a way that a doubling of output is achieved by doubling all three inputs simultaneously. Similarly, a simultaneous increase of 1 percent in each of the inputs would lead to a 1 percent increase in private-sector output.

The Cobb-Douglas production function over K, L, G is as follows:

$$Y = BK^kL^lG^g \quad (2)$$

where

- B = a constant;
- k = elasticity of private capital, i.e., the percent increase in output per unit percent increase in private capital;
- l = elasticity of labor, i.e., the percent increase in output per unit percent increase in labor; and
- g = elasticity of public infrastructure stock, i.e., the percent increase in output per unit percent increase in public infrastructure stock.

As a result of the assumption of constant returns to scale,

$$k + l + g = 1 \quad (3)$$

A statistical test performed to support the assumption of constant returns to scale indicated that, during the sample period, the sum of the estimated coefficients was not significantly different from 1. That is, the empirical evidence strongly suggested that a simultaneous increase of 1 percent in each of the inputs K, L, and G resulted, on the average, in a 1 percent increase in real private-sector output Y.

For this study, the stock of public infrastructure (G) and its respective elasticity (g) were disaggregated. The various components were then directly incorporated in the economy-wide production function and analyzed to reach a conclusion about the role that the stock of highways and streets has played in the growth of U.S. productivity.

The total stock of public infrastructure was disaggregated into a highway component and a nonhighway component, as follows:

$$G = H + N \tag{4}$$

where

H = total stock of highways and streets, and
N = stock of nonhighway infrastructure.

The Cobb-Douglas production function therefore assumed the form

$$Y = BK^kL^lH^hN^n \tag{5}$$

where h and n are the elasticities of highway and nonhighway stock, respectively. Because during the 36-year sample period the relative amount of highway and nonhighway stock remained almost constant (the ratio of highway to nonhighway stock ranged between 0.53 and 0.60), the elasticity for total public infrastructure could be decomposed into the sum of elasticities for highway and nonhighway infrastructure, i.e.,

$$g = h + n \tag{6}$$

Again, as a result of the assumption of constant returns to scale,

$$k + l + h + n = 1 \tag{7}$$

This relationship avoids direct estimation of all possible production function coefficients, which would lead to a problem of multicollinearity. That is, because movements in each input (private capital, public capital, and labor) are themselves strongly correlated over time, direct estimation would be unjustifiable. The technique of using the constant returns to scale assumption reduces the problem of multicollinearity, because one less parameter needs to be estimated.

Adoption of a working hypothesis of constant returns to scale allowed the following log-linear variants of the production function to be deduced.

Capital Productivity Regression Model

Rewriting the specified Cobb-Douglas production function,

$$Y = BK^kL^lH^hN^n$$

Then

$$\begin{aligned} Y &= BK^{(1-l-h-n)}\,L^lH^hN^n \\ &= BKK^{-l}K^{-h}K^{-n}L^lH^hN^n \end{aligned}$$

Dividing by K and collecting terms yields

$$Y/K = B(L/K)^l\,(H/K)^h\,(N/K)^n \tag{8}$$

Taking the natural logarithm yields

$$\begin{aligned} \ln (Y/K) &= \ln B + l \ln (L/K) \\ &\quad + h \ln (H/K) + n \ln (N/K) \end{aligned} \tag{9}$$

This form of the private-sector productivity equation contained the functional dependence of the productivity function most suitable for estimating the parameters l, h, and n directly using the method of ordinary least squares (OLS).

Before estimating the parameters l, h, and n, the remaining factors considered include the capacity utilization rate C of the manufacturing sector used to control for output data fluctuations caused by the influence of the business cycle. In addition at this point, because time series data were used (for 1950 to 1985), the time variable T for changes not otherwise accounted for is included in the general specification of the model.

These adjustments yield the following equation:

$$\begin{aligned} \ln (Y/K) &= b + rT + l \ln (L/K) + h \ln (H/K) \\ &\quad + n \ln (N/K) + c \ln (C) + E \end{aligned} \tag{10}$$

where

b = $\ln B$;
r = average growth rate of ratio of output to capital (capital productivity) unexplained by other specified variables during the period of study [$r = \delta \ln (Y/K)/\delta T$];
c = percentage change in the ratio of output to capital resulting from a 1 percent change in C; and
E = error measure that is a surrogate for all other omitted variables, the joint influence of which is random and negligible in explaining the variation in the output.

The parameters r, l, h, n, and c were numerically estimated by the OLS method.

For the 36 years of historical data analyzed by the OLS procedure, this model yielded the following estimated log-linear private-sector capital productivity regression equation:

$$\begin{aligned} \ln (Y/K) &= -10.9 + 0.0092T + 0.444 \ln (L/K) \\ &\quad + 0.226 \ln (H/K) + 0.163 \ln (N/K) \\ &\quad + 0.37 \ln (C) \end{aligned} \tag{11}$$

where

$\bar{R}^2 = 0.9819$

Standard error of the regression = 0.008674

Durbin-Watson statistics = 1.547942

The t-values corresponding to the six coefficients of Equation 16 were −10.6, 3.78, 4.44, 3.85, 1.65, and 7.95.

All but one of the t-statistics were statistically significant at the 1 percent level. The t-statistic for the nonhighway stock was significant at the 10 percent level but was close to the critical value of 1.69 for the 5 percent level. Therefore, each explanatory variable was significant in helping explain the variation in capital productivity.

Additionally, as the $\bar{R}^2$ measure indicates, 98 percent of the variation in private-sector productivity could be explained by the combined effects of time, labor, private-sector capital, stock of highways, stock of nonhighway infrastructure, and capacity utilization rate.

The Durbin-Watson (D–W) test for serial correlation was employed to address the concern that the effect of omitted variables E was significant or anything other than purely random. The sum of the effects of all omitted variables had to be purely random to preserve a meaningful interpretation of the specified model. Because 36 observations were made using five explanatory variables, the critical values for the D–W d-statistics at the 5 percent significance level were $d_l = 1.175$ and $d_u = 1.799$. Because the calculated sample D–W statistic was 1.559, it lay in the zone of indecision. That is, at the 5 percent significance level the question of whether any correlation existed among the residuals was inconclusive. On the other hand, it was relatively safe to reject the null hypothesis of autocorrelation at the 1 percent significance level because the critical values in this case were $d_l = 0.988$ and $d_u = 1.588$. In summary, the specified functional form (see Equation 10) was close to explaining much of the variation of private-sector capital productivity.

Its relatively high t-statistic showed the significance of the stock of highways and streets in explaining movements in private-sector output.

As expected, the sum of the estimated highway and nonhighway elasticities of 0.389 was close to the estimated elasticity of the total public infrastructure stock of 0.42 (a value derived using a separate model that did not disaggregate the components of total infrastructure).

In addition, even though the average ratio of the real value of highway stock to nonhighway stock was only 0.561 during the sample period, the ratio of elasticities of 0.226 for the highway component and 0.163 for the nonhighway component was 1.39. This comparison indicates that the nation's highway and street system has had a disproportionate effect on U.S. economic growth. In other words, for every 10 percent increase in the stock of highway and streets, private-sector output has grown by 2.26 percent; for every 10 percent increase in all other nonhighway public infrastructure stock, real private-sector output has grown by 1.63 percent. Within the model assumptions, these results indicated that the stock of highways and streets has had on the average 39 percent more influence on private-sector output than the stock of all other infrastructure combined.

Total Factor Productivity Regression Model

In developing the extent to which the stock of highway infrastructure influences total factor productivity growth, the assumption of constant returns to scale in the economywide production function was again used.

Further assuming that each factor is paid according to its marginal product, the elasticities l, k, h, and n also represent the relative shares of total output from labor, capital, and highway and nonhighway public inputs. According to Euler's theorem, the production function of Equation 5 can be written

$$Y = L\frac{\delta Y}{\delta L} + K\frac{\delta Y}{\delta K} + H\frac{\delta Y}{\delta H} + N\frac{\delta Y}{\delta N} \tag{12}$$

where

$$\frac{L}{Y} \cdot \frac{\delta Y}{\delta L} = l$$

$$\frac{K}{Y} \cdot \frac{\delta Y}{\delta K} = k$$

$$\frac{H}{Y} \cdot \frac{\delta Y}{\delta H} = h$$

$$\frac{N}{Y} \cdot \frac{\delta Y}{\delta N} = n$$

Again, the general Cobb-Douglas form for Y yields the following equation in which the variables are accumulated functions of time:

$$Y = BP^zH^hN^n \tag{13}$$

where P is the combined total accumulated unit of private capital and labor and z is the corresponding elasticity with respect to the output.

In constructing an expression for P it was assumed that the rents from public service were appropriated by the private factors of production. In particular, it was assumed that the private-sector input shares were proportional to their true marginal productivities. Thus, the labor share of real output was

$$\frac{L}{Y}\left(w\frac{\delta Y}{\delta L}\right) = wl$$

and the private capital share of real output was

$$\frac{K}{Y}\left(w\frac{\delta Y}{\delta K}\right) = wk$$

where w is the constant of proportionality.

Because of the appropriation process,

$$l + k + g = wk + wl$$

and because of the assumption of constant returns to scale,

$$wk + wl = 1$$

As a result, the combined input variable can be written

$$P = K^{wk}L^{wl} \tag{14}$$

and the production function becomes

$$\begin{aligned} Y &= B(K^{wk}L^{wl})^{(k+l)}H^hN^n \\ &= B(K^{wk}L^{wl})^{1-h-n}H^hN^n \\ &= B(K^{wk}L^{wl})(K^{wk}L^{wl})^{-h}H^h(K^{wk}L^{wl})^{-n}N^n \end{aligned} \tag{15}$$

Dividing by $K^{wk}L^{wl}$ and rearranging terms yields

$$Y/(K^{wk}L^{wl}) = B(H/K^{wk}L^{wl})^h(N/K^{wk}L^{wl})^n$$

Substituting,

$$Y/P = B(H/P)^h(N/P)^n$$

Taking logarithms,

$$\ln (Y/P) = \ln B + h \ln (H/P) + n \ln (N/P) \quad (16)$$

This functional form is again useful for estimating the parameters h and n using the OLS method. Again introducing the capacity utilization rate C and time T for the same reasons as before, the productivity function for combined labor and capital inputs becomes

$$\ln (Y/P) = b + rT + h \ln (H/P) + n \ln (N/P) + c \ln (C) + E \quad (17)$$

When Equation 17 was estimated using the OLS method employing data obtained elsewhere (*6–8*), the following sample regression equation was obtained:

$$\ln (Y/P) = -10.52 + 0.008T + 0.238 \ln (H/P) + 0.134 \ln (N/P) + 0.386 \ln (C) \quad (18)$$

$\bar{R}^2 = 0.996$

D-W statistic = 1.535

The t-values corresponding to the five coefficients of Equation 18 were −13.45, 16.1, 4.34, 1.6, and 14.2.

Again, review of the t-statistics indicated that all specified explanatory variables, except the stock of nonhighways, were significant at the 1 percent level in explaining variations in total factor productivity. (The stock of nonhighways was again significant at a 10 percent level.) Furthermore, the combined effect of these variables explained about 99 percent of the variation observed in total factor productivity (i.e., the variation in private-sector output per combined unit of labor and private-sector capital) during the sample period.

The test for the possible existence of autocorrelation was again inconclusive at the 5 percent significance level. But, with four regressors and 36 observations, the critical values of the D–W d-statistics were $d_l = 1.043$ and $d_u = 1.513$ at the 1 percent level of significance. With a calculated D–W statistic of 1.535, the result indicated no autocorrelation at this significance level.

As expected, the results supported those obtained with the capital productivity model. Because this procedure involved estimating one less parameter, the estimated coefficients were more dependable. That is, as observed from the higher t-statistics, the possible problem of multicollinearity was ameliorated somewhat.

Of particular significance, the estimated elasticity of the stock of highways and streets of 0.238 was consistent with the previous estimate. Also, the estimated elasticity for nonhighway stock was 0.134, which again was close to the result obtained with the capital productivity model.

Further Disaggregated Regression Model

To further support the results obtained so far, the total public infrastructure stock was disaggregated in various ways to analyze the stability of the estimated coefficient of highways and streets.

For example, public infrastructure stock was disaggregated in the following way:

$$G = H + M + S + O \quad (19)$$

where

- M = stock of mass transit and airport facilities as well as that of gas and electric facilities (the data for the four components of M are not separately available);
- S = stock of sewers and water systems; and
- O = all other infrastructure stock.

The same methodology used in the capital productivity model was used to estimate all appropriate parameters of the economy-wide production function. Only one method of disaggregation yielded a significant model specification result:

$$\ln (Y/P) = B + rT + h \ln (H/P) + m \ln (M/P) + q \ln (Q/P) + c \ln (C) + E \quad (20)$$

where m is the elasticity of M with respect to output and q is the elasticity of a combination unit Q of O and S.

When Equation 20 was estimated using the OLS method, the following results were obtained:

$$\ln (Y/P) = -10.17 + 0.009 * T + 0.242 * \ln (H/P) - 0.0221 * \ln (M/P) + 0.13477 * \ln (Q/P) + 0.386 \ln (C) \quad (21)$$

$\bar{R}^2 = 0.996$

D-W statistic = 1.626

The statistical t-values corresponding to the six coefficients of Equation 21 were 13.1, 13.7, 4.45, −0.848, 1.77, and 14.4.

Again, the D-W test was used as a measure of specification error to determine whether the model construction was correctly specified. With five regressors and 36 observations, the lower bound (level of significance of 1 percent) was 0.988 and the upper bound was 1.588. The value obtained of 1.626 indicated that no autocorrelation or specification error existed at a 1 percent level of significance.

The stock of highways and streets again revealed a large t-statistic. Also, the estimated elasticity for the stock of highways and streets of 0.242 did not deviate significantly from the previous estimates.

From the results obtained in the three estimated regression equations (Equations 11, 18, and 21), it could be reasonably concluded that the stock of highways and streets was significant in explaining variations in private-sector productivity. In addition, the estimated elasticity using the three model specifications proved to be stable (ranging between 0.226 and 0.242).

SUMMARY AND FINDINGS

This study was conducted to test the hypothesis that productivity in the private sector of the economy is strongly associated with the availability of highway stock. For this purpose, two separate econometric models were constructed to try to explain this association in terms of the productivity both of capital inputs and of combined labor and capital inputs in the private sector.

The results provide a preliminary support to the proposed hypothesis—i.e., variations in the availability of highway stock can, to a large extent, explain variations in the productivity of private-sector capital investments, as well as in the productivity of capital and labor combined. In other words, full economic benefits of investments in capital and labor in the private sector can be achieved when an adequate supply of public infrastructure in general, and highways in this particular case, exists to go along with the private investment. Conversely, a decline in the availability of highways would lead to a decline in the productivity of both labor and capital in the private sector. These findings were supported by significant statistical results of the models (over 98 percent explanatory power). Some specific findings of the two sets of models included the following:

- On average, for every 10 percent increase in the stock of highway infrastructure (adjusted for inflation), a corresponding increase of between 2.26 and 2.42 percent in real private-sector output was realized.
- The results demonstrate that the stock of U.S. highways has had a proportionally greater effect on private-sector productivity than all other components of public infrastructure combined. In other words, as observed from the data in the sample period, highways comprising only about one-third of the value of total public infrastructure in the United States have been responsible for well over one-half (between 57 and 60 percent) of the gain in private-sector output attributable to public infrastructure.
- Considering the strong association between the level of highway stock and productivity in the private sector, it might be argued that, within the model assumptions, inadequacies of highway facilities could lead to loss of economic production and productivity.

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