Highway capacity and economic growth

The quality and quantity of highway transportation systems have a direct bearing on economic growth—good roads are good business

David A. Aschauer

To the commuter struggling along the clogged freeways of southern California, this statistic must seem unlikely: *the average auto commute in Los Angeles County took only 22 minutes in 1985.* Even more unlikely: *that time was shorter than 1980's average, 23.7 minutes.* After decades of increasing traffic and looming gridlock, how could these daily pilgrimages have become shorter?

One answer is suggested by Peter Gordon, Associate Dean of the School of Urban and Regional Planning at the University of Southern California. Gordon and his colleague, Harry Richardson, say that the highly developed freeway system in the Los Angeles area has allowed business and industry to further decentralize, often locating (or relocating) along the freeway system. It is this shift that has helped to shorten the commuter trips.

Four minutes or so a day per worker may not seem like much. But it adds up to nearly two full working days a year per worker, in a working-age population of some 5.4 million. And industry's intelligent use of the freeway system has other benefits, such as shorter delivery and pick-up times.

The concepts and empirical evidence contained in this article support the idea that transportation infrastructure plays an important role in the process of regional economic growth. While it is common for economists to argue that investment is a key determinant of productivity growth and economic development, it is often the case that the particular investment chosen for analysis is quite limited in scope. Indeed, public investment in infrastructure capital—streets and highways, mass transit, airports, water and sewer systems, and the like—is typically left out of growth discussions, at least at the level of national, aggregate analysis.[1]

Only a relatively small number of studies have sought to establish the importance of infrastructure investment to private sector productivity and income growth. In a series of papers, I have developed a framework (Aschauer 1988, 1989a, 1989b, 1989c) with three basic empirical implications: 1) That infrastructure capital carries a positive marginal product in a private-sector neoclassical production technology; 2) That infrastructure capital is complementary to private capital and is capable of enhancing the marginal product of private capital; and 3) That infrastructure investment is likely to spur private investment in plant and equipment. The empirical results contained in those papers are in broad conformity with the underlying framework.

Holz-Eakin (1989) and Munnell (1990) come to nearly the same conclusions using slightly different empirical approaches or sample periods. Similarly, Garcia-Mila and McGuire (1987) establish a contemporaneous, positive link between the stock of highways and per capita output. Based on the results of

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these studies, one might be convinced that by ignoring public capital stocks the relationship between investment and economic growth is misspecified and potentially underestimated.

Still, legitimate questions may be raised about the results in the aforementioned papers. For instance, the estimates in Aschauer (1989a) seem to suggest a marginal productivity of public capital in private production which is "too high." The elasticity of private sector output with respect to public capital is approximately the same as that with respect to private capital while the public capital stock is approximately one-half the size of the private capital stock. This implies a marginal product of public capital which is approximately twice as large as that of private capital. Perhaps, it may be argued, the correlation between the public capital stock and private sector productivity is merely evidence of economic causation running in the reverse direction—from productivity through per capita output and, in turn, through tax revenues to the demand for public capital.

This article develops an alternative estimation strategy in order to establish the direction of causation from highway investment to economic growth. Specifically, this article searches for a connection between the level of highway capacity and the growth rate of per capita output. The following section lays out the conceptual approach. The next section contains a description of the data and a discussion of empirical results. The article concludes by offering some suggestions for future research.

Conceptual issues

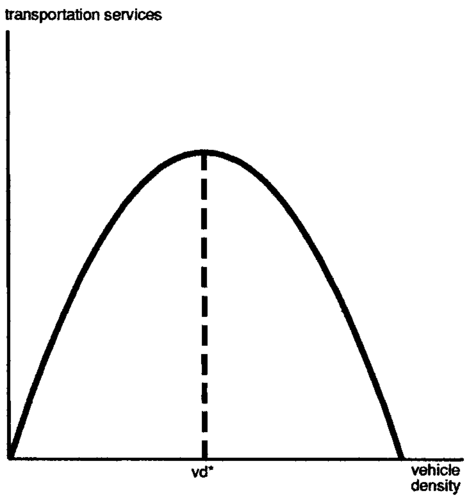
The conceptual analysis centers on the linkages among highway capacity and the production of transportation services, private sector investment, and economic growth. Transportation services are taken to be "produced" by a simple neoclassical technology

1) $t_j = f(\underset{?}{vd_j}, \underset{+}{hi_j})$

where t_j = transportation services (measured as a flow of vehicles per time period) in a particular locale j; vd_j = vehicle density (measured as vehicles per mile of highway); and hi_j = highway capacity (measured as miles of highway). The production technology is characterized by a positive marginal product of highway capacity regardless of the level of vehicle density; additions to the highway stock reduce travel time and, thus, increase traffic flow and the associated transportation services. The production technology can exhibit a positive, a flat, or a negative marginal product of density, however, depending upon whether density is below, at, or above a certain critical level, vd^*, which is typically termed the "bottleneck point" for the highway stock.[2] The production function is depicted as the fundamental diagram of traffic in Figure 1. For a given level of highway capacity, the production of transportation services increases with vehicle density up to the bottleneck point, and declines with further increases in density.[3] A number of empirical studies, such as Fare, Grosskopf, and Yoon (1982), have confirmed this relationship for isolated locales.

FIGURE 1

Fundamental diagram of traffic



This article links the level of highway capacity to a measure of economic growth across localities. I argue that the return to productive activity (apart from transportation services) in any place is positively related to the level of transportation services, measured as a flow of vehicles per time period. Thus, I postulate the rate of return function

2) $r_j = r(\underset{+}{t_j}) = r(\underset{?}{vd_j}, \underset{+}{hi_j})$

so that the return from production, r, in locale j depends on the degree to which the highway stock is congested and on the magnitude of the highway stock.

The level of capital accumulation in a particular locale, in turn, is dependent upon the gap between the return to productive activity, r_j, and the economy-wide cost of capital which we denote p. Hence, we have

$$3)\quad Dk_j = g(r_j - p)$$

where Dk_j = the growth rate of the physical capital stock per person in locale j.

Finally, non-transportation output per person is assumed to be related to the accumulated capital stock per head according to a Cobb-Douglas production function augmented by a common rate of exogenous technological growth and a "catch-up" factor whereby total factor productivity in any given local is allowed to converge on that of other, leading locales. Following Dowdrick and Nguyen (1989), this allows us to write the growth rate of per capita output in the form

$$4)\quad Dy_j = a_0 + a_1 * y_j(0) + a_2 * Dk_j$$

where $y_j(0)$ is the initial level of output in locality j; and where $a_1 < 0$, and $a_2 > 0$. Combining Equations (2), (3), and (4) yields the growth relationship between output, vehicle density, and highway capacity

$$5)\quad Dy_j = y(\underset{-}{y_j(0)}, \underset{?}{vd_j}, \underset{+}{hi_j})$$

so that output growth will be negatively related to the initial level of output; positively or negatively related to vehicle density (depending on whether vehicle density has passed the bottleneck point); and positively related to highway capacity.

The logic of this approach is quite simple. An increase in the stock of highways for a given locale generates a higher return to local, productive activity by raising the level of transportation services available to producers. This higher return to production, in turn, stimulates private investment in these productive facilities. The increased investment carries with it higher growth in output and income for the particular locale.[4]

Increased productivity, of course, is not the only possible mechanism by which infrastructure in general, or highways in particular, might affect the rate of economic growth. Murphy, Shleifer, and Vishny (1989) suggest that investment in infrastructure (in this case, a railroad) may result in lower production costs to a number of economic sectors. These "external effects" of the investment allow for a multiplicity of equilibria, so that infrastructure spending can generate a "big push" to a higher level of output.[5]

In a recent paper, Romer (1989a) constructs a model in which technological change evolves endogenously as the result of profit maximizing investment behavior by imperfectly competitive firms. Knowledge is only partly excludable so that the aggregate production function for final goods exhibits increasing returns to scale. This nonconvexity in the production set allows for steady-state growth in per capita income. Romer shows how market power is necessary for the growth in knowledge to be a result of a response to market incentives; without imperfect competition, total output is less than would be required in payment of all inputs according to their marginal productivities. From the perspective of the current article, the key result of his model is that the rate of growth of a particular economy depends directly on the degree to which it is integrated with other economies. Such integration allows access to a larger stock of human capital which, in turn, raises investment in knowledge or technological improvement and boosts growth.

Sokoloff (1989) offers support for the Romer model. Sokoloff utilizes 19th century United States county-level data to show that the introduction of water transportation (canal construction or river dredging) sparked a sharply higher rate of patenting in those counties adjacent to the transportation system. Presumably, such counties displayed a higher rate of economic growth as well. Clearly, one could argue that similar effects would be expected from the development or improvement of a highway transportation system.

In a model that also admits the possibility of increasing returns to scale, and steady-state growth in per capita income, Barro (1989a) shows how the rate of economic growth can be affected by the size of a government sector. A larger government raises economic growth to the extent that it raises the marginal productivity of private capital but lowers economic growth to the extent that the associated higher rate of taxation discourages productive activity. In a companion empirical paper, Barro (1989b) presents evidence that suggests that governments optimize in their choice of the size of the government sector relative to the economy. In particular, he finds that economic growth is inversely related to "unproductive" government activity (such as government consumptions spending) and weakly positively related to ''productive'' government activity (such as nonmilitary public investment).

Data and empirical results

In this article, I use data on real per capita income growth and measures of highway capacity and quality across the contiguous forty-eight states during the period 1960 to 1985. As the focus of the study is on the longer term relationship between the transportation infrastructure and economic growth, the data on per capita income growth are sample averages of underlying annual observations. The basic highway capacity variable is measured as the total existing road mileage, inclusive of urban and rural roadway, in a given state relative to the square mileage of the state over the period 1960 to 1985.

The separate importance of the urban and rural road systems to per capita income growth will also be investigated. In these data, urban refers to census places with a minimum population of 5,000. The basic highway quality variable is the percent of highway mileage of deficient quality in 1982; such road surface carries a Present Serviceability Rating (PSR) of 2.5 or less for interstate highways and of 2.0 or less for other categories of roadway (other arterial and collector roads).[6]

In order to assess the degree to which the transportation system is congested, a highway usage variable must be employed. The variable chosen for that purpose in this article is vehicle density, expressed as total vehicle registrations (cars, trucks, and motorcycles) per highway mile over the period 1960 to 1985. Of course, this measure of vehicle density will be inaccurate to the extent that vehicles registered in a particular state are operated in other states.

The basic relationship to be investigated is a linearized version of Equation (5):

$$6) \quad Dy_j = b_0 + b_1{*}y_j(0) + b_2{*}vd_j + b_3{*}hi_j + b_4{*}pq_j + c_i{*}d_i + e$$

where Dy_j = per capita income growth in state j; $y_j(0)$ = initial (1960) level of per capita income (in logarithms), vd_j = logarithm of vehicle density; hi_j = logarithm of highway capacity; pq_j = pavement quality; and d_i = dummy variables for the Northeast, Midwest, and West regions of the United States as defined by the Census Bureau.

As the primary focus of this article is on the relationship between highway capacity and economic activity, the above equation is estimated without explicit consideration of the separate effects of vehicle density and pavement quality. Table 1 contains results of estimating this simpler equation by ordinary least squares (OLS) and weighted least squares (WLS) methods. Column 1 reports OLS results including all regional dummy variables. As is shown, there is a significant tendency for states' economies to converge toward a common level of per capita income. Specifically, the coefficient estimate of –1.38 on initial income implies that a one-standard-deviation reduction in the initial level of the logarithm of per capita income results in a faster rate of income growth of .28 percentage point during the period 1960 to 1985. Notably, the central proposition of this article—that economies with a superior surface transportation infrastructure will benefit through higher productivity and per capita income growth—achieves empirical confirmation. The coefficient estimate of .22 on the highway capacity variable indicates that a one-standard-deviation increase in the logarithm of highway capacity induces a .13 of a percentage point increase in the growth rate of per capita income.

The finding that the stock of highways is an important contributor to economic growth parallels the results of recent empirical research by Romer (1989b). Romer focuses on the importance of human capital—measured by the level of literacy of the population—for economic growth across countries. In regressions similar to those in Table 1, he finds a significant positive relationship between human capital and per capita output growth. He also finds that human capital is positively correlated with private investment in plant and equipment. According to the conceptual analysis above, a similar connection between highways and investment would be expected.

The results in Column 1 of Table 1 indicate that, apart from initial per capita income

TABLE 1

Per capita income growth and highway capacity
(Dependent variable: Dy_j)

	1	2	3	4	5	6	7	8	9	10
method	**OLS**	**OLS**	**OLS**	**OLS**	**WLS**	**WLS**	**WLS**	**WLS**	**WLS**	**WLS**
					sq. rt. of y(0)	sq. rt. of y(0)	level of y(0)	level of y(0)	log of y(0)	log of y(0)
constant	–6.53	–6.92	–6.94	–7.69	–7.18	–7.94	–7.47	–8.19	–6.84	–7.61
	1.53	1.10	1.45	1.08	1.15	1.08	1.20	1.09	1.09	1.08
$y_j(0)$	–1.38	–1.44	–1.48	–1.59	–1.49	–1.64	–1.54	–1.69	–1.43	–1.58
	.25	.19	.24	.18	.20	.19	.21	.19	.18	.18
hi_j	.22	.26	.27	.30	.26	.30	.25	.31	.26	.30
	.10	.06	.09	.06	.06	.06	.06	.06	.06	.06
pq_j	--	--	–009	–009	--	–010	--	–011	--	–008
			.004	.003		.003		.003		.003
mw	–27	–25	–37	–31	–26	–32	–26	–33	–25	–31
	.11	.08	.11	.08	.08	.08	.08	.08	.09	.08
ne	<.01	--	–07	--						
	.13		.12							
w	–0.8	--	–11	--						
	.15		.14							
R^2	.61	.63	.66	.67	.39	.49	.32	.46	.69	.73
SER	.26	.25	.24	.24	.26	.23	.26	.23	.25	.24

Variable definitions in appendix.

and highway capacity, only the Midwest region has a growth rate of per capita income statistically different from that of the South, which is used as a benchmark in this Table. Column 2 reestimates the basic equation, dropping the Northeast and West regional dummy variables. As was to be expected, the adjusted coefficient of determination improves marginally upon this alteration and only minor impacts on the individual coefficient estimates can be discerned.

Column 3 includes a measure of pavement quality in the regression equation to determine the separate effect of pavement quality on productivity and income growth. Here, a one-percentage-point erosion in pavement quality induces a reduction of per capita income growth equal to .009 of a percentage point per year. The point estimates of the coefficients on initial income and on highway capacity are left relatively undisturbed and, as before, the Northeast and West regional dummies are statistically insignificant. Column 4 eliminates the latter dummy variables and exhibits nearly the same results for the remaining coefficients.

As estimation is being undertaken over a cross-section of states, there is some presumption that the error structure may not be homoskedastic. Accordingly, Table 1 also contains the results of various generalized least-squares estimations using a variety of weighting series. Columns 5 and 6 use the square root of initial per capita income as a weighting series; columns 7 and 8 use the level of initial per capita income; and columns 9 and 10 use the logarithm of initial per capita income. Only the results with the Midwest regional dummy are presented; as in previous equations, the Northeast and West regional dummies carried little "explanatory" power. In every case, the rate of growth of per capita income is significantly related to highway capacity and pavement quality; further, the quantitative values of the coefficient estimates remain within a small interval of the original unweighted estimates.

Of course, one should be concerned about the potential for simultaneity bias in the estimated coefficients contained in Table 1. For instance, it may be argued that a portion of the positive correlation between highway capacity and per capita income growth is simply due to the fact that high income growth states are likely to be states with adequate resources to invest in additional highways. Similarly, states with such resources would be in a position to undertake appropriate maintenance expenditures in order to avoid an erosion of pavement quality over time.

To address the possibility of such simultaneity bias, Table 2 exhibits results of estimating the relationship between highway quantity and quality variables and per capita income growth by two-stage, least-squares methods. Instruments chosen for estimation are the initial 1960 stock of highway mileage, initial 1960 vehicle registrations, initial 1960 population, new road mileage financed with federal aid highway funds during 1980, seasonal heating degree days, and the number of local governmental units in 1982. The reasoning behind the choice of certain instruments, such as initial highway capacity, initial vehicle registrations, and initial population require no explanation. New road mileage financed through federal grants is taken as exogenous to individual states and is expected to be correlated with highway capacity and quality. Heating degree days is a measure of temperature extremes and is expected to be correlated with pavement quality. Finally, the extent to which a state's governmental decision-making is concentrated, measured by the number of local governmental units, arguably will affect its ability to collect and disburse funds for the purpose of

TABLE 2

Per capita income growth and highway quantity and quality
(Dependent variable: Dy_j)

	1	2	3	4	5	6	7	8
method	**TSLS**	**TSLS**	**WTSLS**	**WTSLS**	**WTSLS**	**WTSLS**	**WTSLS**	**WTSLS**
weight	--	--	sq. rt. of y(0)	sq. rt. of y(0)	level of y(0)	level of y(0)	log of y(0)	log of y(0)
constant	−6.92	−8.28	−7.17	−8.53	−7.45	−8.70	−6.83	−8.18
	1.10	1.30	1.15	1.27	1.20	1.24	1.09	1.31
$y_j(0)$	−1.44	−1.71	−1.48	−1.76	−1.53	−1.79	−1.43	−1.69
	.19	.23	.20	.23	.21	.22	.18	.23
hi_j	.26	.33	.25	.34	.25	.34	.26	.33
	.06	.07	.06	.07	.06	.07	.06	.07
pq_j	--	−016	--	−018	--	−019	--	−015
		.008		.008		.007		.008
mw	−25	−36	−25	−37	−26	−38	−25	−35
	.08	.10	.08	.10	.08	.09	.09	.10
R^2	.63	.64	.39	.42	.31	.38	.69	.70
SER	.25	.25	.26	.25	.26	.25	.25	.25

Instrument list: $y_j(0)$, $hi_j(0)$, $v_j(0)$, $p_j(0)$, $newhi_j(0)$, hdd_j, $govu_j$.

highway construction and maintenance. As before, only results from estimating with a dummy variable for the Midwest region are displayed; inclusion of other regional dummies does not affect the conclusions in any important way.

Column 1 of Table 2 shows that the basic relationship between highway capacity and economic growth is not reflective of a reverse causation from per capita income growth to highways. The point estimate of the effect of highways on economic growth remains the same as with ordinary least squares regression, and there is no change in the standard error associated with the coefficient on highway capacity. The results contained in Column 2 reflect an increase in the quantitative relationship between pavement quality and economic growth, with a near doubling of the relevant coefficient estimate. However, the associated standard error increases by a large amount, with the result that the relationship between pavement quality and per capita income growth is of somewhat diminished statistical significance. Nevertheless, the negative relationship between deficient highway mileage and economic growth still remains at roughly the 5% significance level. Columns 3 and 4 repeat the estimation utilizing weighted two-stage least squares, with the square root of initial per capita income as a weighting series; the point estimates are similar to those in Columns 1 and 2 with some improvement in the statistical importance of pavement quality. Columns 5 and 6 make use of initial per capita income as a weighting series; the only discernible difference in results is a further increase in the importance of the pavement quality variable. Finally, Columns 7 and 8 use the logarithm of initial per capita income to weight the observations; in this case, the statistical association between pavement quality and per capita income growth is attenuated and returns to that obtained in Column 2.

Highway capacity may be acting as a proxy for some other variable that may be of direct and primary importance to economic growth. One such variable might be the degree to which the economy of a state is geographically concentrated; perhaps highly urbanized states exhibit higher per capita income growth due to the compact nature of the particular state's economy. Table 3 allows one to dismiss the validity of this particular argument. As can be seen, urban density—measured by the raw percentage of total population living in standard statistical metropolitan areas in Columns 1 and 2 and by its natural logarithm in Columns 3 and 4—is, at best, only marginally significant and does not attenuate the strength of the basic relationships between highway capacity, highway quality, and economic growth.

TABLE 3

Per capita growth and urbanization
(Dependent variable: Dy_j)

	1	2	3	4
method	OLS	TSLS	OLS	TSLS
constant	−9.41	−13.27	−10.53	−12.71
	1.71	2.96	2.16	2.92
$y_j(0)$	−1.84	−2.44	−1.86	−2.17
	.26	.46	.25	.37
hi_j	.31	.38	.31	.37
	.06	.09	.06	.08
pq_j	−009	−023	−010	−022
	.003	.010	.003	.009
urb_j	.004	.012	.307	.433
	.003	.006	.204	.249
mw	−28	−34	−29	−37
	.08	.12	.08	.11
R^2	.67	.53	.68	.58
SER	.23	.28	.23	.27

Instrument list: see Table 2.

Vehicle density and economic growth

According to the discussion in the theoretical section, an economy with an overburdened highway system—one with traffic density beyond the bottleneck level—will have lower traffic volume and, as a result, lower productivity and per capita income growth. Thus, if during the period under investigation there existed chronic underinvestment in highway capacity across states, one would expect to find a negative relationship between vehicle density—measured as the logarithm of vehicle registrations per highway mile—and per capita income growth. The results contained in Table 4 allow one to gauge the adequacy of the highway capital stock across states.

TABLE 4

Adequacy of highway capital stock
(Dependent variable: Dy_j)

method	1 OLS	2 WLS	3 WLS	4 WTSLS	5 TSLS	6 WTSLS	7 WTSLS	8 WTSLS
weight	--	sq. rt. of y(0)	level of y(0)	log of y(0)	sq. rt. of y(0)	level of y(0)	log of y(0)	log of y(0)
constant	–8.00	–8.30	–8.61	–7.90	–8.80	–9.03	–9.19	–8.70
	.47	1.45	1.42	1.48	1.80	1.71	1.62	1.83
$y_j(0)$	–1.63	–1.68	–1.74	–1.62	–1.78	–1.82	–1.85	–1.76
	.22	.22	.22	.23	.29	.27	.26	.29
hi_j	.28	.27	.27	.28	.30	.30	.30	.30
	.10	.10	.10	.10	.11	.11	.11	.11
pq_j	–009	–010	–011	–008	–016	–018	–020	–016
	.003	.003	.003	.003	.008	.008	.007	.008
vd_j	.027	.033	.038	.026	.041	.043	.044	.040
	.086	.085	.084	.089	.097	.096	.094	.097
mw	–29	–30	–30	–29	–33	–34	–35	–33
	.086	.10	.08	.10	.08	.09	.09	.10
R^2	.66	.47	.45	.72	.62	.40	.36	.69
SER	.24	.24	.24	.24	.25	.25	.25	.25

Instrument list: see Table 2.

Upon scanning the results of Table 4, one finds no evidence of a chronic shortage of highway capacity across states over the entire period 1960 to 1985. The point estimate of the effect of higher vehicle density on per capita income growth is uniformly statistically insignificant regardless of the method of estimation (ordinary least squares, weighted least squares, two-stage least squares, and weighted two-stage least squares). Furthermore, the estimated relationship between highway capacity and economic growth and that between pavement quality and economic growth remain nearly the same as when the vehicle density variable was omitted from the basic empirical specification.

Urban versus rural highway capacity

A natural question is whether urban or rural roads are of greater quantitative and/or statistical importance in determining economic growth across states. Table 5 allows for a decomposition of the initial stock of highways into urban (SSMA) and rural (non-SSMA) mileage. The first Column of Table 5 indicates that both the urban and rural components are quantitatively and statistically important determinants of economic growth, with rural roads having the larger effect. One should note that the diminished statistical significance of the relationship between highways and per capita income growth to a large degree is due to the collinearity between urban and rural highway mileage; the correlation between the two variables across states is .59. Indeed, dropping each of the rural and urban components in turn—as in Columns 2 and 3—leaves significant importance for the remaining highway capacity measure, with individual point estimates of .17 (urban) and .40 (rural) and associated standard errors of .04 (urban) and .09 (rural). Column 4 combines the two components of the highway stock by weighting

TABLE 5

Urban and rural highway capacity
(Dependent variable: Dy_j)

	1	2	3	4	5
constant	−7.35	−6.81	−7.80	−7.37	−7.53
	1.09	1.08	1.120	1.04	1.06
$y_j(0)$	−1.54	−1.42	−1.65	−1.54	−1.61
	.20	.19	.19	.18	.18
hir_j	.24	.40	--	--	--
	.12	.09			
hiu_j	.10	--	.17	--	
	.05		.04		
hit_j	--	--	--	.34	
				.07	
$hita_j$	--	--	--	--	.26
					.05
$area_j$	−.27	−35	−13	−26	--
	.08	.07	.04	.05	
pq_j	−008	−008	−008	−008	−009
	.003	.003	.003	.003	.003
mw	−36	−42	−25	−36	−31
	10	.10	.09	.09	.08
R^2	.68	.66	.66	.69	68
SER	.23	.24	.24	.23	23

according to the coefficient estimates in Column 1 and then summing the two separate components. The coefficient estimate is highly statistically significant. Finally, Column 5 takes the highway capacity measure in Column 4 and normalizes by the surface area of the state. The coefficient estimate can be compared with that of Table 1, whereupon it is seen that this measure of highway capacity bears a stronger statistical association with per capita income growth than did the original, simpler measure.

Conclusion

This article develops a simple model in which the government sector of a particular jurisdiction can influence the rate of growth of output in that locale. A higher level and better quality of highway capacity expands transportation services and, in so doing, raises the marginal product of private capital. The higher marginal product of capital induces higher investment in physical capital and growing per capita incomes and output. Local governments can thereby exert an important influence on the rate of economic growth within their own locality.

In future research, it would be interesting to expand on the theme of this article by looking at the relationship between other measures of infrastructure—water and sewer systems, airports, mass transit, etc.—and local economic growth. Along with existing results on the importance of public capital to metropolitan production, such as contained in Eberts (1988), such evidence would give an improved indication of the importance of the services of government capital to the development and performance of state and local economies.

APPENDIX

Data description and sources

Dy = average annual growth of per capita income (1972$) from 1960 to 1985. SAUS, various issues.

y = logarithm of level of per capita income (1972$). SAUS, various issues.

p = logarithm of population, average over 1960 to 1985. SAUS, various issues.

hi = logarithm of total existing road mileage, average over 1960 to 1985. SAUS, various issues.

hir = logarithm of total existing rural road mileage, average over 1960 to 1985. SAUS, various issues.

hiu = logarithm of total existing urban road mileage, average over 1960 to 1985. SAUS, various issues.

hit = logarithm of weighted sum of hir and hiu.

area = logarithm of square miles of surface area. SAUS.

hita = hit-area.

pq = percent of highway mileage of deficient quality in 1982 (PSR ≤ or = 2.5 for interstate highways, PSR < or = 2.0 otherwise). HS 1982, Table HM63.

v = total vehicle registrations, average over 1960 to 1985. SAUS, various issues.

vd = logarithm of vehicle registrations per highway mile, average over 1960 to 1985. SAUS, various issues.

urb = percent of total population residing in standard metropolitan statistical areas in 1970. SAUS, 1977 Table 17.

newhi = new road mileage financed with federal aid highway funds in 1980. HS 1980, Table FA1.

hdd = seasonal heating degree days (60_ base). SAUS, 1982-83, Table 378.

govu = number of local governmental units in 1982. SAUS, 1988, Table 452.

FOOTNOTES

[1]For example, consider the following statement by Richard Bartel (1989): "...some economists tend to think of investment in narrow terms--private spending on business plant and equipment. We often forget about additions to the stock of public infrastructure--spending on roads, bridges, mass transportation, airports, waterways, water supply, waste disposal facilities, and other public utilities.

[2]See McDonald and d'Ouville (1989).

[3]See McDonald and d'Ouville (1988).

[4]These conceptual results are consistent with the empirical results in Aschauer (1988) and (1989b), which established a link between general infrastructure capital (inclusive of but not confined to highways), the rate of return to private capital, and the level of private investment in nonresidential equipment and structures. .

[5]For related arguments, the reader is referred to Rostow (1960) and Rosenstein-Rodan (1961).

[6]The U.S. Department of Transportation's "PSR is a numerical value between zero and five reflecting poor pavement condition at the lower end and very good pavement condition at the higher values." Highway Statistics (1982), p. 108).

REFERENCES

Aschauer, David A., 1988, "Government spending and the falling rate of profit," *Economic Perspectives*, Vol. 12, pp. 11-17.

_____, 1989a, "Is government spending productive?," *Journal of Monetary Economics*, Vol. 23, pp. 177-200.

_____, 1989b, "Does public capital crowd out private capital?," *Journal of Monetary Economics*, Vol. 24, pp. 171-188.

_____, 1989c, "Public investment and productivity growth in the Group of Seven," *Economic Perspectives*, Vol. 13, No. 5, pp. 17-25.

Bartel, Richard D., 1989, "Introduction," *Challenge*, September/October, pp. 2-3.

Barro, Robert J., 1989a, "Government spending in a simple model of endogenous growth," Rochester Center for Economic Research, *Working Paper*, No. 186.

_____, 1989b, "A cross-country study of growth, saving, and government," unpublished.

Dowdrick, Steven and Duc-Tho Nyugen, 1989, "OECD comparative economic growth 1950-85: catch-up and convergence," *American Economic Review*, Vol. 79, pp. 1010-1030.

Eberts, Randall, 1988, "Estimating the contribution of public capital stock to metropolitan manufacturing production," Federal Reserve Bank of Cleveland, *Working Paper*.

Fare, R., S. Grosskopf and B. Yoon, 1982, "A theoretical and empirical analysis of the highway speed-volume relationship," *Journal of Urban Economics*, Vol. 12, pp. 115-121.

Garcia-Mila, Teresa and Terese McGuire, 1987, "The contribution of publicly provided inputs to states' economies," unpublished.

Holz-Eakin, Douglas, 1989, "A note on the infrastructure crisis," unpublished.

McDonald, John F. and Edmond L. d'Ouville, 1988, ''Highway traffic flow and the uneconomic region of production,'' *Regional Science and Urban Economics*, Vol. 18, pp. 503-510.

_____, 1988, "Optimal road capacity and the uneconomic region of production," unpublished.

Munnell, Alicia, 1990, "Why has productivity growth declined? Productivity and public investment," *New England Economic Review*, January/February, pp. 3-22.

Murphy, Kevin M., Andrei Shleifer, and Robert W. Vishny, 1989, ''Industrialization and the big push,'' *Journal of Political Economy*, Vol. 97, pp. 1003-1026.

Romer, Paul M., 1989a, ''Endogenous technological change,'' National Bureau of Economic Research, *Working Paper*, No. 3210.

_____, 1989b, Human capital and growth: theory and evidence, National Bureau of Economic Research, *Working Paper*, No. 3173.

Rostow, Walt W., 1960, *The stages of economic growth: A non-Communist manifesto*, Cambridge University Press, London.

Rosenstein-Rodan, 1961, ''Notes on the theory of the big push,'' in *Economic development for Latin America*, Howard S. Ellis and Henry C. Wallich (eds.), St. Martin's Press, New York.

Sokoloff, Ken, 1989, ''Inventive activity in early industrial America: Evidence from patent records, 1790-1846,'' *Journal of Economic History*, Vol. 48, pp. 813-850.

Statistical Abstract of the United States, various issues (U.S. Government Printing Office, Washington, D.C.).