Highways and Education: The Road to Productivity?

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From 1948 to 1969, output per hour worked grew at an average rate of 2.5 percent per year. From 1969 to 1987, growth of labor productivity slowed to 1.1 percent per year. Economists and policymakers have acknowledged that the slowdown in productivity growth is one of the major economic problems facing the United States because sluggish productivity growth means slower growth in our standard of living. The decline in investment in public infrastructure and the decline in educational quality may have played a role in this slowdown. Growth of real government spending on nonmilitary public infrastructure declined from an annual rate of 4.1 percent between 1948-69 to only 1.6 percent during 1969-87. There is also some indication that educational quality may have slipped over time as witnessed by the fact that Scholastic Aptitude Test (SAT) scores have been declining since the mid-1960s.[1]

The current Administration would like to increase national productivity by, among other things, increasing investment in public infrastructure and by creating job training programs to improve the quality of the work force. Would

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[1]The data reported in this paragraph are taken from Alicia H. Munnell, "Why Has Productivity Growth Declined? Productivity and Public Investment," *New England Economic Review*, January/February 1990a, pp. 3-22.

programs such as these improve productivity and ultimately the level of output?

Differences across states in investment in public infrastructure and education provide insight into the likely effects of national spending in these areas. A number of recent studies have looked at the impact of public infrastructure and educational attainment on output at the state and local levels. Studies have found that increases in highway density and educational attainment improve a region's productivity and boost output. A recent study by Carlino and Voith found that a 10 percent increase in educational attainment of a state's residents boosts its output by 8 percent, and a 10 percent increase in highway density increases state output by 1.4 percent.[2]

REASONS PRODUCTIVITY DIFFERS ACROSS STATES

Productivity measures the ratio of output to inputs such as land, labor, and capital. If two regions used the same quantities of inputs, output would be greater in the more productive region. One region might have higher productivity than another because the quality of inputs is higher. Regional productivity depends not only on the number of machines used to produce an output but also on their age, technical quality, and degree of utilization. Regional productivity may also depend on the scale at which production takes place within a region's firms. As firms increase their size, they can sometimes increase productivity by having their workers specialize in particular tasks or by using their capital equipment more efficiently. These *internal* factors may vary from one region to another and therefore may influence regional productivity.[3] While these internal factors are an important source of produc-

tivity differentials across regions, this article focuses on public infrastructure and the quality of the region's work force, factors that are *external* to the firm but which influence productivity in a market or region. Before we look at how much public infrastructure and work force quality matter for productivity, we need to understand other external factors that affect productivity, such as a region's industry mix and the degree of urbanization, so that we can control for their effects.

Industry Mix. Regional differences in productivity arise partly because individual regions often specialize in the mix of goods or services they produce. For instance, the growing of wheat and corn tends to be concentrated in the Plains states. Because many of the states in the Northeast and Midwest have historically specialized in the production of manufactured goods, this broad geographic area is commonly referred to as the "industrial belt" or "industrial core." Since some industries are more productive than others, regions with a relatively large concentration of the more productive industries will have greater overall productivity than regions with a concentration of the less productive industries.[4]

Urbanization Economies. Just as a region's industry mix can influence its productivity, the

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[3]These internal decisions by firms may be influenced by external factors. For example, the size of a region's market (external factor) may influence a regional firm's scale of operation (internal factor).

[4]Baumol, Blackman, and Wolff looked at national productivity growth by industry during the 1947-86 period. They found that productivity growth does differ by industry. They also reported that the traditional high-productivity-growth industries continued to perform well during the 1947-86 period, implying long-term differences in the level of productivity across industries. See William J. Baumol, Sue Anne Batey Blackman, and Edward N. Wolff, *Productivity and American Leadership: The Long View* (Cambridge, MA: The MIT Press, 1989).

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[2]Gerald A. Carlino and Richard Voith, "Accounting for Differences in Aggregate State Productivity," *Regional Science and Urban Economics*, 2, December 1992, pp. 597-617.

percentage of a region's firms that are located in metropolitan areas also affects its productivity. Metropolitan areas offer their firms access to a common pool of trained labor, so that firms not only share the cost of training new workers, but any firm can vary its work force without incurring lost productivity during training periods or by carrying idle workers. Metropolitan locations also help firms by providing wholesaling facilities that reduce the level of inventories any one firm needs to keep on hand and by providing access to accounting, data processing, legal, financial, and other specialized business services. Firms located in nonmetropolitan areas would need to employ people who provide these specialized business services on a full-time basis or else spend considerable time and money bringing them from a distance when they are needed. By locating in a metropolitan area firms can contract for these on an as-needed basis.

Economists refer to the advantages offered by metropolitan areas as urbanization economies. These urbanization economies should increase the productivity of urban firms. Thus, other things being equal, the more urbanized regions should have greater productivity than less urbanized regions. In other words, with fewer inputs metropolitan firms can produce the same level of goods and services as nonmetropolitan firms.

Urbanization economies can increase firms' productivity only up to a point. Urbanization brings not only greater productivity but also greater problems, such as congestion, that eventually balance or outweigh the efficiency gains from urbanization. At some point, increases in the number of people and firms residing in a metropolitan area clog its roads and transportation network and raise the average time and cost of transporting goods and commuting either to work or to leisure activities. In addition, as a metropolitan area grows, its boundaries may spread out, which increases both the time and distance of the average commute.

When urban size becomes a hindrance rather than a help, firms experience urbanization diseconomies. Urbanization economies are balanced by these diseconomies, suggesting that there may be some optimal degree of urbanization.

Individual firms that have incentives to exploit urbanization economies are guided by the "invisible hand" of the marketplace to locate in metropolitan areas. Local policymakers can lend a hand to lessen the negative consequences of congestion by providing public infrastructure, such as highways, airports, and mass transit facilities, that link a region's labor and product markets with one another and with those of other regions.

Public Infrastructure. Some economists believe that an increase in the capital stock of the public sector leads directly to increases in private sector output because public infrastructure is an essential input in the production of private output.[5] For example, driver productivity increases when a good highway system allows truck drivers to avoid circuitous back roads and to bring supplies to a firm and goods to market more quickly. Similar arguments can be made for the public provision of police and fire protection, water supply facilities, airports, and mass transit. An increase in the public capital stock, like an increase in any factor of production, directly increases private sector output.[6]

Of course, some public sector spending may actually substitute for private sector spending. This would be the case if close substitutes for

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[5]For a useful survey of the recent literature, see John A. Tatom, "Should Government Spending on Capital Goods Be Raised?" *Review*, Federal Reserve Bank of St. Louis, March/April 1991, pp. 1-15; and Randall Eberts, "Public Infrastructure and Regional Economic Development," *Economic Review*, The Federal Reserve Bank of Cleveland (First Quarter 1990a), pp.15-27.

[6]Munnell (1990a); see footnote 1 for complete citation.

publicly provided services are available from the private sector.[7] Public finance theory tells us, however, that most public sector spending should be for goods and services that would be either not provided or underprovided if left to the private sector. For example, private companies could build roads and bridges and charge tolls for using them. But private provision may not be efficient. Although there is a large initial fixed cost associated with construction of bridges and highways, once constructed, the additional cost of one more vehicle on uncongested roads is nearly zero. In this case, economic efficiency requires setting a zero price for use of uncongested roads. Thus, while it is possible to exclude those unwilling to pay for the use of infrastructure, such exclusion often is inefficient.[8] In such cases, the public sector should provide infrastructure.

Labor-Force Characteristics. Policymakers in state and local government in the U.S. have a great deal of influence on the quality of the work force because their policies affect the cost and quality of the public education system. Studies have shown that higher educational attainment of a region's labor force is an important contributor to higher regional productivity.[9] These investments in human capital may lead to increased regional productivity because education introduces a region's workers to new techniques and skills. Since educational attainment differs across regions, these differences can lead to variations in regional productivity.

THE EVIDENCE

Studies on regional productivity have tended to limit their focus to specific aspects of regional productivity. A number of studies since the mid-1970s have looked at the impact of urbanization economies on manufacturing productivity at the regional level. These studies have shown that manufacturing productivity in general increases with metropolitan population size (a proxy for urbanization economies), at least over the observed ranges of metropolitan sizes.[10] Another group of regional productivity studies has examined the role of public infrastructure in regional production, and most studies find that greater investment in public capital does raise regional productivity.[11]

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[7]Studies have found that labor and public capital are complements in production, while there appears to be some degree of substitutability between public capital and private capital. See Jose da Silva Costa, Richard W. Ellson, and Randolph C. Martin, "Public Capital, Regional Output and Development: Some Empirical Evidence," *Journal of Regional Science*, 27 (1987), pp. 419-37; and Alicia H. Munnell, "How Does Public Infrastructure Affect Regional Economic Performance?" *New England Economic Review*, September/October 1990b, pp. 11-33. Munnell finds that highways and streets appear to be substitutes for private capital and speculates that well-maintained roads reduce wear and tear on commercial vehicles, lowering private sector maintenance and replacement of these vehicles.

[8]See Eberts (1990a; see footnote 5 for complete citation), for a discussion of the public goods aspects of public inputs.

[9]See, for example, Gerald A. Carlino and Edwin S. Mills, "The Determinants of County Growth," *Journal of Regional Science*, 27 (1992), pp. 39-54.

[10]For a survey of this literature, see Ronald Moomaw, "Spatial Productivity Variations in Manufacturing: A Critical Survey of Cross-Sectional Analysis," *International Regional Science Review*, 8 (1983), pp. 1-22.

[11]See Randall Eberts, "Estimating the Contribution of Urban Public Infrastructure to Regional Economic Growth," Working Paper 9004, Federal Reserve Bank of Cleveland (May 1990b). While Eberts concentrates on the influence of public capital on *manufacturing output*, an article by Alicia Munnell and one by Teresa Garcia-Mila and Therese J. McGuire extend the analysis of public infrastructure to *aggregate output* at the state level. See Munnell (1990b; footnote 7 has complete citation); and Teresa Garcia-Mila and Therese J. McGuire, "The Contribution of Publicly Provided Inputs to States' Economies," *Regional Science and Urban Economics*, 22 (1992), pp.229-41. Both studies find that public infrastructure has positive effects on aggregate productivity at the state level.

The examination of each of these factors in isolation can result in misleading conclusions. For example, the contribution of public infrastructure to regional productivity may be overstated if the other factors thought to influence regional productivity are not taken into consideration. The clustering of firms in metropolitan areas creates urbanization economies, which, in turn, increases a region's overall productivity and output. More output leads to increased tax revenue for state and local governments. Some of the increased tax revenue may be used to supply public infrastructure. Perhaps it is urbanization economies that largely contribute to regional productivity, and public infrastructure contributes to a much lesser extent or not at all. Since increased urbanization economies lead to more output, which, in turn, leads to more public infrastructure, studies that look at the role of public infrastructure on regional productivity but fail to control for urbanization economies run the risk of overstating the relative importance of public capital.[12]

The Carlino and Voith study provides a more comprehensive view of the factors affecting state productivity by considering the relative importance of industry mix, urbanization economies, public infrastructure, and labor quality on aggregate production at the state level during the 1967-86 period (see Appendix, page 30).[13]

Industry Mix. Carlino and Voith measured industry mix by the share of state output attributable to each of the nine major industry groupings.[14] By including these industry-mix variables, their study controlled for industrial structure differences across states, which helped to isolate the effects of the other variables thought to have independent effects on state productivity. Carlino and Voith found that state productivity varies a lot, running from about 50 percent above the national average in Delaware to about 35 percent below average in Wyoming. They also found that controlling for industry mix alone explains about 26 percent of the variation (see *Industry Mix Is an Important Component of a Region's Aggregate Productivity*).

Urbanization Economies. The Carlino and Voith study used the percent of a state's population that is metropolitan to capture the effects of urbanization economies. The percent of the population living in metropolitan areas varied widely across states in 1984; for example, it is as low as 14.7 percent in Wyoming and as high as 100 percent in New Jersey.[15] The positive effects

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[12]An unresolved issue is whether public capital precedes private capital formation or vice-versa. There is evidence that the formation of public capital and private capital is a simultaneous process. See Eberts (1990a; footnote 5 has complete citation).

[13]Carlino and Voith (1992; see footnote 2) used multiple regression analysis to examine the relative importance of industry mix, labor-force quality, urbanization economies, and infrastructure on state aggregate productivity. One problem with analyzing the results from a multiple regression analysis is that the variables are generally measured in different units. For example, educational attainment is measured in *years*, and public infrastructure is measured in

terms of *highway density*. To facilitate the comparison of the effects of different variables, we must standardize our findings. A common approach couches relationships in percentage terms—the percent change in one variable associated with the percent change in another. This unitless measure is known as an elasticity. The elasticity for state output tells us the percent change in state output given a percentage change in any of the explanatory variables, while holding all other explanatory variables constant.

[14]These groupings are agriculture; mining; construction; manufacturing; transportation, communication, and public utilities; trade (wholesale and retail combined); finance, insurance, and real estate (FIRE); services; and government. Since the industry shares of state output sum to one, it is necessary to drop the percentage share of one of the industries. Although agriculture is the excluded industry in the Carlino and Voith study, the study could just as easily have excluded any one of the other industries.

[15]Every county in New Jersey is part of a metropolitan area even though large parts of some counties are rural.

Industry Mix Is an Important Component of a Region's Aggregate Productivity

The estimates of total factor productivity from the Carlino/Voith study can be used to compare aggregate productivity across states by looking at the ratio of productivity in a state relative to productivity averaged across all states. If productivity in a state is equal to the national average, the ratio would equal one. If the state is more productive than the average state, the ratio would be greater than one. And the ratio is less than one if the state is less productive than the average state.

State productivity varies from about 50 percent above the national average (48-state average) in Delaware to about 35 percent below the national average in Wyoming (see Table). Even with the exclusion of Delaware, there is a 58 percent differential between Rhode Island, the second most productive state, and Wyoming, the least productive state. But controlling for industry mix alters the picture substantially.

Industry Mix. Total productivity was recalculated for each state, controlling for industry mix differences across states by assigning the national industry mix to each state. Controlling for industrial structure reduces the differential in total productivity across states by 26 percent. The differential in state productivity runs from about 43 percent above the national average (compared with 50 percent above average before standardization) to 19 percent below the national average (compared with 35 percent below before standardization). Of the 16 states in the top one-third of the productivity distribution before standardization, 13 states remain in the top one-third after standardization. Indiana, Maine, and Massachusetts, which were in the top one-third before standardization, moved to the middle third after standardization. Three states, Louisiana, Oklahoma, and New Mexico, were in the bottom one-third before standardization but moved to the top one-third after standardization.

Wyoming is an interesting example of how industry mix can affect a state's productivity in that it moves from being 35 percent below the U.S. before standardization to just about at the national average after controlling for industrial structure. A relatively large portion of total employment in Wyoming is in the extractive industries, especially oil and gas. Mining employment in Wyoming accounted for 22 percent of total employment in 1980, compared with only one percent nationally. Wyoming also tends to be much less manufacturing oriented. In 1980, only 6 percent of total employment in Wyoming was accounted for by manufacturing, compared with 28 percent nationally. One recent study shows that while productivity in the mining industry fell dramatically during the period 1947-86, it improved slightly in manufacturing.[a]

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[a]William J. Baumol, Sue Anne Batey Blackman, and Edward N. Wolff, *Productivity and American Leadership: The Long View* (Cambridge, MA: MIT Press, 1989).

Aggregate Productivity Differences Across States[a]

		Total		Controlling for Industry Mix			Total		Controlling for Industry Mix
1	Delaware	1.5002	1	1.4338	25	Nevada	1.0210	42	0.9058
2	Rhode Island	1.2282	2	1.1886	26	Arkansas	1.0178	19	1.0149
3	South Carolina	1.2081	3	1.883	27	Maryland	1.0177	31	0.9660
4	Georgia	1.1833	12	1.0603	28	Arizona	0.9953	36	0.9350
5	Connecticut	1.1685	6	1.1210	29	Oregon	0.9867	39	0.9144
6	New Hampshire	1.1456	10	1.0723	30	Virginia	0.9751	26	0.9908
7	Tennessee	1.1230	13	1.0595	31	Iowa	0.9687	25	0.9922
8	Vermont	1.1156	14	1.0591	32	Mississippi	0.9653	20	1.0127
9	Indiana	1.1061	17	1.0481	33	Colorado	0.9364	40	0.9102
10	West Virginia	1.1007	5	1.1609	34	Florida	0.9343	46	0.8332
11	Missouri	1.0949	29	0.9780	35	Washington	0.9289	44	0.8700
12	North Carolina	1.0913	11	1.0603	36	Kansas	0.9274	32	0.9642
13	Alabama	1.0868	9	1.0730	37	Nebraska	0.9250	38	0.9184
14	Massachusetts	1.0864	24	0.9997	38	Idaho	0.9138	41	0.9089
15	Michigan	1.0832	16	1.0506	39	Oklahoma	0.9061	7	1.1194
16	Maine	1.0830	21	1.0075	40	Utah	0.9022	43	0.8881
17	Illinois	1.0788	27	0.9870	41	Texas	0.8433	28	0.9816
18	Ohio	1.0662	22	1.0005	42	North Dakota	0.8409	35	0.9426
19	Wisconsin	1.0515	18	1.0324	43	California	0.8285	48	0.8090
20	New York	1.0450	34	0.9528	44	Louisiana	0.8236	4	1.1647
21	Pennsylvania	1.0386	33	0.9533	45	South Dakota	0.8143	45	0.8626
22	New Jersey	1.0381	37	0.9350	46	New Mexico	0.7989	15	1.0531
23	Minnesota	1.0337	30	0.9765	47	Montana	0.7744	47	0.8296
24	Kentucky	1.027	8	1.0880	48	Wyoming	0.6457	23	0.9998

[a]Index represents ratio of aggregate productivity in each state to the national average.

of increased urbanization make up one side of the urban size ledger. The negative effects of congestion brought on by increased urbanization make up the other. Thus, Carlino and Voith allowed for the fact that increasing the degree of urbanization would increase productivity up to a point, after which productivity would decrease.[16] Both forces influence productivity: increased urbanization encourages growth, and increased congestion discourages it. Carlino and Voith found that the positive effects of urbanization economies are greatest when roughly half of a state's population is metropolitan.[17]

Infrastructure. A state can mitigate the effects of congestion by building and maintaining streets and highways. The Carlino and Voith study employed highway density (highway miles per square mile of land area in a state) as a proxy for state infrastructure, partly because of the relative importance of highways and partly because data for the other categories of public capital are generally not available.[18] The study found that state produc-

tivity responds to the availability of a highway network. A 10 percent increase in a state's highway density leads, on average, to a 1.4 percent increase in total output. The Carlino and Voith study corroborates the findings reported in several recent studies in terms of the importance of infrastructure spending on state output. One study, by Garcia-Mila and McGuire, employed annual expenditures on highways by state and local governments during 1969-83 as a measure of public sector capital. The study found that a 10 percent increase in highway spending results in a 0.7 to 1.7 percent increase in aggregate state output.[19] A study by Munnell, using a broader measure of infrastructure than the one employed by Carlino and Voith, found that a 10 percent increase in infrastructure led to a 1.5 percent increase in aggregate state output during the 1970-86 period.[20] The similarity of the findings among the three studies supports the concept of public infrastructure spending as a public policy instrument for fostering productivity growth at the state level.[21]

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[16]To capture the effects of congestion Carlino and Voith took the percent of a state's population that is metropolitan and squared it. This follows William Baumol's reasoning that if each resident of a metropolitan area imposes external costs on every other, and if the magnitude of the cost borne by each resident is roughly proportional to a metropolitan area's population size, then since these costs are borne by each of R residents involved, the total external cost will increase not with R but with R^2. See William J. Baumol, "Macroeconomics of Unbalanced Growth: The Anatomy of Urban Crisis," *American Economic Review*, Vol.57 (1967), pp. 415-26.

[17]Of course, factors other than percent of a state's population that is metropolitan can influence the urbanization economies states offer. For example, urbanization economies may spill over state boundaries so that states that are not highly urbanized may benefit from urbanization economies if they are near highly urbanized states.

[18]In 1988 nonmilitary infrastructure amounted to $2 trillion, compared with $4.4 trillion in private capital.

Most of this infrastructure consists of assets owned by state and local governments. The largest single item is highways and streets, which account for 39 percent of total state and local wealth. See Munnell (1990b; footnote 7 has complete citation).

[19]Garcia-Mila and McGuire (1992; footnote 11 has complete citation).

[20]Munnell (1990b; footnote 7 has complete citation). Munnell found that an additional dollar of public infrastructure spending yielded the same increase in aggregate state output as an additional dollar spent on private capital. Munnell used the stock of state and local public capital, which includes highways and streets, water and sewer systems, buildings (schools, hospitals, etc.), and equipment. The results of this study are somewhat controversial. See John A. Tatom, "Public Capital and Private Sector Performance," *Review*, Federal Reserve Bank of St. Louis, May/June 1991, pp. 3-15; and Alicia H. Munnell, "Infrastructure Investment and Economic Growth," *Journal of Economic Perspectives*, 16, Fall 1992, pp. 189-198.

Labor-Force Characteristics. Differences in labor-force composition—education, experience, degree of unionization—across states can result in differences in aggregate productivity. The Carlino and Voith study uses educational attainment, defined as the percent of a state's population that is 25 years old and over with 12 or more years of schooling, as its measure of labor-force quality. The percent of a state's 25-and-over population with at least a high school diploma varies widely across the United States; for example, in 1980 it was as low as 53 percent in Kentucky and as high as 80 percent in Arizona. Carlino and Voith's results indicate that a 10 percent increase in educational attainment leads, on average, to an 8 percent increase in

aggregate output.[22] This finding suggests that education is an important public policy instrument for promoting productivity growth at the state level.[23]

CONCLUSION

The research summarized in this article supports the view that increased infrastructure spending and greater educational attainment do improve productivity and ultimately the level of output. Further research should help determine the relative effects of additional spending on infrastructure and education. But the findings so far suggest that state governments should pay close attention to investment in public capital and to the level of educational attainment of their workers.

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[21]The magnitude of the effect of public infrastructure on state level output is about half as large as that found for the national economy. For example, Aschauer found that a 10 percent increase in the stock of public capital led to a 3.9 percent increase in national output. See David A. Aschauer, "Is Public Expenditure Productive?" *Journal of Monetary Economics*, 23, March 1989, pp. 177-200. When one state adds to its stock of public infrastructure, this increased investment most likely has a beneficial effect on the output of neighboring states. For example, the opening of Interstate 476 in Pennsylvania in 1992 not only made Pennsylvania's workers more productive, but it may have improved the productivity of workers in Delaware and New Jersey as well. For a general critique of Aschauer's findings, see Laura Rubin, "Productivity and the Public Capital Stock:

Another Look," Working Paper No. 118, Board of Governors of the Federal Reserve System, May 1991.

[22]Of course, more productive workers may place a higher value on educational attainment. To some extent, therefore, productivity and educational attainment may be a simultaneous process.

[23]Factors other than those discussed here could affect state productivity, including state policies and regulations, the degree of unionization, research and development spending, and technical progress. While these factors may determine differences in state productivity, few, if any, data are available to determine the relative importance of these omitted variables.

A state's output of goods and services depends on the quantities of inputs, such as capital and labor, and on the productivity of those inputs. The relationship among output, inputs, and productivity is given in the following production function:

$$Q = AF(K, L)$$

Accordingly, the amount of real output, Q, that a state can produce during some period, such as a year, depends on the size of its capital stock, K, and the number of hours worked, L. The symbol F is a function, or equation, relating output to capital and labor inputs. The symbol A measures the overall effectiveness with which a state uses its capital and labor resources. The symbol A is therefore referred to as a measure of total factor productivity. If two states used the same levels of capital and labor, the more productive state would have a larger A term and would therefore produce more output than the state with a lower A term.

While some studies have treated the various productivity factors as inputs in the production function, the Carlino/Voith study treated them as affecting the efficiency parameter, A. Specifically, the value of A depends on industry mix, urbanization economies, public capital, and the quality of labor. This means that the various productivity factors augment private sector use of labor and capital. In this case, an increase in the level of public capital increases the efficiency of both private capital and labor.

The Empirical Model. Empirical analysis of state productivity has had to deal with an important data problem, namely, data on the stock of capital at the state level are not available. Fortunately, a production function technique has been developed that permits the estimation of productivity without the need for data on the capital stock.[a] The technique involves estimating a wage equation. It is assumed that workers are paid according to their productivity (that is, there is perfect competition in and across local labor markets), and therefore wages and the demand for labor reflect the differentials in productivity across states. Under these conditions, the following wage equation is derived from the aggregate production function:

$$\ln W_{it} = \beta_0 + \Sigma_{j=1}^8 \beta_j S_{jit} + \beta_g P_i + \beta_{10} P_i^2 + \beta_{11} I_i + \beta_{12} E_i + \beta_{13} T_t + \beta_{14} Z_t + \beta_{15} U_i + \theta \ln Q_{it} + \gamma \ln L_{it}$$

where
W_{it} = Annual aggregate real wage bill divided by number of employees in state i for time t.

S_{jit} = The real output share of the j-th one-digit industry (mining; construction; manufacturing; transportation, communication, and public utilities; wholesale and retail trade; finance, insurance, & real estate; services; and government) in state i for time t.

P_i = For each year, the percent of state i's population living in metropolitan areas in 1970 or 1980 (whichever is closest) based on 1983 metropolitan area definitions.

I_i = Total primary Federal-Aid Highway System miles per square mile of land area in state i for 1980.

E_i = Educational attainment (percent of the population 25 years old and over with 12 or more years) in i in 1980.

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[a] See Gerald A.Carlino, "Increasing Returns to Scale in Metropolitan Manufacturing," *Journal of Regional Science*, 19, 1979, pp. 363-73.

APPENDIX (continued)

T_t = Technical progress, represented by a time index.

Z_t = Dummy variable to capture the effects of the energy shock years; $Z_t = 1$ if $t = 1973$ to 1978; and 0 otherwise.

U_i = Union membership as a percent of employees in nonagricultural establishments in i for 1970.

Q_{it} = Real gross state product in state i at time t.

L_{it} = Aggregate employment in state i at time t.

The findings reported in the text of this article are based on a random-effects estimation of a pooled cross-section time series model for the 48 contiguous states for the period 1967-86 (providing 960 observations).[b] While a wage equation was estimated, we obtained the effects of industry mix, urbanization economies, public infrastructure, and labor force quality on output indirectly by transforming the appropriate estimated coefficients of the wage equation.[c]

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[b]The estimated coefficients for industry mix, urbanization economies, public capital, and labor quality capture the direct effect of these variables on labor productivity. There may also be important indirect effects that are not captured by the estimates. For example, states with high educational attainment may also attract the more productive industries.

[c]Let α_k represent the output effect of the k-th productivity variable. Then the output effect is calculated indirectly as $\alpha_k = \beta_j/\rho$, where $\rho = \theta - 1$. For details see Gerald A. Carlino and Richard Voith, "Accounting for Differences in Aggregate State Productivity," *Regional Science and Urban Economics*, 22, 1992, pp. 597-617.