NOTE

THE EFFECT OF PUBLIC CAPITAL IN STATE-LEVEL PRODUCTION FUNCTIONS RECONSIDERED

Teresa Garcia-Milà, Therese J. McGuire, and Robert H. Porter*

Abstract—Using a panel data set for the 48 contiguous states from 1970 to 1983, several estimates are provided of a Cobb-Douglas production function with three types of public capital as inputs Various specification tests are systematically applied to test for both random and fixed state effects, nonstationarity, endogeneity of the private inputs, and measurement error. In the preferred specification, which is first differences with fixed state effects, the public capital variables are not significant, while the fixed state effects and private input variables are significant.

I. Introduction

With the justification for perhaps billions of dollars of federal, state, and local government expenditures riding on a single coefficient, it is no wonder that dozens of estimates of the output elasticity of public capital have appeared in recent years. Although much of the interest in determining the contribution of public capital to private output began with Aschauer (1989), estimates of the elasticity of public capital had appeared earlier in Eberts (1986).

The reason that Aschauer's and not Eberts' findings stimulated much of the subsequent research was the startling finding contained in Aschauer (1989) that the elasticity of private output with respect to public capital was 0.39, higher than the elasticity of output with respect to private capital Aschauer's interpretation and presentation of this finding as being a primary explanation for the productivity slowdown in the United States, was supported by Munnell (1990a) and Lynde and Richmond (1991), but refuted by Aaron (1990), Schultze (1990) and Tatom (1991), among others The primary criticism leveled against Aschauer's finding was that the coefficient merely reflected a strong spurious correlation between output and the public capital stock, and that once one controlled for nonstationarity of the national time series, the purported relationship disappeared (Tatom (1991)).

Using panel data sets, several authors provide estimates of region-wide production functions, which rely on cross-section variability as well as variability over time (Eberts (1986), Garcia-Milà and McGuire (1992), Holtz-Eakin (1994), McGuire (1992), and Munnell (1990b)). These authors estimate elasticity coefficients for public capital that range from zero to 0.15, depending on the data set employed and the specification of the estimating equation. While it is likely to be less of a problem with panel data sets, it is still possible that these estimates are contaminated by nonstationarity of the variables.

This paper has two goals. The first purpose is to test systematically for the proper specification of a state-level production function with public capital as an input. We perform a specification search within Cobb-Douglas production functions, since this is the type of function most commonly used in the literature, and enables us to compare the existing results with ours. We begin with an OLS specification with yearly time dummies, which is common in the literature, and then we systematically test for random and fixed state effects, serial correlation, measurement error, and endogeneity

Received for publication March 1, 1993. Revision accepted for publication March 30, 1995.

* Universitat Pompeu Fabra, University of Illinois, and Northwestern University, respectively

The second purpose is to include three types of public capital—highways, water and sewers, and all other—in the model. In previous studies, most notably in McGuire (1992), estimates of the production function that include aggregate public capital as an input find public capital to be insignificant, but when public capital is disaggregated into its component parts, the coefficients for highways, and water and sewers are positive and significant, while the coefficient on other public capital is negative and significant. Here, we examine the effects of the three components of public capital in several specifications of the estimating equation.

The paper most similar to ours is Holtz-Eakin (1994). Using a somewhat different data set, he demonstrates that Aschauer's finding concerning the productivity of aggregate public capital is not robust. Holtz-Eakin investigates a variety of econometric specifications, and all specifications but OLS in levels without fixed state effects yield small, insignificant, and sometimes negative public capital coefficients. Our contribution is to employ specification tests to guide us to the preferred estimation method, involving first differenced data with fixed effects. Holtz-Eakin did not consider this specification, nor did he examine the three components of public capital.

II. Data, Specification Tests, Estimation Results

The data consist of annual observations from 1970 through 1983 for the 48 contiguous states on GSP, total employment, total private capital, total public capital, and total public capital broken into three categories; highways, water and sewers, and other. The source for the GSP data is the Bureau of Economic Analysis (BEA), U.S. Department of Commerce, and the source for the employment data is the Bureau of Labor Statistics (BLS), U.S. Department of Labor.

The private capital stock variable was calculated using a state-level investment series in private structures and equipment, which BEA maintained until the early 1980s. It is the loss of these investment series data that limits our analysis to no later than 1983. Garcia-Milà and McGuire (1992) describe these data and the process used to convert investment flows to stocks.

The public capital stock variables are from Munnell (1990b). Using state and local expenditures on capital outlays as investment in public capital, public stock variables were generated for three broad types of public infrastructure. There is reason to believe that the coverage of these measures of the public capital stock may be too narrow (see McGuire (1992)), but the three categories represent the major types of state and local infrastructure.

We specify a simple Cobb-Douglas production function for ease of comparison to other estimates in the literature, and we employ a variety of specifications of the error term. Our basic equation is as follows:

$$GSP_{st}=a_s+a_t+bK_{st}+cL_{st}+dG_{st}+e_{st}$$

where *GSP*, private capital *K*, employment *L*, and the three components of public infrastructure *G* (a vector), are measured in natural logarithms, and where the subindices *s* and *t* refer to state and time. The various specifications of this basic equation involve different assumptions about the constant term, *a*, and the error term, *e*.

In table 1 we present the results of estimating three specifications of the basic equation. In column (1) the specification is OLS with annual time dummies (fixed time effects) and no state effects. This specification is comparable to many of the early estimates of state-level production functions with public capital as an input, including Garcia-Milà and McGuire (1992) and Munnell (1990b). In column (2) the specification is GLS with fixed time effects and random state effects. In the table, theta is as defined by Greene (1993, p. 470). Here $(1\text{-}\theta)^2$ measures the weight given to between state variation. Column (3) displays an OLS specification with fixed state and time effects. (These estimates also appear in McGuire (1992).)

Without controlling for state effects, the estimated coefficient on highway public capital is large, positive and significant (column 1) The estimated coefficient on water and sewers in column (1) is positive and significant, but small, while the estimated coefficient on other public capital is insignificant. Once we control for either fixed state effects or random state effects, the estimated coefficients on the public capital variables are either small, positive and significant (highways, and water and sewers); or small, negative, and significant (other public capital). These opposing results for the different types of public capital may explain why estimates employing aggregate public capital are insignificant.

When we apply the test posed in Hausman and Taylor (1981) of fixed state effects against random state effects, we find that fixed effects is the preferred specification. The F-statistic for this test is 72.05, which is significant at the 1% level. Also, a Chow test indicates that the model with fixed state and time effects is preferable to one with fixed time effects alone. Thus, if the variables are measured in levels of natural logarithms, the specification displayed in column (3) is preferred. This is the regression stressed in McGuire's study for the Federal Highway Administration (McGuire (1992)).

The criticism leveled against Aschauer's original estimates may also be valid for the fixed state effects estimates displayed in table 1, that is, that the positive coefficients merely reflect spurious correlation. McGuire (1992) provides a brief discussion of this issue and of the possibility that taking first differences, a common response to nonstationarity, might not be appropriate, if the variables are subject to measurement error.

It might be argued that because we employ a panel data set, the issue of nonstationarity of the variables is less serious. After all, the best estimates using panel data are much more plausible in the size of the public capital elasticities than are Aschauer's and Munnell's estimates using national time series data. Bhargava, Franzini, and Narendranathan (1982) (BFN) provides a test for serial correlation in panel data sets. When we apply their test to the regression displayed in column (3), we cannot reject the hypothesis that the residuals follow a random walk. Their d_p statistic, which is a modified Durbin-Watson statistic, equals 0.43. The test statistic is consistent with a random walk. Further, the implied estimate of the first order autocorrelation coefficient for the residuals, as given by equation (24) on page 540 of BFN, is 0.999

The BFN test indicates that the variables should be transformed into first differences. Table 2 presents the results of estimating the three specifications from table 1, but where the variables are in first differences. Note that the first-differencing reduces the number of observations. The estimated elasticities for the public capital variables are all negative and insignificant. Hausman and Taylor and Chow tests for the state effects indicate that, even with the variables measured as first differences, the specification with fixed state effects is preferred. The Chow test for (1) versus (3) yields an $F(47,559)=1.63$ with a significance level of 0.006. The Hausman and Taylor test for the fixed effects estimator versus the random effects estimator, or (2) versus (3), yields an $F(5,558)=3\ 42$ with a 1% critical value of 3 02. Thus, the tests point to column (3), where we find significant differences in GSP growth rates across the states that are not due to growth in inputs (significant fixed state effects). We also find that public capital does not contribute to GSP at the margin.

TABLE 1. — LOG-LINEAR PRODUCTION FUNCTION ESTIMATES

	(1) No State Effects	(2) Random State Effects	(3) Fixed State Effects
Private Capital	0 327	0.191	0.515
	(10 33)	(4 60)	(7 36)
Labor	0 319	0 756	0 704
	(9 61)	(23.85)	(20 28)
Public Capital·			
Highways	0 370	0 120	0 127
	(18 01)	(4 51)	(4 25)
Water & Sewers	0 069	0 043	0.064
	(3 35)	(2 71)	(4.07)
Other	–0 010	–0 048	–0.071
	(0 49)	(2 40)	(3 50)
theta		0 908	
No of obs	672	672	672
d.o f.	653	653	606
R^2	0 987	0 915	0 755
SSR	9.082	0.686	0 551

Notes All regressions include a complete set of time dummy variables The dependent variable is the log of *GSP* Similarly, the reported explanatory variables are all in logarithms The R^2 measure in (1) is not comparable to the others, because the others refer to the differenced from mean (or quasi-differenced) data The figures in parentheses are t-statistics In the random effects estimation, variables are quasi-differenced, in that x_t is replaced by x_t - theta • $\bar{x}$

The result on growth rates indicates that there are significant differences across the states in output growth rates that are not explained by growth in labor, private capital, or the components of public capital. This is in contrast to Hulten and Schwab (1991), where they find that differences in regional growth rates are largely attributable to differences in the growth rates of private inputs.

One possible explanation for the insignificance of the public capital variables in column (3) of table 2 is that they are measured with error, and thus taking first differences would increase the bias in the estimates. The estimates may also be biased because of endogeneity of the two private input variables, a common criticism of production function estimates.

The two columns of table 3 present the estimates for two further specification tests, one for measurement error and one for endogeneity of the private inputs. The test for measurement error is suggested by Griliches and Hausman (1986) and involves taking long differences. We estimate the basic regression with the variables defined as two-period differences $(x_t–x_{t–2})$ and again with the variables defined as three-period differences. The results are similar and only the estimates with two-period differences are displayed in column (1) of table 3. (The reported regressions are for the sample from 1973 to 1983. A complete set of state and time dummies is included.) The regressions indicate that measurement error is not important for the public capital variables, in that the two-period difference estimates are similar to those in the first difference specification with the same sample period (that is, dropping the first two years of first-differenced observations). The estimates do suggest that private capital may be measured with error, as its coefficient falls by about two-thirds.

The test for endogeneity is a Hausman test (Hausman (1983)) and involves estimating the equations with both the actual variable and an estimate of the variable, in this case both labor and private capital. These estimates are displayed in column (2) of table 3. To generate estimates for the first-differenced private inputs we use lagged values of the variables themselves as instruments, that is, $x_{t-1} - x_{t-2}$ is employed as an instrument for $x_t - x_{t-1}$. The test is essentially an F-test of the joint significance of the two estimated variables. The test yields $F(2,510)=1.48$, with a 1% critical value of 4.61. The test therefore indicates that we cannot reject the null hypothesis of exogeneity of the private inputs.

Finally, we estimate a second-order translog specification of the first difference regression equations with state fixed effects. We append squared terms and cross-product terms to equation (3) of table 2. The higher order terms as a set are marginally insignificant. In the reformulation of equation (3), the F-statistic equals 1.48, with significance level 0.11. (There are (15,544) degrees of freedom under the null.) Almost all of the individual higher order terms are not significantly different from zero. The first order terms are similar to those in equation (3). Therefore, the first-order translog (i.e., Cobb-Douglas) specification in first differences with state and time fixed effects appears to describe the data adequately.

III. Conclusion

Employing a state-level data set on private output, private inputs, and three components of public capital, we estimate several specifications of a Cobb-Douglas production function. Our systematic investigation of specification leads us to measure the variables as first differences; to choose fixed state effects over no state effects and over random state effects; and to reject measurement error and endogeneity. Our tests thus lead to the specification in first differences with fixed state effects as the preferred one (column 3 of table 2).

The estimates of the equation we choose based on our specification search indicate that the coefficients on the three types of public capital in a state-wide aggregate Cobb-Douglas production function are insignificant. Our results thus confirm the conclusion of Holtz-Eakin (1994) We also obtain the result that different growth rates of the states cannot be accounted for only by variability in input growth rates, and that the states have unmeasured characteristics that cause them to grow faster or slower than average. In Garcia-Milà and McGuire (1993), industrial mix is suggested as an important factor in explaining differences in states' growth rates.

What do our results imply for the public infrastructure policy debate? This systematic search for the proper specification of a state-level production function has led to a specification in which the three types of public capital make no contribution to private output. This is in contrast to many previous estimates using panel data sets, including those by two of the authors, where public capital, in particular highways, appeared to have a small, positive effect on output. Our analysis implies that the previous estimates reflect spurious correlation, rather than any causal effect of public capital on output.

The conclusion that public capital does not contribute to private output is obtained here within a very narrow framework, that being estimation of state-level Cobb-Douglas production functions. It is clear that this approach does not exhaust all possible methods for examining the linkage between public infrastructure and productivity. For example, the approach does not allow for lags in the impact of

TABLE 2. — PRODUCTION FUNCTION ESTIMATES WITH FIRST DIFFERENCES

	(1) No State Effects	(2) Random State Effects	(3) Fixed State Effects
Private Capital	0.289	0 303	0 348
	(2.90)	(3.02)	(3 30)
Labor	0.898	0.919	0.985
	(17.64)	(17 53)	(16 34)
Public Capital·			
Highways	−0 007	−0.024	−0.058
	(0.13)	(0.39)	(0 77)
Water & Sewers	−0 002	−0.012	−0.029
	(0.07)	(0 47)	(1 07)
Other Public Capital	−0 056	−0.049	−0 022
	(1 63)	(1 37)	(0.55)
theta		0.204	
No. of obs.	624	624	624
d.o.f.	606	606	559
R^2	0.469	0 450	0.414
SSR	0 227	0 218	0.200

Notes The dependent variable is the first difference of log *GSP* Similarly, the reported explanatory variables are all first differences of logarithms All regressions include a complete set of time dummy variables The figures in parentheses are *t*-statistics

TABLE 3. — TESTS FOR MEASUREMENT ERROR AND ENDOGENEITY

	Measurement Error (1)	Endogeneity Test (2)
Private Capital	0 144	0 422
	(1.58)	(2 56)
Estimated Private Capital		−0 234
		(1.00)
Labor	1 053	1 010
	(17 68)	(15 36)
Estimated Labor		−0 166
		(0 74)
Public Capital·		
Highways	−0 017	−0 044
	(0.25)	(0 52)
Water & Sewers	−0 038	−0 045
	(1 62)	(1 44)
Other Public Capital	−0 038	−0 058
	(0.96)	(1.20)
No of obs	528	576
d o f	465	510
R^2	0 847	0 794
SSR	0.310	0 179

Notes See the notes to table 2 See the text for a description of the construction of the estimated variables included in (2) The measurement error model uses the 1973 to 1983 subsample, and the variables are two-period differences ($x_t - x_{t-2}$)

public capital on private output, nor does it allow for network effects, whereby the quality of the connections facilitated by investment in public infrastructure may be more important than the level of the capital stock. The point is that we have not demonstrated that public infrastructure is unproductive. Instead, we have found that within the aggregate production function framework, there is no evidence of a positive linkage between public capital and private output.

REFERENCES

Aaron, Henry J , "Discussion of 'Why is Infrastructure Important?'," in Alicia H. Munnell (ed) *Is There a Shortfall in Public Capital Investment?* (Boston Federal Reserve Bank of Boston, 1990), 51–63.

Aschauer, David Alan, "Is Public Expenditure Productive?," *Journal of Monetary Economics* 23 (1989), 177–200

Bhargava, A , L. Franzini and W Narendranathan, "Serial Correlation and the Fixed Effects Model," *Review of Economic Studies* 49 (158) (Oct 1982), 533–549

Eberts, Randall W , "Estimating the Contribution of Urban Public Infrastructure to Regional Growth," Working Paper 8610, Federal Reserve Bank of Cleveland (Dec. 1986)

Garcia-Milà, Teresa, and Therese J McGuire, "The Contribution of Publicly Provided Inputs to States' Economies," *Regional Science and Urban Economics* 22 (June 1992), 229–241.

——— "Industrial Mix as a Factor in the Growth and Variability of States' Economies," *Regional Science and Urban Economics* 23 (4) (Dec 1993), 731–748

Griliches, Zvi, and Jerry A. Hausman, "Errors in Variables in Panel Data," *Journal of Econometrics* 31 (1986), 93–118.

Greene, William H., *Econometric Analysis*, 2nd Edition (New York· Macmillan, 1993).

Hausman, Jerry A , "Specification and Estimation of Simultaneous Equation Models," in Zvi Griliches and Michael D. Intriligator (eds), *Handbook of Econometrics*, Volume 1 (Amsterdam· North-Holland, 1983), 391–448

Hausman, Jerry A , and William E. Taylor, "Panel Data and Unobservable Individual Effects," *Econometrica* 49 (Nov 1981), 1377–1398.

Holtz-Eakin, Douglas, "Public-Sector Capital and the Productivity Puzzle," This REVIEW 76 (Feb. 1994), 12–21.

Hulten, Charles R., and Robert M. Schwab, "Public Capital Formation and the Growth of Regional Manufacturing Industries," *National Tax Journal* 44 (4, part 1) (Dec 1991), 121–134.

Lynde, Catherine and James Richmond, "Public Capital and Total Factor Productivity," working paper (July 1991).

McGuire, Therese J., "Highways and Macroeconomic Productivity: Phase Two," Federal Highway Administration (March 1992)

Munnell, Alicia H , "Why Has Productivity Growth Declined? Productivity and Public Investment," *New England Economic Review* (Jan /Feb , 1990a), 4–22.

Munnell, Alicia H , "How Does Public Infrastructure Affect Regional Economic Performance?," in Alicia H. Munnell (ed.), *Is There a Shortfall in Public Capital Investment?* (Boston: Federal Reserve Bank of Boston, 1990b), 69–103.

Schultze, Charles L., "The Federal Budget and the Nation's Economic Health," in Henry J. Aaron (ed.), *Setting National Priorities* (Washington, DC: The Brookings Institution, 1990), 19–63.

Tatom, John A , "Public Capital and Private Sector Performance," *St. Louis Federal Reserve Bank Review* 73 (May/June 1991), 3–15.