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The Effect of Public Capital in State-Level Production Functions Reconsidered

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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 public capital as an input. Various specification tests are systematically applied to the estimates to test for state effects (both random and fixed), nonstationarity, endogeneity of the private inputs, and measurement error. In the preferred specification, which is first differences with state fixed effects, the public capital variables are not significant, while the state fixed effects and private input variables are significant, These results indicate that while growth in public capital does not contribute to growth in output (GSP), the different output growth rates of the states cannot be accounted for only by differences in the states' input growth rates.

1 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 U.S., was supported by Munnell (1990, a) 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 1992, McGuire 1992, and Munnell 1990, b). 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. Both Holtz-Eakin (1992) and McGuire (1992) provide estimates of state-level production functions where the variables are in first differences, a specification commonly used to address nonstationarity, and both find that the estimated coefficient on public capital is either not significant or negative. Neither of these authors provides a test that justifies first differences, nor do they test for measurement error, which would be exacerbated by taking first differences.

The purpose of this paper 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 employ the data set used in McGuire (1992), which draws variables from two data sets, Munnell (1990, b) and Garcia-Milà and McGuire (1992). We adopt a Cobb-Douglas production function with Gross State

Product (GSP) as the measure of output, and with two private inputs, labor and private capital. We incorporate public capital either as an aggregate or as three components; highways, water and sewers, and all other. We begin with an OLS specification with yearly time dummies, which is common in the literature, and then we systematically test for state effects, serial correlation, measurement error, and endogeneity.

The tests point to a specification in first differences with state fixed effects in growth rates. We cannot reject the null hypothesis of exogeneity of the private inputs, nor do we find evidence of measurement error. The estimated coefficients on the public capital variables are insignificant. Thus, the evidence gleaned from this particular data set and this particular methodology indicates that public capital does not contribute to private output as measured by GSP.

2 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) describes these data and the process used to convert investment flows to stocks.

The public capital stock variables are from Munnell (1990, b). 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 fuction 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 public infrastructure G, are

measured in natural logarithms, and where the sub-indices 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, ϵ. There are, in fact, two basic equations, as each specification is estimated twice, once where G is defined to be total public capital, and once where G is a vector comprised of the three types of public capital.

In Table 1 we present the results of estimating three specifications of the two basic equations. In columns (1) and (4) the specification is OLS with annual time dummies (time fixed 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 (1990, b). In columns (2) and (5) the specification is GLS with time fixed effects and state random effects. Columns (3) and (6) display an OLS specification with state and time fixed effects. (These estimates also appear in McGuire (1992).)

Without controlling for state effects, the estimated coefficients on aggregate public capital and on highway public capital are large, positive and significant (columns 1 and 4). The estimated coefficient on water and sewers in column (4) is positive and significant, but small, while the estimated coefficient on other public capital is insignificant. Once we control for either state fixed effects or state random effects, the estimated coefficients on the public capital variables are either small, positive and significant; insignificant; or small, negative, and significant (other public capital).

When we aply the test posed in Hausman and Taylor (1991) of state fixed effects against state random effects, we find that fixed effects is the preferred specification. The F-statistic for this test is 40.41 for the regression equation with the aggregate public capital variable. In the regression with public capital split into three components, the F-statistic is 72.05. Both are significant at the one percent level. Also, a Chow test indicates that the model with state and time fixed effects is preferable to one with time fixed effects alone. Thus, if the variables are measured in levels of natural logarithms, the specifications displayed in columns (3) and (6) are preferred. These are the regressions 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 state fixed 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 non-stationarity 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 regressions displayed in columns (3) and (6), we cannot reject the hypothesis that the residuals follow a random walk. Their d_p statistic, which is a modified Durbin-Watson statistic, equals 0.40 in column (3), and 0.43 in column (6). In both cases 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 in both cases.

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 state fixed effects is preferred. The Chow test for (1) versus (3) yields and $F(47, 561) = 1.62$ with a significance level of 0.006, and for (4) versus (6) yields an $F(47, 559) = 1.59$ with a significance level of 0.008. The Hausman and Taylor test for the fixed effects estimator versus the random effects estimator, or (2) versus (3), yields an $F(3, 561) = 9.68$ with a 1% critical value of 3.78, and for (5) versus (6) yields an $F(5, 559) = 17.12$ with a 1% critical value of 3.02. Thus, the tests point to columns (3) and (6), where we find significant differences in GSP growth rates across the states that are not due to growth in inputs (significant state fixed effects). We also find that public capital does not contribute to GSP.

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 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 columns (3) and (6) is that public capital is measured with error, and thus taking first differences would bias 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 four 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 tests for measurement error is suggested by Griliches and Hausman (1986) and involves taking long differences. We estimate the two basic regressions 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 columns (1) and (2) 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 a third.

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 columns (3) and (4) 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. For (3) the test yields $F(2,512) = 1.46$, and for (4) the test yields $F(2,510) = 1.48$. Both statistics have a 1% critical value of 4.61. The tests therefore indicate 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 fixed state effects. We append squared terms and cross-product terms to equations (3) and (6) of Table 2. In both cases, the higher order terms as a set are marginally insignificant. In the reformulation of equation (3), which employs aggregate public capital, an F-statistic for the test of the joint significance of the six second-order terms equals 1.89, with significance level 0.08. (There are (6,555) degrees of freedom under the null hypothesis.) In the reformulation of equation (6), with the three public capital measures, the F-statistic equals 1.48, with significance level 0.11. (There are (15,544) degrees of freedom under the null.) In both cases, almost all of the individual higher order terms are not significantly different from zero. The first order terms are similar to those in equations (3) and (6). Therefore, the first-order translog (i.e., Cobb-Douglas) specification in first differences with fixed state and time effects appears to describe the data adequately.

3 Conclusion

Employing a state-level data set on private output, private inputs, and 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 (based on the BFN test using residuals from columns 3 and 6 in Table 1); to choose state fixed effects over no state effects and over state random effects (based on the Hausman and Taylor and the Chow tests using Table 2); and to reject measurement error and endogeneity (based on the Griliches and Hausman test and the Hausman endogeneity test using Table 3). Our tests thus lead to the specification in first differences with state fixed effects as the preferred one (columns 3 and 6 of Table 2).

The estimates of the equation we choose based on our specification search indicate that the coefficient on public capital in a state-wide aggregate Cobb-Douglas production function is insignificant. 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 (forthcoming), industrial mix is suggested as an important factor in explaining differences in states' growth rates.

What do these 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 public capital makes 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 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 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.

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Table 1:

	(1) No State Effects	(2) Random State Effects	(3) Fixed State Effects	(4) No State Effects	(5) Random State Effects	(6) Fixed State Effects
Private Capital	0.255	0.239	0.461	0.327	0.191	0.515
	(8.57)	(5.96)	(6.67)	(10.33)	(4.60)	(7.36)
Labor	0.383	0.743	0.704	0.319	0.756	0.704
	(10.99)	(23.17)	(19.63)	(9.61)	(23.85)	(20.28)
Public Capital	0.394	0.052	0.035	–	–	–
	(14.93)	(1.84)	(1.19)			
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 Public	–	–	–	-0.010	-0.048	-0.071
				(0.49)	(2.40)	(3.50)
theta		0.918			0.908	
#of obs.	672	672	672	672	672	672
d.o.f	655	655	608	653	653	606
R^2	0.984	0.900	0.740	0.987	0.915	0.755
SSR	10.707	0.690	0.585	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) and (4) 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 - $theta * \overline{X}$.

Table 2:

	(1) No State Effects	(2) Random State Effects	(3) Fixed State Effects	(4) No State Effects	(5) Random State Effects	(6) Fixed State Effects
Private Capital	0.273	0.295	0.351	0.289	0.303	0.348
	(2.80)	(3.00)	(3.39)	(2.90)	(3.02)	(3.30)
Labor	0.898	0.923	0.986	0.898	0.919	0.985
	(17.75)	(17.70)	(16.53)	(17.64)	(17.53)	(16.34)
Public Capital	-0.082	-0.100	-0.121	–	–	–
	(1.41)	(1.59)	(1.55)			
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	–	–	–	-0.056	-0.049	-0.022
				(1.63)	(1.37)	(0.55)
theta		0.222			0.204	
#of obs.	624	624	624	624	624	624
d.o.f	608	608	561	606	606	559
R^2	0.468	0.448	0.415	0.469	0.450	0.414
SSR	0.227	0.217	0.200	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:

	Measurement Error			Endogeneity Tests	
	(1)	(2)		(3)	(4)
Private Capital	0.142 (1.58)	0.144 (1.58)	Private Capital	0.418 (2.54)	0.422 (2.56)
			Estimated Private Capital	-0.245 (1.07)	-0.234 (1.00)
Labor	1.056 (17.89)	1.053 (17.68)	Labor	1.012 (15.44)	1.010 (15.36)
			Estimated Labor	-0.148 (0.67)	-0.166 (0.74)
Public Capital	-0.131 (1.89)	–	Public Capital	-0.166 (1.68)	–
Highways	–	-0.017 (0.25)	Highways	–	-0.044 (0.52)
Water& Sewers	–	-0.038 (1.62)	Water& Sewers	–	-0.045 (1.44)
Other Public Capital	–	-0.038 (0.96)	Other Public Capital	–	-0.058 (1.20)
# of obs.	528	528	#of obs.	576	576
d.o.f.	467	465	d.o.f.	512	510
R^2	0.846	0.847	R^2	0.794	0.794
SSR	0.310	0.310	SSR	0.179	0.179

Notes: See the notes to Table 2. See the text for a description of the construction of the estimated variables included in (3) and (4). The measurement error model uses the 1973 to 1983 sub-sample, and the variables are two-period differences ($x_t - x_{t-2}$).

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