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Do states optimize? Public capital and economic growth

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Abstract. This paper develops a non-linear theoretical relationship between public capital and economic growth in order to obtain estimates of the growth-maximizing ratio of public capital to private capital. The model is empirically implemented using data on the 48 contiguous U.S. states over the period 1970 to 1990. The empirical results provide evidence that (i) the relationship between public capital and economic growth is non-linear, (ii) the growth-maximizing public capital stock is approximately 60% to 80% as large as the private (tangible) capital stock, and (iii) permanent changes in public capital are associated with permanent changes in economic growth.

1. Introduction

In recent years, a substantial research effort has focused on estimating the contribution of public capital to the productivity of private factors of production and to economic growth. This research initiative appears to have sprung from the recognition of two facts about public capital spending in the United States. First, public nonmilitary capital accumulation, expressed as a percentage of output or of the government budget, peaked in the latter half of the 1960's and, as a result, has been seen as a potential explanatory force in the productivity growth slowdown of 1970's and 1980's. Second, over the past few decades the United States has devoted a smaller share of gross domestic product to public capital investment than have other industrialized countries, which has led to the possibility that public capital might partly explain the relatively low rate of productivity growth in the United States *vis-a-vis* other countries such as Japan and Germany.

The early empirical work in this area, conducted largely at the aggregate level, indicated quite high returns to public capital investment and led some researchers to strong conclusions about the role of public capital in the productivity slowdown. For instance, Munnell (1990a) once stated that "the drop in labor productivity [*sic*] has not been due to some mystical concept of multifactor productivity or technical progress. Rather, it has been due to a decline in the growth of public infrastructure." As it now stands, the literature contains a relatively wide range of estimates, with a marginal product of public capital which is well in excess of that of private capital (e.g., Aschauer 1989, Fernald 1992, and Kocherlakota and Yi 1996), approximately equal to that of private capital (e.g., Munnell 1990b), well below that of private capital (e.g., Eberts 1986 and Holtz-Eakin 1994) and, in some instances, even negative (e.g., Evans and Karras 1994 and Hulten and Schwab 1991). Some economists argue that the wide range of estimates render the results useless from the policy perspective (Aaron 1991). Others point to a list of potential statistical problems – a reverse causation from productivity to public capital, a spurious correlation due to nonstationarity and/or to the omission of relevant variables – to argue that the empirical results are built on "fragile statistical foundations" and should be viewed with extreme skepticism (Jorgenson 1991). A few economists go as far as to conclude that "there is no statistically significant relationship between public capital and private output" (Tatom 1993).

Still, some economists involved in the debate about the macroeconomic effects of public capital have been convinced enough by the empirical results to assert that an increase in public investment spending can be safely expected to raise economic growth. Yet the finding that public capital is productive, even if valid, is not sufficient to ensure that boosting public investment spending will stimulate long term growth.[1] At least three considerations must be addressed. First, there is the question of whether a permanent increase in public investment induces a permanent, or merely a temporary, increase in economic growth. The traditional neoclassical growth model of Solow (1956) predicts that any positive effect of an increase in the national savings and investment rate on economic growth will be transitory; the steady-state growth rate is fully determined by population growth and exogenous technological progress. In the neoclassical setting, an increase in spending on productive public capital will induce a period of temporarily high investment, but the pace of capital accumulation, and of economic growth, will slow over time as the accumulation of capital diminishes the return to capital and the incentive for further investment. In the long run, the level of output will be higher but the growth rate of output will return to the same level as before the public spending initiative.

Second, the effect of an increase in public investment on economic growth is likely to depend on the relative marginal productivity of private versus public capital. In the neoclassical setting, an increase in public investment (at the expense of private investment) will raise or lower the economic growth rate depending on whether the marginal product of public capital exceeds, or, respectively, is exceeded by the marginal product of private capital.[2] This consideration validates the concerns of Aaron and others that the range of empirical estimates of the output elasticity of public capital is too large to be informative to the public policy process; we need to know, rather precisely,

[1] Nor is it a necessary condition. See, for example, Flores de Frutos and Periera (1992).

[2] On the transition path between steady states we have

$$\left.\frac{d\gamma_y}{d\dot{kg}}\right|_{d\dot{kg}=-d\dot{k}} = \frac{[mp_{kg} - mp_k]}{y}$$

where γ_y = growth rate of output per worker, kg = public capital, k = private capital, mp_x = marginal product of input x $(x = kg, k)$, y = output per worker, and dots denote time derivatives.

not only that public capital is *productive* but that it is *sufficiently productive* to be confident of a beneficial effect of increased public investment on economic growth.

Third, the effect of public investment on growth is likely to depend on how the increased spending is financed. Empirical studies such as Engen and Skinner (1996) find evidence that increases in tax rates reduce the rate of economic growth. Thus, it is to be expected that an increase in public capital – which, in most cases, will require a corresponding increase in tax rates – will stimulate economic growth only if the productivity impact of public capital exceeds the adverse tax impact.

This paper focuses on some of these considerations by investigating the relationship between public capital, productivity, and economic growth in an endogenous growth setting. The next section of the paper lays out a simple model of an economy with productive public capital. The subsequent section reports on empirical results linking the ratio of public and private capital to productivity growth. The final section concludes by suggesting directions for future research.

2. A model of productive public capital and economic growth

As is typical in recent work in economic growth, we begin with a consumer/producer who maximizes a constant intertemporal elasticity of substitution utility function over an infinite planning horizon as given by

$$V = \int_0^\infty \frac{c^{1-\sigma} - 1}{1 - \sigma} e^{-\rho t}\, dt \tag{1}$$

where c represents consumption, $-\sigma$ the constant elasticity of the marginal utility of consumption, and ρ the rate of time preference.[3] The agent has access to a Cobb-Douglas production function

$$y = k^{\alpha_k} kg^{\alpha_{kg}} \quad \alpha_k + \alpha_{kg} = 1 \tag{2}$$

where y is output, k is a *broad* measure of private capital (inclusive of tangible *and* human capital), and kg is public infrastructure capital.[4] All variables are expressed in per worker terms. Thus, the production function exhibits constant returns to scale across the private and public capital inputs, but can be shown to exhibit increasing returns to scale across *raw* labor and capital. The model ignores technological progress, population growth, and depreciation of

[3] The approach expands on the model in Barro (1990) by focusing on the productive services of public *capital* rather than of flow government spending. Although fairly subtle, the distinction is important from theoretical and policy perspectives. For instance, some researchers have drawn the (incorrect) conclusion from Barro's model that the "condition for productive efficiency is that the share of government capital in output is equal to its elasticity" and have performed "back-of-the-envelope" calculations to show that the U.S. has grossly underinvested in government capital (Ho and Sorenson 1993).

[4] Note that this production function is the natural extension to that in Barro (1990) for the case of public capital rather than flow government spending. Also, it is straightforward to extend the analysis using a constant elasticity of substitution production function.

private or public capital in order to bring out the essential points in the clearest manner.

The government purchases and maintains the stock of public capital which enters as an input to the private sector production function (2). At an initial point in time, the government is viewed as choosing a particular level of public capital, kg_0. The initial purchase of government sector capital is assumed to be financed by the sale of perpetuities at a coupon rate of r percent. Subsequently, the government is taken to maintain a particular ratio of public to private capital

$$\phi = \frac{kg}{k} \tag{3}$$

which requires an increase in the public capital stock over time at the rate

$$\dot{kg} = \gamma \cdot kg \tag{4}$$

where γ is the rate of growth of the private capital stock.

It is assumed that the government levies a tax on private production at rate θ for the purpose of financing (i) the on-going public expenditure needed to maintain the public capital stock ratio against growth in the private capital stock and (ii) the interest payments on the initial stock of debt. Accordingly, the government budget constraint is

$$kg_0 + \int_0^\infty \dot{kg}\, e^{-rt}\, dt = \int_0^\infty \theta \cdot y\, e^{-rt}\, dt. \tag{5}$$

Given steady state growth at the rate γ, the government budget constraint reduces to[5]

$$r \cdot kg_0 = \theta \cdot y_0. \tag{6}$$

[5] In this expression, the tax rate, θ, can be viewed as consisting of two components. The government needs to service the initial stock of debt at the interest rate r, but due to output growth and a rising tax base the required tax rate would be given by

$$\theta_{kg_0} = \frac{(r-\gamma) \cdot kg_0}{y_0}.$$

In addition, the government must finance on-going public investment at rate γ to maintain the public capital ratio, necessitating a tax rate of

$$\theta_{\dot{kg}} = \frac{\gamma \cdot kg_0}{y_0}.$$

The overall tax rate is then given by

$$\theta = \theta_{kg_0} + \theta_{\dot{kg}} = \frac{(r-\gamma) \cdot kg_0}{y_0} + \frac{\gamma \cdot kg_0}{y_0} = \frac{r \cdot kg_0}{y_0}$$

which is consistent with Eq. (6) in the text.

The agent maximizes utility as given in Eq. (1) taking the public capital stock and the tax rate as beyond his influence. The maximization of utility is subject to a standard resource constraint which determines the level of private capital accumulation as the difference between after-tax income from production and private consumption[6]

$$\dot{k} = (1 - \theta)k^{\alpha_k} kg^{\alpha_{kg}} - c. \tag{7}$$

In this environment, the steady state equilibrium involves a common growth rate of consumption, public and private capital, and per worker output given by

$$\gamma = \frac{1}{\sigma}[(1 - \theta)(1 - \alpha_{kg})\phi^{\alpha_{kg}} - \rho]. \tag{8}$$

Evidently, the common growth rate of consumption, capital, and output depends positively on the ratio of public to private capital and negatively on the tax rate. In order to determine the *net* effect of government capital accumulation on economic growth, it is necessary to eliminate the tax rate from the growth rate expression in Eq. (8).

This elimination of the tax rate is accomplished in the following manner. First, note that in equilibrium the government's maintenance of a particular ratio of public to private capital, ϕ, implies that private sector output may be written as

$$y = k^{\alpha_k} kg^{\alpha_{kg}} = k^{\alpha_k}(k\phi)^{\alpha_{kg}} = k^{\alpha_k + \alpha_{kg}}\phi^{\alpha_{kg}} = k\phi^{\alpha_{kg}}. \tag{9}$$

As a further equilibrium condition, the agent must be willing to hold the available stocks of debt and private capital. Consequently, the interest rate on government perpetuities must equal the net of tax return to private capital, so that

$$r = (1 - \theta)(1 - \alpha_{kg})\phi^{\alpha_{kg}}. \tag{10}$$

The steady state budget constraint in Eq. (6) and the level of output in Eq. (9) may be solved for the tax rate as a function of the interest rate on public debt and the public capital stock ratio

$$\theta = r \cdot \phi^{\alpha_k} \tag{11}$$

which, after substituting into Eq. (10) allows us to obtain the steady state equilibrium interest rate as

$$r = \frac{(1 - \alpha_{kg})\phi^{\alpha_{kg}}}{1 + (1 - \alpha_{kg})\phi}. \tag{12}$$

[6] There is also a transversality condition to rule out explosive paths for consumption. This is given by the condition that the interest rate exceed the growth rate of income which can be seen to be equivalent to $\rho > r(1 - \sigma)$.

Finally, from Eqs. (8) and (12) we get the solution for the growth rate of per worker output as a function of the public capital ratio:

$$\gamma = \frac{1}{\sigma}\left[\frac{(1-\alpha_{kg})\phi^{\alpha_{kg}}}{(1+(1-\alpha_{kg})\phi)} - \rho\right]. \tag{13}$$

Simple differentiation of Eq. (13) with respect to the public capital ratio reveals that the growth rate initially rises with the ratio of public to private capital, reaches a maximum, and then falls toward zero. The intuition, similar to that described for flow government spending in Barro (1990), is straightforward. Consider an increase in ϕ induced by a marginal increase in the public capital stock. For a given tax rate, the increase in the ratio of public to private capital increases the after-tax marginal product of capital in the amount[7]

$$\left.\frac{d[(1-\theta)mp_k]}{d\phi}\right|_{\theta=\bar{\theta}} = \frac{\alpha_{kg}\phi^{\alpha_{kg}-1}}{1+(1-\alpha_{kg})\phi}. \tag{14}$$

where mp_k represents the marginal product of private capital. Taken alone, this increase in the marginal product of capital would be conducive to growth. However, the increase in the public capital stock also requires a rise in the tax rate which, in turn, reduces the after-tax return to capital in the amount

$$\left.\frac{d[(1-\theta)mp_k]}{d\phi}\right|_{mp_k=\overline{mp}_k} = -\frac{(1-\alpha_{kg})\phi^{\alpha_{kg}}}{(1+(1-\alpha_{kg})\phi)^2}. \tag{15}$$

This decrease in the after-tax marginal product of capital, when taken by itself, would deter growth. At low levels of ϕ, the productivity effect in Eq. (14) dominates the tax rate effect in Eq. (15), and the after-tax marginal product of capital rises. This rise in the return to investment, in turn, stimulates private capital accumulation and raises the growth rate. But at sufficiently high levels of ϕ, the tax effect overwhelms the productivity effect, the after-tax return to capital is depressed, and private investment and the growth rate decline.[8]

Specifically, the growth rate rises with the ratio of public to private capital from a minimum of $\gamma^{\min} = -\rho/\sigma$ to reach a maximum of

$$\gamma^{\max} = \frac{1}{\sigma}[(1-\alpha_{kg})^{2(1-\alpha_{kg})}\alpha_{kg}^{\alpha_{kg}} - \rho]. \tag{16}$$

[7] We use the result that the tax rate may be shown to equal

$$\theta = r\cdot\phi^{\alpha_k} = (\rho+\gamma\cdot\sigma)\cdot\phi^{\alpha_k} = \frac{(1-\alpha_{kg})\phi}{1+(1-\alpha_{kg})\phi}.$$

[8] Note that if the income tax were replaced by a consumption tax growth in per worker output would be monotonically increasing in the public capital ratio in the amount

$$\frac{d\gamma}{d\phi} = \alpha_{kg}(1-\alpha_{kg})\phi^{\alpha_{kg}-1}.$$

This is because in the present model the consumption tax acts as a lump sum tax, leaving only a beneficial effect of public capital similar to (but greater than) that captured in Eq. (14) of the text.

Eqs. (14) and (15) can be used to show that the maximal growth rate of per worker output, $\gamma^{\max}$, corresponds to a ratio of public to private capital given by

$$\phi^{\max} = \frac{\alpha_{kg}}{(1-\alpha_{kg})^2}. \tag{17}$$

When the tax rate function (14) is evaluated at the ratio of public to private capital which maximizes the economic growth rate, $\phi^{\max}$, we obtain the result that the tax rate should be set equal to the output elasticity of government capital, or

$$\theta^{\max} = \alpha_{kg}. \tag{18}$$

Combining Eqs. (17) and (18) then yields the result that the economic growth rate is maximized when the government chooses a ratio of public to private capital so as equate the *after-tax* marginal product of private capital to the marginal product of public capital:

$$(1-\theta)mp_k = mp_{kg} \tag{19}$$

where mp_x denotes the marginal product of input x ($x = k, kg$) and we have used the fact that for the Cobb-Douglas specification of the production function the output elasticities of private and public capital are equal to α_k and α_{kg}, respectively.

Thus, the model of this section implies that there is a non-linear relationship between public capital and economic growth such that permanent increases in the public capital ratio bring forth permanent increases in growth – but only if the marginal product of public capital exceeds the after-tax marginal product of private capital. Quite possibly, this predicted non-linearity between public capital and growth may be evident in the data and, as a consequence, is important to take into account when performing empirical work.

3. Empirical evidence on productive public capital and economic growth

This section contains an empirical investigation of the relationship between public capital and economic growth using data for the 48 contiguous United States during the decades of the 1970s and 1980s. Table 1 provides descriptive

Table 1. Descriptive statistics

	Mean	Maximum	Minimum	Standard deviation
γ	0.004	0.031	−0.026	0.011
y	10.416	11.201	10.121	0.176
kg/k	0.446	0.793	0.194	0.136
g/k	0.139	0.293	0.049	0.049
$kg(core)/k$	0.267	0.522	0.128	0.075
$kg(other)/k$	0.179	0.451	0.047	0.082

statistics on the variables used in this study. Economic growth [γ] is measured as average annual growth in real gross state product per employed person; the basic data on current dollar gross state product were obtained from various issues of the *Survey of Current Business* (Renshaw et al. 1988; Beemiller and Dunbar 1993) and were placed in constant (1982) dollar, per worker terms using the deflator for gross domestic product from the *Survey of Current Business* (U.S. Bureau of Economic Analysis (annual)) and non-agricultural employment from *Employment, Hours, and Earnings, State Areas* (U.S. Bureau of Labor Statistics (annual)). As measured, economic growth ranged from a high of 3.1% per year (Massachusetts in the 1980s) to a low of −2.6% per year (Wyoming in the 1980s). The initial level of output per worker [y] is represented as the logarithm of real gross state product per employed person in 1970 and 1980, respectively, and also was obtained from the above-mentioned sources. The public capital variable [kg/k] is measured as the ratio of public capital to private capital (both in constant (1982) dollars) and was constructed using data from Munnell (1990b). This variable is expressed in initial year (1970, 1980) values in order to eliminate, or at least minimize, a potential endogeneity of the public capital stock. On average over the 48 states and the decades of the 1970's and 1980's, the public capital stock was 44.6% as large as the private capital stock, and took on a minimum value of 19.4% (Wyoming in 1980) and a maximum value of 79.3% (Rhode Island in 1970). The flow government spending variable [g/k] is measured as the ratio of total general government expenditure to private capital (both in constant (1982) dollars), with the former variable being obtained from *Governmental Finances* (U.S. Bureau of the Census (annual)). This variable averaged 13.9% and ran from a low of 4.9% (Wyoming in 1970) up to a high of 29.3% (New York in 1970). The core public capital ratio [$kg(core)/k$], which is expressed as the ratio of highway and water and sewer capital to private capital, averaged 26.7% and attained a minimum of 12.8% (Louisiana in 1970) and a maximum of 52.2% (Rhode Island in 1970). Finally, the other public capital variable [$kg(other)/k$], measured as total public capital minus core public capital as a ratio to private capital, reached a low of 4.7% (Wyoming in 1980), a high of 45.1% (New York in 1970), and averaged 17.9% over the entire sample.

3.1. Growth and government capital: Linear impact

We begin the empirical analysis by considering the regression equation

$$\gamma_{it} = a + b \cdot \phi_{it} + \underline{c} \cdot \underline{z}_{it} + \varepsilon_{it} \tag{21}$$

where a, b, and $\underline{c}$ are coefficients to be estimated, $\phi = kg/k$, $\underline{z}$ represents control variables such as the logarithm of initial output per worker and the unemployment rate, i refers to individual states, and t refers to particular decades. Table 2 indicates a rather sizeable and statistically significant relationship between the public capital ratio and economic growth, with a coefficient estimate for kg/k ranging between 0.020 and 0.041. These estimates suggest that a one standard deviation increase in the public capital ratio – say from its average value of 0.446 to 0.582 – would induce a contemporaneous 0.27 to 0.54 standard deviation increase in economic growth of between 0.3 and 0.6 percentage points per year. Table 2 also indicates a strong conver-

Table 2. Growth and government capital OLS regressions independent variable = γ

ϕ	0.040	0.020	0.041	0.021
	(0.007, 0.009)	(0.006, 0.007)	(0.007, 0.009)	(0.006, 0.007)
y	—	−0.035	—	−0.034
		(0.005, 0.005)		(0.005, 0.005)
u	—	—	0.002	0.002
			(<0.001, <0.001)	(<0.001, <0.001)
R^2	0.242	0.498	0.293	0.545
SER ($x10^{-3}$)	9.384	7.635	9.059	7.265
LL	312.994	333.304	316.894	338.591

Notes: All regressions also contain a constant term. Ordinary and White heteroskedasticity corrected standard errors are in parentheses.

gence of output per worker across states, with a coefficient estimate on the logarithm of initial year output per worker of −0.034 or −0.035. This result suggests that an increase in public capital will have transitory, but not permanent, effects on economic growth. Nevertheless, there would be a significant effect on the level of output; the same one standard deviation increase in the public capital ratio would cumulate to a 8.4% increase in output per worker in the long run.[9] Finally, the regressions in the last two columns of the table allow for an influence of the unemployment rate [u] on economic growth. One might suspect that the inclusion of the unemployment rate would help to ensure that the regression of economic growth on public capital would be picking up long-run (or secular) effects rather than short-run (or cyclical) effects, in which case the estimated coefficient on the unemployment rate would be expected to be positive. Specifically, the rate of growth as the economy emerges from a recession (and its associated high level of unemployment) can be expected to be higher than growth on the normal transition path to the steady state. While the unemployment rate carries the appropriate positive sign in these regressions to substantiate this argument, the effect is quantitatively small and statistically weak.

Table 3 introduces separate fixed effects for the individual states and a separate effect of the decade of the 1970s [d70s] and, in doing so, communicates a far different message for the role of public capital in determining economic growth rates. While the sign and magnitude of the impact of public capital on growth remains in the same neighborhood as the previous estimates – between 0.031 and 0.039 – the associated standard errors increase by a factor of 5 or 6 which, in turn, renders the relationship statistically insignificant. Thus the previous finding of a significant role for public capital – at least in this linear form – cannot be taken as robust to estimation methods. A similar message is conveyed for the role of the initial level of per worker output. In this case, the estimated coefficients become somewhat smaller in magnitude – in absolute terms, between 0.018 and 0.028 – and also are rendered statistically insignificant. This is a result of independent interest, as it implies a lack

[9] The long-run impact on output per worker is calculated from the estimated equation in the last column of Table 2 where, in the steady state, we obtain

$$\Delta\gamma = 0 = -0.035\Delta y + 0.021\Delta(kg/k) \Rightarrow \Delta y = 0.618\Delta(kg/k) = (0.618)(0.136) = 0.084.$$

Table 3. Growth and government capital fixed effect regressions independent variable = γ

ϕ	0.039	0.034	0.038	0.031
	(0.032, 0.033)	(0.033, 0.034)	(0.033, 0.034)	(0.034, 0.035)
y	—	−0.018	—	−0.028
		(0.027, 0.024)		(0.031, 0.027)
u	—	—	<0.001	0.001
			(0.001, 0.001)	(0.001, 0.001)
d70s	−0.008	−0.007	−0.007	−0.005
	(0.002, 0.002)	(0.002, 0.002)	(0.003, 0.003)	(0.004, 0.004)
R^2	0.410	0.402	0.398	0.396
SER ($x10^{-3}$)	8.279	8.329	8.360	8.375
LL	359.322	359.800	359.440	360.350

Notes: See Table 2.

of convergence in productivity levels across states economies – a finding in sharp contrast to other empirical studies of state economic growth (such as Barro and Sala-I-Martin 1991). Presumably, the difference in results is due to the inclusion (in the present case) and exclusion (as in Barro and Sala-I-Martin 1991) of individual state effects.

3.2. *Growth and government capital: Non-linear impact*

We next consider equations of the general form

$$\gamma_{it} = a + b \cdot f_{it} + \underline{c} \cdot \underline{z}_{it} + \varepsilon_{it} \tag{22}$$

where the variable f denotes transformed public capital as given by

$$f_{it} = \frac{\phi_{it}^{\alpha_{kg}}}{1 + (1 - \alpha_{kg})\phi_{it}} \tag{23}$$

and, as before, z represents other explanatory variables. Table 4 contains OLS regressions of economic growth on transformed public capital under the maintained assumption that the output elasticity of public capital equals 0.30 – an elasticity estimate lying between that of Aschauer (1989) at 0.39 and that of Munnell (1990b) at 0.15.[10] As with the estimates in Table 2, there is a strong positive effect of public capital on the growth rate of output per worker; there is evidence of convergence effects across state economies; and there is little substantive role for the unemployment rate. Comparing the adjusted coefficients of determination of the analogous equations in the two tables (2 and 4) indicates no clear preference for the linear or non-linear version of the relationship; for instance, the estimates contained in the first column of each table suggest a preference for the non-linear version, while the estimates con-

[10] The estimation strategy employed in the text is to assume various values for the output elasticity of public capital to suitably transform the public capital ratio from ϕ to f and then to use ordinary least squares (with fixed effects). An alternative strategy would be to estimate the output elasticity of public capital (along with other parameters) using non-linear least squares. The two strategies give identical results, of course, for the assumed value of the output elasticity of public capital which maximizes the log likelihood function.

Table 4. Growth and government capital OLS regressions independent variable = γ (assumed elasticity = 0.30)

f	0.446	0.202	0.455	0.217
	(0.059, 0.055)	(0.074, 0.065)	(0.057, 0.053)	(0.071, 0.064)
y	—	−0.030	—	−0.029
		(0.006, 0.006)		(0.006, 0.006)
u	—	—	0.002	0.001
			(<0.001, <0.001)	(<0.001, <0.001)
R^2	0.367	0.487	0.419	0.534
SER ($x10^{-3}$)	8.570	7.714	8.210	7.359
LL	321.701	332.321	326.332	337.366

Notes: All regressions include a constant term. Ordinary and White heteroskedasticity corrected standard errors in parentheses.

Table 5. Growth and government capital fixed effect regressions independent variable = γ (assumed elasticity = 0.30)

f	1.226	1.224	1.225	1.220
	(0.237, 0.275)	(0.236, 0.262)	(0.239, 0.282)	(0.237, 0.262)
y	—	−0.023	—	−0.033
		(0.021, 0.017)		(0.024, 0.022)
u	—	—	<0.001	0.001
			(0.001, 0.001)	(0.001, 0.001)
d70s	−0.011	−0.011	−0.010	−0.009
	(0.002, 0.002)	(0.002, 0.002)	(0.002, 0.003)	(0.003, 0.003)
R^2	0.616	0.617	0.608	0.616
SER ($x10^{-3}$)	6.680	6.669	6.744	6.679
LL	379.931	381.145	380.062	382.072

Notes: See Table 4.

tained in the fourth column of each table indicate a preference for the linear version.

Just as with Table 3, Table 5 allows for individual state and decade effects – yet with significantly different results. The introduction of separate state and decade effects in Table 3 did not change, in any marked fashion, the coefficient estimates on the public capital ratio but did raise the standard errors of the coefficient estimates and left no statistically significant role for public capital. The addition of individual state and decade effects in Table 5, however, not only leaves a statistically significant role for public capital but raises the coefficient estimates from Table 4 by a factor of 2 to 3 – comparing the estimates in the last column of each of these tables, from 0.217 (Table 4) to 1.220 (Table 5). Further, the results of Table 5 provide little support for a significant convergence effect across states economies; the coefficient estimates on the initial output per worker variable carry the appropriate sign and magnitude, but are not significantly different from zero at conventional levels. Finally, the explanatory power of the regression – as measured by the adjusted coefficient of determination – is considerably higher for the equations contained in Table 5 than for the analogous equations in Table 3, in the range of 61 to 62% (Table 5) as opposed to 40 to 41% (Table 3). Consequently, the results justify a preference for the non-linear over the linear version of the relationship between public capital and growth.

Table 6 contains estimation results for various parameterizations of f,

Table 6. Growth and government capital fixed effect regressions independent variable = γ (varying elasticity)

elasticity	0.20	0.25	0.30	0.35
f	0.284	1.040	1.220	0.821
	(0.253, 0.267)	(0.297, 0.349)	(0.237, 0.266)	(0.179, 0.204)
R^2	0.401	0.519	0.616	0.583
SER ($x10^{-3}$)	8.339	7.746	6.679	6.955
LL	360.767	371.250	382.072	378.184

Notes: See Table 4.

where the output elasticity of public capital equals 0.20, 0.25, 0.30, and 0.35, respectively. Each of these equations in the table also contains (but does not report coefficient estimates for) a constant term, the initial level of the logarithm of output per worker, the initial unemployment rate, and a separate time effect for the 1970s.[11] Of these values for the output elasticity of public capital, the log likelihood function is maximized for the previously assumed value of 0.30. Values for the output elasticity of public capital either lower or higher than 0.30 yield lower (and less significant) coefficient estimates for the impact of public capital on growth. Finally, we note that the ascent and descent of the log likelihood values is relatively steep around the maximizing value of 0.30.

Having settled on the a reasonable estimate of the output elasticity of public capital, the growth maximizing level of the public capital ratio can be calculated as

$$\phi^{\max} = \frac{\alpha_{kg}}{(1-\alpha_{kg})^2} = \frac{.3}{(0.7)^2} = 0.612. \tag{24}$$

This suggests that for most of the sample – specifically, for 87 of 96 observations – the actual public capital ratio of 0.446 falls below the estimate of the growth maximizing value of the public capital ratio of 0.612. Thus, for these 87 observations an increase in the public capital ratio is associated with an increase in the economic growth rate.

The magnitude of the effect of a change in the public capital ratio on growth can be obtained by differentiating Eq. (13) and can be shown to be given by

$$d\gamma/d\phi = \left[\frac{b\cdot(1-\alpha_{kg})^2\cdot\phi^{\alpha_{kg}-1}}{(1+(1-\alpha_{kg})\phi)}\right]\cdot[\phi^{\max}-\phi]. \tag{25}$$

Consequently, for $b = 1.220$ and $\alpha_{kg} = 0.3$, a one standard deviation increase in the public capital ratio from its sample average value of 0.446 is coupled with a 1.636 standard deviation increase in the growth rate of output per worker, equal to 1.8% per year. This is a sizeable impact, one which may be seen to give some substance to the argument that for many states an insufficient level of investment in public capital may have been responsible for relatively sluggish productivity growth in recent decades.

[11] The results are not sensitive to the inclusion or exclusion of either the initial output per worker or initial unemployment rate variables.

3.3. Public capital, government spending, and economic growth

In recent empirical work, a number of authors have found that economic growth rates are adversely affected by higher levels of government spending. For example, using cross-country data over the period 1960 to 1985 Barro (1991) and Barro and Sala-I-Martin (1995) find that a 6.5 percentage point rise in government consumption spending – defined as total government consumption spending minus defense and non-capital expenditures on education – is associated with a drop in the growth rate of 0.7% per year. This suggests that such spending is either unproductive by nature or, if productive, has been taken well beyond its growth maximizing level.

To investigate the impact of flow government expenditures on economic growth in the present context, we postulate the regression equation

$$\gamma_{it} = a + b_{kg} \cdot f_{kg,it} + b_g \cdot f_{g,it} + \underline{c} \cdot \underline{z}_{it} + \varepsilon_{it} \tag{26}$$

where transformed government capital (as before) is given by

$$f_{kg,it} = \frac{\phi_{it}^{\alpha_{kg}}}{1 + (1 - \alpha_{kg})\phi_{it}} \tag{27}$$

transformed government spending is expressed as

$$f_{g,it} = \phi_{g,it}^{\alpha_g} \cdot (1 - \phi_{g,it}^{1-\alpha_g}) \tag{28}$$

and ϕ_g denotes the ratio of government spending to private capital. We note that the difference in form between the transformed government capital and government spending variables arises because the former involves the *stock* of government capital whereas the latter involves the *flow* of government spending.

Table 7 shows the results of fixed effects regressions of Eq. (26) under the assumption that the output elasticities of public capital and government spending are equal to 0.33 and 0.05, respectively. Regardless of the inclusion

Table 7. Growth, government capital, and government spending fixed effect regressions independent variable = γ (public capital elasticity = 0.33, government spending elasticity = 0.05)

f_{kg}	1.019	1.001	1.019	0.993
	(0.182, 0.225)	(0.180, 0.211)	(0.184, 0.229)	(0.181, 0.212)
f_g	0.354	0.390	0.352	0.394
	(0.120, 0.121)	(0.121, 0.125)	(0.121, 0.125)	(0.121, 0.129)
y	—	−0.029	—	−0.039
		(0.020, 0.015)		(0.023, 0.019)
u	—	—	<0.001	0.001
			(0.001, 0.001)	(0.001, 0.001)
d70s	−0.012	−0.012	−0.011	−0.010
	(0.002, 0.002)	(0.002, 0.002)	(0.002, 0.003)	(0.003, 0.003)
R^2	0.666	0.674	0.659	0.673
SER ($x10^{-3}$)	6.224	6.155	6.295	6.160
LL	387.695	389.911	387.751	390.947

Notes: All regressions also contain a constant term. Ordinary and White heteroskedasticity corrected standard errors in parentheses.

or exclusion of one or both of the initial output per worker or unemployment variables, each of the transformed public sector variables f_{kg} and f_g is significantly associated with output growth. As with the results in the previous section, these fixed effects regressions allow little explanatory power for the initial level of output per worker, casting further doubt on the existence of strong convergence effects across state economies. Furthermore, the lack of a significant effect for the initial output variable implies that a permanent increase in either of the transformed governmental variables f_{kg} or f_g may well have a permanent, rather than a temporary, positive effect on economic growth – a result in agreement with Kocherlakota and Yi (1996).

Table 8 indicates the effects of varying the output elasticities of public

Table 8. Growth, government capital, and government spending fixed effect regressions independent variable = γ (varying elasticities)

			g/k			
	elasticity		0.00	0.02	0.04	0.06
			0.893	0.893	0.895	0.899
			(0.305, 0.338)	(0.304, 0.335)	(0.303, 0.333)	(0.302, 0.33)
	0.25		0.203	0.234	0.269	0.309
			(0.125, 0.129)	(0.141, 0.147)	(0.160, 0.167)	(0.183, 0.190)
		R^2	0.536	0.537	0.538	0.538
		SER ($x10^{-3}$)	7.334	7.333	7.327	7.322
		LL	374.136	374.213	374.286	374.348
			1.171	1.172	1.172	1.174
			(0.223, 0.242)	(0.223, 0.241)	(0.223, 0.239)	(0.223, 0.238)
	0.30		0.268	0.305	0.348	0.398
			(0.102, 0.103)	(0.116, 0.118)	(0.132, 0.136)	(0.151, 0.157)
		R^2	0.661	0.661	0.662	0.662
kg/k		SER ($x10^{-3}$)	6.275	6.270	6.266	6.267
		LL	389.167	389.249	389.297	389.290
			0.863	0.862	0.861	0.859
			(0.160, 0.192)	(0.160, 0.191)	(0.160, 0.190)	(0.161, 0.189)
	0.35		0.353	0.400	0.455	0.515
			(0.101, 0.109)	(0.115, 0.125)	(0.131, 0.144)	(0.150, 0.168)
		R^2	0.668	0.668	0.667	0.666
		SER ($x10^{-3}$)	6.210	6.210	6.215	6.228
		LL	390.165	390.167	390.086	389.883
			0.611	0.609	0.607	0.604
			(0.124, 0.148)	(0.124, 0.147)	(0.125, 0.147)	(0.125, 0.146)
	0.40		0.394	0.447	0.506	0.572
			(0.106, 0.117)	(0.120, 0.135)	(0.137, 0.156)	(0.157, 0.182)
		R^2	0.643	0.643	0.642	0.639
		SER ($x10^{-3}$)	6.435	6.439	6.448	6.470
		LL	385.745	386.693	386.537	386.233

Note: In each cell, the first entry represents the effect of transformed government capital on growth and the second entry the effect of transformed government spending on growth. Standard errors in parentheses.

capital and government spending away from the assumed values of 0.33 and 0.05, respectively. As the table indicates, values of the output elasticities smaller or larger than 0.35 and 0.04, respectively, produce poorer estimation results (as measured by the log likelihood value or the adjusted coefficient of determination). More specifically, the log likelihood function takes on its maximum value when the output elasticity of public capital equals 0.33 and the output elasticity of government spending equals 0.05. We note that the log likelihood function is much more sharply peaked in the public capital dimension than in the government spending dimension, so that we may have somewhat more confidence in the precision of the estimate of the output elasticity of public capital than of the output elasticity of government spending.

The growth maximizing ratio of public capital can be computed as

$$\phi_{kg}^{\max} = \frac{\alpha_{kg}}{(1-\alpha_{kg})^2} = 0.735 \tag{29}$$

which implies that the level of government capital lies below its growth maximizing level for 92 of 96 observations. Similarly, the growth maximizing level of government spending is determined by[12]

$$\phi_g^{\max} = \alpha_g^{1/(1-\alpha_g)} = 0.043 \tag{30}$$

so that the level of government spending is negatively associated with economic growth for all sample observations.

The magnitude of the effects on economic growth of increases in public capital and government spending, respectively, may be determined (in a fashion analogous to the discussion surrounding Eq. (25) above) as

$$d\gamma/d\phi_{kg} = 0.174 \tag{31}$$

and

$$d\gamma/d\phi_g = -0.266. \tag{32}$$

Accordingly, a one standard deviation increase in the public capital ratio from its mean value of 0.446 is associated with an increase in economic growth in an amount equal to 2.4 percentage points per year (or some 2.182 standard deviations of output growth), while a one standard deviation increase in the government spending ratio from its mean value of 0.139 is associated with a reduction in economic growth in an amount equal to 1.3 percentage points per annum (or some 1.185 standard deviations of output growth).

[12] This result can be shown to be consistent with a growth maximizing ratio of government spending to output (rather than private capital) given by

$$\frac{g}{y} = \alpha_g = 0.05$$

which is consistent with Barro (1990).

3.4. Core public capital, other public capital, and economic growth

This section allows a distinction between what has been termed *core* public capital and *other* types of public capital. Here, core public capital is defined as the composite of streets and highways, and water and sewer systems, while other public capital (as a residual measure) includes educational buildings, office buildings, and conservation and development structures. In the literature (e.g., Aschauer 1989 and Munnell 1990b) core public capital has been found to have a larger estimated output elasticity than other types of public capital.

Accordingly, the final set of regressions are of the form

$$\gamma_{it} = a + b_{kg(core)} \cdot f_{kg(core),it} + b_{kg(other)} \cdot f_{kg(other),it} + b_g \cdot f_{g,it} + \underline{c} \cdot \underline{z}_{it} + \varepsilon_{it} \tag{33}$$

where $f_{kg(core)}, f_{kg(other)}$, and f_g represent transformed ratios of core public capital, other public capital, and government spending to private capital, respectively. Here, the transformed ratios of core and other public capital are given as

$$f_{kg(x),it} = \frac{\phi_{kg(x),it}^{\alpha_{kg(x)}}}{1 + (1 - \alpha_{kg(x)})\phi_{kg(x),it}} \tag{34}$$

where $x =$ core and other, respectively, and the transformed ratio of government spending is measured as[13]

$$f_{g,it} = \phi_{g,it}^{\alpha_g} \cdot (1 - \phi_{g,it}^{\alpha_g}). \tag{35}$$

Table 9 presents estimates of the impact of transformed core and other public capital and government spending on growth in per worker output under the assumption that the output elasticities of core public capital, other public capital, and government spending equal 0.25, 0.20, and 0.05, respectively. All of the government policy variables are significantly related to economic growth, with the largest quantitative effects for core public capital, then other public capital and, finally, government spending. In absolute value, the estimated coefficient on the initial level of per capita output is quantitatively (now in the range of 0.008 to 0.017) and statistically minor, indicating weak or even nonexistent convergence effects.

Tables 10 through 12 allow for different assumed values for the output elasticities of core public capital (ranging from 0.20 to 0.30), other public capital (ranging from 0.15 to 0.25), and government spending (ranging from 0.04 to 0.06). As the tables indicate, a departure of either of the two public capital elasticities from the values assumed in Table 9 – 0.25 and 0.20, respectively – causes a rather significant deterioration in the fit of the regressions

[13] This is merely a translation of the results for flow government expenditures in Barro (1990); whereas he focused on the ratio of government spending to output, the present paper focuses on the ratio of government spending to private capital.

Table 9. Growth, government capital, and government spending fixed effect regressions independent variable = γ (core elasticity = 0.25, other elasticity = 0.20, government spending elasticity = 0.05)

$f_{kg(core)}$	0.764	0.772	0.726	0.728
	(0.213, 0.233)	(0.216, 0.243)	(0.219, 0.243)	(0.220, 0.252)
$f_{kg(other)}$	0.651	0.662	0.700	0.655
	(0.191, 0.176)	(0.209, 0.200)	(0.201, 0.196)	(0.212, 0.206)
f_g	0.452	0.458	0.454	0.467
	(0.138, 0.144)	(0.141, 0.147)	(0.139, 0.149)	(0.141, 0.152)
y	—	−0.008	—	−0.017
		(0.022, 0.014)		(0.024, 0.016)
u	—	—	0.001	0.001
			(0.001, 0.001)	(0.001, 0.001)
d70s	−0.012	−0.012	−0.010	−0.010
	(0.002, 0.003)	(0.002, 0.003)	(0.003, 0.004)	(0.003, 0.004)
R^2	0.670	0.663	0.667	0.663
SER ($x10^{-3}$)	6.190	6.252	6.217	6.253
LL	389.372	389.515	390.063	390.631

Notes: All regressions also contain a constant term. Ordinary and White heteroskedasticity corrected standard errors in parentheses.

(as measured by the adjusted coefficients of determination or the log likelihood values) and tends to reduce the statistical significance of one or both of the transformed public capital variables. On the other hand, assuming different values for the output elasticity of government spending has little impact on the explanatory power of the regressions or on the magnitudes or statistical significance of the government policy variables.

The corresponding growth-maximizing values of core public capital, other public capital, and government spending can be calculated to equal 0.444, 0.313, and 0.043, respectively, to be compared with actual sample average values of 0.267, 0.179, and 0.139. This comparison indicates that higher core public capital is associated with higher growth for 94 of the 96 observations; that higher other public capital is associated with higher growth for 90 of the 96 observations; and that higher government spending is coupled with lower growth for 94 of 96 total observations.

The corresponding effects of changes in these governmental variables on growth can be shown to be

$$d\gamma/d\phi_{kg(core)} = 0.045$$

$$d\gamma/d\phi_{kg(other)} = 0.061$$

$$d\gamma/d\phi_g = -0.315.$$

Perhaps surprisingly, the economic growth effects of core public capital are exceeded by the effects of other public capital. Specifically, a one standard deviation increase in core capital can be expected to induce roughly a one-third standard deviation increase in output growth (equal to 0.3% per year) while a one standard deviation increase in other capital can be predicted to bring forth approximately a one-half standard deviation increase in economic growth (equal to 0.5% per year). As before, however, a one standard deviation

Table 10. Growth, core government capital, and other government capital fixed effect regressions independent variable = γ (varying public capital elasticities, government spending elasticity = 0.04)

			$kg(other)/k$		
	elasticity		0.15	0.20	0.25
			0.816	0.752	0.813
			(0.308, 0.329)	(0.276, 0.241)	(0.271, 0.233)
	0.20		0.595	0.736	0.482
			(0.365, 0.409)	(0.215, 0.214)	(0.139, 0.141)
			0.288	0.410	0.470
			(0.185, 0.165)	(0.138, 0.145)	(0.140, 0.151)
		R^2	0.567	0.640	0.642
		SER ($x10^{-3}$)	7.093	6.465	6.446
		LL	378.533	387.425	387.708
			0.850	0.727	0.739
			(0.227, 0.270)	(0.220, 0.252)	(0.222, 0.252)
	0.25		0.648	0.656	0.410
			(0.333, 0.367)	(0.212, 0.207)	(0.141, 0.134)
$kg(core)/k$			0.316	0.438	0.489
			(0.145, 0.148)	(0.132, 0.141)	(0.137, 0.152)
		R^2	0.621	0.663	0.656
		SER ($x10^{-3}$)	6.635	6.253	6.319
		LL	384.946	390.637	389.622
			0.650	0.526	0.523
			(0.170, 0.227)	(0.171, 0.222)	(0.176, 0.226)
	0.30		0.756	0.661	0.401
			(0.328, 0.341)	(0.216, 0.206)	(0.146, 0.137)
			0.333	0.463	0.512
			(0.144, 0.147)	(0.134, 0.147)	(0.139, 0.159)
		R^2	0.624	0.654	0.641
		SER ($x10^{-3}$)	6.605	6.337	6.456
		LL	389.377	389.350	387.569

Note: in each cell, the first entry represents the effect of transformed government core capital on growth, the second entry the effect of transformed government other capital, and the third entry the effect of transformed government spending on growth. Standard errors in parentheses.

increase in government spending is associated with more than a one standard deviation decrease in output growth (equal to 1.5% per year).

4. Conclusions and directions for further research

The results of this paper indicate that for most of the United States during the 1970s and 1980s the actual levels of public capital were below the levels estimated to maximize the rate of productivity growth. Specifically, the growth maximizing ratio of public capital to private capital is estimated to equal 0.444 for core public capital and 0.313 for other public capital, while the actual sample averages equal the smaller values of 0.267 and 0.179, respectively. Thus, the empirical results suggest that a one standard deviation increase in either core or other public capital is associated with a one-third to one-half standard deviation increase in output growth per worker.

Table 11. Growth, core government capital, and other government capital fixed effect regressions independent variable = γ (varying public capital elasticities, government spending elasticity = 0.05)

			kg(other)/k		
	elasticity		0.15	0.20	0.25
			0.820	0.758	0.818
			(0.307, 0.327)	(0.275, 0.238)	(0.271, 0.230)
	0.20		0.591	0.735	0.482
			(0.365, 0.410)	(0.214, 0.213)	(0.139, 0.140)
			0.310	0.439	0.504
			(0.165, 0.177)	(0.147, 0.155)	(0.150, 0.163)
		R^2	0.567	0.640	0.643
		SER ($x10^{-3}$)	7.089	6.460	6.438
		LL	378.586	387.507	387.827
			0.851	0.728	0.740
			(0.222, 0.270)	(0.220, 0.252)	(0.222, 0.251)
	0.25		0.647	0.655	0.409
			(0.333, 0.347)	(0.212, 0.206)	(0.141, 0.134)
kg(core)/k			0.338	0.467	0.523
			(0.155, 0.158)	(0.141, 0.152)	(0.146, 0.163)
		R^2	0.621	0.663	0.656
		SER ($x10^{-3}$)	6.635	6.253	6.319
		LL	384.943	390.631	389.629
			0.649	0.526	0.522
			(0.171, 0.227)	(0.171, 0.222)	(0.176, 0.225)
	0.30		0.756	0.661	0.400
			(0.328, 0.341)	(0.216, 0.205)	(0.146, 0.137)
			0.354	0.493	0.546
			(0.154, 0.157)	(0.143, 0.159)	(0.149, 0.172)
		R^2	0.624	0.653	0.640
		SER ($x10^{-3}$)	6.610	6.343	6.461
		LL	385.304	389.261	387.487

Note: in each cell, the first entry represents the effect of transformed government core capital on growth, the second entry the effect of transformed government other capital, and the third entry the effect of transformed government spending on growth. Standard errors in parentheses.

At the same time, the results suggest that for nearly all states the actual levels of government spending were above the levels estimated to maximize productivity growth. While the growth maximizing ratio of government spending to private capital is estimated to equal 0.043, the sample average ratio equals a much larger 0.139. Consequently, a one standard deviation increase in government spending is coupled with somewhat more than a one standard deviation decrease in the rate of economic growth.

Statistically (though not necessarily quantitatively) the empirical results of this paper also indicate a lack of convergence effects across state economies. From a policy perspective, this implies that permanent changes in government policy variables – such as a permanent increase in public capital or a permanent decrease in government consumption spending – are consistent with permanent changes in economic growth rates. This result is compatible with some recent empirical work, such as Kocherlakota and Yi (1996), but stands in stark contrast with other work, such as Barro and Sala-I-Martin (1995). In

Table 12. Growth, core government capital, and other government capital fixed effect regressions independent variable = γ (varying public capital elasticities, government spending elasticity = 0.06)

			kg(other)/k		
	elasticity		0.15	0.20	0.25
			0.825	0.764	0.825
			(0.307, 0.325)	(0.275, 0.236)	(0.270, 0.228)
	0.20		0.587	0.733	0.482
			(0.365, 0.411)	(0.214, 0.211)	(0.138, 0.140)
			0.333	0.471	0.540
			(0.177, 0.189)	(0.157, 0.161)	(0.160, 0.174)
		R^2	0.568	0.641	0.644
		SER ($x10^{-3}$)	7.086	6.456	6.432
		LL	378.634	387.573	387.926
			0.852	0.730	0.742
			(0.227, 0.270)	(0.220, 0.251)	(0.222, 0.250)
	0.25		0.646	0.654	0.409
			(0.333, 0.367)	(0.212, 0.205)	(0.141, 0.133)
kg(core)/k			0.361	0.499	0.558
			(0.165, 0.169)	(0.151, 0.164)	(0.156, 0.177)
		R^2	0.621	0.663	0.656
		SER ($x10^{-3}$)	6.636	6.255	6.321
		LL	384.926	390.596	389.601
			0.649	0.525	0.521
			(0.171, 0.226)	(0.171, 0.221)	(0.177, 0.224)
	0.30		0.756	0.660	0.400
			(0.328, 0.341)	(0.216, 0.204)	(0.146, 0.137)
			0.376	0.524	0.581
			(0.165, 0.169)	(0.153, 0.172)	(0.159, 0.186)
		R^2	0.623	0.653	0.639
		SER ($x10^{-3}$)	6.616	6.351	6.470
		LL	385.212	389.134	387.362

Note: in each cell, the first entry represents the effect of transformed government core capital on growth, the second entry the effect of transformed government other capital, and the third entry the effect of transformed government spending on growth. Standard errors in parentheses.

subsequent research, therefore, it would be of some value to further investigate the role of convergence effects in order to obtain a more accurate assessment of the impact of public capital and spending levels on economic growth rates.

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