Public Capital and Economic Growth: Issues of Quantity, Finance, and Efficiency

by

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Introduction

In the past decade, a large body of theoretical and empirical research has considered the importance of the quantity of public capital for economic growth. For the most part, the empirical results of this line of research point to a positive role for public capital in determining steady state levels of output per capita and transitional growth rates. At the same time, other work has pointed out the importance of the means of financing government spending for economic growth. Here, the empirical results indicate a negative influence of higher government spending, proxying for a higher rate of taxation of private sector economic activities, on economic growth. Finally, there is a budding literature on the importance of the effectiveness, or efficiency, of public capital to the growth process. Here, the limited results in the literature suggest that the effectiveness of use of the public capital stock has a meaningful positive influence on growth.

This paper develops a common framework to investigate the importance of all three of the above aspects of the provision of public capital for growth in output per worker. The following section fixes ideas with a simple extension of the neoclassical growth model of Solow (1956) and Swan (1956). A subsequent section of the paper then consider the relative importance of the three aspects of public capital: "how much you have," "how you pay for it," and how you use it." A final section concludes the paper.

Conceptual Approach

The approach is an elaboration on the familiar neoclassical growth model and so only the essential elements are presented here. The analysis centers on a Cobb-Douglas production function which relates output, Y, to various sorts of capital, K, and labor, L. This production function, written in labor intensive form, is

$$y = A \cdot \prod_{j=1}^{n} k_j^{a_j} \tag{1}$$

where y = output per worker and k_j = type j capital per worker. It is assumed that the production function exhibits constant returns to scale across all inputs and, therefore, diminishing returns to all capital inputs, so that $\sum_j a_j < 1$. Finally, A represents other, presently unspecified, factors which may be important to the production process.

In the steady state, there is an exogenous rate of technological progress, γ, and rate of growth of the labor force, λ. Each of the various capital stocks is assumed to depreciate at the common rate δ. Consequently, in the steady state--with unchanging capital stocks per effective worker--the level of gross investment in each of the various types of capital is given by

$$i_j \cdot y = (\gamma + \lambda + \delta) \cdot k_j \quad j = 1,2,\ldots,n \tag{2}$$

where i_j = share of output devoted to gross investment in type j capital. Substituting from (2) for the steady state capital stocks into (1) and solving for y then yields the steady state level of output per worker as

$$y(\infty) = \left(\frac{A \cdot \Pi_j i_j^{a_j}}{(\gamma+\lambda+\delta)^{\sum_j a_j}}\right)^{\frac{1}{1-\sum_j a_j}}. \tag{3}$$

In the transition to the steady state, the growth rate of output per worker is given by

$$ln\left(\frac{y(s)}{y(0)}\right) = (1 - exp(-\mu s)) \cdot ln\left(\frac{y(\infty)}{y(0)}\right) \tag{4}$$

where μ represents the rate at which the economy converges to the steady state. Substituting from equation (3) for the steady state level of output in equation (4) yields

$$ln\left(\frac{y(s)}{y(0)}\right) = c + b_0 \cdot ln(y(0)) + \sum_j b_j \cdot ln\left(\frac{i_j}{\gamma+\lambda+\delta}\right) \tag{5}$$

where c is a constant and $b_0 = -(1- exp(-\mu s))$. The coefficients b_j, $j = 1,2,...,n$, representing the effect of changes in the steady state levels of type j capital on the transitional growth rate, are given by

$$b_j = -\frac{a_j \cdot b_0}{1-\sum_j a_j} \quad j = 1,2,...,n. \tag{6}$$

This latter set of n equations can be solved for the output elasticities of the various types of capital; specifically, we obtain

$$a_j = \frac{b_j}{\sum_j b_j - b_0} \quad j = 1,2,...,n. \tag{7}$$

In the following empirical analysis, a stochastic version of equation (5) will be estimated in order to obtain estimates of the convergence rate [$\mu = -ln(1+b_0)/s$], growth sensitivities [$b_j, j = 1,2,...,n$], and output elasticities [$a_j, j = 1,2,...,n$].

Data

The data set covers forty-six low and middle income countries over the period 1970 to 1990. The definitions and sources of the data are:

y = real gross domestic product per capita, with purchasing power parity adjustment, from Summers and Heston (1991)

i_1 = 1970 to 1990 average ratio of gross private investment to output, from Summers and Heston (1991)

i_2 = percentage of working age population in secondary school, from UNESCO yearbook

i_3 = 1970 to 1990 average ratio of gross public investment to output, from Summers and Heston (1991).

In the empirical implementation of the model, the investment rates are deflated by the country-specific average annual rate of population growth, plus an assumed combined rate of technological progress and depreciation of .05 per year, to yield estimates of steady state capital output ratios.

Empirical Results

The Quantity of Public Capital is Important

Table 1 shows the results of estimating the basic model in three forms: with private physical capital;

Table 1: Capital and economic growth
46 countries 1970-1990

Dependent variable: *ln(y(90)/y(80)*

	(1)	(2)	(3)
c	.86 (.64)	1.49 (.59)	1.42 (.56)
b_0	-.10 (.09)	-.36 (.11)	-.36 (.10)
implied μ	.005	.022	.022
b_1	.32 (.09)	.24 (.08)	.34 (.08)
implied a_1	.76	.28	.27
b_2	—	.25 (.07)	.24 (.07)
implied a_2	—	.29	.19
b_3	—	—	.30 (.11)
implied a_3	—	—	.24
R^2	.20	.37	.45
SER	.37	.33	.30
CRTS test: F-statistic (p-value)	1.77 (.18)	<.01 (.98)	<.01 (.91)

Standard errors in parentheses.

with private physical capital and human capital; and with private physical capital, human capital, and public physical capital.

At first glance, the empirical results in equation (1) appear to be broadly consistent with the predictions of the neoclassical growth model. The steady state private physical capital stock (measured relative to output) is highly positively correlated with output growth. A one standard deviation increase in the private capital stock ratio (*i.e.,*by an amount equal to 59 percent of output) can be seen to lead to a .34 standard deviation increase in output growth, or some .7 of one percent per year. The implied value of the output elasticity of private capital, .76, is high but consistent with previous estimates in the literature.[1] In addition, the negative coefficient on the 1970 level of output per worker is consistent with a convergence effect, whereby countries with relatively low levels of output per capita grow at a relatively faster rate, though the implied convergence rate is quite low--at .5 of one percent per year--and statistically quite weak.

However, it was precisely these sorts of results that led Aschauer (1993) and Mankiw, Romer, and Weil (1992) to augment the basic Solow model by including a measure of human capital along with physical capital in the production function. Equation (2) includes a proxy for human capital--the secondary school enrollment rate deflated by capital's effective depreciation rate--and shows a clear improvement in the explanatory power of the model. The private physical capital and human capital stock variables are highly statistically significant and indicate an important quantitative role for both

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[1] See, for instance, the results for the "textbook Solow model" in Mankiw, Romer, and Weil (1992) and in Nonneman and Vanhoudt (1996).

sorts of capital in growth. Specifically, one standard deviation increases in physical capital and in human capital, respectively, are calculated to boost output growth by .25 and .51 standard deviations, or some .5 and 1 percent per year, respectively. The coefficient on the 1970 level of output per capita differs in a statistically significant manner from zero, and the implied convergence rate, at 2.2 percent per year, is in the same range as earlier estimates to be found in Mankiw, Romer, and Weil (1992), Barro and Sala-I-Martin (1992) and elsewhere. The estimated convergence rate is somewhat lower than the theoretical value

$$\mu = (\gamma+\lambda+\delta)\cdot(1-a_1-a_2) \tag{8}$$

which, given the implied estimates of the output elasticities of private physical capital and human capital, is equal to 3.3 percent per year.[2] Finally, it should be noted that the model as estimated contains the restriction that there are constant returns to scale over the capital inputs included in the particular empirical specification--here, private physical capital and human capital--and labor. This restriction is tested by running the regression equation in an unrestricted form--that is, allowing the logarithm of the effective depreciation rate $\gamma+\lambda+\delta$ to have a separate explanatory role in the equation--and performing a Wald test. As indicated in the table, the data contain virtually no evidence against this restriction; the relevant F-statistic takes on a very low value of less than .01 and carries a p-value of .98.

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2 This theoretical value pertains to a closed economy version of the neoclassical model. Barro, Mankiw, and Sala-I-Martin (1995) show that the convergence rate can be expected to be higher in an open economy version of the neoclassical growth model which allows (partial) capital mobility. The countries in the data sample employed in the present paper are, for the most part, significant net debtors in the international capital market. Thus, an estimated convergence rate which lies somewhat below the theoretical value for a closed economy version of the model presents something of an empirical puzzle.

In the economic growth literature, there is considerable controversy regarding the relative importance of public and private physical capital in the economic growth process. In a sample of seventy-six countries, Barro (1991) finds that public capital investment and private capital investment have similar effects on economic growth. Easterly and Rebelo (1993), in a sample composed of one hundred countries (a subset of which comprises the sample of forty-six countries in the present paper), estimate an important role for infrastructure capital--especially transportation and communications--in economic growth. Hulten (1996), however, finds little impact of public capital on economic growth--after controlling for the efficiency of use of public capital.

Equation (3) of Table 1 includes the steady state measure of public capital along with private capital and human capital. The coefficient estimate on public capital is statistically and quantitatively important, and indicates that a one standard deviation increase in public capital (*i.e.,* in an amount equal to 63 percent of output) can be expected to raise economic growth by .34 of one standard deviation, or approximately .7 percent per year. Generally speaking, the introduction of the public capital variable leaves unaffected the estimated coefficients on the 1970 level of output per capita and on human capital but raises the estimated coefficient on private physical capital. The adjusted coefficient of determination rises substantially, from .37 to .45, and a test of the constant returns to scale restriction shows little evidence against the restricted model.

The Cobb-Douglas production structure allows a comparison of the sample average marginal products of public and private physical capital by use of the formula

$$\frac{mp_1}{mp_3} = (\frac{a_1}{a_3}) \cdot (\frac{i_3}{i_1}) \tag{9}$$

where mp_1 = marginal product of private physical capital and mp_3 = marginal product of public physical capital. Since the sample average values of the ratios of private physical capital and public physical capital to output are 1.37 and 1.32, respectively, we obtain

$$\frac{mp_1}{mp_3} = 1.36$$

which indicates that the data contains some evidence that a reallocation of physical capital from public to private uses would exert a positive influence on average growth.

The Financing of Public Capital Is Important

A number of theoretical and empirical studies have pointed to the possibility that a relatively large government sector places a burden on the private sector and, thereby, may depress the rate of economic growth. In an explicit optimizing framework, Barro (1990) shows how the benefits from "productive" government spending need to be weighed against the costs of "distortional" taxes which results in an optimal (*i.e.*, growth maximizing) ratio of government spending to output which is equal to the output elasticity of government spending. Aschauer (1997a, b, c) extends this analysis to consider government capital and empirically estimates growth maximizing ratios of public capital to private capital.

In the present context, we capture these notions in a tractable fashion by postulating that the constant term in the production function (1) now depends negatively on the tax burden associated with the accumulation of public capital. The tax burden, in turn, is taken to be directly related to the level of external public debt, expressed as a ratio to output, which is issued (at least in part) to finance the initial acquisition of public capital.[3] Specifically, we assume

$$A = A_0 \cdot exp(d \cdot debt) \tag{10}$$

where $d < 0$ and *debt* = ratio of 1980 level of external public debt to output. This allows an expanded version of the growth equation of the form

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[3] Strictly speaking, the total tax burden associated with a certain level of public capital can be expressed in the following way. In the steady state, the government must raise tax revenues equal to (a) the interest charge associated with the initial purchase of government capital and (b) the on-going gross investment necessary to maintain the public capital stock against technological progress, population growth, and physical depreciation. Letting kg represent public capital, r the real interest rate, and τ a tax rate on labor and capital income,

$$\tau \cdot y = r \cdot kg + (\gamma + \lambda + \delta) \cdot kg = (r + \gamma + \lambda + \delta) \cdot kg.$$

Assuming that public debt is used to finance the initial acquisition of public capital, we have

$$\tau = (r + \gamma + \lambda + \delta) \cdot debt$$

where *debt* denotes the ratio of public debt to output. Thus, the tax burden is associated with the ratio of public debt to output. In the empirical work, external public debt is used as a proxy for total public debt since data on total public debt are unavailable for many of the countries in the sample. Also, the empirical results are not particularly sensitive to the use of *debt* or τ as the measure of the tax burden; accordingly Tables (2) and (3) only report results from empirical equations using *debt*.

$$ln(\frac{y(s)}{y(0)}) = c + b_0 \cdot ln(y(0)) + \sum_j b_j \cdot ln(\frac{i_j}{\gamma + \lambda + \delta}) + d \cdot debt. \tag{11}$$

Table 2 presents estimates of the various specifications of the growth model including the debt variable. As expected, in all three equations the public debt variable is negatively associated with growth in output per capita, ranging from a low (absolute) value of .28 in equation (2) to a high (absolute) value of .69 in equation (3). In the latter case, a one standard deviation increase in external public debt (*i.e.,* by an amount equal to 23 percent of output) can be expected to induce a .51 standard deviation decrease in output growth, or some 1.0 percent per year.

In general, the other empirical results in Table 2 conform closely to those in Table 1. In particular, all three types of capital are quantitatively and statistically important in the determination of the rate of growth of output per capita. As before, the addition of human capital (in equation (2)) and public physical capital (in equation (3)) results in a clear improvement in the explanatory power of the model. The implied output elasticities of the various forms of capital are reasonable--particularly in equation (3)--and the constant returns to scale restriction cannot be rejected at conventional significance levels.

In the context of the empirical model, the growth maximizing ratio of public capital to output is given by the expression

$$\frac{\partial[ln(y(s)/y(0))]}{\partial[i_3/(\gamma + \lambda + \delta)]} = \frac{b_3}{i_3/(\gamma + \lambda + \delta)} + d = 0 \tag{12}$$

Table 2: Capital, debt and economic growth
46 countries 1970-1990

Dependent variable: *ln(y(90)/y(80)*

	(1)	(2)	(3)
c	1.21 (.66)	1.69 (.61)	1.85 (.51)
b_0	-.13 (.09)	-.37 (.11)	-.36 (.09)
implied μ	.007	.023	.022
b_1	.34 (.09)	.27 (.08)	.40 (.06)
implied a_1	.72	.31	.28
b_2	—	.23 (.07)	.20 (.06)
implied a_2	—	.26	.14
b_3	—	—	.34 (.11)
implied a_3	—	—	.24
d	-.41 (.23)	-.28 (.21)	-.69 (.21)
R^2	.24	.38	.56
SER	.36	.32	.27
CRTS test: F-statistic (p-value)	1.25 (.27)	<.01 (.95)	.25 (.62)

Standard errors in parentheses.

or

$$\frac{i_3}{(\gamma+\lambda+\delta)} = -\frac{b_3}{d}. \tag{13}$$

Using the estimated coefficients for the growth sensitivities of public capital ($b_3 = .34$) and external debt ($d = -.69$) we find that the growth maximizing level of public capital equals 49 percent of output. The actual sample average level of public capital equals 132 percent of output--so that further increases in public capital, financed by external borrowing, can be expected to diminish the economic growth rate of a representative country in the sample. Specifically, a one standard deviation increase in public capital financed in this manner is estimated to reduce the growth rate of output per capita by .68 of a standard deviation, or fully 1.4 percent per year. Consequently, despite the fact that public capital is beneficial to growth in a gross sense--with an estimated output elasticity of .34--the average country in the sample appears to have accumulated an excessive amount of public capital, resulting in a dampening effect on growth.

The Efficiency of Public Capital Is Important

In recent work, Hulten (1996) has presented empirical evidence which suggests that the efficiency with which public capital is utilized is just as--if not more--important as is the size of the public capital stock for the economic growth process. Hulten defines the relationship between the effective public capital stock, kg^e, and the actual public capital stock, kg, as

$$kg^e = \theta \cdot kg \tag{14}$$

where θ is a measure of the average level of public capital effectiveness. In order to implement his model empirically, Hulten constructs a measure of public capital effectiveness by aggregating four indicators of public capital performance (mainline faults per 100 telephone calls for telecommunications, electricity generation losses as a percent of total system output for power, and the percentage of paved roads in good condition and diesel locomotive availability as a percent of the total rolling stock for transportation) into an aggregate index. Noting that each of the individual indicators is measured in its own units, Hulten sorts each of the above indicators into quartiles, assigning values of .25, .50, .75, and 1.00, and then averages across quartile rankings for each performance indicator to obtain an aggregate performance index.

In the present paper, we depart from Hulten's approach in two directions. First, an aggregate measure of public capital efficiency is derived from the same basic data source but in a fashion which allows for a somewhat more precise measure of efficiency. Specifically, each individual indicator is normalized (as opposed to being given a quartile ranking) so that performance is measured in terms of standard deviations from the average level of performance. The individual normalized indicators are then averaged to obtain an aggregate performance indicator.

Second, for the sake of consistency with the normalized efficiency measure--which carries a mean value of zero--the average level of public capital effectiveness is written as

$$\theta = exp(\varepsilon \cdot eff) \tag{15}$$

where eff is the public capital effectiveness measure. Here we note that if $eff = 0$ then $\theta = 1$ and the capital stock is at an average level of effectiveness. This allows the expanded growth equation

$$ln(\frac{y(s)}{y(0)}) = c + b_0 \cdot ln(y(0)) + \sum_j b_j \cdot ln(\frac{i_j}{\gamma + \lambda + \delta}) + d \cdot debt + e \cdot eff \qquad (16)$$

where the coefficient on the efficiency variable is given by $e = b_3 \cdot \varepsilon$.

Table 3 presents results pertaining to the estimation of equation (16) for the various definitions of capital. In this table, the first two equations are estimated without the external public debt variable in order to allow comparison with the results in Hulten (1996). In equation (1) of Table 3, the public capital efficiency variable enters in a positive and statistically significant manner. Quantitatively, a one standard deviation increase in efficiency (*i.e.*, equal to .61 efficiency units) can be expected to induce a .49 standard deviation increase in economic growth. At the same time, the introduction of the public capital efficiency variable erodes the statistical and quantitative importance of the measured stock of public capital; the growth rate sensitivity of the stock of public capital falls to .11 and becomes statistically weak, while the output elasticity of the stock of public capital drops to .15.

These results would seem to confirm the results in Hulten (1996) which led him to conclude that "those countries that fail to use their infrastructure effectively pay a penalty in the form of lower growth rates" and that "international aid programs aimed only at new infrastructure construction may have a limited impact on economic growth, and may have a perverse effect if they divert scarce

Table 3: Capital, debt, efficiency and economic growth
46 countries 1970-1990

Dependent variable: *ln(y(90)/y(80)*

	(1)	(2)	(3)	(4)
c	1.34 (.46)	1.34 (.47)	1.70 (.43)	1.71 (.43)
b_0	-.29 (.08)	-.31 (.09)	-.31 (.08)	-.31 (.07)
implied μ	.017	.019	.019	.019
b_1	.17 (.07)	.23 (.06)	.26 (.07)	.27 (.06)
implied a_1	.23	.27	.26	.26
b_2	.18 (.06)	.19 (.06)	.15 (.05)	.15 (.05)
implied a_2	.24	.22	.15	.15
b_3	.11 (.10)	.24 (.05)	.28 (.11)	.29 (.04)
implied a_3	.15	.28	.28	.30
d	—	—	-.56 (.18)	-.57 (.16)
e	.33 (.08)	.24 (.05)	.29 (.07)	.29 (.04)
R^2	.62	.61	.69	.70
SER	.25	.26	.23	.23
CRTS test: F-statistic (p-value)	<.01 (.95)	<.01 (.97)	.10 (.76)	.11 (.75)

Standard errors in parentheses.

domestic resources away from the maintenance and operation of existing infrastructure stocks."[4] However, the potential importance of public capital stocks is enhanced in equation (2) of Table 3, which invokes the constraint that $\varepsilon = 1$ so that the effective public capital stock is given by

$$kg^{e} = exp(eff) \cdot kg$$

which, in turn, implies an equality between the coefficients on the measured public capital stock and the efficiency variables. As is evident from the results pertaining to equation (2) of Table 3, the growth sensitivities of the public capital stock and public capital effectiveness equal .24 and are highly statistically significant. A test of the coefficient restriction $\varepsilon = 1$ (or $b_3 = e$) leads to a value of the relevant F-statistic equal to 2.17 and an associated p-value of .15; consequently, the hypothesis of a parallel importance of quantity and effectiveness of public capital cannot be rejected at conventional levels. The common coefficient estimate of .24 implies that one standard deviation increases in the public capital stock and public capital effectiveness can be envisioned to stimulate, respectively, .28 and .36 standard deviation increases in economic growth.

This argument for the importance of the quantity of public capital is strengthened by the results in the third and fourth columns of Table 3 which include the external public debt variable to capture the adverse effect of the financing of public capital on growth. In equation (3), the coefficient on the public capital variable increases from .11 (the value of the coefficient in equation (1)) to .28 and

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Hulten (1996), pp. 23 and 25.

becomes highly statistically significant. In equation (4), which invokes the constraint that the quantity and efficiency of public capital have parallel effects on growth, the coefficient on public capital is equal to .29 and nearly five times as large as the associated standard error. These results point out in bold terms the importance of considering both the level (and effectiveness) of public capital and the means of financing public capital in a proper assessment of the impact of public capital accumulation on the growth process. Specifically, in the data sample the public capital measure (based on public investment) and the external public debt variable themselves are positively correlated. While the former has a positive effect on growth, the latter has a negative effect on growth so that the exclusion of either variable from the regression equation can be expected to generate biased estimates of the effects of public capital and public debt on growth.

Conclusion

This paper has extended the neoclassical model to assess the importance of three aspects of government intervention on economic growth on the transition path to the steady state. First, public physical capital is included along with private physical capital and human capital as an input in the steady state production function. Second, the means of financing public capital is allowed to affect the level of productivity. Third, the efficiency of use of public capital--along with the quantity of public capital--is taken to determine the effective public capital stock.

In this setting, three questions pertaining to economic growth may be asked, namely: Does how much public capital you have matter? Does how you finance public capital matter? And does how you use public capital matter? The empirical results presented in this paper allow affirmative answers to each of these questions. Specifically, one percentage point increases in either the quantity or the efficiency of public capital are estimated to *increase* transitional growth by .29 percentage points per year while a one percentage point increase in external public debt is estimated to *decrease* transitional growth by .57 percentage points per year. Thus, an "average" increase in public capital, financed by external debt, is estimated to detract from economic growth while an "above average" increase in public capital--defined as a simultaneous increase in quantity and efficiency of public capital--is estimated to have a neutral impact of economic growth.

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