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Abstract

This paper estimates the impact of public capital on economic growth for forty-eight OECD and non-OECD countries during 1960–2001. Using the production function and its extensions, it finds a positive—but concave—elasticity of output with respect to public capital, which is robust to changes in time intervals and varying depreciation rates. Furthermore, in non-OECD countries the growth impact of public capital is higher once longer time intervals are considered.

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I. INTRODUCTION

An understanding of the impact of public investment on growth is relevant for at least three reasons. First, it has been argued that tight budgets constrain public investment more than current spending because it is easier to cut the former for political and other reasons (Roy, Heuty, and Letouze, 2006). Since the late 1990s, this has led to calls to correct the bias against public investment, most importantly in infrastructure, and create "fiscal space" for funding such investment (Heller, 2005).[2] Underlying this premise is the belief that public investment is productive.

Second, in a somewhat similar vein, it has been argued that constraints on external borrowing have prevented governments with large "infrastructure gaps" from undertaking productive investments. Although a country's borrowing capacity depends primarily on its macroeconomic policies, ability to collect taxes, and strength of its public financial and debt management systems, the contribution of debt-financed public investment to growth and exports also plays a role in external borrowing limits.

Finally, fiscal policy has a countercyclical role to play in supporting growth and recovery, which has been recognized during the recent financial crisis. In this context, fiscal stimulus packages in many countries have included a large share of public investment spending in the belief that such investment is productive and better for future growth.[3]

However, the empirical evidence on the impact of public investment on growth is mixed. Previous studies on the impact of public investment on growth have not produced clear-cut results (IMF 2004 and IMF 2005b). This has led some to conclude that public investment is not productive. Some have also argued that total factor productivity (TFP), rather than capital accumulation, matters in explaining growth differentials (Easterly and Levine (2001).

At the same time, a more recent study by the World Bank (2007) concluded that there are positive growth effects of public spending in general, and that of infrastructure, education, and health spending in particular. The report from the Commission on Growth and Development (2008) came to an even stronger conclusion by noting that a common element in fast-growing countries is high public investment, defined as 7 percent of GDP or more. Other studies have argued that fiscal multipliers for investment spending are higher than those for other types of public spending or tax cuts (Perotti, 2005; Zandi, 2008).

Why is the evidence on the relationship between public investment and growth mixed? There could be three reasons. First, many empirical studies use the *public investment rate*, as

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[2] Fiscal space refers to room in a government's budget that allows it to provide resources for a desired purpose without jeopardizing the sustainability of its financial position (IMF, 2005a).

[3] The share of infrastructure spending in fiscal stimulus packages for 2009–10 is about 20 percent for advanced G-20 countries, and more than 50 percent for emerging G-20 countries (Horton et al. 2009).

opposed to the *rate of change in public capital* in explaining differences in growth across countries. This is because public investment data are easier to obtain, even though public investment and public capital variables can differ substantially for a country. In particular, these variables can grow at different rates, depending on the initial level of capital stock.

Second, there is an endogenous link between public investment and growth that can complicate econometric identification. Public investment and growth are flow variables determined in equilibrium and observed over the same period. For example, public investment may fall in an economic downturn simply due to lack of resources, as it is often among the first expenditure items to be cut in a downturn. In contrast, public capital stock does not suffer from this drawback, given that it is measured at the *beginning of the period.* A year in which growth is low would not affect the (beginning of the period) capital stock.

Third, most studies do not take into account the government's budget constraint and the *costs* of financing public investment, which could lead to diminishing returns to investment. The relationship between public investment and growth could even turn negative once public capital is above a certain threshold. For example, maintaining and/or expanding the existing capital stock may require high (and potentially distortionary) tax rates, which would reduce growth, all else being equal (Aschauer 1998; Barro 1990). Thus, the productivity of public investment can vary depending on the initial stock of public capital.

We therefore use measures of the capital stock, rather than investment rates in our study, notwithstanding difficulties in estimating the capital stock. We find that the importance of assumed initial capital stock diminishes significantly in long time series.[4] We address the issue of choosing an appropriate depreciation rate by using different rates. Indeed, our sensitivity analysis shows that under varying depreciation rates, the results of the paper hold.

An important contribution of the paper lies in the construction of public capital stock series for 26 middle-income and low-income countries. Such estimates already exist for 22 OECD countries (Kamps 2006). Our estimates rely on the same methodology as that used for OECD countries.

Our results for a panel of 48 OECD and non-OECD countries show that there is a positive elasticity of output with respect to public capital. This supports the view that changes in public capital stock can explain growth differences across countries, even though the evidence on the impact of public investment is mixed. The literature review in the appendix table, drawn from Romp and de Haan (2005), further indicates that studies that used changes in public capital stock have typically obtained positive results, while the picture is less clear for those using public investment rates.

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[4] In particular, if the capital stock in 1960 is assumed to be zero in our sample, the capital stock in 2001 would differ by only 6 percent for the average country in the sample.

We also find that the elasticity of output with respect to public capital depends on the income level of countries (OECD versus non-OECD) and the initial level of public capital. The elasticity is somewhat stronger for OECD countries, possibly suggesting the importance of institutional factors. At the same time, we find that the positive impact of public capital on output varies with the level of public capital, and that it can be partially offset by high levels of public capital. Such inefficiencies may be engendered by taxes levied to maintain or expand the existing capital stock.

The paper is organized as follows. Section II presents the theoretical models underlying the empirical estimation. Section III explains the construction of the public capital stock dataset. Section IV discusses the empirical results and Section V presents sensitivity analysis with respect to depreciation rates. Section VI concludes and discusses policy implications.

II. THEORY

We use the standard production function approach in the literature and its extension to estimate the impact of public capital on output (Aschauer 1989; Aschauer 1998).

A. Standard Model

In this model, public capital is explicitly included in the aggregate production function by redefining the production function Y= A* F(L,K) as

$$Y = \tilde{A} * F(L,K,G)$$

where Y is the level of output, A is the level of productivity, L is employment, K is private capital, G is public capital and Ã is the total factor productivity purged of the influence of public capital.[5] A commonly used specification is the Cobb-Douglas production function:

$$Y = \tilde{A}\, L^a K^b G^c$$

Taking natural logarithms yields the equation:

$$\ln Y = \ln\tilde{A} + a \ln L + b \ln K + c \ln G$$

Taking first differences yields the equation:

$$\Delta \ln Y = \text{constant} + a\, \Delta\ln L + b\, \Delta\ln K + c\, \Delta\ln G$$

The elasticity of output with respect to public capital, c, is the main variable of interest in this study. The other production elasticities, a and b, are of interest mainly to assess the shape of the production function. Assuming perfect competition in factor markets, private capital and labor must be paid their marginal products (i.e., a + b = 1). In this case, given that c is

[5] Some studies also include human capital in the production function. We stick to the standard approach, where human capital is assumed to be included in the TFP measure Ã.

expected to be positive, the model would generate *increasing* returns to scale ($a + b + c > 1$). On the other hand, if one assumes *constant* returns to scale ($a + b + c = 1$), then labor and private capital must be paid more than their marginal products (i.e., $a + b < 1$). That would be the case when public capital generates indirect income for labor and private capital, even though it is not paid directly for its services. In this paper, the model is estimated without any restrictions on the coefficients a, b, and c, but they are subsequently tested.

B. Extended Model

The extended model is the same as the standard model, except that it allows for a diminishing elasticity of public capital as a function of the initial stock of public capital (in percent of GDP). The motivation for this control variable is the potential non-linearities in the productivity of public capital. For example, if public investment is financed by capital taxes, a higher public investment would reduce after-tax profits for investors and curtail their incentive to invest. At some point, the disincentive effect from higher taxes would exceed the productivity gains from higher public investment, and the net impact on growth would become negative (Barro 1990). Furthermore, the marginal productivity of public capital could decline due to inefficiencies in the capital spending process and due to difficulties in finding investment projects with high returns.

To capture this relationship, we extend the standard model by adding an interaction on the right hand side of the equation. In particular:

$$\Delta \text{InY} = \text{constant} + a\ \Delta \ln L + b\ \Delta \ln K + c\ \Delta \ln G + d \ln G * (G/Y)$$

The interaction term implies that the production elasticity of public capital is no longer just c, but is equal to ($c + d\ G/Y$). This implies that the productivity of public capital can vary according to its initial level. The coefficient on the interaction term, d, is expected to be negative, while the coefficient c is expected to remain positive.

III. Data

A. Construction of the Dataset

The dataset includes public and private capital stock series for 48 countries from 1960 to 2001. Table 1 lists the countries in the sample. The data for 22 OECD countries is from Kamps (2006).[6] We construct public and private capital stock data for the other 26 non-OECD countries[7] using the same methodology for OECD countries. The estimation is based on internationally comparable total investment series from Penn World Tables (Heston,

[6] The underlying investment data used in Kamps (2006) are from the OECD Analytical Database, Version 2002 and available for 1960-2001.

[7] The countries referred to as "non-OECD" include the countries not covered in Kamps (2006).

Summers, Aten 2006) and public and private investment series from the World Economic Outlook database (IMF, April 2009).[8]

Table 1. List of Countries in the Sample

OECD	Non-OECD (Middle-income)	Non-OECD (Lower-income)
Australia	Argentina	Bangladesh
Austria	Brazil	Bolivia
Belgium	Colombia	Egypt
Canada	Dominican Republic	Guatemala
Denmark	Malaysia	Honduras
Finland	Mexico	India
France	Panama	Jordan
Germany	Peru	Kenya
Greece	South Africa	Morocco
Iceland	Thailand	Pakistan
Ireland	Tunisia	Paraguay
Italy	Turkey	Senegal
Japan	Uruguay	Swaziland
Netherlands		
New Zealand		
Norway		
Portugal		
Spain		
Sweden		
Switzerland		
United Kingdom		
United States		

Note: Middle income non-OECD countries have per capita income of more than $3,700 in 2000 prices. Lower income non-OECD countries have per capita income of less than $3,700 in 2000 prices.

The Penn World Table (PWT) is one of the most widely used sources for cross-country growth studies. It provides data on internationally comparable output and investment series for a broad group of countries. The data are based on national accounts and adjusted for purchasing power parity (PPP) to make them internationally comparable.[9] PWT also assigns grades to countries from A to D based on the quality and consistency of their data over time. Countries with a grade of D are excluded from the sample.

[8] The public and private capital stock estimates for the non-OECD countries in this paper are available for download at http://www.imf.org/external/pubind.htm.

[9] The output and investment series are in constant (2000) international prices. For investment, we use total gross domestic investment in 2000 international prices (PWT code: KI).

One drawback of PWT is that it does not provide a breakdown of investment into its public and private components. For that, we turn to the World Economic Outlook (WEO) database (IMF 2009), which provides disaggregated data on public and private investment.[10] We use the share of public and private investment in total investment to split the PWT investment series into public and private components.

Based on the disaggregated PWT investment series, the public and private capital stocks are estimated using the *perpetual inventory method* employed by Kamps (2006) for OECD countries. First, the initial capital stock is set to zero for all countries in 1860. Second, a hypothetical investment series is constructed between 1860 and 1960 based on a 4 percent growth rate for investment during 1860–1960 to calculate the capital stock in 1960. Lastly, the investment series for 1960–2000 are accumulated to construct the capital stock series for 1960–2001.

B. Depreciation Rates

The net capital stock accounts for the wear and tear of an asset (i.e., depreciation), thus it excludes assets that are no longer used in production. The choice of depreciation rates present perhaps the biggest challenge in the construction of the capital stock estimates because country specific estimates of depreciation rates are typically not available, with the U.S. being an important exception. According to the Bureau of Economic Analysis, estimated depreciation rates for public capital in the U.S. were about 2.5 percent in 1960 and increased to 4 percent in 2001 (and from 4.25 to 8.5 percent for private capital, respectively). Kamps (2006) uses these U.S. depreciation rates to construct the capital stock estimates for other OECD countries.

Different depreciation assumptions may be more appropriate for non-OECD countries, given differences in the types of assets they hold. The composition of underlying assets affects the average depreciation rate of the aggregated stock because different types of assets have different life spans. For instance, concrete structures are typically estimated to have longer lifetime (e.g., 80–100 years), while assets related to IT tend to have much shorter life span (e.g., a few years). As countries become richer, the share of assets with shorter life span rises, thereby raising the overall depreciation rate.

The rising depreciation rates in OECD countries reflect the growing importance of high technology assets in their public capital. In contrast, non-OECD countries with relatively lower share of technological assets and more "traditional" physical infrastructure in their public capital are more likely to have lower depreciation rates, as the average life span of those assets is higher. Arestoff and Hurlin (2006) find that this is in fact the case for a number of developing countries.[11]

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[10] We use the series gross public fixed capital formation, current prices (WEO code: NFIG) and gross private fixed capital formation, current prices (WEO code: NFIP).

[11] Arestoff and Hurlin (2006) estimate depreciation rates based on six components of public investment(roads, railways, electricity, gas, water and telecom).

Table 2 shows the depreciation rates for public and private capital assumed for constructing the capital stock for non-OECD countries. For middle-income countries, we use a time-varying profile for public and private capital with a flatter slope than the one used for OECD countries. For low-income countries, we hold the depreciation rate constant over time.

Table 2. Depreciation Rates
(In percent)

	1860	1960	2001
Public capital			
OECD	2.50	2.50	4.00
Non-OECD (middle-income)	2.50	2.50	3.25
Non-OECD (low-income)	2.50	2.50	2.50
Private capital			
OECD	4.25	4.25	8.50
Non-OECD (middle-income)	4.25	4.25	7.00
Non-OECD (low-income)	4.25	4.25	4.25

C. Caveats

Our capital stock dataset is novel in several ways: It includes both OECD and non-OECD countries, differentiates between public and private capital, and applies time- and income-level varying depreciation rates to capture the nature of the underlying public and private assets. Previous studies, such as by Nehru and Dhareshwar (1993) and Marquetti and Foley (2008), have estimated the capital stock of non-OECD countries but have not made a distinction between public and private capital. On the other hand, Collier, Hoeffler and Pattillo (2001) have estimated the public capital stock for 22 sub-Saharan African countries, but assuming constant depreciation rates. Finally, Arestoff and Hurlin (2006) have estimated the public capital stock for a group of non-OECD countries using infrastructure specific depreciation rates, but not the private capital stock. Our dataset includes both public *and* private capital stock data, which are necessary to estimate production functions, and covers countries with different income groups from all five continents.

However, some caveats are in order:

First, investments in public capital may not always be productive (Pritchett 1996, Canning 1999, Easterly and Serven 2004). Reasons range from administrative inefficiencies to pork-barrel politics to corruption. This unobservable factor could cause public capital in some countries to be overestimated. While this is clearly an important issue, the estimated elasticity of output with respect to public capital should reflect this spending inefficiency. All else being equal, a country with a lower spending efficiency and overstated capital stock would have a lower elasticity of output with respect to public capital.

Second, non-OECD countries tend to spend less on operations and maintenance, which could cause depreciation rates to be *higher* in non-OECD countries compared to OECD countries.

On the other hand, as mentioned above, non-OECD countries tend to have a lower share of high-technology assets, which would make depreciation rates *lower* in non-OECD countries. While the net effect is unknown, we address this issue by conducting a sensitivity analysis using different depreciation rates (Section V).

Third, there may be differences in the way countries classify their investments as public or private, given the presence of public-private partnerships and the treatment of quasi-public enterprises in the national accounts. We do not address this issue in the paper, but note that this problem is common to all studies on the subject, regardless of whether they use public investment or public capital as the explanatory variable.

Finally, by applying the same depreciation rate to a group of countries, the approach disregards natural disasters and other *Force Majeure* events that may impact the capital stock of any particular country.

IV. RESULTS

A. Descriptive Statistics

Table 3 provides the average real GDP growth, public investment rate, and the public capital stock growth for each income group during 1960–2000.[12] It shows that the average GDP growth for the OECD countries was 3.4 percent during this period. For the average non-OECD countries, the growth rates were higher at 4.4 percent, suggesting that some catching-up took place during this period.

Table 3. GDP Growth, Public Investment and Public Capital Stock Growth, 1960–2000

	OECD	Non-OECD
Real GDP growth	3.4 (0.7)	4.4 (1.3)
Public investment (percent of GDP)	3.6 (1.2)	3.9 (1.7)
Public capital stock growth	3.3 (1)	5.7 (2.3)

Source: Authors' calculations. Standard deviations in paranthesis.

The difference in public investment rates between OECD and non-OECD countries was relatively small during 1960–2000 (3.6 versus 3.9 percent of GDP). This contrasts with the difference in public capital growth, which was much higher—almost twice as much—in non-OECD countries (5.7 versus 3.3 percent).

[12] The growth rate for each country, ΔYi, is calculated as the geometric average growth rate between 1960 and 2000. More specifically, $\Delta Y_i = 1/40\ [\log (Y_{i2000} - Y_{i1960})]$. The average for the income group is calculated as the average of the growth rates for each country in the group.

Figure 1 plots a scatter of real GDP growth, public investment, and public capital growth in sample countries during 1960–2000. It shows that public capital growth is better in explaining the variation in GDP growth than public investment rates. Public investment rates lie in a narrow range, between 2 and 6 percent of GDP for most countries, whereas variation in public capital growth is larger. The public investment rate explains only 12 percent of the cross-country variation in GDP growth, whereas public capital growth explains 51 percent of the variation.

Figure 2 plots the public investment rate and public capital stock (both as a percent of GDP) for the average OECD and non-OECD countries. Note that public investment and public capital follow significantly different paths for each group. For example, public investment in the average OECD country started declining in the 1970s, whereas public capital was still increasing until the mid-1980s. For the average non-OECD country, both public investment and public capital stock "peaked" in the mid-1980 and since then has been on a declining trend.

Figure 2 also shows that the peak level of public capital was found in non-OECD countries. This is explained by the higher public investment rates in these countries (4 percent of GDP), compared to OECD countries (around 3½ percent of GDP), during this period. Finally, Figure 2 shows the relationship between public capital and GDP growth. During the "pre-peak" years, the average real GDP growth was consistently high for OECD and non-OECD countries. In fact, Table 4 shows that real GDP growth was about one percentage point higher for both OECD and non-OECD countries in the pre-peak period when public capital stock was still increasing as a percent of GDP.

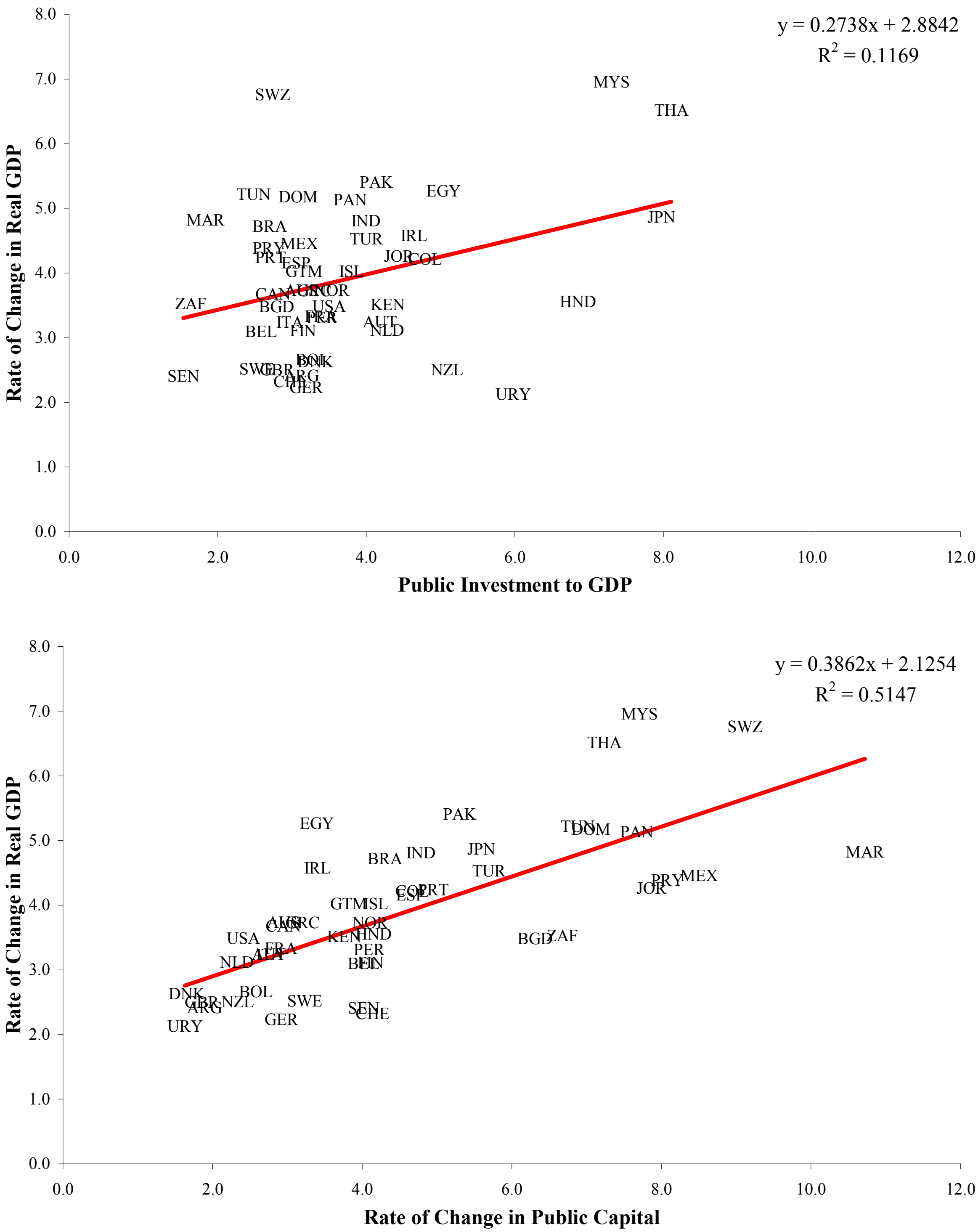
Table 4. Average Real GDP Growth Before and After Public Capital Stock

	Before the peak	After the peak
OECD	3.8 (1.8)	2.8 (1.1)
Non-OECD	4.8 (1.5)	3.7 (1.1)

Source: Authors' calculations. Standard deviations in paranthesis.

Note: Public capital stock (as a percent of GDP) peaked in 1983 for the average OECD country and in 1985 for the average non-OECD country. The peak level was 60 percent of GDP for the average OECD country, 62 percent of GDP for the average non-OECD country.

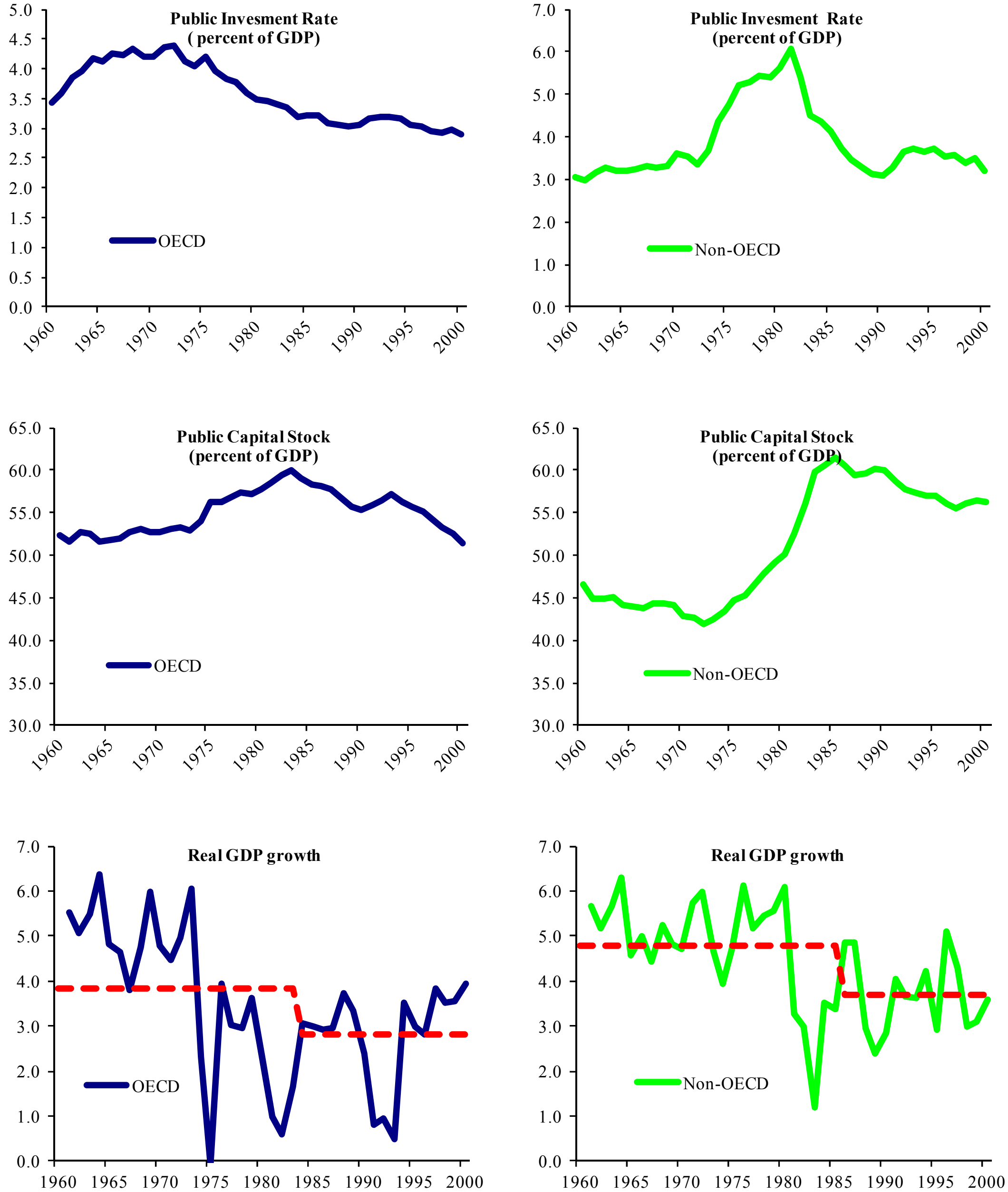
Figure 1. Long-Term Real GDP Growth, Public Investment and Public Capital Growth Rates, 1960–2000



Sources: PWT (Version 6.2), Kamps (2006), Authors' calculations.

Figure 2. Public Investment, Public Capital Stock and Real GDP Growth for OECD and non-OECD Countries, 1960–2000

(percent of GDP and annual percentage change)



Source: PWT (Version 6.2), Kamps (2006), Authors' calculations.
The red dotted lines indicate the average real GDP growth before and after the year in which the public capital stock peaked for each income group. Public capital stock (as a percent of GDP) peaked in 1983 for the average OECD country and in 1985 for the average non-OECD country. The peak levels were 60 percent of GDP for the average OECD country and 61percent of GDP for non-OECD countries.

B. Regression Results

We first examine the question whether regressions should be run in levels or differences. Table 5 shows that the variables of interest for non-OECD countries are stationary when expressed in first differences, extending a previous finding for OECD countries (Kamps 2006). We do not find any relationship between the variables in levels that would point to a common cointegrating relationship in the panel, neither for the combined dataset nor for non-OECD and OECD countries separately.[13] We thus proceed to estimate the equation in differences to obtain consistent estimates of the coefficients.

Table 5. Panel Unit Toot Tests for Non-OECD Countries

Variable	Deterministic	IPS (t-value)	LLC (t-value)	Result
ln GDP	constant	1.29	-1.07	at least I(1)
	trend	-0.80	-1.96	at least I(1)
ln L	constant	-0.08	-1.77	at least I(1)
	trend	-3.97	-7.14	I(0)
ln K	constant	1.79	-1.36	at least I(1)
	trend	-0.11	-2.93	at least I(1)
ln G	constant	-2.81	-5.40	I(0)
	trend	-1.14	-6.32	inconclusive
IG/GDP	constant	-3.22	-4.31	I(0)
	trend	-1.20	-1.05	at least I(1)
G / GDP	constant	-1.38	-5.27	inconclusive
	trend	-2.91	-4.36	I(0)
Δ ln GDP	constant	-10.52	-9.78	I(0)
Δ ln L	constant	-0.97	-2.34	I(0)
Δ ln K	constant	-3.04	-3.00	I(0)
Δ ln G	constant	-2.97	-3.14	I(0)
Δ (IG/GDP)	constant	-15.98	-13.49	I(0)
Δ G / GDP	constant	-6.03	-6.00	I(0)

Source: Authors' calculations. IPS and LLC columns report the Im, Pesaran and Shin (2003) and the Levin, Lin and Chu (2002) corrected t-value of the lagged variable, which is normally distributed under the null hypothesis of nonstationarity. One lagged difference included. Panel unit root tests for OECD countries are conducted by Kamps (2006).

Table 6, 7, and 8 provide the main results of the paper. The OLS panel regressions include fixed effects. These are better at capturing cross-country differences in technological growth, human capital accumulation, and any other factor affecting total factor productivity, which are reflected in the intercept term ($\ln\tilde{A}$). This is confirmed by Hausman tests on alternative random effect specifications. Table 6 shows results for the combined OECD and non-OECD

[13] We test for common panel cointegration using a two step approach and residual based panel (non)stationarity tests. We focus on a common cointegrating relation because we are interested in exploiting the cross section information in the panel, reflecting the common set of assumptions underlying the capital stock estimate. While country specific cointegrating relations between the variables may exist—possibly including additional country specific variables —we do not identify them as we are interested in a cross country validation of the model, and therefore use a first difference representation of the model.

dataset; Tables 7 and 8 provide separate results. The results are presented for three models: naive, standard and extended. We also present three different time intervals in the analysis, namely one year, five years, and ten years.[14]

One reason for analyzing different time intervals is the existence of both long and short-term effects of public capital accumulation on growth that may not be captured well in annual data. For example, some public investments may take more than a year to complete and, in addition, the payoff may accrue over a longer time horizon. The longer time horizons, especially the five-year interval, may be better suited to capture the indivisibility of investment and lags in its effectiveness.

Naive model

The naive model uses the public investment rate (IG/GDP) instead of public capital growth ($\Delta \ln G$) in the standard model.[15] As expected, we do not find any statistically significant relationship between the public investment rate and GDP growth for the combined dataset and for the non-OECD countries. For the OECD, the coefficient is significant but negative only in the five-year interval specification.

Non-zero depreciation rates imply that the same gross investment can lead to very different rates of net capital accumulation. For example, in our sample of non-OECD countries, countries with a low public capital stock (30 percent of GDP, the 25th percentile) on average lose public capital worth around one percent of GDP annually due to depreciation, whereas those with a high stock of public capital (70 percent of GDP, the 75th percentile) lose more than double that amount, close to two percent of GDP. Consequently, a gross investment rate of 7 percent of GDP (Growth Commission report, 2008) would translate into net investment rates between 5 and 6 percent of GDP, different paths of capital accumulation, and different growth effects. Another way of making the same point is as follows: a 7 percent of GDP *gross* investment rate implies a public capital accumulation rate of 20 percent if the initial stock is 30 percent of GDP, while it implies an accumulation rate of only 7 percent, if the initial stock is 70 percent of GDP. This shows that there could be large differences between the public investment rate and the rate of change in the public capital stock depending on the initial capital stock.

Standard model

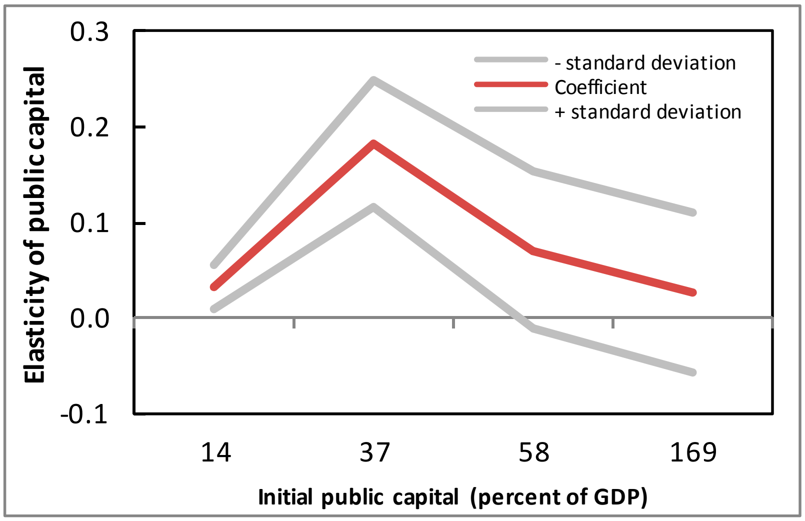
In the combined OECD and non-OECD panel dataset (Table 6) the standard model produces plausible and statistically significant results in the one-year specification, with a public capital stock coefficient of 0.05. Coefficients for L and K are significant and positive in all specifications. When varying the coefficient for G with the distribution of public capital

[14] When moving to the five and ten-year intervals, we redefine Y and L as flows over a five or ten-year period, while K, and G are defined as the stock at the beginning of these periods.

[15] Arithmetically, the growth rate of public capital ($\triangle G/G$) is equal to the investment rate ($\triangle G/Y$) divided by the capital stock in percent of GDP (G/Y) if the depreciation rate is zero.

stock (by multiplying with quartile dummy variables), a concave pattern emerges with respect to the elasticity of public capital, indicating a maximum impact of additional public capital (growth elasticity of 0.2) when the public capital stock is between 15 and 60 percent of GDP (Figure 3). For very high levels of public capital, the coefficient loses statistical significance. We now proceed to estimate separate models for OECD and non-OECD countries.

Figure 3. Standard Model with Varying Coefficients of Public Capital



Source: Authors' calculations.

For OECD countries alone, we also find a positive and statistically significant relationship between public capital and output for OECD in the one-year interval specification. The coefficients for L, K, and G have values that are consistent with those found in the literature. Public capital is significant with a coefficient of 0.13, and the coefficients attached to labor and private capital are also significant and in the plausible range. When moving to five and ten-year time intervals, the coefficient on private capital is the only one to remain significant, and the estimate increases to 0.5. At the same time, the fit of the model improves when moving to higher time intervals, a feature that cannot be related to the literature since earlier studies do not report measures of fit.

For non-OECD countries, the standard model has a poor fit in the one-year interval specification, but the fit improves significantly when moving to the five and ten-year interval. While public capital remains insignificant in most specifications, private capital and labor are highly significant and the estimated coefficients increase with time intervals. In the five-year interval the coefficient on labor is estimated to be 0.5, whereas that on private capital is 0.2, in line with the one-year interval estimate obtained for OECD countries.

Extended model

The extended model produces estimates that are statistically more significant than those produced by the standard model, while the fit of the model also improves. For non-OECD countries, the coefficient on public capital, c, becomes statistically significant, while the coefficient on the interaction term, d, is negative, as expected.

For OECD countries, the coefficient c is estimated to be 0.13 (using one-year interval), however, when moving to higher time intervals—just as in the standard model—the coefficients for public capital lose significance. For example, in the five-year interval the estimated coefficient for public capital in OECD countries is smaller (0.08) and not significant. The interaction variable d—that captures non-linearities—is not significant in the case of OECD countries.

For non-OECD countries, the coefficient c on public capital averages 0.2 and is significant in all specifications. Its value and significance increases with the length of time interval, from 0.12 in the one-year specification to 0.26 in the ten-year specification. The coefficient d attached to the interaction term is negative and significant in all specifications, and averages -0.5. This suggests that in some instances, a significant scaling up of investment may not yield positive returns, depending on the size of the existing public capital stock. Evaluated at the 25 percentile of public capital stock for non-OECD countries (public capital is around 30 percent of GDP), the marginal effect of additional public capital is positive (0.1), the effect eventually reduces to zero around the 50^{th} percentile (public capital is 50 percent of GDP), before turning slightly negative, reaching -0.06 at the 75^{th} percentile (public capital is 70 percent of GDP).

Finally, the fit of the model improves as one moves from one-year to five and ten-year intervals. This indicates that in non-OECD countries, capital spending impacts growth over a period of time in reflection of indivisibility of investments.

In summary, once we enter the interaction term in the standard model, we find the following: (i) the fit of the regressions improve; (ii) the impact of public capital on growth becomes positive also for non-OECD countries; (iii) a negative relationship between growth and the level of public capital is uncovered, in particular for non-OECD countries. These results are robust to a variety of alternative specifications and to inclusion and exclusion of outliers.[16]

The results suggest that some non-OECD countries may not absorb a large scaling up of capital investment, reflecting implementation weaknesses, and that weak absorptive capacity should be taken into account in setting borrowing limits for non-concessional loans. Furthermore, from a policy perspective, the results also suggest that public investment can be used to boost aggregate demand in OECD countries, while it can boost aggregate supply in non-OECD countries.

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[16] We also estimated specifications in which we scaled the capital stock to the population (G/L), and modeled the diminishing returns by including a quadratic term of the public capital variable. In each of these cases, the concave curvature of the elasticity of public capital was confirmed, with sample extreme points very similar to the ones presented.

Table 6. Regression Results for All Countries

Regression Results for OECD and Non OECD Countries Dependent variable: Δln GDP			
	Naive model	Standard model	Standard model (interacted)
		(1 year intervals)	
Δln L	0.213*	0.219*	0.216*
	(0.128)	(0.127)	(0.127)
Δln K	0.204***	0.176***	0.169***
	(0.041)	(0.043)	(0.043)
IG/GDP	0.018		
	(0.035)		
Δln G		0.049**	
		(0.022)	
Δln G [1st quartile]			0.032
			(1.342)
Δln G [2nd quartile]			0.183***
			(2.769)
Δln G [3rd quartile]			0.072
			(0.866)
Δln G [4th quartile]			0.028
			(0.336)
Countries	44	44	44
Observations	1782	1782	1782
R-squared (within)	0.02	0.02	0.02
R-squared (between)	0.47	0.52	0.50
Hausman test (p-val)	0.13	0.03	0.00
Δln K=Δln G (p-val) 1/		0.02	0.87
Δln L+Δln K+Δln G=1 (p-val) 1/		0.00	0.00
		(3 year intervals)	
Δln L	0.285	0.327	0.337
	(0.213)	(0.214)	(0.214)
Δln K	0.366***	0.273**	0.258***
	(0.082)	(0.108)	(0.109)
IG/GDP	-0.016*		
	(0.008)		
Δln G		0.076	-0.096
		(0.084)	(0.176)
Δ ln G * (G/GDP)			0.868
			(0.781)
Countries	22	22	22
Observations	282	282	282
R-squared (within)	0.10	0.09	0.09
R-squared (between)	0.10	0.64	0.13
Hausman test (p-val)	0.06	0.08	0.06
Δln K=Δln G (p-val)	…	0.26	0.28
Δln L+Δln K+Δln G=1 (p-val)	…	0.12	0.15

Table 6. Regression Results for All Countries (concluded)

Regression Results for OECD and Non OECD Countries
Dependent variable: Δln GDP

	Naive model	Standard model	Standard model (interacted)
		(5 years intervals)	
Δln L	0.357**	0.337**	0.334**
	(0.164)	(0.163)	(0.165)
Δln K	0.278***	0.249***	0.266***
	(0.056)	(0.058)	(0.059)
IG/GDP	-0.020		
	(0.201)		
Δ ln G		0.040	
		(0.028)	
Δln G [1st quartile]			0.036
			(1.177)
Δln G [2nd quartile]			0.215**
			(2.301)
Δln G [3rd quartile]			-0.093
			(-0.953)
Δln G [4th quartile]			-0.010
			(-0.095)
Countries	44	44	44
Observations	347	347	347
R-squared (within)	0.10	0.11	0.13
R-squared (between)	0.50	0.52	0.41
Hausman test (p-val)	0.13	0.03	0.06
Δln K=Δln G (p-val) 1/		0.00	0.65
Δln L+Δln K+Δln G=1 (p-val) 1/		0.02	0.32
		(10 year intervals)	
Δln L	0.957***	0.897***	0.874***
	(0.185)	(0.192)	(0.197)
Δln K	0.238***	0.201**	0.190**
	(0.080)	(0.083)	(0.085)
IG/GDP	-0.109		
	(0.462)		
Δ ln G		0.042	
		(0.040)	
Δln G [1st quartile]			0.032
			(0.744)
Δln G [2nd quartile]			0.099
			(0.854)
Δln G [3rd quartile]			0.098
			(0.703)
Δln G [4th quartile]			0.076
			(0.524)
Countries	173	173	173
Observations	44	44	44
R-squared (within)	0.26	0.27	0.27
R-squared (between)	0.40	0.41	0.44
Hausman test (p-val)	0.13	0.03	0.03
Δln K=Δln G (p-val) 1/		0.13	0.57
Δln L+Δln K+Δln G=1 (p-val) 1/		0.46	0.44

Note: Standard errors in parenthesis, statistical significance at the 10, 5 and 1 percent levels denoted by *, ** and *** respectively. Hausman test indicates p-value of the null hypothesis that the difference in estimated coefficients between the fixed effect and a random effects specification (not reported) is not systematic. L: Labor; K: Private Capital Stock; IG/GDP: Public Investment to GDP ratio; G: Public Capital Stock.

1/ In extended model, coefficient of the second quartile.

Table 7. Regression Results for OECD Countries

Regression Results for OECD Countries (different time intervals) Dependent variable: ΔIn GDP			
	Naive model	Standard model	Extended model
		(1 year intervals)	
ΔIn L	0.392**	0.391**	0.392**
	(0.164)	(0.164)	(0.164)
ΔIn K	0.365***	0.253***	0.255***
	(0.065)	(0.082)	(0.082)
IG/GDP	-0.002		
	(0.002)		
ΔIn G		0.129**	0.132**
		(0.064)	(0.065)
Δ In G * (G/GDP)			-0.000
			(0.002)
Countries	22	22	22
Observations	892	892	892
R-squared (within)	0.05	0.06	0.06
R-squared (between)	0.03	0.63	0.61
Hausman test (p-val)	0.25	0.02	0.02
ΔIn K=ΔIn G (p-val)	…	0.34	0.35
ΔIn L+ΔIn K+ΔIn G=1 (p-val)	…	0.16	0.17
		(5 years intervals)	
ΔIn L	0.140	0.192	0.173
	(0.225)	(0.227)	(0.227)
ΔIn K	0.499***	0.401***	0.422***
	(0.087)	(0.118)	(0.118)
IG/GDP	-0.038**		
	(0.016)		
Δ In G		0.064	0.084
		(0.089)	(0.090)
Δ In G * (G/GDP)			-0.003
			(0.002)
Countries	22	22	22
Observations	174	174	174
R-squared (within)	0.22	0.20	0.21
R-squared (between)	0.09	0.68	0.10
Hausman test (p-val)	0.08	0.38	0.17
ΔIn K=ΔIn G (p-val)	…	0.08	0.08
ΔIn L+ΔIn K+ΔIn G=1 (p-val)	…	0.11	0.14
		(10 year intervals)	
ΔIn L	0.248	0.317	0.265
	(0.309)	(0.312)	(0.310)
ΔIn K	0.573***	0.496***	0.531***
	(0.119)	(0.163)	(0.162)
IG/GDP	-0.082		
	(0.051)		
Δ In G		0.045	0.065
		(0.116)	(0.116)
Δ In G * (G/GDP)			-0.004
			(0.002)
Countries	22	22	22
Observations	87	87	87
R-squared (within)	0.40	0.37	0.40
R-squared (between)	0.04	0.62	0.12
Hausman test (p-val)	0.48	0.86	0.51
ΔIn K=ΔIn G (p-val)	…	0.08	0.07
ΔIn L+ΔIn K+ΔIn G=1 (p-val)	…	0.60	0.60

Note: Standard errors in parenthesis, statistical significance at the 10, 5 and 1 percent levels denoted by *, ** and *** respectively. Hausman test indicates p-value of the null hypothesis that the difference in estimated coefficients between the fixed effect and a random effects specification (not reported) is not systematic. L: Labor; K: Private Capital Stock; IG/GDP: Public Investment to GDP ratio; G: Public Capital Stock.

Table 8. Regression Results for Non-OECD Countries

Regression Results for Non-OECD Countries (different time intervals)
Dependent variable: Δln GDP

	Naive model	Standard model	Extended model
		(1 year intervals)	
Δln L	0.224	0.221	0.206
	(0.174)	(0.174)	(0.173)
Δln K	0.170***	0.150***	0.143***
	(0.052)	(0.054)	(0.054)
IG/GDP	-0.001		
	(0.067)		
Δ ln G		0.034	0.123***
		(0.025)	(0.035)
Δ ln G * (G/GDP)			-0.342***
			(0.095)
Countries	26	26	26
Observations	1043	1043	1043
R-squared (within)	0.01	0.01	0.03
R-squared (between)	0.25	0.34	0.08
Hausman test (p-val)	0.61	0.02	0.00
Δln K=Δln G (p-val)	…	0.08	0.77
Δln L+Δln K+Δln G=1 (p-val)	…	0.00	0.00
		(5 years intervals)	
Δln L	0.511**	0.491**	0.435**
	(0.223)	(0.224)	(0.214)
Δln K	0.251***	0.235***	0.168**
	(0.071)	(0.073)	(0.071)
IG/GDP	-0.077		
	(0.370)		
Δ ln G		0.021	0.183***
		(0.032)	(0.049)
Δ ln G * (G/GDP)			-0.460***
			(0.109)
Countries	26	26	26
Observations	202	202	202
R-squared (within)	0.10	0.10	0.18
R-squared (between)	0.24	0.28	0.08
Hausman test (p-val)	0.80	0.14	0.10
Δln K=Δln G (p-val)	…	0.02	0.89
Δln L+Δln K+Δln G=1 (p-val)	…	0.27	0.33
		(10 year intervals)	
Δln L	1.189***	1.123***	0.984***
	(0.227)	(0.242)	(0.211)
Δln K	0.163	0.134	0.030
	(0.104)	(0.108)	(0.096)
IG/GDP	-0.032		
	(0.799)		
Δ ln G		0.036	0.256***
		(0.046)	(0.060)
Δ ln G * (G/GDP)			-0.644***
			(0.129)
Countries	26	26	26
Observations	100	100	100
R-squared (within)	0.31	0.32	0.44
R-squared (between)	0.16	0.18	0.21
Hausman test (p-val)	0.05	0.01	0.00
Δln K=Δln G (p-val)	…	0.46	0.64
Δln L+Δln K+Δln G=1 (p-val)	…	0.24	0.58

Note: Standard errors in parenthesis, statistical significance at the 10, 5 and 1 percent levels denoted by *, ** and *** respectively. Hausman test indicates p-value of the null hypothesis that the difference in estimated coefficients between the fixed effect and a random effects specification (not reported) is not systematic. L: Labor; K: Private Capital Stock; IG/GDP: Public Investment to GDP ratio; G: Public Capital Stock.

C. Post Estimation Tests

First, even after controlling for non-linearities, non-OECD countries have a slightly lower coefficient for public capital than OECD countries (0.123 versus 0.132) in the one-year specification. All else being equal, this could be attributed to lower spending efficiency in non-OECD countries. However, the difference is not statistically significant.

Second, private capital has a higher coefficient than public capital in all models for both OECD and non-OECD countries. This is consistent with other studies that find private investment to be more productive than public investment (Khan and Kumar 1997). However, the difference is not significant for OECD countries and is significant only in non-OECD countries when using the standard model.

Third, the estimation results with one year intervals for OECD countries (standard model) yield elasticities of output with respect to public capital of 0.13, private capital of 0.25, and labor input of 0.39. Therefore, one cannot reject the null hypothesis that the production function has constant returns to scale (a+b+c=1). The estimation results for non-OECD countries (extended model, one year interval) are also reasonable with elasticities of output with respect to public capital of 0.12, private capital of 0.14, and labor input of 0.20 (all coefficients are significant at the 5 percent level, except for labor). However, one can reject the null hypothesis that the production function in non-OECD countries displays constant returns to scale in the one year interval. Results for non-OECD countries differ slightly if five-year intervals are considered. In this case, in line with results for OECD countries, the null hypothesis of constant returns to scale cannot be rejected, and the estimated coefficients move somewhat closer to the findings for OECD countries.

Finally, we ran Hausman tests, finding that the random effect specification is rejected in most cases.

V. Alternative Depreciation Rates

We vary the depreciation rates used in the construction of the public capital stock. We run three scenarios. In each scenario, depreciation rates are the same for both OECD and non-OECD countries. In the first scenario, they are *time-varying* and equal to the ones used by Kamps (2006), which increase from 2.5 to 4.0 percent between 1960–2001. In the second scenario, they are *constant* and equal to the *average* rate of 3.25 percent over the same period. In the third scenario, they are *constant* and equal to the *maximum* rate of 4.0 percent.

The results are provided in Tables 9 and 10. Using alternative depreciation rates *does not* change the results significantly. For OECD countries, the estimated coefficient c varies between 0.129 and 0.110 in the standard model, and 0.22 and 0.25 in the extended model. For non-OECD countries, c varies between 0.21 and 0.036 in the standard model and 0.09 to 0.2 in the extended model. More importantly, in all cases, c and d remain statistically significant, despite the use of different depreciation rates.

Table 9. Sensitivity Analysis: Alternative Depreciation Rates for OECD Countries

Regression Results for OECD Countries (different depreciation rates)			
Dependent variable: Δln GDP			
	Naive model	Standard model	Extended model
		(Scenario 1)	
Δln L	0.392**	0.391**	0.392**
	(0.164)	(0.164)	(0.164)
Δln K	0.365***	0.253***	0.255***
	(0.065)	(0.082)	(0.082)
IG/GDP	-0.002		
	(0.002)		
Δln G		0.129**	0.132**
		(0.064)	(0.065)
Δ ln G * (G/GDP)			-0.000
			(0.002)
Countries	22	22	22
Observations	892	892	892
R-squared (within)	0.05	0.06	0.06
R-squared (between)	0.03	0.63	0.61
Hausman test (p-val)	0.25	0.02	0.02
Δln K=Δln G (p-val)	…	0.34	0.35
Δln L+Δln K+Δln G=1 (p-val)	…	0.16	0.17
		(Scenario 2)	
Δln L	0.392**	0.394**	0.388**
	(0.164)	(0.164)	(0.164)
Δln K	0.365***	0.276***	0.285***
	(0.065)	(0.079)	(0.079)
IG/GDP	-0.002		
	(0.002)		
Δ ln G		0.110*	0.131**
		(0.063)	(0.065)
Δ ln G * (G/GDP)			-0.003
			(0.002)
Countries	22	22	22
Observations	892	892	892
R-squared (within)	0.05	0.06	0.06
R-squared (between)	0.03	0.63	0.08
Hausman test (p-val)	0.25	0.02	0.01
Δln K=Δln G (p-val)	…	0.19	0.22
Δln L+Δln K+Δln G=1 (p-val)	…	0.17	0.22
		(Scenario 3)	
Δln L	0.392**	0.394**	0.391**
	(0.164)	(0.164)	(0.164)
Δln K	0.365***	0.267***	0.274***
	(0.065)	(0.079)	(0.079)
IG/GDP	-0.002		
	(0.002)		
Δ ln G		0.115*	0.129**
		(0.059)	(0.060)
Δ ln G * (G/GDP)			-0.002
			(0.002)
Countries	22	22	22
Observations	892	892	892
R-squared (within)	0.05	0.06	0.06
R-squared (between)	0.03	0.63	0.29
Hausman test (p-val)	0.25	0.02	0.01
Δln K=Δln G (p-val)	…	0.22	0.24
Δln L+Δln K+Δln G=1 (p-val)	…	0.16	0.20

Note: Standard errors in parenthesis, statistical significance at the 10, 5 and 1 percent levels denoted by *, ** and *** respectively. Hausman test indicates p-value of the null hypothesis that the difference in estimated coefficients between the fixed effect and a random effects specification (not reported) is not systematic. L: Labor; K: Private Capital Stock; IG/GDP: Public Investment to GDP ratio; G: Public Capital Stock. Scenaro 1: Time-varying Kamps depreciation rates for public capital from 2.5 to 4.0 percent; Scenaro 2: Constant depreciation rate at 3.25 percent; Scenaro 3: Constant depreciation rate at 4.0 percent.

Table 10. Sensitivity Analysis: Alternative Depreciation Rates for Non-OECD Countries

Regression Results for Non-OECD Countries (different depreciation rates)			
	Dependent variable: Δln GDP		
	Naive model	Standard model	Extended model
		(Scenario 1)	
Δln L	0.224	0.221	0.206
	(0.174)	(0.174)	(0.173)
Δln K	0.170***	0.150***	0.143***
	(0.052)	(0.054)	(0.054)
IG/GDP	-0.001		
	(0.067)		
Δln G		0.034	0.123***
		(0.025)	(0.035)
Δ ln G * (G/GDP)			-0.342***
			(0.095)
Countries	26	26	26
Observations	1043	1043	1043
R-squared (within)	0.01	0.01	0.03
R-squared (between)	0.25	0.34	0.08
Hausman test (p-val)	0.61	0.02	0.00
Δln K=Δln G (p-val)	…	0.08	0.77
Δln L+Δln K+Δln G=1 (p-val)	…	0.00	0.00
		(Scenario 2)	
Δln L	0.224	0.222	0.201
	(0.174)	(0.173)	(0.173)
Δln K	0.170***	0.148***	0.143***
	(0.052)	(0.054)	(0.054)
IG/GDP	-0.001		
	(0.067)		
Δ ln G		0.037	0.116***
		(0.025)	(0.035)
Δ ln G * (G/GDP)			-0.301***
			(0.096)
Countries	26	26	26
Observations	1043	1043	1043
R-squared (within)	0.01	0.01	0.02
R-squared (between)	0.25	0.35	0.11
Hausman test (p-val)	0.61	0.02	0.00
Δln K=Δln G (p-val)	…	0.09	0.70
Δln L+Δln K+Δln G=1 (p-val)	…	0.00	0.00
		(Scenario 3)	
Δln L	0.224	0.224	0.204
	(0.174)	(0.173)	(0.173)
Δln K	0.170***	0.145***	0.143***
	(0.052)	(0.054)	(0.054)
IG/GDP	-0.001		
	(0.067)		
Δ ln G		0.035	0.102***
		(0.021)	(0.031)
Δ ln G * (G/GDP)			-0.313***
			(0.102)
Countries	26	26	26
Observations	1043	1043	1043
R-squared (within)	0.01	0.01	0.02
R-squared (between)	0.25	0.35	0.12
Hausman test (p-val)	0.61	0.02	0.00
Δln K=Δln G (p-val)	…	0.08	0.55
Δln L+Δln K+Δln G=1 (p-val)	…	0.00	0.00

Note: Standard errors in parenthesis, statistical significance at the 10, 5 and 1 percent levels denoted by *, ** and *** respectively. Hausman test indicates p-value of the null hypothesis that the difference in estimated coefficients between the fixed effect and a random effects specification (not reported) is not systematic. L: Labor; K: Private Capital Stock; IG/GDP: Public Investment to GDP ratio; G: Public Capital Stock. Scenario 1: Time-varying Kamps depreciation rates for public capital from 2.5 to 4.0 percent; Scenaro 2: Constant depreciation rate at 3.25 percent; Scenaro 3: Constant depreciation rate at 4.0 percent.

VI. CONCLUSIONS

This paper revisits the debate on the effect of public investment on growth by estimating a production function for forty-eight OECD and non-OECD countries, using capital stock as the explanatory variable. The results indicate that increases in public capital stock are positively correlated with growth, after controlling for the initial level of public capital. The effect is stronger for OECD countries in the short-term, while it is stronger for non-OECD countries in the long-term. This is in contrast with the mixed results obtained by studies that mainly use the investment rate as the explanatory variable.

In some countries, the positive impact of public capital on output partially or wholly offset if the initial capital stock is high in relation to GDP. However, these considerations do not seem to matter in countries with a relatively low public capital stock. An important by-product of this study is the construction of a public capital stock series for 26 middle- and low-income countries. Such estimates are already available for 22 OECD countries.

A number of policy implications could be drawn from these results. First, while debate on fiscal space has centered on creating room in the budget for higher public investment, the results show that certain types of constraints (financing or the ability to absorb) can limit growth benefits of higher capital stock. Second, developing countries can avail of non-concessional foreign borrowing to finance new investments, provided these resources are invested in projects that have been subjected to a rigorous cost-benefit analysis and hold strong prospects for enhancing future growth. However, unlike OECD countries, the benefits tend to accrue over time. This would necessitate extending the timeframe of debt sustainability frameworks so that they can take into account the positive effects of public investments. Finally, public investment projects included in fiscal stimulus packages for 2009–10 should increase growth, even with lags in their implementation, provided public capital levels are not too high to begin with and the resulting financing costs and high tax rates do not negate the positive benefits of new public investments.

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Appendix Table: Literature Survey

Study	Countries	Sample	Variable / Concept	Specification	Conclusion
Albala-Bertrand & Mamatzakis (2004)	Chile	1960-98	Infrastructure capital stock	Translog production function	Infrastructure capital growth appears to reduce productivity slightly up to 1971. From 1972 onwards, the reverse seems true
Albala-Bertrand (2004)	Chile and Mexico, regions	1950-2000	Infrastructure capital stock	Gap approach using a Leontief production function (with private and public capital as inputs)	In Chile potential output is mostly constrained by shortages of 'normal' capital, in Mexico infrastructure is the binding factor
Boscá et al. (2000)	Spain, regions	1980-93	Infrastructure capital stock	Generalized Leontief	Elasticity is 0.08
Cadot et al. (1999)	France, regions	1985-91	Infrastructure capital stock	Production function combined with policy equation for transport infrastructure	Elasticity is 0.10
Cadot et al. (2002)	France, regions	1985-92	Infrastructure capital stock	Cobb-Douglas production function combined with policy equation for transport infrastructure	Elasticity is 0.08
Calderón & Servén (2002)	101 countries	101 countries	Infrastructure capital stock	Cobb-Douglas production function with different types of infrastructure as separate factor	Elasticity is 0.16
Canaleta et al. (1998)	Spain, regions	1964-91	Infrastructure capital stock	'Flexible' cost function	Public capital reduces private production costs, public and private capital factors are complementary;
Canning & Bennathan (2000)	62 countries	1960-90	Infrastructure capital stock	Cobb-Douglas and translog production function with different types of infrastructure as separate factor	On average, only the low- and middle-income countries benefit from more infrastructure
Canning (1999)	57 countries	1960-90	Infrastructure capital stock	Cobb-Douglas production function with different types of infrastructure as separate factor	Electricity and transportation routes have 'normal' capital's rate of return, telephone above normal
Canning and Pedroni (1999)	Panels of countries with different size	1950-92	Infrastructure capital stock	Tests whether infrastructure has long-run effect on growth based on dynamic error-correction model	Evidence of long-run effects running from infrastructure to growth, but results differ across countries and type of infrastructure.
Cohen and Morrison Paul (2004)	US, states	1982-1996	Infrastructure capital stock	Generalized Leontief	Infrastructure investment reduces own costs and increases cost reducing effect of adjacent states
Fernald (1999)	US, 29 sectors	1953-89	Infrastructure capital stock	Sectoral productivity growth taking network approach.	Roads contribute about 1.4 percent per year to growth before 1973 and about 0.4 percent
Flores de Frutos et al. (1998)	Spain	1964-92 (A)	Infrastructure capital stock	VARMA (first differences log levels)	Transitory increase of public capital growth implies a permanent increase of output, private capital and employment
Holtz-Eakin & Schwartz (1995)	US states	1971-86	Infrastructure capital stock	Neo-classical growth model that separates adjustment effects from steady state effects	Infrastructure has a negligible effect on output nowadays
Kemmerling & Stephan (2002)	87 large German cities	1980, 1986 and 1988	Infrastructure capital stock	Cobb-Douglas production function combined with policy equation for transport infrastructure and investment function for private capital	Rate of return on infrastructure is 16%. Political color is important determinant for receiving grants
Mamatzakis (1999a)	Two digit Greek industries (20)	1959-90	Infrastructure capital stock	Translog cost function	Cost elasticity of public infrastructure ranges from 0.02% in food manufacturing to 0.78% in wood and

Appendix Table: Literature Survey (continued)

Study	Countries	Sample	Variable / Concept	Specification	Conclusion
Moreno et al. (2003)	Spain, regions and sectors	1980–91	Infrastructure capital stock	Translog cost function	Public and private investments increase efficiency.
Pereira & Roca Sagales (2003)	Spain (regional and national)	1970-95 (A)	Infrastructure capital stock	VAR, first differences log levels	Positive and significant long-run effects on output, employment, and private capital
Stephan (2000)	West-German and French regions	Germany: 1970-95, France: 1978-92	Infrastructure capital stock	Cobb-Douglas production function with public capital as separate factor and translog production function	Cobb Douglas gives elasticity of 0.11. Translog specification runs into multicolinearity problems.
Stephan (2003)	West-German regions (11)	1970-96	Infrastructure capital stock	Cobb-Douglas production function with public capital as separate factor	Elasticity between 0.38 (first differences) and 0.65 (log levels)
Vijverberg et al. (1997)	US, time series	1958-89	Infrastructure capital stock	Cobb-Douglas and semi-translog	Result are not reliable due to multicollinearity
Vijverberg et al. (1997)	US	1958-89	Infrastructure capital stock	Translog cost and profit functions	Both cost and profit function estimates suffer from multicollinearity
Batina (1998)	US	1948-93 (A)	Public capital stock	VAR and VECM	Public capital has long-lasting effects on output and vice versa
Bonaglia et al. (2001)	Italy, regions	1970-94	Public capital stock	Cobb-Douglas production function with public capital as separate factor	Elasticity is 0.05 (insignificant) for Italy as a whole, large variation between regions
Bonaglia et al. (2001)	Italy, regions	1970-94	Public capital stock	Cobb-Douglass variable cost function	Inconclusive, no good measure of the social user cost of public capital available
Charlot & Schmitt (1999)	France, regions	1982–93	Public capital stock	Cobb-Douglas and translog production function with public capital as separate factor	Elasticity is 0.3 (Cobb-Douglas), 0.4 (translog), but very sensitive to region and period
Crowder and Himarios (1997)	US	1947-89 (A)	Public capital stock	VECM	Public capital is at the margin slightly more productive or as productive as private capital
Demetriades & Mamuneas (2000)	12 OECD countries	1972-91	Public capital stock	Quadratic cost function	Output elasticity varies from 2.06 (Norway) to 0.36 (UK)
Duggall et al. (1999)	USA, national	1960-89	Public capital stock	Production function, technology index is non-linear function of infrastructure and time trend	Elasticity for infrastructure is 0.27
Everaert (2003)	Belgian regions	1953-96 (A)	Public capital stock	VECM	Output elasticity of public capital is 0.14, which is only a fraction (0.4) of output elasticity of private capital
Ferrara & Marcellino (2000)	Italy, total and per region	1970-94	Public capital stock	Cobb-Douglas production function with physical capital stocks as separate input	Italy: Negative output elasticity in the 1970s, positive in the 1980s and 1990s. Regions: Negative in 'North-West' and 'North-East', positive in 'Centre' and 'South'.
Ferrara & Marcellino (2000)	Italy, total and regions	1970-94	Public capital stock	Cobb-Douglas and generalized Leontief with physical capital stocks as separate input	Public capital is cost increasing over the whole sample (only cost decreasing in the 90's). Suggests over-investment in public capital
Ghali (1998)	Tunesia	1963-93	Public capital stock	VECM	Public investment has a negative effect on growth
Kamps (2006)	22 OECD countries	1960-2001	Public capital stock	Aschauer (1989) model for individual countries and panel	Elasticity is 0.22 in panel, but much higher in time-series models'
Kamps (2004)	22 OECD countries	1960-2001 (A)	Public capital stock	VECM	For majority of countries there is a positive and significant effect on growth
Ligthart (2002)	Portugal	1965-95	Public capital stock	Cobb-Douglas production function, with and without CRS	Positive and significant output effects of public capital
Ligthart (2002)	Portugal	1965-95 (A)	Public capital stock	VAR (log levels)	Positive output effects of public capital
Mamatzakis (1999b)	Greece	1959-93	Public capital stock	VECM	Positive effect of public capital on productivity, no reverse effect

Appendix Table: Literature Survey (concluded)

Study	Countries	Sample	Variable / Concept	Specification	Conclusion
Pereira and Flores de Frutos (1999)	US	1956-89 (A)	Public capital stock	VAR, first differences log levels	Public capital is productive, but substantially less than suggested by Aschauer (1989)
Seung & Kraybill (2001)	Ohio	Calibrated on 1990	Public capital stock	Computable general equilibrium model with congestion adjusted infrastructure as third factor in Cobb-Douglas production function	Welfare effects of infrastructure are non-linear
Shioji (2001)	US states and Japanese regions	US: 1963-93, 5 year interval, Japan: 1955-95 (5 year interval)	Public capital stock	Computable general equilibrium model with public capital in the technology term of a Cobb-Douglas production function	Elasticity between 0.10 and 0.15
Bose et al (2003)	30 LICs, MICs,	1970-90	Public investment		Significant positive effect
Dessus and Herrera (2000)	29 LICs and MICs	1981-91	Public investment		Significant positive effect
Devarajan et al. (1996)	43 LDCs		Public investment		Significant negative effect
Everaert & Heylen (2004)	Belgian regions	1965-96	Public investment	Translog production function. Using a general equilibrium model, they analyze labor market effects	Elasticity is 0.31
Gupta et al. (2005)	39 LICs	1990s	Public investment		Significant positive effect
Gwartney et al. (2004)	86 countries of which 66 LDCs	1980-2000	Public investment		Significant positive effect, but coefficient is less than coefficient of private investment
Haque (2004)	33 LICs, MICs	1970-99	Public investment		Significant positive effect
Milbourne, Otto and Voss (2003)	74 countries	1960-85	Public investment		Not significantly different from zero in steady state model; in transition model with IV also not significantly different from zero
Mittnik & Neumann (2001)	Canada, France, UK, Japan, The Netherlands and Germany	Different periods per country (Q)	Public investment	VECM	Weak positive output effect of infrastructure, public investment induces private investment; no reverse causation from GDP to public capital
Pereira & Andraz (2001)	US (sectoral and national)	1956-97 (A)	Public investment	VAR, first differences log levels	Public investment positively affects private investment, employment and output
Pereira (2000)	US	1956-97 (A)	Public investment	VAR, first differences log levels	Positive effect through crowding in of private investment
Pereira (2001)	US	1956-97 (A)	Public investment	VAR, first differences log levels	All types of public investment are productive, but 'core infrastructure' displays the highest rate of return
Sturm et al. (1999)	Netherlands	1853-1913	Public investment	VAR, levels	Positive and significant short-run effect; no long-run effect
Voss (2002)	US and Canada	US: 1947-88 (Q); Canada: 1947-96 (Q)	Public investment	VAR (11 lags); first differences	Public investment tends to crowd out private investment

Source: Romp and de Haan (2005), IMF (2004) and World Bank (2007)