Efficiency-Adjusted Public Capital and Growth*

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Abstract

This paper constructs an efficiency-adjusted public capital stock series and re-examines the public capital and growth relationship. The paper also examines the effects of four specific stages of the public investment process–appraisal, selection, implementation and evaluation–on capital accumulation and growth. The results show that public capital is a significant contributor to economic growth. Although the estimated coefficient for the income share of public capital is larger in middle- than in low-income countries, the opposite is true for the marginal product of public capital. The quality of public investment, as measured by variables capturing the adequacy of project selection and implementation, are statistically significant in explaining variations in economic growth, a result mainly driven by low-income countries.

Keywords: Public capital stock, public investment efficiency, appraisal, selection, implementation and evaluation of public investment, growth accounting.

JEL Classification: O19, O23, O40, O47.

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> "... less-accountable poor-country governments are likely to be disproportionately less efficient (relative to the private sector) than rich country ones. Hence, there are good reasons to expect the government to play an especially detrimental role in the productivity of investment in poor countries. This implies that the 'effective' variance of K is larger than in the baseline model."

Francesco Caselli (2005)

1 Introduction

One of the main questions in economics is why some countries are rich while many others remain poor. Recent advances in growth and development accounting suggest that the contribution of factors of production, such as capital (physical and human), is about the same as the contribution of the productivity from using these same factors. While much attention in the existing literature is focused on productivity and human capital, much less work has been done on distinguishing the contributions of private and public physical capital. A typical approach for constructing capital stocks is using an aggregate measure of private and public investment series from Penn World Tables. However, public investment in many developing economies are much more inefficient than private investment.

More specifically, many developing countries have a long legacy of failed public projects. Besides negating potential benefits that could have flowed from these projects, the poor record in undertaking public investments has bred skepticism about the ability of these countries to scale up public investment. At the same time, developing countries are under pressure to invest more on infrastructure in order to accelerate and/or sustain growth. The effectiveness of public investment also depends on institutional factors, such as the quality of project selection, management and evaluation, and the regulatory and operational frameworks. It is generally believed that such institutions are relatively weak in developing countries. Observing a poor track record and weak institutions, it is not uncommon for skeptics to ask if public capital is at all productive in developing countries.

With these issues in mind, this paper takes a close look at the productivity of public capital. In doing so, it makes three contributions: First, it constructs a new dataset of total capital stock for a large number of developing countries and disaggregates it into private and public capital. A particularly novel feature of the dataset is that the public capital stock is adjusted for the efficiency of public investment. This paper is the first to construct such a measure of public capital stock, which has been suggested by Pritchett (2000), Caselli (2005) and Agénor (2009). Public investment efficiency is measured by Public Investment Management Index (PIMI) as constructed by Dabla-Norris et al. (2011). Second, following the literature on the public capital-growth nexus the paper investigates the effect of adjusted public capital on growth. Third, taking advantage of the subcomponents of PIMI, the paper examines the effects of four specific stages of the public investment process–appraisal, selection, implementation and evaluation–on capital accumulation and growth.

The paper yields two main findings: First, there is a statistically significant but relatively small contribution of this efficiency-adjusted public capital to total income. The public capital share is larger in middle-income than in low-income countries. Also, while the share of public capital is small in low-income countries, the marginal product of public capital is relatively large because of the lower efficiency-adjusted capital stock. Second, when specific stages of the public investment process are incorporated in the analysis, project selection and implementation turn out to be important contributors to public capital and growth.

The remainder of the paper proceeds as follows. Section II provides a brief review of the literature on public investment and growth, paying particular attention to the relationship between public investment efficiency and growth. Section III describes in detail the construction of the private and efficiency-adjusted public capital series. Section IV discusses estimation issues and presents the baseline results as well as various robustness tests. Section V summarizes the main findings and draws conclusions.

2 Literature Review

Substantial research has been devoted to measuring the productivity of public capital. Sturm, Kuper and De Hann (1998) and Romp and de Haan (2007) are two excellent surveys of the literature. Many studies are based on the production function approach with the public capital stock added as an additional input factor. Some relied on a cost or profit function in which the public capital stock is included, while others used the VAR approach, which imposed as few restrictions as possible to address the problems raised by production function and behavioral approaches.

The early strand of papers typically found that public capital is productive, notwithstanding the wide range of theoretical and empirical frameworks employed. Aschauer (1989, 1998) was the first to hypothesize that there is an important role for public capital in explaining the fall in productivity observed in the US in the 1970s and 1980s. The literature that followed Aschauer also found a large impact of public capital on growth. Munnell's (1990a) estimates of the impact of public capital on growth (0.31-0.39) are consistent with those of Aschauer's.[1] In a similar setting, Lynde and Richmond (1993) found that the services of public capital are an important part of the production process, and that about 40 percent of the productivity decline is explained by a fall in the public capital-labor ratio. Several other papers reached similar conclusions.[2]

The elasticities reported in this first wave of papers were substantial and suggested large effects of public capital on growth. However, over time these estimates were questioned on the grounds that they were fraught with methodological and econometric problems (Gramlich, 1994). Issues ranking high on the list of potential problems included reverse causation from productivity to public

[1] In a subsequent paper at the state level, Munnell (1990b) confirmed her earlier findings. However, the coefficient of 0.15 on public capital found at the state level is noticeably smaller than the 0.3-0.4 estimated by Aschauer (1989) and Munnell (1990a, 1992) in their analysis of national data.

[2] See Sturm et al. (1998) for a comprehensive review of this generation of studies. Notable contributions include, Lynde and Richmond, (1992), Holtz-Eakin (1994), and Vijverberg et al. (1997).

capital and spurious correlation due to non-stationarity of the data. This controversy sparked a new generation of research. Compared to the results surveyed by Sturm, Kuper and de Haan (1998), these studies estimated substantially lower effects of public capital on growth (Romp and de Haan 2007). Moreover, these studies unveiled large heterogeneity among countries, regions, and sectors. This is not surprising, as the effects of new investment spending depend on the quantity and quality of the capital stock in place. In general, the larger the stock and the better its quality, the lower will be the impact of additions to this stock. The network character of public capital, notably infrastructure, also results in non-linearities, and explains some of the heterogeneity. The effect of new capital will crucially depend on the extent to which investment spending aims at alleviating bottlenecks in the existing network.[3]

Bom and Litghart (2010) assessed the output elasticity of public capital by means of a meta-regression analysis using results of previous studies. They find that the average output elasticity of public capital is positive and significant despite a wide variation in primary estimates. They estimate the output elasticity to be 0.15 but suggest substantial heterogeneity across countries.[4] Their results also suggest that the high output elasticities found in the early time-series literature are compatible with long-run (cointegrating) estimates found more recently. The conditional output elasticity of public capital in their benchmark specification which captures typical study characteristics is estimated to be 0.17, which is not that far from its unconditional (without controlling for study design parameters) value of 0.15. These values imply a marginal productivity of public capital for the United States in the range of 28.8–32.6 percent in 2001.

[3]Some studies suggest that the effect of public investment spending on growth may also depend on institutional and policy factors (Tanzi and Davoodi, 2000; Sawyer, 2010).

[4]They also find that studies that impose constant returns to scale restrictions across private labor and capital (Mas et al., 1993; Otto and Voss, 1994; and Kavanagh, 1997), control for the business cycle (Aschauer, 1989; Hulten and Schwab, 1991; and Sturm and De Haan, 1995), and incorporate some measure of education (Garcia-Milà and Mc Guire, 1992) find larger output elasticities of public capital, whereas studies that include energy prices (Tatom, 1991) tend to find lower estimates. Imposing constant returns to scale across private inputs implies increasing returns to scale across all inputs if the factor share of public capital is positive. This could produce upward bias in the estimates if the true model is characterized by decreasing returns to scale across private inputs.

There are, however, important limitations in the extensive literature on the subject. First, most studies focused on advanced countries, in part because of data problems. Given these data limitations and the difficulty in constructing public capital stock series for developing countries, the empirical literature on these countries looked directly at the impact of public investment on economic growth (Devarajan, Swaroop and Zou, 1996). Second, almost all studies were based on public capital series constructed by cumulating depreciated public investment effort.

Arslanalp et al. (2010) revisited this debate by estimating a production function for 48 developed and developing countries, using public capital stock as the explanatory variable. The effect of public capital on growth is estimated to be stronger for developed countries in the short-term (0.13), while it is stronger for developing countries in the long-term (0.26). In some countries, they find that the positive impact of public capital on output is partially or wholly offset if the initial ratio of the capital stock to GDP is high. A number of policy implications were drawn for developing countries from their 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 the growth benefits of higher capital stock. Second, unlike advanced countries, the benefits of new investment tend to accrue over time. This would necessitate extending the timeframe of debt sustainability frameworks so that developing countries can take into account the long-term effects of public investments.

Last but not least, Pritchett (2000) has criticized the conclusions drawn from the empirical studies that relate public investment or capital to growth. He argues that cross-country empirical research using investment rates or Cumulated Depreciated Investment Effort (CUDIE) cannot be used to derive the impact of public capital or investment on growth. This is because such studies ignore the efficiency with which public investment is turned into productive physical capital. And it is this gap in the literature that this paper aims to fill.

3 Data

The empirical literature has focused on searching for a relationship between economic activity and the cumulated public investment effort, using the perpetual inventory method for estimating public capital stock. The methodology for building the capital stock series is similar to that used by Collier, Hoeffler and Pattillo (2001), Kamps (2006) Arslanalp et al. (2010) (see Appendix A for the country list and Appendix B for a detailed description of the methodology). It is based on the perpetual inventory equation:

$$K_{it} = K_{it-1} - \delta_{it} * K_{it-1} + I_{it-1}, \tag{1}$$

where for each country i, K_t is the stock of public capital at time t, and $I_{t-1}$is public investment spending at time *t-1*.[5] δ_{it} is country i's time-varying rate of depreciation of the capital stock. Data for 71 countries on total investment and GDP are taken from Penn World Table (PWT) version 6.2 and start in 1960 for most of the sample. Before 1960, and as in Kamps (2006), we build an artificial investment series assuming that investment grew by 4 percent a year to reach its level observed in 1960. Total investment is disaggregated by applying public and private investment shares from IMF World Economic Outlook (WEO) database. Total public and private capital stocks are then constructed using the initial capital stock, investment flows and the depreciation rates. The resulting dataset is the largest available for developing countries. Countries included in the sample are those for which (i) data on investment and growth are available from the Penn World Table and the WEO, and (ii) an index of the quality of public investment processes was available (see below).[6]

Table 1 provides trends in key variables that empirical studies have focused on. It shows that in

[5]Following Kamps (2006) we assume I_{it-1} (rather than I_{it}) which implies that capital stock is calculated at the beginning of the period.

[6]The complete dataset of public and private capital stocks (including PIMI-adjusted public capital for 52 countries used in the baseline estimation of this paper, and unadjusted public capital stocks along with private capital stocks for over 120 countries), is available upon request from the authors.

the sample of 71 countries the average GDP growth for middle-income countries was almost 1 percentage point above that of low-income countries during the last 50 years. However, middle-income countries' started to grow at higher rates several decades before their low-income counterparts.

Differences between the low and middle-income group are more striking when considering the public investment effort. Middle-income countries invested on average over 2 percentage points of GDP more than low-income countries. As shown in Figure 1, the ratio of public spending on investment to GDP for middle-income countries has been consistently above that for low-income countries for almost the entire 50-year period analyzed. However, differences between the two groups are smaller for the growth rate of the public capital stock. This could be attributable to the fact that a small addition to public capital can yield a large growth rate of the public capital stock when the level of capital is low (the base effect.)

Serious data issues could undermine the quality of results on the productivity of public capital obtained from cross-country regressions. In particular, a large body of literature recognizes the importance of the quality and efficiency of public investment spending in determining the marginal productivity of investment. The real challenge in empirical research has been to find a good proxy for "efficiency-adjusted" public capital stock. To date, all empirical studies on the contribution of public capital to growth have assumed that public investment spending translates fully into productive capital assets.

Several considerations can explain why cumulative public investment may not provide full information on growth of public capital. First, valuation issues make the measurement of any flows in a single currency problematic. Second, the cost of a given infrastructure asset can also vary significantly across countries, even after controlling for difference in conditions such as geology or geography. For example, the cost of building a road can be significantly higher in a country where procedures are not in place for project appraisal or where the environment is not conducive to competitive bidding. Third, weaknesses in the selection of the project could lead to an oversized project.

The approach employed in this paper attempts to address these problems. In implementing this approach, we apply the methodology outlined by Pritchett (2000) to construct a new public capital series that explicitly takes into account the efficiency of public investment. We measure the capital stock in country i and time period t as follows:

$$K'_{it} = K'_{it-1} - \delta_{it} * K'_{it-1} + q_i * I_{it-1}, \tag{2}$$

where q_i is a time-invariant index that captures the efficiency of public investment. While the efficiency of investment processes is likely to evolve over time, it is also likely to change slowly reflecting the fact that structural reforms to improve these processes take time to implement. Thus we assume that q_i is time-invariant. This index varies between 0, when all public resources are totally wasted, and 1, when full efficiency is achieved for government spending. However, we let this index vary in the robustness tests reported later in the paper.

We use the normalized Public Investment Management Index (PIMI) as a proxy for q_i; the traditional perpetual inventory equation is a specific case of this more general formulation, where $q_i = 1$. PIMI is composed of 17 indicators grouped into four stages of the public investment management cycle: (i) Project Appraisal; (ii) Project Selection; (iii) Project Implementation; and (iv) Project Evaluation. In this index, countries are scored on the basis of different indicators and sub-indices, which are then combined to construct the overall index. The construction of the index relies upon an extensive data collection effort as described in Dabla-Norris et al. (2011).[7] The sources largely cover the 2007–2010 periods, and include 71 countries (40 low-income countries and 31 middle-income countries).[8] A word of caution is in place here. While PIMI captures the efficiency of

[7]Data were compiled from a large number of sources including from World Bank Public Investment Management case studies, Public Expenditure and Financial Accountability assessment reports, the Budget Institutions database, World Bank Public Expenditure Reviews, World Bank Country Procurement Assessment Reviews, World Bank Country Financial Accountability Assessments, and country websites.

[8]The PIMI score is a simple average of the score for each stage of the public investment process. Countries with good investment processes have high scores. Scores for these stages are between 0 and 1 so that the total PIMI score is between 0 and 4 (for the full set of countries and country scores see Appendix A).

different stages of the investment process, it is an ordinal index and therefore interpretation is not as transparent as with a cardinal index. Having said that, PIMI is the only available index of public investment management to date and while it could be arguably a noisy measure it surely provides value added to the existing practice of not adjusting for public investment inefficiencies.

Table 2 suggests that, on average, in our set of countries only about half of public investment effort translates into actual productive public capital. This masks, however, significant heterogeneity between countries as illustrated in Figure 2. Beyond the large cross-country variation in overall scores described above, there is an even more notable variation for each of the sub-indices. This suggests that the observed differences in public investment management processes across countries stem largely from the substantial cross-country heterogeneity across the four stages of the investment process. To capture the variation across stages we also construct four alternative capital stock series for every country that correspond to three out of four investment stages (leaving one stage out) at a time. Estimation with these alternative series aim to identify which of the four public investment processes are the most important in capital accumulation and subsequently aggregate output.

The fact that not all public investment spending translates into incremental, effective public capital leads to a significant gap between traditional estimates of public capital stock (Arslanalp et al., 2010, and Kamps, 2006) and our estimates. Table 3 shows that for all the 71 countries for which PIMI is available, this gap was about 7 percentage points of GDP in the first decade. It subsequently increased to more than 40 percent of GDP in recent years. This suggests that traditional measures of public capital stock are overestimated—at least, from the standpoint of public investment that is of good quality. Table 3 further indicates that effective public capital has declined from 57 percent of GDP in the 1960s to 36 percent of GDP in recent years.

However, while the PIMI-adjusted public capital stock has declined steadily in low-income countries because of the low efficiency of new investments, the large investment effort by middle-income countries has offset losses from inefficiencies between 1960-70 and 1970-90. During this period, effective public capital increased by 10 percentage points of GDP in middle-income countries, while it fell by almost double that amount in low-income countries.

The differences are however less dramatic when considering the growth rates in capital stock (Table 4). During the period 1960–2009 PIMI-adjusted public capital grew by about 2.8 percent per year for all countries taken together, a rate that is 1.3 percentage points slower than the rate of growth of unadjusted public capital.

As mentioned above, unlike the non-adjusted public capital stock the PIMI-adjusted public capital stock is characterized by a downward trend, although middle-income countries experienced some growth in the earlier periods. Figure 3 also shows that the gap between the two series is substantial. Therefore, growth regressions using non-adjusted public capital series would produce biased estimates of factor shares. This bias is likely to be more important for a model explaining output levels than for models explaining growth rates.

Before plunging into the data and the calculations, it is important to point out three qualifications related to the PIMI adjustment of public capital are in place. First, while the efficiency of public investment management is in all likelihood a dynamic process, our PIMI index is not time varying – it is based on a single observation collected for each country in the sample during the period 2003-2005. In constructing the PIMI-adjusted public capital series we assume that the PIMI index stays constant throughout the sample's time dimension starting in 1960. It should be noted that the initial condition assumption (i.e. the assumption on what PIMI is at the beginning of our estimation sample, 1960) matters for the subsequent evolution of efficiency adjusted public capital. Introducing the PIMI in 1960 is one of four different options we have considered, as this was critical to the public capital series time paths (slopes) we obtained. While these scenarios are available by request, here we focus on the extreme case in which we introduce PIMI in 1860, using Kamp's initial capital condition methodology, implying that PIMI has remained constant since 1860, an unlikely assumption but a good counterfactual. In this case, by 1960 the growth of PIMI-adjusted public capital is virtually identical to that of non-PIMI adjusted public capital; this is shown analytically in Appendix C (also see Buffie et al. 2011, Appendix A). As we show in one of the robustness analysis we perform later on, results with non-PIMI adjusted capital (equivalent to this assumption) obtain a share that is higher and more significant than in our baseline set of results. Thus even in this extreme case the main results of our paper hold unaltered.

Second, beyond the PIMI correction to initial condition of capital our analysis still omits the variation of public capital in the time dimension, given our prior that inefficiencies are changing across time. This omission would potentially bias downward our coefficient estimates of public capital and mask a more pronounced effect that public investment inefficiencies may have on aggregate output. In our robustness analysis we consider an alternative efficiency measure that we construct by merging PIMI with an existing time varying institutional index.

Third, PIMI by construction is an ordinal and not a cardinal index. It should be noted that Isham, Narayan and Pritchett (1995) show evidence that subjectively coded indexes can behave as if they were cardinal exhibiting a linear relationship. We cannot make any claims of such relationship in our analysis. Therefore while the ordinal nature of PIMI is not problematic in the current analysis, caution should be exercised in interpreting PIMI-adjusted capital for policy recommendations.

4 Public capital and Growth: Panel Regression Analysis

4.1 Estimation Method

We use the production function approach to estimate the contribution of public capital to growth. The production function is specified as:

$$Y_t = Af\left(S_t, K_t, G_t\right) = A_t S_t^{\alpha} K_t^{\beta} G_t^{\gamma}, \tag{3}$$

where Y_t is the real aggregate level of output (GDP) at period t, K_t is the aggregate private capital stock, G_t is the aggregate public capital stock, and S_t is skill-adjusted aggregate labor supply. This represents an additional deviation of our analysis from existing work: rather than using raw labor, we construct and use skill-adjusted labor incorporating data on average years on education. Following the literature on returns to education S_t is computed according to $S_{it} = L_{it} * e^{\varphi(h)}$, where L_{it} is raw labor and h is the average years of schooling in the population aged 15 years and older. $\varphi(h)$ is a stepwise linear function adjusting the average years of schooling by estimates for returns on education. Assuming Cobb-Douglas production function technology, A, α, β and γ are parameters satisfying $A > 0$, and α, β, $\gamma \in (0, 1)$.[9]

We begin our empirical analysis by specifying the aggregate input-output production relationship:

$$Y_{it} = A_0 S_{it}^{\alpha} K_{it}^{\beta} G_{it}^{\gamma} e^{\lambda_t + \varepsilon_{it}}, \tag{4}$$

where A_0 denotes the initial (1960) value of the scale factor, i is a country identification, and we assume year-specific intercepts λ_t that could reflect common (Hicks-neutral) exogenous technology shocks.

Taking logarithms of both sides gives us:

$$lnY_{it} = a_0 + \lambda_t + \alpha lnS_{it} + \beta lnK_{it} + \gamma lnG_{it} + \varepsilon_{it}. \tag{5}$$

Admitting the possibility of country-specific effects implies that the error term in (5) can be written as $\varepsilon_{it} = \eta_i + \upsilon_{it}$, where η_i captures time-invariant fixed factors in country i and υ_{it} captures the omitted factors. Traditional approach to estimation is to difference this equation to yield 5-year average growth rates in the respective variables. This would eliminate fixed effects, thus controlling for any country-specific but time-invariant characteristic (such as colonial legacies, legal origins, ethnic fragmentation, etc.) that could affect both the capital stocks and per capita income growth. The reasons for using 5-year, rather than annual frequency data are twofold: first, it mitigates

[9] In the robustness analysis, we also consider the more flexible CES aggregate production function specification.

business-cycle effects and second, it allows us to capture investment in human capital by using Barro and Lee (2010) data, which are available as five-year averages.

While it is straightforward to estimate (5) using a panel estimation that incorporates country fixed effects (to purge individual growth effects) as well as time effects, concerns regarding simultaneity still remain. Many authors argue that public capital itself is an endogenous variable due to feedback from income-savings decision on capital accumulation.[10]

A traditional approach to deal with this problem would be to use lagged levels to instrument for differences. However, if the underlying series are close to a unit root (which is usually the case with macro-variables such as public capital), past levels contain little or no information about future changes and are thus weak instruments. To address this issue we chose to use a system Generalized Method of Moments (GMM) (Blundell and Bond, 1998) estimator.[11] In addition, in the GMM estimation strategy, we allow for an AR(1) component in the idiosyncratic shock υ_{it}, of the form $\upsilon_{it} = \rho\upsilon_{it-1} + \varepsilon_{it}$ that Blundell and Bond (2000) have found important in obtaining valid instruments. This leads to a dynamic (common factor) representation of equation (3) of the form:[12]

$$\begin{aligned} lnY_{it} &= \rho lnY_{it-1} + \alpha lnS_{it} - \rho\alpha lnS_{it-1} + \beta lnK_{it} - \rho\beta lnK_{it-1} + \gamma lnG_{it} \\ &\quad -\rho\gamma lnG_{it-1} + (1-\rho)\alpha_0 + (1-\rho)\eta_i + \left(\lambda_t - \rho\lambda_{t-1}\right) + \varepsilon_{it}. \end{aligned} \tag{6}$$

[10]The first-difference specification further magnifies this problem; even if independent variables are predetermined, in the first-differenced equation their time t values are likely to be correlated with the lagged error term, υ_{it-1}. More generally, the capital accumulation equation used to construct the capital stock series (see the data appendix for details) implies that K_{it} will depend on such lagged error terms. Therefore, instrumental variables are needed to correct for endogeneity.

[11]This approach permits us to transform the instruments to make them orthogonal to the fixed effects.

[12]This dynamic representation implies three non-linear (common factor) restrictions on the unrestricted parameters that generally hold in the baseline regressions. To save space the lagged terms are compressed in the presentation of the estimation results. This form incorporates the traditional dynamic panel endogeneity bias that we address with system GMM internal instruments. We assume that all factors of production (K_{it}, G_{it}, S_{it}) are potentially contemporaneously correlated with the country specific effects (η_i) as well as idiosyncratic shocks (ε_{it}).

4.2 Results

Our empirical analysis is organized in two parts: First, we present baseline results that include estimation of the contribution of the overall PIMI-adjusted public capital stock to growth, and also the contribution of different stages of the public investment process to the efficiency of capital and growth. Second, we present numerous robustness tests for alternative specifications, econometric approaches and samples. The sample size is reduced to 52 because of missing observations for some countries.

4.3 Baseline results

Contribution of adjusted public capital

Tables 5 and 6 present results using fixed-effects and system GMM, respectively. Specifically, columns 1-3 of Table 5 report fixed-effects coefficients for our entire sample (ALL), middle-income countries (MICs) and low-income countries (LICs), respectively, using the unadjusted public capital stock series.[13] Columns 4-6 report fixed-effects estimates with adjusted public capital stock.

Comparing the fixed-effects models' results using "unadjusted" public capital stocks with efficiency-adjusted capital shows that coefficient estimates for private and efficiency-adjusted public capital increase somewhat (except in the LIC subsample, where the coefficient of efficiency-adjusted public capital decreases slightly). Perhaps more importantly, this comparison shows that using raw public capital leads to underestimating the contribution of private capital inputs.

Under the panel fixed-effects specification with PIMI-adjusted capital, all coefficient estimates are significant at least at the 5 percent level. The unconstrained factor share estimates for the entire sample of counties (ALL; column 4) are 52.3 percent for skilled labor, 26.5 percent for private capital and 19.7 percent of for public capital. This contribution of public capital is consistent with the

[13]We use the World Bank definition of MICs and LICs based on a fixed threshold income level. We have carried out an additional robustness test with a time-varying definition of MICs and LICs showing very little change in the baseline results. These results are available upon request.

finding by Bom and Litghart (2010). Our estimate is higher than the unconditional average they report (15 percent), but this could result from the inclusion of a measure of education in our production function.

Although the fixed-effect results may provide a comparison with many existing studies, our preferred specification is dynamic system-GMM that corrects for endogeneity (Table 6).[14] The coefficient estimates for adjusted public capital are now notably smaller in magnitude compared to those for unadjusted public capital, dropping from 0.23 to 0.15 for the entire sample. This is driven by LICs where factor share of public capital falls from 0.25 to 0.14, while for MICs estimated coefficients are almost the same. All coefficient estimates retain their significance at least at 10 percent significance level.

Interestingly, coefficient estimates for private capital show a corresponding increase in all samples that is much larger in magnitude than in case of fixed effects. For example, for ALL and LIC samples the estimated coefficients increase from 0.23 to 0.3, while for the MIC sample there is a more modest increase from 0.29 to 0.31. Table 6 (columns 4-6) also shows that there is an almost twofold difference between adjusted public and private capital in all three samples (around 15 percent for public capital and 30 percent for private capital).

Tables 5 and 6 present calculations of respective marginal product of factors defined as $MPX = a(Y/X)$, where a is the income factor share, Y is GDP and $X \in (S, K, G)$. For public capital $MPG = \beta(GDP/GPIMI)$. Focusing on MPG under the fixed effect model (Table 5) it is shown that for the entire sample there is large jump from 0.42 to 0.88 after correcting the capital series for public investment inefficiencies. This is not unexpected given that the modified Y/G ratio in the MPG equation increases substantially and especially for LICs. Under the dynamic GMM

[14] Table 6 also reports p-values from joint tests of the common factor restrictions implied by our dynamic equation (6). The common factors are marginally rejected at 10 percent only for the MICs subsample, however, closer inspection revealed that this is related to somewhat underestimated factor share of skilled labor (in PWT labor is based on working-age population and might not properly capture variations in hours worked). Imposing constant returns to scale would increase the labor share and yield a p-value of 0.42, thus supporting the validity of restrictions.

model this jump is smaller but still quite significant from 0.52 to 0.69. These results highlight that although the income share of public capital is low (only 14 percent for LICs), the MPG is high given downward corrections in the public capital series to capture inefficiencies.

Overall, this result suggests that ignoring public investment inefficiencies leads to an underestimation of marginal productivities of both private and public capital, which can have important policy implications. Furthermore, the marginal productivity of public capital is only slightly larger than that of private capital when public investment inefficiencies are ignored. However, once public investment inefficiencies are corrected for, the absolute gap between the productivities of public and private capital widens.[15] It is also noteworthy that the regressions with efficiency adjusted public capital seem to better explain the variation in output. Although standard goodness of fit measures are not readily available for GMM, regressions with PIMI-adjusted public capital show lower error variance and more than 11 percent reduction in the mean-squared-errors of predicted output levels.

Contribution of investments processes

Next we investigate the effects of productivity of capital as reflected by the four different stages of the public investment process, project "Appraisal" (indicating strategic guidance, transparency and independent review of appraisal), "Selection" (assessing the existence of multi-year forecasts and their linkage to annual budgetary policies), "Implementation" (capturing timely budget execution and efficient procurement, sound internal budgetary monitoring and control that supports financial and program management) and "Evaluation" (assessing ex-post evaluation of completed projects, which in its basic form focuses on the comparison of the project's costs with those established during project design) on growth.

Table 7 presents results from a modified regression specification in which we replace the aggre-

[15] A cautionary remark is in place here. Our estimation of marginal products is based on how the PIMI adjustment affects the physical marginal product of capital and not the financial (price-adjusted) marginal product of capital as in Caselli and Feyrer (2007).

gate PIMI-adjusted public capital with four alternative public capital stock series generated using three out of four PIMI sub-indexes at a time. For example, in column 1 the efficiency adjusted public capital omits the "Appraisal" stage, so that PIMI is calculated as a weighted average over three other stages. If the appraisal stage would be relatively more important compared to other stages, then omitting a productive stage should lead to lower marginal productivity (and possibly lower estimated factor share). Columns 2–4 follow the same approach for the other three stages of the public investment process.

The results show considerable variation across country groups, indicating that policy recommendations should be tailored to country circumstances. For LICs, exclusion of implementation and selection stages leads to lower implied marginal productivities as well as insignificant estimates of factor shares. This suggests that implementation and selection are relatively more important public investment management stages in LICs. In MICs, marginal productivities and estimated factor shares drop once appraisal and evaluation stages are omitted from overall PIMI, implying that these stages of the public investment process carry disproportionately higher weight in explaining the effect of efficiency-adjusted public capital on growth. The results for the entire sample are necessarily mixed though implementation stands out as the stage with higher relative productivity.[16]

4.4 Robustness checks

Here we subject our baseline results to a number of robustness tests as reported in Tables 8 and 9.

Time varying index of efficiency

In order to add a time dimension to the PIMI index, we apply the observed variation in the ICRG (International Country Risk Guide)[17] Investment Profile to extend PIMI backwards. The ICRG Investment Profile measures the government's general attitude towards investment, and

[16]See Appendix D for an alternative approach to incorporating stages of public investment process in the analysis that, however, deliver similar conclusions.

[17]ICRG dataset is compiled by the PRS (Political Risk Services) http://www.prsgroup.com/PRS.aspx.

can be considered as a relatively close proxy of factors affecting public investment in a country.[18] Coefficient estimates on adjusted public capital based on such "time-varying" PIMI increase slightly to 0.17, indicating robustness of baseline results.

Alternative weights for the investment process

Next we "scanned" for alternative weights for the four investment processes in search of "optimal" fit of our regressions. Alternative weights were obtained from a two-step production function estimation procedure, where in the first step the PIMI-adjusted public capital was regressed on four public capital components, pertinent to each of the four investment stages. The estimated coefficients provided the following new weights: 0.215 for appraisal; 0.311 for selection; 0.334 for implementation and 0.140 for evaluation. Reweighing our overall PIMI using the resulting alternative weights and accumulating new aggregate public capital stock obtains results very similar to those in our baseline regressions in terms of both estimated factor shares as well as observed "fit" of the regressions.[19]

Alternative production technology

Here, we examine the robustness of our baseline results to alternative production technologies. First, we consider a nested CES production specification that allows different patterns of substitutability or complementarities between public and private capital stocks (see Appendix E for details). In particular, we test for the following functional form:

$$Y_{it} = A_0(S_{it})^{\alpha}\left[\delta K_{it}{}^{-\rho} + (1-\delta)G_{it}{}^{-\rho}\right]^{\frac{(1-\alpha)*\upsilon}{\rho}} e^{-\lambda * t + \varepsilon_{it}}. \tag{7}$$

The key parameter for the elasticity of substitution in Table 8 has an insignificant coefficient

[18] While we recognize that our constructed "time-varying" index presented as a robustness test is not entirely satisfactory, as the correlation between PIMI scores and the ICRG index is not that high, it is our only viable alternative at this point. We have tried to also use POLITY and CPIA without much success because POLITY seemed to be too broad a concept and CPIA had severe data limitations (was available only for a few years)

[19] We also tested two alternative methodologies for scanning PIMI weights. First, we derived the first principal component (eigenvector) from the four PIMI stages; however, this procedure gave close to uniform weights consistent with the original PIMI. Secondly, and following Baldacci et al. (2011) we computed z-scores for each stage though using the cross-sectional variation only. This method yielded higher weights for evaluation and appraisal. Accumulating new aggregate capital stock and using it in the regressions yielded qualitatively similar results as in the baseline without any improvement in fit.

indicating that the Cobb-Douglas production specification used in the baseline analysis is appropriate.

Second, we test for constant returns to scale (CRTS) to all inputs in the production technology. Imposing CRTS delivers a public capital share that is only marginally higher at 17 percent, while the coefficient on skill-adjusted labor increases by more than 40 percent compared to the estimates in Table 6. This is an important result indicating that (i) there is no evidence of bias in the unrestricted coefficient on public capital as estimated in our baseline regressions, (ii) any measurement errors are likely to be confined to labor as PWT is based on working-age population and may not adequately capture the variation in hours worked; and (iii) the standard long-run feature of CRS cannot be rejected.

Third, we check for alternative definitions of labor by splitting the quality adjusted labor into raw labor and human capital:

$$lnY_{it} = a_0 + \lambda_t + \alpha_1 lnL_{it} + \alpha_2 lnH_{it} + \beta lnK_{it} + \gamma lnG_{it} + \varepsilon_{it}. \tag{8}$$

The coefficient estimate for raw labor is insignificant with specification being identified via human capital, thus providing support to the quality-adjustment of labor as used in the baseline specifications. This is an important finding in its own right indicating that not appropriately adjusting labor for skill level can seriously bias results in growth accounting.

Alternative sample sizes

Next, we investigate the robustness of our baseline results to different sample sizes. First, we restricted our sample to a period after 1980 in an effort to eliminate base effects coming from our constructed capital stocks. While coefficients increased slightly, the overall statistical significance remained the same as in our baseline. We also included the entire set of 122 developing countries for which we have constructed public (not PIMI-adjusted) and private capital stocks. We find that the unadjusted public capital stock income share at 16.7 percent is significant and somewhat larger than our baseline estimate. Therefore, even without any PIMI adjustment to public capital our result of a positive contribution of public capital to aggregate output remains valid.

Alternative instrument matrix size

Finally, we perform robustness checks with alternative instrument sets. The identification strategy exploited here is in many respects very demanding: (i) all independent variables must be treated as endogenous, (ii) the error structure calls for an AR(1) component in the idiosyncratic shock, leading to a dynamic common factor equation and thus need for additional instruments to address the dynamic panel bias, (iii) high degree of persistence in the data calls for a system-GMM and thus higher number of instruments, and (iv) a high degree of colinearity, especially between the private and public capital stocks both across time and countries further hinders the identification of point estimates as well as the choice of instruments. Given these features there will necessarily be a trade-off between addressing these concerns and improving efficiency from one hand and the danger of over-fitting the endogenous variables on another hand.

To investigate concern with over-fitting (Rodman, 2009) Table 9 reports variations on the size of the instrument matrix. Column 1 reports a specification with 3 lags for the equation in differences and one lag for the equation in levels. In columns 2 and 3 we collapse the instruments in levels and difference equation, respectively. In column 4 we reduce the instruments into one lag only, in column 5 we impose the constant returns to scale to all inputs (that allows dropping one endogenous variable) and in column 6 we further reduce the instrument matrix by collapsing the instruments in the difference equation. All variables are treated as endogenous.

The following observations are worth noting. First, the point estimate of the coefficient on public capital—the main object of interest—remains rather stable. Most variation estimates are related to the labor share that is not surprising given that we are only able to use data based on working age population for our sample of countries. Second, in any of the reported specifications the null of instrument exogeneity cannot be rejected neither jointly nor individually. Third, the joint significance of public and private capital cannot be rejected at 0.1 percent significance even when individual point estimates are usually significant at 5 or 10 percent level. The latter is suggestive that difficulties with multicollinearity are the primary reason for some variation in the point estimates of the capital shares.

5 Conclusion

This paper makes three contributions to the existing literature that investigates the contribution of public capital to growth. First, it constructed a new dataset on private and public capital in which public capital takes into account public investment inefficiencies. Controlling for these inefficiencies showed that the actual accumulation of productive public capital was significantly slower than suggested by government spending on investment. Our results suggest that the stock of effective public capital might be up to one-half of the stock suggested by the traditional method for computing public capital stock.

Second, it provides further evidence in favor of a significant role for public capital in explaining output variations. Our baseline specification as well as alternative robustness specifications showed a consistently significant impact of public capital on output. We find that the productivity of public capital has been grossly underestimated by the previous studies. Moreover, our study indicated that the productivity of public capital, controlling for the efficiency of investment processes, is significantly higher than the marginal cost of funds under normal financing conditions. This is especially true for LICs.

Finally, results suggest that project implementation is the most important component of the overall investment process. This result is driven by LICs followed by project selection. Thus improving project implementation comprising competitive bidding and internal audit, and project selection, comprising existence of medium-term frameworks and their linkage to annual budgetary policies, can significantly benefit public investment and growth in low-income countries.

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Table 1. GDP Growth, Public Investment and Public Capital Stock Growth, 1960–2009

	1960-70	1970-90	1990-2000	2000-09	1960-2009
GDP growth					
Low-Income	3.7	2.8	2.5	5.2	3.5
Middle-Income	5.8	4.4	2.0	5.1	4.3
All countries	4.6	3.4	2.3	5.2	3.9
Public Investment (% of GDP)					
Low-Income	4.6	5.1	3.9	4.2	4.4
Middle-Income	5.0	9.9	5.2	4.6	6.2
All countries	4.7	6.9	4.4	4.4	5.1
Public capital stock growth					
Low-Income	4.4	5.1	2.9	4.4	4.2
Middle-Income	4.5	6.2	3.0	2.3	4.0
All countries	4.4	5.6	2.9	3.5	4.1

Source: Authors' calculations using data from Penn World Tables version 6.2 and IMF WEO.

Table 2. Public Investment Management Index (PIMI) by Income Group

	PIMI	Appraisal	Selection	Implementation	Evaluation
Low Income (40)	0.47	0.21	0.28	0.30	0.20
	(0.26)	*(0.13)*	*(0.11)*	*(0.10)*	*(0.10)*
Middle Income (31)	0.57	0.21	0.30	0.28	0.22
	(0.25)	*(0.09)*	*(0.11)*	*(0.07)*	*(0.07)*
All countries (71)	0.51	0.21	0.29	0.29	0.21
	(0.26)	*(0.11)*	*(0.11)*	*(0.09)*	*(0.09)*

Sources: Dabla-Norris et al. (2011) and authors' calculations. Standard deviations are in parenthesis.

Table 3. Unadjusted and PIMI-adjusted Public Capital Stock by Income Group
(In Percent of GDP)

	Unadjusted Public Capital Stock				PIMI-adjusted Public Capital Stock			
	1960-70	1970-90	1990-2000	2000-09	1960-70	1970-90	1990-2000	2000-09
Low-Income (LICs)	64.9	73.4	84.0	71.0	57.9	40.0	38.4	30.1
Middle-Income (MICs)	62.7	119.3	119.1	93.2	56.9	66.5	58.0	44.4
All countries	64.0	90.3	98.3	80.2	57.4	49.8	46.4	36.1

Source: Authors' calculations using data from PWT version 6.2, IMF WEO, and Dabla-Norris et al. (2001).

Table 4. Growth Rate of Public Capital Stock by Income Group
(In Percent)

	Unadjusted Public Capital Stock					PIMI-adjusted Public Capital Stock				
	1960-1970	1970-1990	1990-2000	2000-2009	1960-2009	1960-1970	1970-1990	1990-2000	2000-2009	1960-2009
Low-Income	4.4	5.1	2.9	4.4	4.2	2.6	2.7	2.0	3.7	2.7
Middle-Income	4.5	6.2	3.0	2.3	4.0	3.0	4.2	2.4	1.9	2.9
All countries	4.4	5.6	2.9	3.5	4.1	2.8	3.3	2.1	2.9	2.8

Source: Authors' calculations using data from PWT version 6.2, IMF WEO, and Dabla-Norris et al (2001).

Table 5. Static Fixed Effects Regressions with PIMI-adjusted Public Capital

	Static Fixed Effects - No PIMI			Static Fixed Effect - PIMI		
	ALL (1)	MIC (2)	LIC (3)	ALL (4)	MIC (5)	LIC (6)
Estimated Factor Shares						
Skilled Labor	0.522***	0.393**	0.602**	0.523***	0.399**	0.610**
	(0.18)	(0.17)	(0.29)	(0.19)	(0.17)	(0.29)
Private Capital	0.245***	0.248**	0.221**	0.265***	0.258***	0.253**
	(0.08)	(0.10)	(0.10)	(0.07)	(0.08)	(0.10)
Public Capital	0.189***	0.197*	0.193***	…	…	…
	(0.07)	(0.11)	(0.06)			
PIMI-adjusted Public Capital	…	…	…	0.197***	0.226**	0.187**
				(0.07)	(0.10)	(0.08)
Implied Marginal Productivities						
Private Capital	0.42	0.22	0.52	0.45	0.23	0.60
Public Capital	0.42	0.36	0.50	…	…	…
PIMI-adjusted Public Capital	…	…	…	0.88	0.71	1.04
R-squared	0.25	0.32	0.25	0.25	0.32	0.25
Adjusted R-squared	0.23	0.27	0.21	0.23	0.28	0.21
Observations	414	186	228	414	186	228
Countries	52	24	28	52	24	28

Note: Dependent variable is the log-difference of real GDP in international dollars. Independent variables are the log-difference in skilled labor, private capital and (adjusted) public capital, respectively. Standard errors in parentheses: *p<0.1, **p<0.05, ***p<0.01. All is our entire sample of 52 countries, MIC is the subsample of 24 middle-income countries, and LIC is the subsample of 28 low-income countries.

Table 6. Dynamic System GMM Regressions with PIMI-adjusted Public Capital

	Dynamic GMM - No PIMI			Dynamic GMM - PIMI		
	ALL	MIC	LIC	ALL	MIC	LIC
	(1)	(2)	(3)	(4)	(5)	(6)
Estimated Factor Shares						
Skilled Labor	0.390**	0.265*	0.583***	0.336*	0.249*	0.637***
	(0.18)	(0.14)	(0.22)	(0.19)	(0.15)	(0.23)
Private Capital	0.231**	0.286***	0.231**	0.297***	0.314***	0.300***
	(0.09)	(0.10)	(0.09)	(0.09)	(0.10)	(0.09)
Public Capital	0.233***	0.167**	0.253***	…	…	…
	(0.07)	(0.08)	(0.09)			
PIMI-adjusted Public Capital	…	…	…	0.154*	0.162**	0.143*
				(0.08)	(0.07)	(0.09)
Implied Marginal Productivities						
Private Capital	0.40	0.26	0.55	0.51	0.28	0.71
Public Capital	0.52	0.30	0.65	…	…	…
PIMI-adjusted Public Capital	…	…	…	0.69	0.51	0.80
Hansen J-test	[1.00]	[1.00]	[1.00]	[1.00]	[1.00]	[1.00]
AR(2) test	[0.71]	[0.51]	[0.77]	[0.60]	[0.50]	[0.86]
Common factors	[0.13]	[0.04]	[0.64]	[0.14]	[0.09]	[0.75]
Observations	414	186	228	414	186	228
Countries	52	24	28	52	24	28

Note: Dependent variable is the log-difference of real GDP in international dollars. Independent variables are the log-difference in skilled labor, private capital and (adjusted) public capital, respectively. Standard errors in parentheses: *p<0.1, **p<0.05, ***p<0.01. All is our entire sample of 52 countries, MIC is the subsample of 24 middle-income countries, and LIC is the subsample of 28 low-income countries.

Table 7. Regressions for Public Investment Stages

	Dynamic GMM: ALL				Dynamic GMM: MIC				Dynamic GMM: LIC			
Omitted category:	Appraisal	Selection	mplementatior	Evaluation	Appraisal	Selection	mplementatior	Evaluation	Appraisal	Selection	mplementatior	Evaluation
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Estimated Factor Shares												
Skilled Labor	0.327*	0.322*	0.360*	0.348*	0.260*	0.234[*]	0.242*	0.265*	0.649***	0.637***	0.647***	0.620***
	(0.19)	(0.19)	(0.19)	(0.19)	(0.15)	(0.15)	(0.14)	(0.16)	(0.23)	(0.23)	(0.23)	(0.22)
Private Capital	0.290***	0.297***	0.307***	0.299***	0.320***	0.329***	0.296***	0.314***	0.294***	0.302***	0.312***	0.303***
	(0.09)	(0.09)	(0.09)	(0.09)	(0.10)	(0.09)	(0.09)	(0.10)	(0.10)	(0.10)	(0.09)	(0.09)
PIMI-adjusted Public Capital	0.154*	0.157*	0.143*	0.158*	0.155**	0.166***	0.183***	0.155**	0.149[*]	0.133	0.122	0.152*
	(0.08)	(0.08)	(0.09)	(0.08)	(0.07)	(0.06)	(0.06)	(0.07)	(0.10)	(0.09)	(0.09)	(0.08)
Implied Marginal Productivities												
Private Capital	0.496	0.508	0.525	0.512	0.290	0.298	0.268	0.284	0.696	0.715	0.739	0.718
PIMI-adjusted Public Capital	0.680	0.753	0.665	0.674	0.474	0.551	0.591	0.467	0.822	0.798	0.709	0.803
Hansen J-test	[1.00]	[1.00]	[1.00]	[1.00]	[1.00]	[1.00]	[1.00]	[1.00]	[1.00]	[1.00]	[1.00]	[1.00]
AR(2) test	[0.61]	[0.59]	[0.59]	[0.61]	[0.50]	[0.50]	[0.51]	[0.49]	[0.84]	[0.88]	[0.88]	[0.85]
Common factors	[0.10]	[0.14]	[0.20]	[0.14]	[0.08]	[0.13]	[0.09]	[0.07]	[0.55]	[0.83]	[0.88]	[0.78]
Observations	414	414	414	414	186	186	186	186	228	228	228	228
Countries	52	52	52	52	24	24	24	24	28	28	28	28

Note: Dependent variable is the log-difference of real GDP in international dollars. Standard errors in parentheses: [*] p<0.15, * p<0.1, ** p<0.05, *** p<0.01.

All is our entire sample of 52 countries, **MIC** is the subsample of 24 middle-income countries, and **LIC** is the subsample of 28 low-income countries

Table 8. Results of Robustness Tests

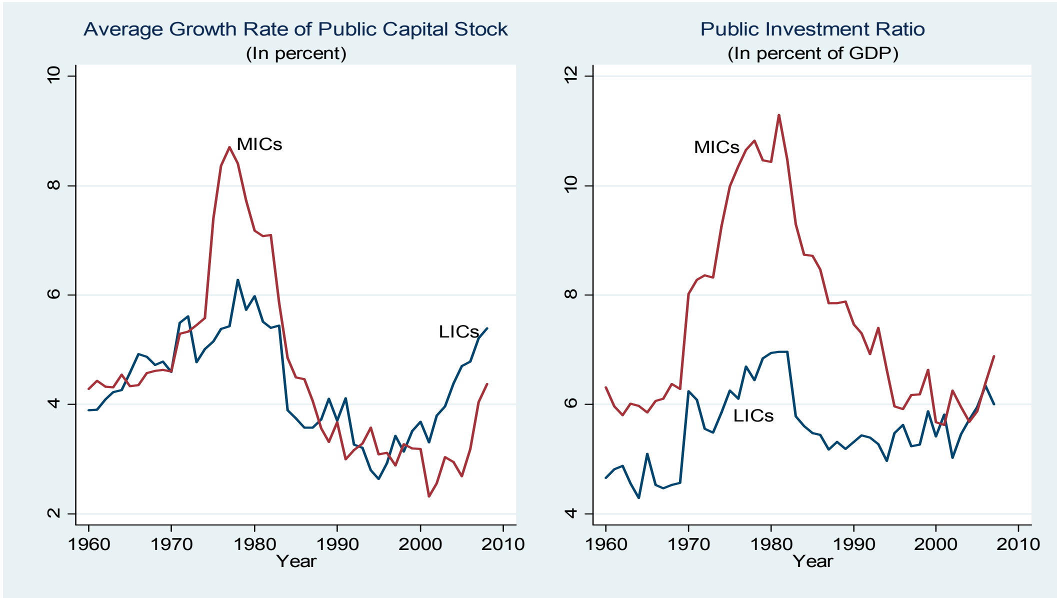
Parameters	Estimate	Std. Err.	z	P>z	[95% Conf. Interval]	
Time varying PIMI			**328 observations**			
α	0.425	0.075	5.67	0.000	0.278	0.572
β	0.401	0.080	5.03	0.000	0.245	0.557
γ	0.174	0.071	2.44	0.015	0.034	0.313
Re-weighted PIMI			**414 observations**			
α	0.337	0.191	1.77	0.077	-0.037	0.711
β	0.294	0.090	3.25	0.001	0.117	0.471
γ	0.158	0.082	1.92	0.055	-0.003	0.319
Constant Elasticity of Substitution			**414 observations**			
α	0.371	0.156	2.38	0.017	0.066	0.676
δ	0.408	0.226	1.80	0.071	-0.035	0.851
ν	0.783	0.204	3.83	0.000	0.382	1.184
ρ	-0.839	0.756	-1.11	0.267	-2.322	0.643
Constant Returns to All Inputs			**414 observations**			
α	0.475	0.091	5.22	0.000	0.297	0.653
β	0.356	0.098	3.65	0.000	0.165	0.547
γ	0.170	0.087	1.95	0.051	-0.001	0.34
Labor and human capital			**414 observations**			
α_1	0.214	0.200	1.07	0.285	-0.178	0.605
α_2	0.354	0.148	2.39	0.017	0.064	0.644
β	0.334	0.086	3.87	0.000	0.165	0.503
γ	0.142	0.073	1.95	0.051	-0.001	0.284
Sample starting from 1980			**290 observations**			
α	0.306	0.176	1.74	0.083	-0.040	0.651
β	0.284	0.091	3.12	0.002	0.105	0.462
γ	0.176	0.087	2.03	0.042	0.006	0.346
Full sample without PIMI			**973 observations**			
α	0.465	0.197	2.36	0.018	0.080	0.851
β	0.305	0.081	3.76	0.000	0.146	0.463
γ	0.167	0.075	2.22	0.026	0.020	0.315

Table 9: Results of Robustness Tests (cont.)
Variations on the Instrument Matrix

	(1) Baseline	(2) Baseline, level eq. collapsed	(3) Baseline, diff eq. collapsed	(4) One lag	(5) One lag CRS	(6) One lag diff. eq. collapsed CRS
Estimated Factor Shares						
Skilled Labor	0.336*	0.186	0.268	0.365*	0.544***	0.584***
	(0.19)	(0.20)	(0.27)	(0.20)	(0.103)	(0.115)
Private Capital	0.297***	0.328***	0.229*	0.241**	0.262**	0.256**
	(0.09)	(0.12)	(0.13)	(0.12)	(0.119)	(0.120)
Public Capital	0.154*	0.193**	0.178*	0.183*	0.194**	0.160**
	(0.08)	(0.09)	(0.10)	(0.10)	(0.091)	(0.079)
Joit significance of private and public capital	[0.0000]	[0.0000]	[0.0003]	[0.0000]	[0.0000]	[0.0008]
Hansen J-test	[1.00]	[1.00]	[0.598]	[0.998]	[0.658]	[0.518]
AR(2) test	[0.60]	[0.617]	[0.578]	[0.589]	[0.648]	[0.641]
Number of instruments	125	97	53	73	57	36
Observations	414	414	414	414	414	414
Countries	52	52	52	52	52	52

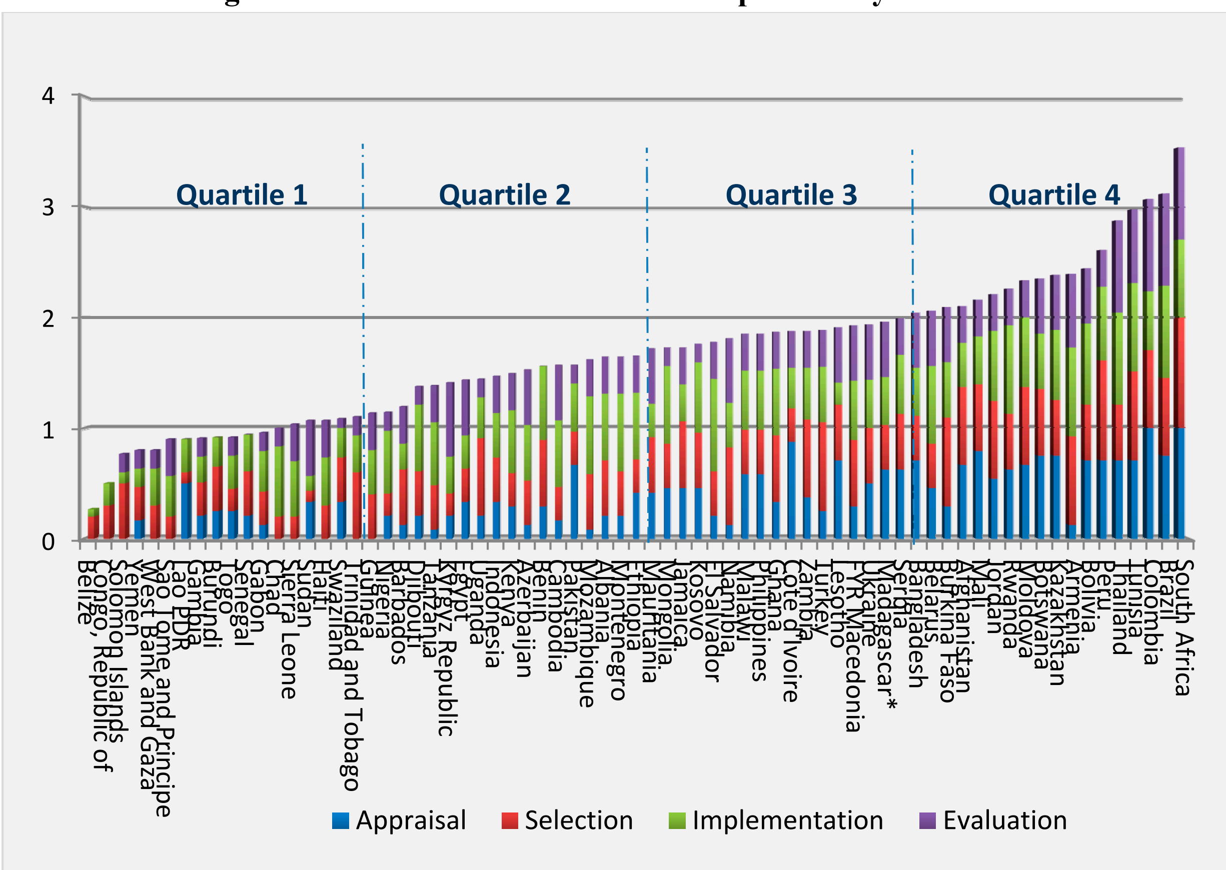
Note: Dependent variable is the log-difference of real GDP in international dollars. Independent variables are the log-difference in skilled labor, private capital and (adjusted) public capital, respectively. Standard errors in parentheses: *p<0.1, **p<0.05, ***p<0.01. All is our entire sample of 52 countries, MIC is the subsample of 24 middle-income countries, and LIC is the subsample of 28 low-income countries.

Figure 1. Investment Ratio and Growth Rate of Public Capital



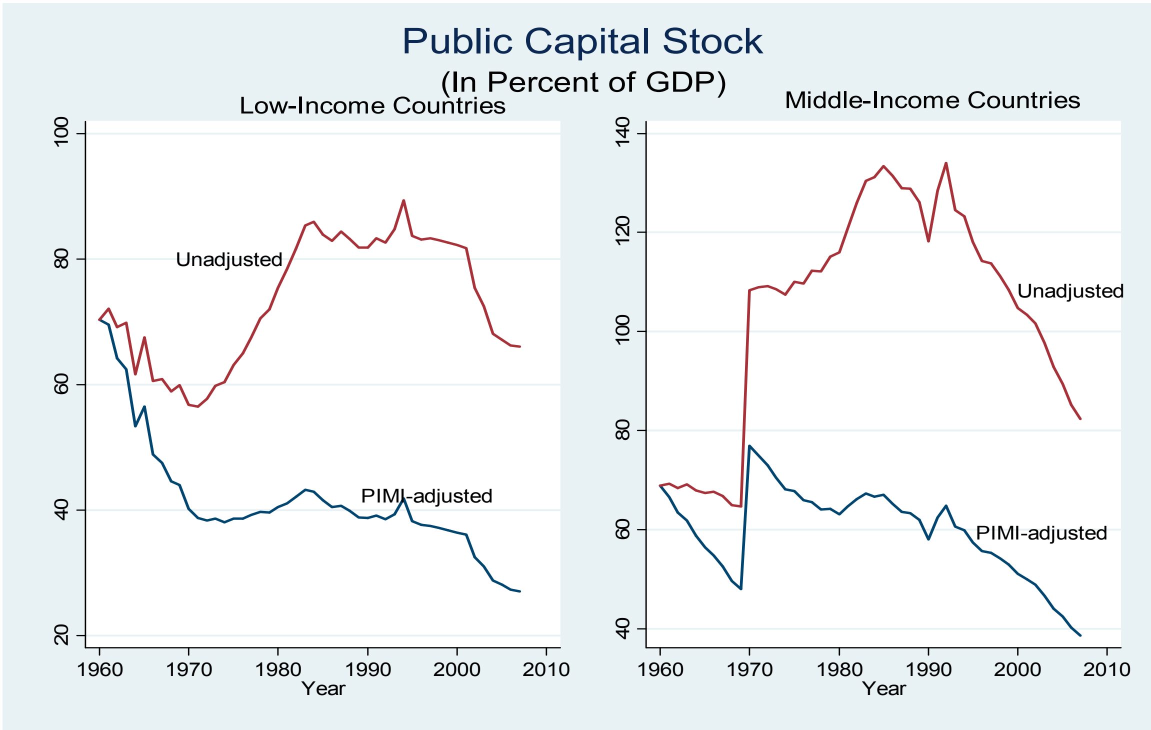
Sources: Penn World Table version 6.2, IMF WEO and authors' calculations.

Figure 2. PIMI Distribution and Decomposition by Sub-Index



Source: Dabla-Norris et al. (2011) Note: For details see Dabla-Norris et al. (2011).

Figure 3. Unadjusted and PIMI-adjusted Capital Stock by Income Group



Source: Authors' calculations using data from PWT version 6.2, IMF, WEO, and Dabla-Norris et al. (2001).

Appendix A. List of 52 Countries used in Baseline Analysis

Afghanistan, Albania, Armenia, Bangladesh, Barbados, Belize, Benin, Bolivia, Botswana, Brazil, Burundi, Cambodia, Colombia, Congo, Cote d`Ivoire, Egypt, El Salvador, Gabon, Gambia, Ghana, Haiti, Indonesia, Jordan, Kazakhstan, Kenya, Laos, Lesotho, Malawi, Mali, Mauritania, Moldova, Mongolia, Mozambique, Namibia, Pakistan, Peru, Philippines, Rwanda, Senegal, South Africa, Sudan, Swaziland, Tanzania, Thailand, Togo, Trinidad & Tobago, Tunisia, Turkey, Uganda, Ukraine, Yemen, Zambia.

Appendix B. Details on the Construction of PIMI-adjusted Public Capital Stock Series

This appendix explains the methodology to construct PIMI-adjusted public capital stock series for our sample of 52 low-income and middle-income countries. The basic capital accumulation equation takes the form B1 below:

(B1) $K_t = K_{t-1} + q_i * I_{it-1} - D_{t-1}$.

Assuming a geometric depreciation rate the capital accumulation equation can be rewritten as:

(B2) $K_t = (1-\delta)^{t-1} * K_0 + \sum_{i=1}^{t}(1-\delta)^i * (q_i * I_{it-1})$.

The inputs necessary for constructing these series are the depreciation rate, the initial public capital stock, the unadjusted public investment series and the PIMI-adjusted public investment series.

- The depreciation rate is assumed to be constant over time for low-income countries at 2.5 percent per year. For middle-income countries, the depreciation rate increases monotonically at a constant rate from 2.5 percent in 1960 to 4.3 percent in 2010.
- The initial capital public capital stock (in year 1960) is obtained by first creating an artificial investment series before 1960 by assuming that public investment increased by 4 percent per year to its observed level in 1960. These investment flows before 1960 and the assumption of a zero stock of capital in 1860 gives a series of public capital stock up to 1960.
- The unadjusted public investment series is in turn obtained by applying the investment share from the WEO database to the total investment series from Penn World Table.
- The effective public investment series is obtained by applying the normalized overall PIMI index (q_i) to the gross public investment series I_{it}.

Appendix C. Initial Conditions and PIMI Effect on Efficiency Adjusted Capital

Assume that PIMI in 1860 same as today

This case can be shown analytically.[1] In continuous time, using an asterisk to indicate adjusted capital stock, and allowing for a time varying depreciation rate the motion equation of public capital is

$$(C1)\quad \dot{K}_i^*(t) = q_i I(t) - \delta_i(t) K^*(t)$$

which integrates to (now ignoring the *i* except on the *q*):

$$(C2)\quad K^*(t) = q_i \int_0^t I(v) e^{-\int_v^t \delta_i(s)ds} dv + K^*(0)\, e^{-\int_0^t \delta_i(s)ds}$$

Meanwhile, the <u>un</u>adjusted capital stock *K* is

$$(C3)\quad K(t) = \int_0^t I(v) e^{-\int_v^t \delta_i(s)ds} dv + K(0)\, e^{-\int_0^t \delta_i(s)ds}$$

Comparing (C2) and (C3) gives

$$(C4)\quad K^*(t) = q_i \left[K(t) - K(0) e^{-\int_0^t \delta_i(s)ds}\right] + K^*(0) e^{-\int_0^t \delta_i(s)ds}$$

$$(C5)\quad K^*(t) = q_i K(t) + [K^*(0) - q_i K(0)] e^{-\int_0^t \delta_i(s)ds}$$

This says that the adjusted capital stock at any date is a country specific linear transformation of the unadjusted, where the shift part of transformation is time and country dependent.

If starting value is

$$(C6)\quad K^*(0) = q_i K(0)$$

Then (C5) becomes just

$$(C7)\quad K^*(t) = q_i K(t)$$

So in this case the adjustment is just a time invariant proportional scaling down.

[1] We thank Mick Keen for this derivation.

Appendix D: Alternative Approach to Assessing the Effect of Different Stages of Public Investment on Aggregate Output

In addition to aggregate efficiency-adjusted public capital stocks, we also construct *notional* capital stocks for each investment process corresponding to each of PIMI components (appraisal, selection, implementation and evaluation). Specifically, we use

(D1) $K'_{it} = K'_{it-1} - \delta_{it} * K'_{it-1} + q_i q_{ij} * I_{it-1}$,

where q_{ij} corresponds to each of the four PIMI components.

In this alternative approach to incorporating stages of public investment process in the analysis, we add percent shares of effective capital due to each stage (i.e. public capital stocks attributed to each of the four public investment stages divided by total public capital stock). This approach responds to the question whether at a given level of quality of the overall investment process some combinations of the components of PIMI would have a higher (or lower) effect on output and growth. This relates to the Figure 2 that for many countries with comparable overall scores shows large variations in the PIMI components. This approach also provides some indication on the optimal allocation of resources between the different stages of public investment.

Table D1 presents the coefficient estimates for “Appraisal Share,” “Selection Share” and “Implementation Share”, which reflect the variation in the shares of efficiency-adjusted capital due to appraisal, selection and implementation to total PIMI-adjusted public capital.[2] Consistent with the results in the main text, they suggest that increasing the share of project appraisal by one unit (compared to the share of evaluation) increases output or growth by about 3 percent. Results seem to be driven by LICs in which project selection and implementation appear to be the most efficient stages of public investment management.

[2] Note that the evaluation share was omitted to avoid multicolinearity.

Table D1. Regressions with Shares of Each Stage of the Investment Process

	ALL	MIC	LIC
	(1)	(2)	(3)
Skilled Labor	0.486***	0.400**	0.588***
	(0.18)	(0.19)	(0.19)
Private Capital	0.332***	0.402***	0.316***
	(0.09)	(0.04)	(0.07)
Appraisal Share	0.033**	0.028**	0.036*
	(0.02)	(0.01)	(0.02)
Selection Share	0.038**	0.012	0.053***
	(0.02)	(0.01)	(0.02)
Implementation Share	0.034**	0.007	0.042**
	(0.01)	(0.01)	(0.02)
Observations	414	186	228

Note: Dependent variable is the log-difference of real GDP in international dollars. Standard errors in parentheses: * $p<0.1$, ** $p<0.05$, *** $p<0.01$. All is our entire sample of 52 countries, **MIC** is the subsample of 24 middle-income countries, and LIC is the subsample of 28 low-income countries.

Appendix E. Recovering the Parameters of the CES Production Function

Our specification of the CES function with quality-adjusted labor, private capital and PIMI-adjusted public capital takes the following form:

(C1) $Y_{it} = A_0(H_{it}L_{it})^{\alpha}[\delta K_{it}{}^{-\rho} + (1-\delta)G_{it}{}^{-\rho}]^{\frac{(1-\alpha)*\upsilon}{\rho}} e^{-\lambda*t+\varepsilon_{it}}$.

H and L stand for human capital and labor, respectively. K and G denote private capital and PIMI-adjusted public capital, respectively.

Taking logs gives:

(C2) $\log Y_{it} = \log A_0 + \alpha\log(H_{it}L_{it}) - \frac{(1-\alpha)\upsilon}{\rho}\log\left[\delta K_{it}^{-\rho} + (1-\delta)G_{it}^{-\rho}\right] + \lambda t + \varepsilon_{it}$.

The first-order linearization around $\rho = 0$ gives:

(C3) $\log Y_{it} = \log A_0 + \lambda t + \alpha\log(H_{it}L_{it}) + (1-\alpha)\upsilon\delta\log K_{it} + \upsilon(1-\alpha)(1-\ \delta)\log G_{it} - \frac{(1-\alpha)}{2}\upsilon\rho\delta(1-\delta)\,(\log K_{it} - \log G_{it})^2 + \varepsilon_{it}$.

This can be rewritten in the following form that can be directly estimated:

(C4) $\log Y_{it} = \log A_0 + \alpha\log(H_{it}L_{it}) + a\log K_{it} + b\log G_{it} + c\,(\log K_{it} - \log G_{it})^2 + \varepsilon_{it}$.

The parameter α is directly identifiable from the results of the regression. Other parameters of the CES function need however to be recovered. The following equations help identify each of these parameters:

$$a = (1-\alpha)*\upsilon*\delta,$$
$$b = \upsilon*(1-\alpha)*(1-\delta),$$
$$c = -\frac{(1-\alpha)*\upsilon\rho\delta(1-\delta)}{2}.$$

These equations can be solved in the unknown and parameters of the CES function that are not directly estimated:

$$\delta = \frac{a}{a+b}\ ;\ \ \upsilon = \frac{a+b}{1-\alpha};\ \ \rho = -\frac{2c(a+b)}{ab}$$