CHAPTER 3

Getting the Most from Public Investment

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INTRODUCTION

Examples of inefficient spending in infrastructure abound in all countries. In the United States, 11 miles of a subway tunnel lie abandoned under the streets of Cincinnati. Residents approved the subway in 1916, but cost overruns meant that it was never completed. Its bond issue was paid off in 1966—at twice the cost of the project, with interest.[1] In Italy, Rome's Vigna Clara railway station, built at a cost of $50 million to transport fans to soccer matches for the 1990 World Cup, was used only for two weeks and shut down in 1993.[2] Williams (2017), analyzing a database of 14,000 development projects in Ghana, found that one-third of projects that start are never completed, wasting on average one-fifth of local government investment. In a sample of Nigerian federal government social sector projects, Rasul and Rogger (2016) found that a quarter were not completed.[3] These are but a few instances of public spending that is not fully reflected in a greater stock of infrastructure assets or improvements in the delivery of public services.

Countries will need to reap the full benefit of their spending to achieve their growth and development goals. Substantial evidence shows that public investment in infrastructure can significantly contribute to economic growth and improve other development outcomes, including those of the Sustainable Development Goals (see Chapter 2 on the investment-growth nexus and Chapter 4 on the goals). Reaching these goals will be challenging. As noted in Chapter 4, total cumulative investment needs in infrastructure between today and 2030 are more than 36 percent of GDP in emerging markets and low-income developing countries. Spending needs are large and financing options are limited:

[1] See https://www.cincinnati-oh.gov/dote/about-transportation-engineering/historical-information/the-cincinnati-subway/.

[2] See https://www.washingtonpost.com/archive/politics/1993/02/28/deepening-scandal-threatens-italian-state/b9cf68d4-f195-44f3-8ac0-45d9ee8a7332/?utm_term=.882e189c658b.

[3] The sample of projects covered 8 percent of the federal government social sector expenditures. Four out of every five of the projects considered were for infrastructure.

- There is little scope to increase *debt financing*. In low-income developing countries, the public debt burden has risen since 2013, and 40 percent of countries in this group face debt-related challenges (IMF 2018b). In advanced economies, debt stands at 105 percent of GDP, a record since World War II (IMF 2018a).
- Increased *domestic revenue mobilization* will cover only part of spending needs, at least in low-income developing countries. Gaspar and others (2019) estimated that in low-income developing countries, an increase in revenue of 5 percent of GDP is ambitious but feasible. Yet, this will be insufficient given the size of the needs.
- *Private sector financing* options are not without fiscal risks. For example, public-private partnerships can provide benefits relative to traditional procurement (such as private sector efficiency and innovation), but their cost must be borne by taxpayers or users and can have explicit or implicit risks and liabilities for governments. (Chapter 11 features a discussion on fiscal risks in infrastructure.)

Boosting the efficiency of public spending—that is, increasing the volume and quality of infrastructure assets without adding to expenditure—can simultaneously tackle the dual challenges of pressing needs and limited financial options. In this balancing act, no effort should be spared to make public investment more efficient—reduce cost overruns, complete ongoing projects, eliminate white elephants and trains to nowhere, and cut opportunities for fraud in the use of public resources.

On average, countries lose more than one-third of their resources in the public investment process, according to estimations made in this chapter. A measure of the efficiency of public investment spending is provided by comparing the value of public capital and resulting outcomes in infrastructure volume and quality across countries. The analysis finds that most countries have an efficiency gap and could substantially increase the return to public investment. Improvements in infrastructure governance are crucial in capturing these gains.

The analysis suggests that the average country could close more than half of the efficiency gap if it adopted the infrastructure governance and public investment management practices of the best performers. The chapter estimates he link between efficiency and the strength of a country's infrastructure governance as measured by the IMF's Public Investment Management Assessment (PIMA; IMF 2018c). The relationship is robust and significant. Indeed, strengthening public investment management institutions can be key to increasing the efficiency of public investment.

INFRASTRUCTURE AND PUBLIC INVESTMENT EFFICIENCY

Efficiency estimates help assess the degree of inefficiency in public spending. Policymakers are expected to improve social welfare and long-term growth prospects and, in this process, use scarce public resources efficiently. At a time of increased pressure on public balances, analyses that provide guidance on how to make the most out of spending resources take on additional importance. However, providing good guidance is complicated, given that spending data are imperfect, spending outcomes are often ill-defined, cross-country and time-series coverage are limited, and methods to estimate efficiency are flawed. In addition, outcomes may be affected by factors outside the control of policymakers.[4]

Public investment efficiency is defined as the ability to improve the volume and quality of infrastructure assets for a given level of spending. Efficiency is measured through benchmarking—a systematic comparison of the performance of one country's infrastructure outcomes against peers for a given level of spending. For example, if two otherwise similar countries spend the same on roads, the country that ends up with greater kilometers of paved roads is more efficient. While there is abundant literature on benchmarking health and education spending, similar exercises for public investment are scarce (Herrera and Pang 2005; Grigoli and Kapsoli 2013; Albino-War and others 2014; IMF 2015; and Kapsoli and Teodoru 2017; among others).

A country's public investment efficiency is benchmarked relative to an "efficiency frontier." The efficiency frontier is based on the best performers in terms of output (infrastructure outcomes) for any given level of input (cumulative spending or the capital stock). A country on the efficiency frontier is considered "efficient" and assigned a score of 1, whereas a country below the frontier is considered "inefficient" and given a score of less than 1. The further a country is from the frontier the more inefficient it is.[5] The performance of all countries is therefore assessed by measuring distance from this efficiency frontier. This distance is called the efficiency gap.[6] Figure 3.1 illustrates the efficiency frontier based on a single-input (public capital), single-output (infrastructure outcome) model, but estimation methods allow the possibility of multiple inputs and outputs.[7]

Estimates of public investment efficiency are provided for over 100 countries across the income spectrum. For given levels of the public capital stock and GDP per capita (inputs), data are combined on the volume of economic (length of road network, electricity production, and access to water) and social infrastructure (number of secondary teachers and hospital beds), and its quality (derived from the World Economic Forum survey on the quality of infrastructure).[8]

[4] Mandl, Dierx, and Ilzkovitz (2008) discusses this.

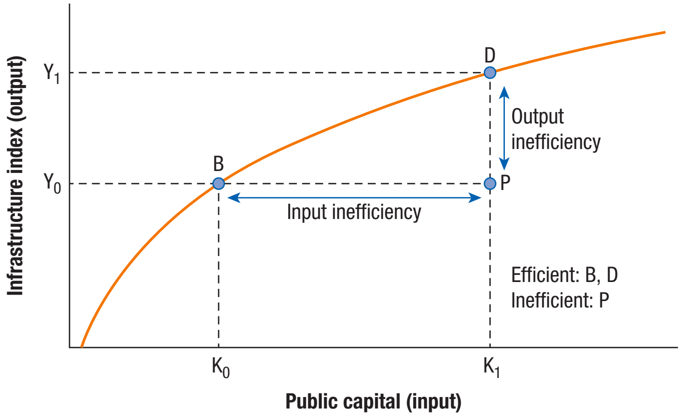
[5] A hypothetical country that produces no infrastructure outcomes for a given level of input has a score of 0.

[6] The focus of this chapter is on technical efficiency. Countries may efficiently produce the wrong infrastructure—that is, they may be technically efficient while being allocatively inefficient. Estimating allocative efficiency would require comparable cross-country input prices and is outside the scope of the analysis in this chapter.

[7] Figure 3.1 illustrates both input and output efficiency; this chapter focuses on output efficiency estimates.

[8] Roads, electricity, and water receive a large share of public investment, and the public sector also still dominates the provision of social infrastructure. See the Annex for a discussion on data use and treatment.

Figure 3.1. Investment Efficiency Frontier



Source: Authors.

The resulting efficiency score is a hybrid indicator, accounting for the volume of economic and social infrastructure and its quality. For robustness, efficiency scores, which are exclusively based on economic infrastructure, are considered.[9] Two methods, described in Box 3.1, are used to estimate efficiency—data envelopment analysis and stochastic frontier analysis.

Estimates in this chapter confirm that there is substantial scope for improving public investment efficiency in most countries. Investment efficiency is estimated for up to 164 countries (using various efficiency score estimation methods), and the results are shown in Figure 3.2. The estimated median efficiency gap is large—over one-third of resources are lost in the public investment process. The gap ranges between 33 percent for the data envelopment analysis estimation and 43 percent for the stochastic frontier analysis (adjusted for skewness), with wide variation across countries around this overall range. Skewness adjustments matter particularly for low-income developing countries, significantly improving the efficiency scores for the top 25th percentile.[10] The different efficiency score outcomes also indicate that the 33 percent average gap resulting from the data envelopment analysis may be a lower bound.

Efficiency varies widely across income groups and regions. In general, the size of the gap shrinks as income rises. For example, as shown in Figure 3.2, panel 1

[9] See Annex 3.3 for data sources and Annex 3.1 for a more detailed discussion of the construction of the efficiency score.

[10] This result is driven by heavy skewness in electricity and road indicators, for which most data from low-income developing countries are clustered on the left of the distribution, leading to overall worse efficiency scores. Skewness adjustment creates normal distributions over all indicators, effectively comparing all indicators in relative terms and reducing this kind of bias. See Box 3.1.

Box 3.1. Robust Estimation of Spending Efficiency

This box details the methods and data treatment used in this chapter to ensure robustness of the efficiency estimates.

Methodologies to Estimate Spending Efficiency

There are two families of methodologies to estimate efficiency—parametric and nonparametric. Both estimate a frontier of best performers to identify the efficiency of individual countries relative to a reference set of countries. Each methodology has advantages and disadvantages (and is reviewed in Murillo-Zamorano 2004).

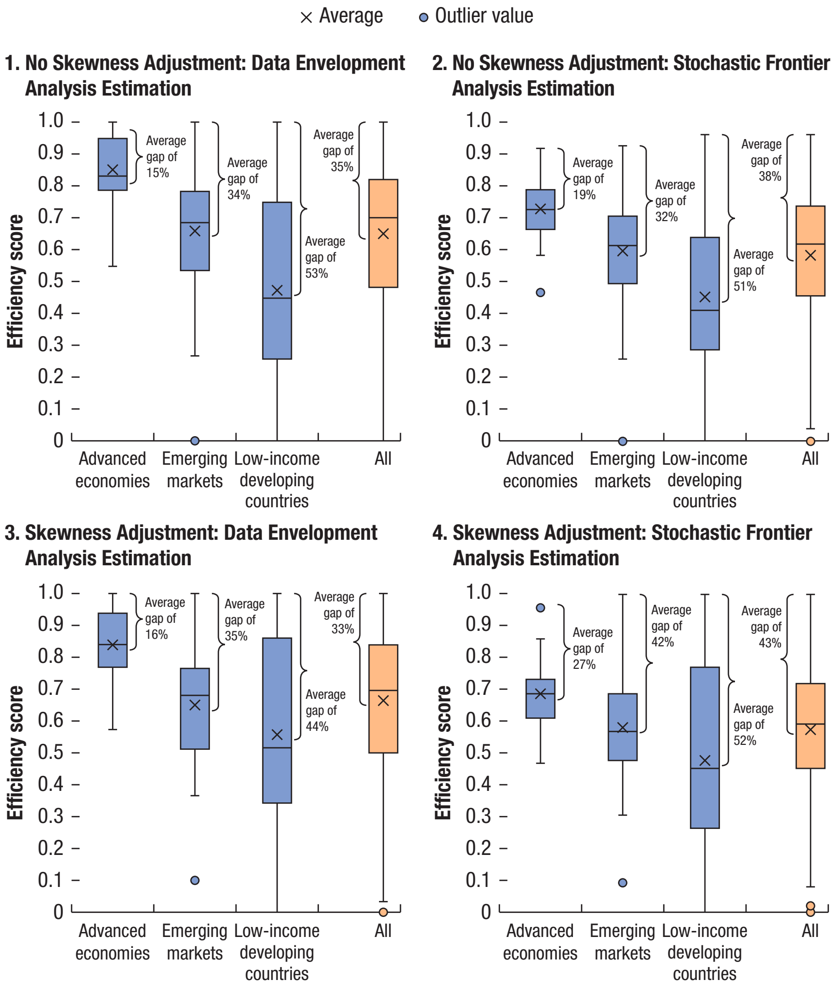
- *Parametric* methods assume a specific functional form for the relationship between spending and outcomes. Efficiency is estimated using econometric methods that require assumptions on the statistical distribution of error terms. For example, stochastic frontier analysis assumes a stochastic relationship between inputs and outputs, allowing the identification of deviations from the frontier as inefficiencies, separating them from measurement error or other noise in the data.
- *Nonparametric* methods are deterministic and based on mathematical programming to identify an "efficient frontier." They do not require assumptions about the distribution of error terms or functional forms. However, all deviations from the frontier are assumed to come from inefficiencies, which makes these models sensitive to the presence of outliers or noise in the data. Data envelopment analysis is—by far—the most widely used method in the nonparametric benchmarking literature (Herrera and Ouedraogo [2018] discusses other nonparametric techniques).

Each method has advantages and disadvantages. Stochastic frontier analysis separates random noise from efficiency; data envelopment analysis incorporates it as part of the efficiency score. The stochastic frontier analysis is estimated using econometric methods; data envelopment analysis directly uses the best-performing countries in the sample to establish the efficiency frontier. IMF (2015) conducted an efficiency estimate analysis for the data envelopment analysis only. Both methods for robustness are presented in this chapter.

Data Treatment

Some data are corrected for skewness to adjust for the impact of outliers. Some outcome indicators are highly skewed. For example, the observations for electricity production are clustered around low values—a high proportion of low-income countries produce low levels of electricity per capita. However, if there are a few outliers—countries with high production—they will have a disproportionate impact on the aggregate standardized indicator for infrastructure outcomes. The skewness adjustment reduces this effect (see Annex 3.1 for more information on skewness adjustment).

Figure 3.2. Public Capital and Infrastructure Performance: Hybrid Public Investment Efficiency Score, by Income Level



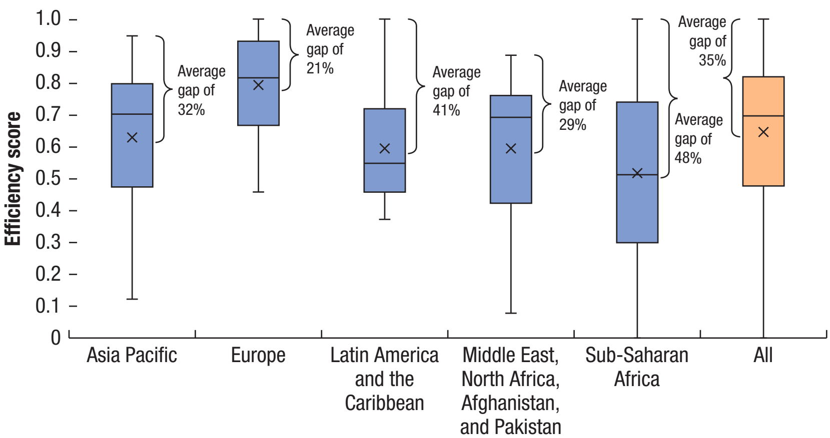
Sources: Feenstra, Inklaar, and Timmer 2015; OECD 2018; World Development Indicators 2018; World Economic Forum 2018; World Economic Outlook database; and IMF staff estimates.
Note: Each box shows the median and the 25th and 75th percentiles, and the whiskers show the nonoutlier maximum and minimum values. Scores range between 0 and 1. The average efficiency gap is computed as the mean percentage difference between the highest and the average efficiency scores. The four panels reflect different combinations of two aspects in the efficiency score derivation methodology.

(data envelopment analysis, nonadjusted efficiency scores), on average, low-income developing countries face an efficiency gap of 53 percent, while emerging markets have a gap of 34 percent, and advanced economies a gap of 15 percent. The range between top and bottom performers declines as income rises. For advanced economies, the maximum efficiency gap ranges from 42 to

49 percent (depending on the method used to derive efficiency scores), and it ranges from 96 to 100 percent for low-income developing countries. Similarly, efficiency gaps in the middle 50 percent of countries—those within the blue and orange boxes in Figure 3.2—vary more across low-income developing countries than across emerging markets or advanced economies. The greater heterogeneity across low-income developing countries suggests that greater scope exists for efficiency improvements in this income group. Regional disparities are prevalent too (Figure 3.3). Average public investment efficiency also varies widely across regions, from an efficiency gap of about 21 percent in Europe to 48 percent in sub-Saharan Africa.

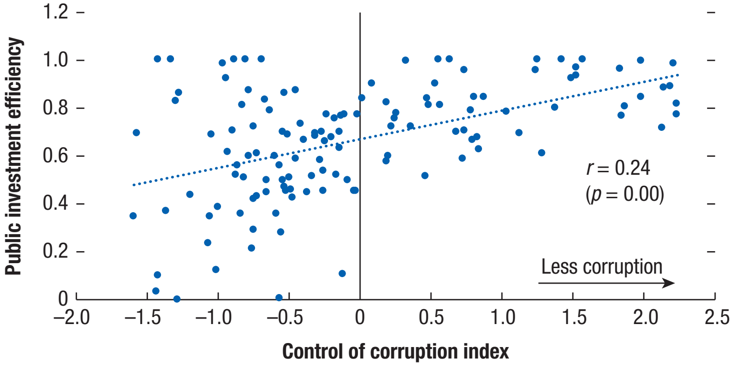
Efficiency gap estimates provide a measure of wasted resources and hint at potential institutional weaknesses. For example, the gap might reflect corruption in the form of cost overruns and bid rigging. Figure 3.4 shows that higher public investment efficiency goes together with lower corruption, measured here as perceived control of corruption. The variance of efficiency scores also declines with declining corruption levels (for a more detailed analysis of the link between corruption and public investment efficiency, see Chapter 10 of this book and IMF 2019). Efficiency gaps could equally reflect weak infrastructure governance institutions, such as weak project design, appraisal, and selection. The next section further explores this link.

Figure 3.3. Public Capital and Infrastructure Performance: Hybrid Public Investment Efficiency Score, by Region



Sources: Feenstra, Inklaar, and Timmer 2015; OECD 2018; WEO 2018; World Development Indicators 2018; World Economic Forum 2018; and IMF staff estimates.
Note: Each box shows the median and the 25th and 75th percentiles, and the whiskers show the nonoutlier maximum and minimum values. Scores range between 0 and 1. The average efficiency gap is computed as the mean percentage difference between the highest and the average efficiency scores. Some groupings with too few countries to be meaningful (North America and the Commonwealth of Independent States) are not shown, but they are included in the "All" country grouping.

Figure 3.4. Corruption and Public Investment Efficiency



Sources: Worldwide Governance Indicators 2017; and IMF staff estimates.
Note: Efficiency indicators are corrected for skewness and based on the data envelopment analysis methodology.

INFRASTRUCTURE GOVERNANCE AND EFFICIENCY

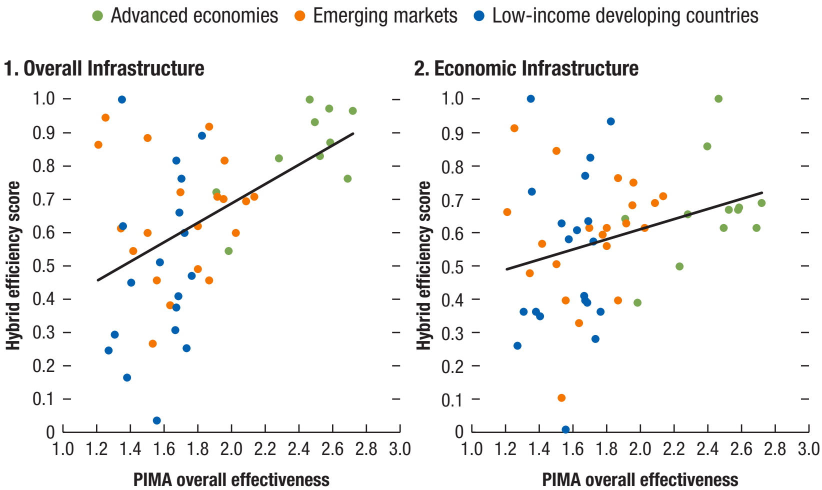
The link between infrastructure governance and public investment efficiency is investigated using a regression framework. The analysis assesses how levels of efficiency in public investment spending relate to the quality of public investment management institutions, using the efficiency score estimates described earlier in this chapter and the PIMA effectiveness index.[11]

Fiscal institutions are crucial for economic growth and the efficiency of public spending. Institutional quality has been shown to have a positive impact on economic growth (Aron 2000; Easterly, Ritzen, and Woolcock 2006; Acemoglu and Robinson 2012). As discussed in Chapter 2, additional public investment has a higher growth impact on average in countries with better infrastructure governance. IMF (2015) also established a link between public investment efficiency and infrastructure governance as measured by the IMF's PIMA. Field PIMA missions conducted in the past four years with data collected from 62 countries offer a fresh opportunity to assess the role of infrastructure governance using comparable metrics in a unified framework. The PIMA methodology is discussed in detail in Chapter 5.

The quality of public investment management institutions is highly correlated with estimated measures of public investment efficiency. As shown in Figure 3.5, this relationship holds for efficiency scores based on both overall and economic infrastructure. Advanced economies are set apart as a group of strong performers

[11] See Annex 3.2 for details on the empirical framework.

Figure 3.5. PIMA Effectiveness and Public Investment Efficiency, by Income Group



Source: IMF staff calculations.
Note: Efficiency scores are derived using data envelopment analysis and are not adjusted for skewness. PIMA = Public Investment Management Assessment.

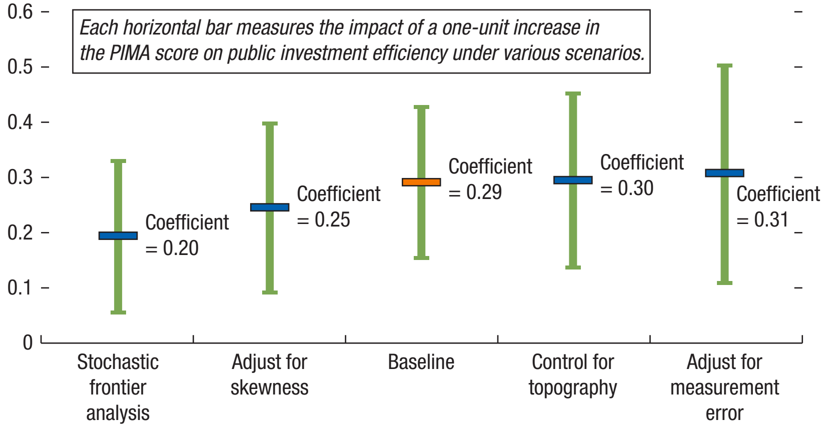
in both dimensions of investment management and investment efficiency (Figure 3.5). In contrast, while emerging markets show better results along both parameters than low-income developing countries, significant overlap exists between the two income groups.

The regression analysis shows a statistically and economically significant association between strength of public investment management institutions and public investment efficiency. Figure 3.6 displays the main regression results (the regression coefficient measuring the impact of PIMA on efficiency) when outcome indicators include overall infrastructure (both economic and social).[12] The baseline in Figure 3.6 reflects the scenario with the fewest adjustments—no adjustment for skewness, no additional controls, and estimated using the data envelopment analysis methodology. Additional scenarios are considered for robustness. The analysis makes the following clear:

- *The link between efficiency and PIMA scores is strong and statistically significant*. In terms of magnitude, the estimates suggest that by increasing its PIMA score by one unit (on a scale of 1 to 3), an emerging market economy could rise from the median to the group of best performers for its

[12] See Annex Table 3.2.1 for these and additional results based on further analytical variants.

Figure 3.6. Infrastructure Governance and Public Investment Efficiency: Increase in Efficiency Associated with a One-Unit Increase in PIMA Score (Overall Infrastructure)



Source: Authors' calculations.
Note: Each horizontal bar represents the coefficient from a separate regression of efficiency scores on PIMA, that is, the figure reflects results from five regressions. Bars are arranged in ascending order of coefficients. The vertical lines indicate 95 percent confidence intervals around the point estimates. Public investment efficiency is measured by the hybrid efficiency score including the quality and volume of overall infrastructure. The baseline result reflects efficiency scores with no adjustment for skewness, estimated using data envelopment analysis, and regression analysis that does not adjust for measurement error and does not control for topography. The other bars correspondingly consider each of these adjustments and variations in estimation methodology. Annex 3.2 discusses the details of the underlying regression analysis and presents results based on additional robustness tests.
PIMA = Public Investment Management Assessment.

income level in efficiency.[13] Estimates are only slightly lower and remain statistically significant when infrastructure outcome indicators are adjusted for skewness. Further assessment of the economic significance of these estimates opens up discussion in the rest of this chapter about how much of the efficiency gap could be closed when public investment management is improved.

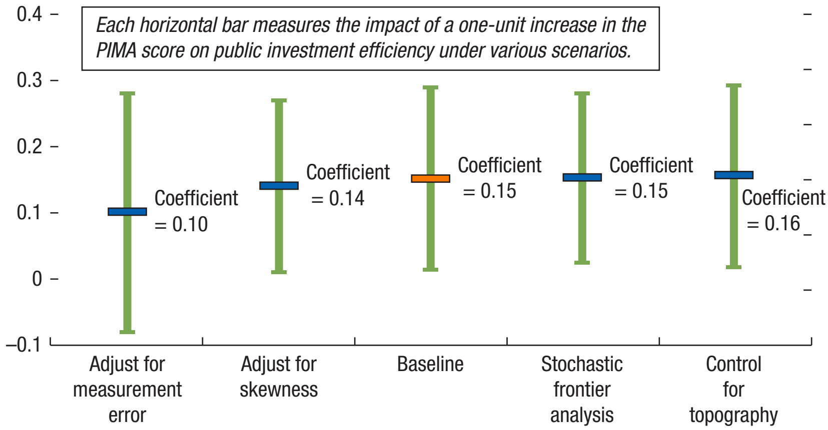
- *The results are robust to the estimation method for efficiency*. Although the relationship is somewhat weaker in the regression based on stochastic frontier analysis efficiency scores, regression results are statistically significant for both data envelopment analysis and stochastic frontier analysis estimates.

[13] A one-unit increase in PIMA scores is associated with an increase in the efficiency score by close to 0.3 units across most scenarios in Figure 3.6. To gain perspective on these magnitudes: the one-unit increase in the PIMA score is approximately equal to the difference between the average PIMA scores of low-income developing countries and advanced economies. The associated efficiency gain of 0.3 units is substantive, given that scores only range from 0 to 1.

- *Additional controls do not alter the magnitude of the coefficients*. While efficiency scores account for GDP (see the "Infrastructure and Public Investment Efficiency" section), other factors may affect the efficiency of spending. Additional regressions also control for topography, given that more rugged terrain usually increases the cost of creating infrastructure (in building roads, for example). The result is robust to its inclusion.
- *The results are robust to adjustments for measurement error*. Of the available 62 country PIMAs, 52 were conducted using primary data collected during field missions, while 10 are based on desk assessments based on secondary sources. To correct for potential measurement error in desk assessments, the estimation uses a mission-visit dummy variable as an instrumental variable for the PIMA score.

Sound institutions for public investment also go together with better efficiency in producing economic infrastructure—although by a lesser magnitude than for overall infrastructure. In the analysis so far, consideration has been given to how accumulated public investment translates into infrastructure across multiple

Figure 3.7. Infrastructure Governance and Public Investment Efficiency: Increase in Efficiency Associated with a One-Unit Increase in PIMA Score (Economic Infrastructure)

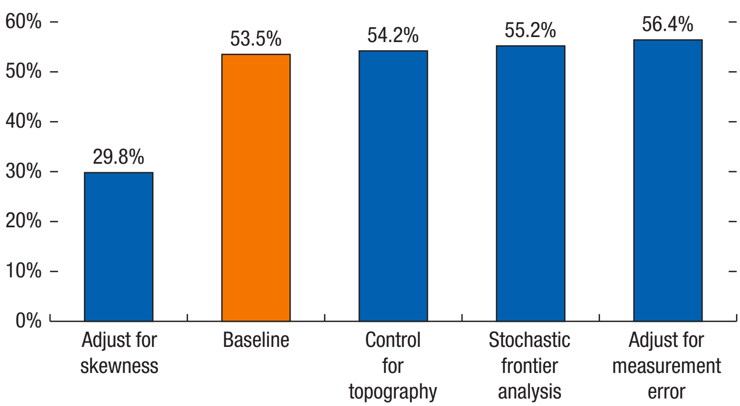


Source: Authors' calculations.
Note: Each horizontal bar represents the coefficient from a separate regression of efficiency scores on PIMA, that is, the figure reflects results from five regressions. Bars are arranged in ascending order of coefficients. The vertical lines indicate 95 percent confidence intervals around the point estimates. Public investment efficiency is measured by the hybrid efficiency score including the quality and the volume of overall infrastructure. The baseline result reflects efficiency scores with no adjustment for skewness, estimated using data envelopment analysis, and regression analysis that does not adjust for measurement error and does not control for topography. The other bars correspondingly consider each of these adjustments and variations in estimation methodology. Annex 3.2 discusses the details of the underlying regression analysis, and presents results based on additional robustness tests.
PIMA = Public Investment Management Assessment.

sectors combined: economic sectors (roads, electricity, water) and social sectors (using proxies for health and education infrastructure). The analysis also considers only the economic sectors, in light of the distinct attention paid to economic infrastructure in many policy settings (Figure 3.7 and Annex Table 3.2.2). There remains a statistically significant association—but of reduced magnitude—between public investment management practices and investment efficiency. The results for economic infrastructure are fairly stable across measures of efficiency and econometric specifications.

Improvements in public investment management could reduce the public investment efficiency gap by half. Figure 3.8 provides a way to assess whether the statistical relationships above are also economically meaningful in magnitude. By how much could countries close the efficiency gap if they improved their public investment management practices? Consider the gains the median country could make by adopting the public investment management practices of the best performers. As shown in Figure 3.8, under the baseline, a country with the median efficiency gap could close more than 53 percent of its gap by adopting the public investment management practices of the country with the 90th percentile PIMA score. The result holds under most scenarios, robust to the measurement of efficiency scores, the estimation method, and the model used in the regression analysis. This suggests that countries could significantly

Figure 3.8. Share of the Efficiency Gap Reduced by Achieving the PIMA Score of Best Performers, 90th Percentile and Above



Source: IMF staff calculations.
Note: Results are based on efficiency scores for the quality and volume of overall infrastructure. Best performers are defined as countries at the 90th percentile of PIMA scores. The baseline result reflects efficiency scores with no adjustment for skewness that are estimated using data envelopment analysis, and regression analysis that does not adjust for measurement error and does not control for topography. The other bars correspondingly consider each of these adjustments and variations in estimation methodology. PIMA = Public Investment Management Assessment.

increase the benefits of public investment spending—greater quality and access to infrastructure and resulting higher growth—through improvements in infrastructure governance.

CONCLUSIONS

This study, which builds on and updates a 2015 report (Box 3.2), finds that more than one-third of resources are lost in the process of managing public investment. Inefficiencies in public investment spending are therefore substantial. This is a nonnegligible source of wasted resources when needs are high and fiscal space is limited.

Better infrastructure governance would raise the efficiency of public investment spending and improve infrastructure outcomes. Adopting the public investment practices of best performers could help countries to close about half their efficiency gap. The data and methods used in this study, while imperfect, help identify priority reform areas.

Box 3.2. Comparison to Previous Results

This chapter updates the work done in IMF (2015) but uses a more updated and expanded data set and enhances the methodology in the estimation of the following:

Efficiency

- *Data*. This chapter uses updated data on the capital stock data and infrastructure outcome indicators (to 2017 or the latest available year). Some indicators are adjusted for skewness to control for outliers (see Box 3.1).
- *Methodology*. As discussed in Box 3.1, the results use both the data envelopment analysis and stochastic frontier analysis methodologies (while IMF 2015 was focused on the former).

The Link between Efficiency and Infrastructure Governance

- *Data*. The PIMA sample size is larger (from 25 desk assessments in 2015 to 62 desk and mission assessments in this chapter).
- *Methodology*. The chapter uses additional control for geography (rugged terrain) and possible measurement errors in desk assessments for robustness.

The results are broadly in line with IMF (2015) and confirm that efficiency gaps are sizeable and that public investment management institutions have a role to play in reducing them.

- IMF (2015) found an average efficiency gap of 27 percent, whereas the comparable gap is 35 percent in this chapter's analysis.
- IMF (2015) found that the average country could close two-thirds of the efficiency gap by adopting the public investment management practices of the best performer while the preferred specification used in this chapter suggests a number closer to one-half. Qualitatively, both studies suggest that improving public investment management institutions could dramatically reduce the inefficiency of public investment spending.

Better infrastructure governance also helps to increase fiscal space. Traditional means to increase fiscal space—increasing revenue or reducing spending—should go hand in hand with improvement in infrastructure governance, that is, reforms geared at strengthening relevant fiscal institutions. The IMF's PIMA can help countries identify key sources of inefficiencies across the planning, allocation, and implementation stages of public investment (see Chapter 5 for examples).

Future analytical work should focus on closing gaps in knowledge about the relationship between public investment management and investment efficiency. As more PIMAs become available, the analysis can be extended to a larger sample. A priority would be to close sectoral data gaps. Country-level data on capital spending in transportation, energy, health, and education are scarce. Such data would be particularly useful as they would allow the analysis of sector-specific spending efficiency and help guide policymakers in allocation decisions. Analyses of energy or transportation may be particularly useful as these sectors often constitute a large share of public investment. As a second step, the availability of input prices could help in welfare assessments—not only to determine whether countries are spending well—minimizing costs—but also whether they are allocating spending to sectors that maximize the welfare of their citizens.

ANNEX 3.1. MEASURING EFFICIENCY USING FRONTIER METHODS

The efficiency analysis is based on evaluating the relationship between infrastructure inputs and outputs. Inputs are measured by the real capital stock and GDP per capita. Infrastructure output is a combined measure of both physical and quality indicators. The physical indicator is a quantitative index combining outcome indicators in various sectors.

The physical indicator may combine pure infrastructure indicators and indicators related to the provision of social services:

- *Pure infrastructure indicators* include the length of road networks (kilometers per capita), access to an improved water source (percent of population) and electricity production (kilowatt-hours per capita). Electricity production and water still receive a large share of public investment (European Investment Bank 2008 and PricewaterhouseCoopers 2014 discuss the composition of public investment spending across infrastructure sectors). Ideally, infrastructure data on ports, railways, and other infrastructure would be added, but country data are still limited, while extensive coverage is needed for the regression analysis.
- *Social sector indicators* are included as the public sector still dominates their provision, usually because of equity considerations as such universal access and social mobility. For example, in education, the public sector accounts for more than half of total investment in both advanced economies and

emerging markets; for health, it ranges from about one-third of investment in selected emerging markets, to about two-thirds in advanced economies, with a significant dispersion across countries (IMF 2015). In addition, especially in developing economies and low-income countries, increases in productivity are closely linked to the expansion in the provision of health and education services (see de la Fuente 2011 for more details). Social sector data used here are the number of secondary teachers and the number of hospital beds, both measured as per 1,000 people.

- Each variable is averaged from the year 2000 until its last available observation. Because each variable is measured on a different scale, all variables are first standardized (following skewness adjustment where needed) and then aggregated as follows:

$$x_i = \frac{1}{5}\sum_{j=1}^{5} \frac{x_{ij} - \bar{x}_j}{\sigma_j}$$

where x_{ij} is the value of the variable j in country i, and $\bar{x}_j$ and σ_j are the mean and standard deviation of variable j over the considered period.

Several series are adjusted for skewness. Data skewness means that an individual indicator could both lose explanatory power and be overpowering for some countries in the aggregation across indicators. For example, if one or a few countries have much better electricity outcomes than most countries, the distribution of standardized data will be skewed to the left. The electricity outcomes of those outliers will lie far to the right of the distribution. As all data series are standardized, electricity for those few countries would become dominant in the aggregation across indicators (the outcomes of other infrastructure series become less relevant). At the same time, the electricity outcomes for the others would be clustered around a narrow interval on the left of the distribution, making them hard to distinguish, leading to less relevance of the electricity outcomes in the aggregation across indicators. In the present analysis, efficiency scores are both presented in their standard form and adjusted for potential skewness, to examine robustness of results to this variation. Electricity, roads, and water data are corrected for skewness through logarithmic transformations.

The hybrid indicator is constructed by combining the physical indicator with the survey-based qualitative indicator from the World Economic Forum. It obtains an assessment from experts on the general state of infrastructure in each country, generating a rating from 1 (worst) to 7 (best). The hybrid indicator used in the analysis is the arithmetic mean of the two previous indicators (physical and quality) and provides a measure of both the volume and quality of public infrastructure.

The data envelopment and stochastic frontier analyses are then used to estimate investment efficiency scores based on the hybrid indicator and the two inputs: capital stock and GDP per capita. As discussed in the main text, both methodologies have advantages and disadvantages, therefore both are used here. The stochastic frontier analysis needs assumptions on error distributions. Here, it is specified as a normal/half-normal model of the reduced form equation:

$$\ln y_i = f(x_i;\beta) + \varepsilon_i$$
$$\varepsilon_i = \nu_i - u_i$$

where the variable set x is an (m x 1) vector of inputs, here GDP per capita and the public capital stock, and β is the corresponding vector of parameters. v is normally distributed with $\left(\nu_i : i.i.d.N\left(0,\sigma_\nu^2\right)\right)$, and the inefficiency term u is specified as a half-normal distribution with zero mean $\left(u_i : i.i.d.N^+\left(0,\sigma_u^2\right)\right)$. The smaller the variance of u, the closer the inefficiency terms will be clustered around zero, and the closer the efficiency scores are clustered around one. Efficiency scores based on the hybrid indicator and for both estimation methods cover 130 countries over 2000–17 (unbalanced panel).

ANNEX 3.2. ASSESSING THE LINK BETWEEN INFRASTRUCTURE GOVERNANCE AND PUBLIC INVESTMENT EFFICIENCY

To determine the association between public investment management institutions and public investment efficiency in the "Infrastructure Governance and Efficiency" section, the following regression framework is used:

$$\theta_i = \alpha + \beta \cdot PIMA_i + \gamma X_i + \varepsilon_i$$

where θ_i is the efficiency score for country i, with variations in its estimations as described in Annex 3.1. $PIMA_i$ refers to the PIMA index value for country i, which aggregates public investment management indexes across the three stages of the investment cycle (planning, allocation, and implementation; see Chapter 5 for further details on the PIMA index). The regression includes a control, X_i, for the average ruggedness of a country's land surface, as this may affect the efficiency with which public resources are deployed to create infrastructure. Nunn and Puga (2012) developed the index using a global data set from the US Geological Survey (1996). The index sums up, for each country, the squared difference in elevation of each point in a spatial grid from that of its neighbouring points.

Efficiency scores for overall infrastructure are available for 130 countries, while 141 countries have scores for economic infrastructure, and 62 have PIMA indicators. The overlap of observations (countries) with both PIMA values and efficiency scores is 48 and 53 for overall and economic infrastructure, respectively. PIMAs were conducted once for each sample country, with the corresponding missions taking place between 2015 and 2019. The efficiency scores rely on public capital and infrastructure data averaged over time for each country, as described in Annex 3.1. Given that the regressions are therefore of a cross-sectional nature, additional extensive controls were not included, to retain adequate degrees of freedom for the statistical analysis.

The baseline regression is estimated using ordinary least squares.

A variant of the empirical model also takes into account that a subset of the PIMA data (for 10 out of the 62 countries) was collected through desk review rather than through mission visits. An instrumental variable approach is used to mitigate the effect of potential measurement error in desk reviews on the analysis (Hu and Schennach 2008). Specifically, the PIMA index is instrumented with a dummy variable that indicates whether the country's PIMA was derived through field data (dummy takes on the value of 1) or through desk data collection (value of 0). As appropriate for a suitable instrument, this variable is related to the PIMA index that it instruments for but does not independently explain efficiency outcomes (the dependent variable in the

ANNEX TABLE 3.2.1

Cross-Country Regressions: Relationship between Public Investment Efficiency (Overall Infrastructure) and PIMA

		(1)	(2)	(3)	(4)
		Efficiency Scores Using			
		Data Envelopment Analysis		**Stochastic Frontier Analysis**	
		Regression Estimation		***Regression Estimation***	
		Ordinary Least Squares	**Adjusted for Measurement Error**	**Ordinary Least Squares**	**Adjusted for Measurement Error**
1. Standard	Public investment management index (PIMA)	0.29***	0.31***	0.20***	0.17*
		(0.08)	(0.10)	(0.07)	(0.09)
	Control for topography	No	No	No	No
	No. of countries	48	48	48	48
	R^2	0.23	0.23	0.15	0.14
2. Skew adjusted	Public investment	0.25***	0.28***	0.17**	0.15*
	management index (PIMA)	(–0.08)	(–0.10)	(–0.07)	(0.09)
	Control for topography	No	No	No	No
	No. of countries	47	47	47	47
	R^2	0.18	0.18	0.12	0.12
3. Standard	Public investment	0.30***	0.31***	0.20***	0.18*
	management index (PIMA)	(0.08)	(0.10)	-0.07	(0.09)
	Control for topography	Yes	Yes	Yes	Yes
	No. of countries	47	47	47	47
	R^2	0.24	0.24	0.15	0.15
4. Skew adjusted	Public investment	0.25***	0.28***	0.16**	0.15*
	management index (PIMA)	(0.08)	(0.10)	(0.07)	(0.09)
	Control for topography	Yes	Yes	Yes	Yes
	No. of countries	47	47	47	47
	R^2	0.18	0.18	0.12	0.12

Source: IMF staff calculations.
Note: The figures in each set of row-column combinations result from a separate regression, that is, the table represents results from 16 regressions. Although there are 62 PIMA countries, efficiency scores are available only for 48 of these (the use of the topography control variable and the process of skew adjustment reduces the number of observations by one more unit). Public investment efficiency is measured by the hybrid efficiency score including the quality and volume of overall—that is, economic and social—infrastructure. PIMA = Public Investment Management Assessment.
*$p < 0.1$. **$p < 0.05$. ***$p < 0.01$.

regressions). Results are presented with and without this adjustment for measurement error.

Annex Tables 3.2.1 and 3.2.2 present the regression results that were illustrated in graphical form and discussed in the "Infrastructure Governance and Efficiency" section. They, respectively, show the association of PIMA with investment efficiency for overall infrastructure and for economic infrastructure. The results of the baseline regressions appear in the first column and row of each table, while the other coefficients represent alternative specifications and estimation methods to examine the robustness of the main results.

ANNEX TABLE 3.2.2

Cross-Country Regressions: Relationship between Public Investment Efficiency (Economic Infrastructure) and PIMA

		(1)	(2)	(3)	(4)
		Efficiency Scores Using			
		Data Envelopment Analysis		**Stochastic Frontier Analysis**	
		Regression Estimation		*Regression Estimation*	
		Ordinary Least Squares	**Adjusted for Measurement Error**	**Ordinary Least Squares**	**Adjusted for Measurement Error**
1. Standard	Public investment management index	0.15**	0.10	0.15**	0.14
		(0.07)	(0.09)	(0.07)	(0.09)
	Control for topography	No	No	No	No
	No. of countries	55	53	53	53
	R^2	0.09	0.08	0.10	0.10
2. Skew adjusted	Public investment management index	0.14**	0.16*	0.09	0.08
		(0.07)	(0.09)	(0.06)	(0.08)
	Control for topography	No	No	No	No
	No. of countries	52	52	52	52
	R^2	0.08	0.08	0.04	0.04
3. Standard	Public investment management index	0.16**	0.11	0.16**	0.15*
		(0.07)	(0.09)	(0.07)	(0.09)
	Control for topography	Yes	Yes	Yes	Yes
	No. of countries	52	52	52	52
	R^2	0.12	0.11	0.14	0.14
4. Skew adjusted	Public investment management index	0.14**	0.16*	0.09	0.08
		(0.07)	(0.09)	(0.06)	(0.08)
	Control for topography	Yes	Yes	Yes	Yes
	No. of countries	52	52	52	52
	R^2	0.09	0.09	0.04	0.04

Source: IMF staff calculations.
Note: The figures in each set of row-column combinations result from a separate regression; that is, the table represents results from 16 regressions. Public investment efficiency is measured by the hybrid efficiency score including the quality as well as the volume of economic infrastructure. OLS = ordinary least squares; PIMA = Public Investment Management Assessment.
$*p < 0.1$. $**p < 0.05$. $***p < 0.01$.

ANNEX 3.3. DATA SOURCES

Data Series	Source
General government capital stock (2011 purchasing power parity US dollar-adjusted, per capita)	IMF Public Investment and Capital Stock Database
GDP per capita	IMF World Economic Outlook
Population, total	IMF World Economic Outlook
Electricity in terawatt-hours	OECD Library International Energy Agency Electricity Information Statistics
Roads per kilometer	International Road Federation
Access to treated water (percentage of population)	World Bank World Development Indicators
Secondary school teachers	World Bank World Development Indicators
Hospital beds	World Bank World Development Indicators
Quality of overall infrastructure, 1–7 (best)	World Economic Forum's Global Competitiveness Report
PIMA index	IMF's Fiscal Affairs Department PIMA database
Ruggedness of topography index, derived from the sum of squared differences in elevation of neighboring points in a spatial grid	Nunn and Puga (2012), based on GTOPO30 (US Geological Survey 1996)

Note: OECD = Organisation for Economic Co-operation and Development; PIMA = Public Investment Management Assessment.

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