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On the Capacity to Absorb Public Investment: How Much is Too Much?

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Abstract

While expanding public investment can help fill infrastructure bottlenecks, scaling up too much and too fast often leads to inefficient outcomes. This paper rationalizes this outcome by looking at the association between cost inflation and public investment in a large sample of road construction projects in developing countries. Consistent with the presence of absorptive capacity constraints, our results show a non-linear U-shaped relationship between public investment and project costs. Unit costs increase once public investment is close to 10% of GDP. This threshold is lower (about 7% of GDP) in countries with low investment efficiency and, in general, the effect of investment scaling up on costs is especially strong during investment booms.

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"...hikes in public investment, just like commodity booms, all too often end in tears...as economic and social returns decline and money dries up."

Dani Rodrik (2016)

1 Introduction

Against the background of an extended period of weak global economic growth, a handful of developing countries have been rapidly scaling up public investment, to stem infrastructure bottlenecks and promote long-run economic growth. While the existing evidence shows that public capital can indeed contribute to economic growth, especially in the case of infrastructure investment (Leduc and Wilson, 2012; Bom and Ligthart, 2005; Calderon et al., 2015), the analysis of historical episodes of sharp public investment accelerations would suggest a certain degree of skepticism about the real effect on public investment scaling up on output growth. There is no dearth of anecdotes about bridges and roads to nowhere. More systematically, at the macro level, Warner (2014) looks at the evidence on past public investment drives (and then zoom in on five case studies) and shows that they ended with higher public debts and little or no long-run growth dividends. Consistent with this result, evidence based on project-level data shows that projects' outcomes worsen in periods of public investment scaling up (Presbitero, 2016). While this literature—and anecdotal evidence—suggests weak real economy effects of public investment booms, mostly because of a variety of inefficiencies related to public investment spending (Pritchett, 2000; Caselli, 2005), not much is said about the actual mechanisms that can weaken the output elasticity of public investment during a boom.

In this study we expand on this strand of literature and argue that one potential mechanism behind the limited economic returns of large public investment episodes could be rapid cost inflation—a situation in which project unit costs sharply increase because of absorptive capacity constraints. In particular, we look at the relationship between public investment and the unit cost of road construction, using project-level data for a large sample of countries. Our analysis first investigates whether there is a size of public investment beyond which cost inflation kicks in (the *velocity* effect). Then, we examine whether these thresholds are different for countries with different investment efficiency levels. Finally, we zoom in on the relationship between investment booms and unit cost inflation (the *acceleration* effect).

Cost inflation is a pervasive phenomenon across the world, especially in public infrastructure projects (Bajari and Tadelis, 2001; Ganuza, 2007; Flyvbjerg, 2009). Using project level data from 20 countries across five continents, Flyvbjerg et al. (2003) finds evidence of cost escalation in 86% of projects, where actual costs exceeded estimated cost by an average of 28%. Such cost and time overruns are also observed in multilateral development bank financed projects. Similarly, 86% of sampled development projects financed by the Asian Development Bank experienced marked cost overruns (Ahsan and Gunawan, 2010). Similar cost escalations are also observed in World Bank financed projects. Perhaps an extreme example is the Jordan-Amman development transport corridor where total costs at completion were 298% above planned funds. Another striking example is the Madagascar transport infrastructure development project that took 63% longer than anticipated with an associated cost escalation of 505%. These cases seem to be common rather than isolated.

Evidence from several countries suggest that both large public investment programs relative to GDP (unsustainable *velocity*) and its rapid scaling up (*acceleration*) could lead to severe absorptive capacity constraints—defined narrowly as the marginal cost of public investment governance. In practice, one could think that when public investment is above a certain threshold (or it accelerates too fast), recipient countries do not have the capacity—in terms of skills, institutions, and management—to reap the benefit of additional public investment, as the implementation of several investment projects would require a varied set of technical and managerial resources which cannot be expanded in the short-run, leading to cost inflation.[1] For example, Ethiopia saw a massive increase in public investment from around 5% of GDP in the early 1990s to 11% in 2010 and 16% by 2016 (IMF, 2019). Correspondingly, average cost overrun went up from 58% in 2010 to 76% in 2016 as rapid investment scaling up continued. In about 92% of projects with cost inflation, overruns were due either to incomplete design or design change, implying serious absorptive capacity constraints (CoST, 2011, 2016). Elsewhere, India's rapid growth since 2002 is also underpinned by a substantial infrastructure drive. While much of this increase came from private sources, the public sector has in recent years played an important role. However, infrastructure governance has not kept pace with the continued importance of the sector to the economy. A World Bank (2008*a*) report shows that

[1]See Presbitero (2016) and references cited therein for a more extensive discussion of absorptive capacity constraints in the context of public investment scaling up.

nearly half of all road projects see cost overruns in excess of 25%, and more than half see time overruns of 50% or more to completion times. Understanding thresholds of public investment at which unit costs of infrastructure delivery start rising is critical to reduce investment inefficiencies emanating from absorptive capacity constraints.

Several studies have investigated the dynamics of unit costs in developing countries (World Bank, 2008*b*), the magnitude of these overruns (Flyvbjerg et al., 2003; World Bank, 2008*b*), and the impact of conflict and corruption on unit cost (Collier et al., 2016). To our knowledge, this literature has not investigated the extent to which public infrastructure investment could affect unit costs. This is an relevant research question, as such relationship would signal the presence of absorptive capacity constraints and could inform public policies when deciding the pace and sequencing of investment. We contribute to the literature documenting a positive association between public investment and project unit costs, exploring the presence of a non-linear relationship and of heterogeneity across countries, depending on their investment efficiency.

Cost escalations can be caused by a host of factors. While tight construction markets and supply constraints are considered the usual culprits, the marginal cost of public investment governance has not received much attention. As public investment programs grow, so does the marginal cost of governance including but not limited to acute shortages of skills and expose deficiencies in institutional frameworks to manage public investment. Such mismanagement is manifest in payment delays to contractors, contract cancellations, and design changes and renegotiation. Our proposed framework shows that unit costs could be even higher when firms account for these uncertainties (production uncertainties). We build on the empirical approach proposed by Collier et al. (2016) to control for supply side factors, either directly or through a large set of fixed effects and extend their framework to account for the marginal cost of public investment management. We discuss in the next section a simple theoretical framework that extends that by Collier et al. (2016) to capture residual unit cost differences, which are due either to the size of public investment (its *velocity*) or its sharp scaling-up, measured by public investment booms (its *acceleration*).

We build on this framework to estimate the effect of public investment velocity and acceleration on unit costs on a large sample of 3,322 road construction projects with contract dates between 1984 and 2008 from 99 developing countries. We report three main results.

First, after controlling for a range of road characteristics, geographical features, and financing instruments, we find a statistically significant U-shaped relationship between public investment levels and unit costs, which suggests the presence of absorptive capacity constraints when investment levels are particularly high (the *velocity* effect). Second, our estimates indicate that the positive association between public investment and cost escalation kicks in at different levels of investment, depending on the country's public investment efficiency. In particular, for low-efficiency countries, unit costs start increasing when public investment is above 7% of GDP, while for high-efficiency countries this threshold is at 10% of GDP. These results are economically meaningful, given that, over the period 2013-2015, public investment was above 7% (10%) of GDP in 32% (15%) of developing countries. Third, unit costs increase sharply during episodes of investment booms (the *acceleration* effect). For instance, scaling up public investment from 8% to 15% of GDP is associated with a 38% increase in unit costs in the lowest efficiency quantile vis-á-vis a 3% increase for those in the higher efficiency quantiles.

Overall, we argue that the effects captured in the analysis are short term adjustment costs associated with large public investment and/or its rapid scaling up, as fixed effects filter out unobserved country specific effects like market organization (e.g., rules governing an often-oligopolistic construction industry or technology) that cause persistent unit cost differences.

2 Theoretical Framework

This section develops a simple theoretical framework to help guide the following empirical analysis. Collier et al. (2016) specified a cost function for road work activity in developing countries where the environment in which contractors operate is captured by a catch-all 'productivity shock' $A^{-\delta}$ [see (eq 1): w_1, w_2, q, and A are, respectively, input prices, road length, and an exogenous inefficiency parameter]. In their framework, the average cost-per-kilometer depends on exogenous factors such as failure of governments to honor contractual obligation and/or bribe to government officials to get construction permits. These inefficiencies are assumed to be linear with respect to the 'environment' such as the size of public investment programs (PIPs).

$$\frac{C(w_1, w_2, q)}{q} = \theta A^{\frac{\delta}{\alpha+\beta}} q^{\frac{1-(\alpha+\beta)}{\alpha+\beta}} w_1^{\frac{\alpha}{\alpha+\beta}} w_2^{\frac{\beta}{\alpha+\beta}} \quad (1)$$

However, if contractors optimize by appropriately accounting for time and cost overruns induced by absorptive capacity constraints (Compte et al., 2005), then inefficiencies are likely to vary with the size of the public investment program (PIP). The larger the size of public investment programs in developing countries, the greater the opportunities for rent seeking; weaknesses in ex-ante project appraisal and selection; and lack of transparency in the execution phase.

These inefficiencies result either in lower infrastructure quality (Abed and Gupta, 2002), or incomplete projects (Williams, 2017; Rasul and Rogger, 2018). Not only are projects yielding lesser flows of capital services likely to be chosen for the same investment spending (Berg et al., 2019). But it is also easier to hide large bribes and inflated claims in big programs with large projects than in small ones (Mauro, 1997). In what follows, the firm's cost minimization problem is modified to account for uncertainties arising from the size of PIPs or the nature of the construction industry in developing countries.

Consider a roadwork where the contracted length is designated by q. The contractor employs labor x_1, capital x_2 and minimizes a cost function subject to expected output $\bar{q} = \mathbb{E}(q)$ and given by (eq 2). Payment delays for completed work is a perennial problem faced by contractors in many developing countries. These delays are particularly burdensome to credit and capital constrained contractors that face steep overhead costs or rely on regular payments for material procurement. Such difficulties are amplified when PIP are bigger prompting partial delivery of contracted roadwork $\hat{q}$. We model these difficulties by introducing the probability of production uncertainty ψ such that $\mathbb{E}(q) = \psi\hat{q} + (1-\psi)q \leq q$.

$$\min_{\mathbf{x}}(\mathbf{w}'\mathbf{x} \mid \mathbb{E}f(\mathbf{x},\varepsilon) \geq \bar{q}) = C(\mathbf{w},\bar{q}) \tag{2}$$

The contractor's cost minimization problem can be specified as (3), given the input vector $\mathbf{x}$, the corresponding price vector $\mathbf{w}$, a random disturbance ε and the random and separable road-production function $q = f(\mathbf{x},\varepsilon) = f(\mathbf{x})g(\varepsilon)$ such that $q = A^{-\delta}(\pi_1 x_1^{\zeta} + \pi_2 x_2^{\zeta})^{\frac{1}{\zeta}} g(\varepsilon)$, where absorptive capacity costs are captured by $g(\varepsilon)^{-1}$.

$$\mathcal{L} = \min_{x_1,x_2} w_1x_1 + w_2x_2 + g(\varepsilon) + \lambda\big[q - A^{-\delta}(\pi_1 x_1^{\zeta} + \pi_2 x_2^{\zeta})^{\frac{1}{\zeta}} g(\varepsilon)\big] \tag{3}$$

As a result, the appropriate cost function is given by $C(\mathbf{w}, \mathbb{E}(q))$, where $\mathbf{w}$ is the input price vector and $\mathbb{E}(q)$ is the road length the contractor expects to complete, instead of $C(\mathbf{w}, q)$ as in (eq 1). On the one hand, contractors account for growing inefficiencies such as payment delays or contract cancellations [2], or time and cost overruns by economizing on key production inputs or other means. In this case $g(\varepsilon)^{-1}$ is cost escalation due to absorptive capacity constraints and ε is the extent of the problem. On the other hand, the construction industry may be in oligopolistic competition, where contractors have either markup power, or can form bid-rigging cartels or both.[3] In this case $g(\varepsilon)^{-1}$ could be the markup over cost and ε might be the firm's leverage over authorities. 'A' is an exogenous productivity shock as in (1) and A^{δ} captures inefficiencies other than absorptive capacity constraints.

We specify $g(\varepsilon)$ as dependent on the GDP share of public investment P_z vis-à-vis some threshold $\tilde{P}_z$.[4]

$$g(\varepsilon) = \begin{cases} \exp(-\varepsilon^*), & \text{if } P_z > \tilde{P}_z; \varepsilon^* \approx P_z - \tilde{P}_z \\ 1, & \text{if } P_z < \tilde{P}_z \end{cases}$$

The average cost per kilometer of road construction $c(w_1, w_2, \bar{q}) = \frac{C(w_1, w_2, \bar{q})}{\bar{q}}$ is given by

$$c(w_1, w_2, \bar{q}) = \begin{cases} \sum_{j=1,2} w_j (\frac{w_j}{\pi_j})^{\frac{1}{\zeta-1}} A^{\delta} \big[\sum_{j=1,2} \pi_j (\frac{w_j}{\pi_j})^{\frac{\zeta}{\zeta-1}} \big]^{\frac{-1}{\zeta}} g(\varepsilon)^{-1}, & \text{if } P_z \geq \tilde{P}_z \\ \sum_{j=1,2} w_j (\frac{w_j}{\pi_j})^{\frac{1}{\zeta-1}} A^{\delta} \big[\sum_{j=1,2} \pi_j (\frac{w_j}{\pi_j})^{\frac{\zeta}{\zeta-1}} \big]^{\frac{-1}{\zeta}}, & \text{if } P_z < \tilde{P}_z \end{cases} \tag{4}$$

This dichotomous function captures cost movements as an economy transitions between moderate and large public investment programs. It differentiates between costs borne due to inefficiencies associated with large public investment programs $A^{\delta} g(\varepsilon)^{-1}$, and due to inefficiencies despite moderate levels of public investment A^{δ}. The contractor, government or both bear costs depending on the type of the road contract.[5]

[2] Cancellations could be due to financial burden from large projects, political and social opposition due to lack of transparency in contract awards.

[3] Additionally, construction firms might walk away from projects in small countries that have fewer repeat projects, or where penalties are not effective deterrents.

[4] Others like Berg et al. (2013) model absorptive capacity constraint as a linear function, or as an internal adjustment cost (van der Ploeg, 2012).

[5] For example, in fixed price contracts, the contractor agrees to build a specified road length for a specified price. If construction costs are less (more) than the fixed price, the contractor incurs a profit (loss). Once the fixed price is established, the government shares in neither the contractor's profits nor losses. For more discussion on incentive contracting, see McCall (1970). Additional references on modelling cost overruns in public procurement are Ganuza (2007) (with fixed price contracts), Bajari and Tadelis (2001) (cost overruns due to design changes), Thomas (2019) (cost overruns due to poor project management), and Herweg and Schwarz (2018) (cost overruns due to contract renegotiations).

3 Estimation and Identification

Section 2 gave a sketch of how the cost function changes when production uncertainties are introduced. Since the goal is to empirically estimate the dichotomous cost function (eq 4), in this section we introduce a second order approximation of this function. This approximation helps us identify the bias associated with estimating (eq 1) and proceed to account for it in the approximated translog cost function. To simplify, output q is generated by $q = f(\mathbf{x})g(\varepsilon)$, where $g(\varepsilon) = \exp(-\varepsilon^*)$ and $\mathbb{E}(\varepsilon) = 0$, $\mathbb{E}(\varepsilon^2) = \sigma^2$ and the dichotomous cost function is approximated by the translog form:

$$\ln C = \gamma_0 + \sum_{j=1,2} \gamma_j \ln w_j + \gamma_q \ln \bar{q} + \frac{1}{2} \sum_i \sum_j \gamma_{i,j} \ln w_i \ln w_j + \sum_{j=1,2} \gamma_{j,q} \ln w_i \ln \bar{q} + \frac{1}{2} \gamma_q (\ln \bar{q})^2 \tag{5}$$

Since C is estimated with actual q, inserting $\bar{q} = \frac{q\mathbb{E}(e^{-\varepsilon})}{e^{-\varepsilon}}$ in (4):

$$\ln C = \gamma_0 + \sum_j \gamma_j \ln w_j + \gamma_q \ln q + \frac{1}{2} \sum_i \sum_j \gamma_{i,j} \ln w_i \ln w_j + \sum_{j=1,2} \gamma_{j,q} \ln w_j \ln q + \frac{1}{2} \gamma_q (\ln q)^2 + \xi \tag{6}$$

where $\xi = \frac{1}{2}\gamma_q \varepsilon^2 - \sum_{j=1,2} \gamma_{j,q} \ln w_i \varepsilon - \gamma_q \ln q \varepsilon - \gamma_q \varepsilon$ is the error term and $\mathbb{E}(\xi) \neq 0$. Estimating (eq 5) yields biased and inconsistent estimates of γ_0 especially if firms actually consider production uncertainties during optimization (eq 6).

To account for this bias, we introduce a quadratic cost component to the estimable equation (eq 7). We approximate the 'bias' $\xi \approx \phi_4 P_z + \phi_5 {P_z}^2$ since $g(\varepsilon)$ is observable only to firms. Then, for work activity $a = 1, ..., A$, work type $k = 1, ..., K$, country $i = 1, ..., N$, and time $t = 1, ..., T$, c is the cost per kilometer and q is a dummy variable that is equal to one if the length of the road is above 50 km. For each work type (*e.g.* routine maintenance), there are matching work activities (routine maintenance of earth road, gravel road, block 2L highway...).

$$\ln c_{akit} = \phi_0 A_{it} + \sum_{j=1,2} \phi_j \ln w_{jakit} + \phi_3 \ln q_{akit} + \phi_4 P_{zit} + \phi_5 P_{zit}^2 + \gamma_{akit} + \tau_t + \eta_{kt} + \rho_{ak} + \epsilon_{akit} \tag{7}$$

Controls are selected to proxy for the determinants of factor prices $w_{i,j}$ since project specific input costs are not available . Access to the nearest ice-free-coast proxies for the cost of capital and equipment. Terrain attributes (flat, mountainous, hilly, or rolling) similarly proxy for the cost of capital and inputs. A three-year average of lagged precipitation is used to capture input costs due to rainfall levels. The log of 1985 GDP per capita is used to proxy for the price of labor and capital. Measures of institutional quality (corruption and conflict) similarly proxy for $'A'$. Work-activity fixed effects are included to control for systematic differences in costs across work activities ρ_{ak}. Year fixed effects τ_t account for construction industry trends, interaction terms between work type and five-year dummies η_{kt} allows for differences in the evolution of costs for different work types, due to the terrain and weather conditions in which the road works are undertaken. γ_{akit} accounts for unit cost variances due to differences in procurement, financing body, and contractor type. γ are vectors of dummies capturing the source of costs (actual, contracted, estimated), the financing body (World Bank, bilateral donor, government, other donors), and contractor origin (local, international, joint venture). Finally, ε_{akit} is an idiosyncratic error term.

4 Data

Unit cost data are drawn from Roads Cost Knowledge System (ROCKS), Version 2.3, developed by the World Bank's Transport Unit to provide comparable information on costs of road work activities across countries. These costs differentiate between the cost of an individual road section from an average cost of a maintenance, rehabilitation, or improvement program of works. A breakdown of unit costs by source shows that 64% of observations are at individual segment (section) level, while the rest are at program level and could include average costs for five or more road segments. In each case, information is provided on the names of the projects, or sections that are parts of programs. Several unit cost measurements are provided in the dataset including cost per length ($/km) and cost-per carriageway ($/m^2). Cross country comparison is made possible by deflating unit costs by respective Consumer Price Indices and converting local currency units into year 2000 US$.[6]

Cost types vary from actual and contract to estimated costs since data is extracted from a range of reports including bidding documents, disbursement reports, completion reports

[6] An extensive discussion of the data is provided in Collier et al. (2016, p. 8-13).

or certificate of payment to contractors. About 45% of entries are estimated costs, 27% are contracted costs, and 29% are actual costs. Representative cost dates of each road work are used to bring all the costs of the database to a same reference year and currency using the price index and exchange of a country, for comparison purposes. The date of the feasibility study or the date when the works are expected to begin is used for estimated costs. Contracted unit costs are computed at contract signature dates or bid opening date. A series of payment dates used to generate actual costs and a mid-point is used when only contract-signing and closing date are available.

The public investment series are drawn from the Investment and Capital Stock Dataset—published by the International Monetary Fund—that compiles a comprehensive database on public investment flows for 170 countries over 1960 and 2017.[7] Data on conflict episodes is drawn from the UCDP/PRIO Armed Conflict Dataset:V4−2012, published by the Uppsala Conflict Data Program (UCDP) and the International Peace Research Institute, Oslo (PRIO). Additional governance indicators are drawn from the World Bank's Worldwide Governance Indicators (WGI). Merging the different data sets produces a sample composed of 3,322 projects in 99 developing countries between 1984 and 2006.

Table 1: Public investment and unit costs of asphalt overlays

WB Income Group	Variable	Mean	Median	S.D	Min	Max	n
Low (n=780)	Public Investment (%GDP)	5.60	5.60	0.75	1.76	7.25	766
	Cost-per-m^2	11.27	11.29	2.41	6.85	16.73	710
	Cost-per-m^2 (log)	2.40	2.42	0.22	1.92	2.82	710
	Cost-per-km (log)	11.28	11.31	0.22	10.78	11.67	780
	Bureaucratic Quality	1.63	2.00	0.57	0.00	2.00	636
	Rule of Law	3.02	3.00	0.44	1.00	3.50	636
Lower Middle (n=1352)	Public Investment (%GDP)	4.61	4.05	2.03	1.25	10.93	1,314
	Cost-per-m^2	10.73	9.59	5.77	2.75	31.49	1,151
	Cost-per-m^2 (log)	2.23	2.26	0.55	1.01	3.45	1,151
	Cost-per-km (log)	11.10	11.16	0.52	9.91	12.26	1,352
	Bureaucratic Quality	2.26	2.08	0.78	0.00	3.00	1,153
	Rule of Law	3.32	3.63	0.92	1.00	5.00	1,153
Upper Middle (n=1190)	Public Investment (%GDP)	4.33	2.85	2.51	1.43	11.51	1,165
	Cost-per-m^2	9.11	8.68	3.20	3.43	22.49	1,012
	Cost-per-m^2 (log)	2.15	2.16	0.35	1.23	3.11	1,012
	Cost-per-km (log)	11.01	11.03	0.36	10.16	12.01	1,190
	Bureaucratic Quality	2.09	2.00	0.41	1.00	3.00	1,152
	Rule of Law	4.34	5.00	0.93	2.00	5.00	1,152

Notes: The database contains data from 3,322 work activities in 99 developing countries, between 1984 and 2008 (with 82% of contracts taking place between 1996 and 2006).

[7]Readers are referred to the Dataset Codebook for details.

Table 1 shows the range of average unit costs for asphalt overlays between 40 and 59 mm, the size of public investment and institutional quality. This is intended to give the reader a snapshot of cost variations across different country groups that are in different institutional cohorts. Generally, public investment tends to be a higher percentage of national income in low income countries; the average cost of asphalt overlays is higher and institutional quality is poorer.

These numbers could be interpreted in different ways. Evidently, low income countries have larger basic-infrastructure gaps (physical and non-physical) and therefore have greater spending need. In turn, larger average unit cost could be due to input supply constraints, or higher import content of infrastructure projects. At the same time, the absence of institutional restraint in developing countries can drive up the number of capital projects. The incentives to enlarge projects and inflate project costs is larger when illicit payments can be effectively disguised in investment contracts. The GDP share of public investment could, therefore, rise while the quality of public investment declines when investment contracts are opaque (Collier and Hoeffler, 2005). Table 1 shows such a correlation between poorer institutions, higher public investment and higher cost of asphalt overlays. However, none of the road projects in the sample is large enough to materially influence the public investment share of GDP. On average, the cost of road projects is around 0.04% of GDP and 0.9% of public investment when the sample is collapsed at the country-year level and, more broadly, 90% of the distribution of cost-to-GDP and cost-to-public investment ratios fall below 0.4% and 7% of GDP and public investment, respectively.

5 Results and discussion

We begin in section 5.1 by merging an empirical estimate of (eq 1) in columns 1–3 with estimates of (eq 7) in columns 4–7. In section 5.2, we split the sample into two groups of public investment efficiency quantiles and repeat our first set of regressions. These quantiles are generated based on DEA scores of public investment efficiency. In section 5.3, we identify episodes of public investment accelerations in two alternative ways (*surges* and *booms*) and estimate a variant of (eq 7) to further account for non-linearities. Standard errors are clustered at country level to account for arbitrary within country correlation of unit costs. Within-country correlations are possible partly because unit costs are collated into the database from various sources, but are likely to be similar within countries. Secondly, while projects are randomly selected into the database from an unobserved population of projects within each country, some projects are likely to be subsets of bigger projects.

5.1 How much is too much public investment?

Collier et al. (2016) show the high residual costs associated with active conflicts or political instability conditional on environmental drivers, project financing sources and the length of road projects. The first three columns of table 2 summarize these principal findings and show that these result remain robust across a range of measures of conflict and political instability. Then, in columns 4 - 6, we augment the model by Collier et al. (2016) with the public investment-to-GDP ratio (linear and squared) to estimate the empirical equivalent of (eq 7). After controlling for a range of road characteristics, geographical features, financing instruments, and country and time fixed effects, we find a statistically significant U-shaped relationship between public investment and unit costs. Specifically, the costs of road construction rapidly increases once public investment goes beyond 10% of GDP.

This relationship between investment budgets and unit costs can be attributed to the marginal cost of public investment governance. Public investment portfolio mix are particularly likely to be inefficient when investment budgets are small. There is likely a minimum efficient scale for public investment management. Such budgets are likely to be composed of portfolios dominated by 'prestige projects' with limited social value and comparatively higher unit costs. As budgets and investment portfolio expand, the mix of projects could become more balanced and likely to include financially affordable and sustainable projects better fitting national strategies. This change in mix and availability of some investment evaluation and prioritization capacity in Finance Ministries is likely to lower unit costs. However, as investment budgets expand further, absorptive capacity constraints arise. Appraisal capacity is not able to grow commensurate with the pool of projects, and as phase, size and project specificity disproportionately grow.[8]

Even well-intentioned large public investment budgets can overwhelm a government's

[8] These arguments are different from project-specific engineering scale economies, captured by the variable *Length>50km*. Road projects exhibit substantial economies of scale in total operating costs and its components such as raw materials, utilities, capital usage and supervision and management.

capacity to use funds effectively. When a public investment budget is large, it creates demand for resources that are both in short supply and necessary for the effective design and implementation of projects. These resources include the burden of skilled project managers, industry regulators, administrative staff, construction equipment, port capacity and customs clearance processes. Isham and Kaufmann (1999) show that the economic rate of return (ERR) of projects implemented under non-distorted macroeconomic environments, i.e., with low inefficiency and large absorptive capacity, is on average about 13% in countries where public investment as a share of GDP is 5% or less. Investment productivity declines as the share of public investment exceeded 10% of GDP.

Overspending on mega-infrastructure projects creates opportunities for political patronage. The link between weak governance and dramatically higher public investment is a recurring theme in public choice theory (Collier and Hoeffler, 2005; Keefer and Knack, 2007). The larger the size of the public investment budgets and the scale of infrastructure investments, the easier it is to conceal bribes and inflate claims. Another large body of work, mainly focusing on Sub-Saharan Africa, attributes cost overruns to a variety of reasons including project size and delays between contract signing and building (Flyvbjerg et al., 2003; Alexeeva et al., 2008); insufficient numbers of bids with tight spreads; and limited competition in large-scale road works contracts (Alexeeva et al., 2008).

Absorptive capacity constraints may not be limited to large public investment budgets replete with mega-projects. Budgets composed of many small projects could face the same problem, especially in developing countries. While studies of smaller civil works projects in advanced economies find comparatively lower probabilities of cost overruns[9], studies of small-scale routine construction and maintenance projects in developing countries reveal nontrivial cost-escalation and non-completion rates. For instance, Williams (2017) finds delayed payments and underpayment of contractors contributes to cost overruns and non-completion in one in three local government infrastructure projects in Ghana.

These mid-project interruptions are largely attributed either to budgets spread out thinly over many projects, deviation from plan and budget during execution, or political directives. Rasul and Rogger (2018) show that a fundamental source of project non-completion in Nigeria arises from civil service organizations being tasked to implement different

[9]Evidence on Portugal and Norway shows that only half of small road projects experienced cost overruns, and escalation is moderate and ranged between 4% and 10% (Odeck, 2014; Sarmento and Renneboog, 2016).

Table 2: Public investment and project unit costs

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Collier et al. (2016), table 4			Including public investment-GDP			
Length >50 km	-0.1522***	-0.1284***	-0.1333***	-0.1285***	-0.1521***	-0.1287***	-0.1344***
	(0.0410)	(0.0441)	(0.0433)	(0.0437)	(0.0414)	(0.0446)	(0.0439)
Log Ruggedness	0.0621**	0.1001***	0.1037***	0.1274***	0.0473	0.0959***	0.0927***
	(0.0274)	(0.0330)	(0.0322)	(0.0349)	(0.0288)	(0.0356)	(0.0328)
Log of Rainfall	-0.1347**	-0.1269*	-0.1236*	-0.1009	-0.1511***	-0.1454**	-0.1493**
	(0.0591)	(0.0642)	(0.0662)	(0.0673)	(0.0568)	(0.0631)	(0.0659)
Log of Surface Area	0.0447**	0.0627***	0.0735***	0.0616***	0.0225	0.0474**	0.0555***
	(0.0194)	(0.0211)	(0.0189)	(0.0195)	(0.0206)	(0.0209)	(0.0190)
Log Distance to Coast	-0.0115	-0.0369	-0.0405	-0.0157	0.0017	-0.0241	-0.0311
	(0.0366)	(0.0408)	(0.0406)	(0.0438)	(0.0351)	(0.0405)	(0.0394)
Population Density	0.1187***	0.0926***	0.0869***	0.0988***	0.1127***	0.0929***	0.0838***
	(0.0159)	(0.0157)	(0.0149)	(0.0206)	(0.0183)	(0.0196)	(0.0183)
Bilateral Donor	0.1534	0.1656	0.1458	0.1444	0.1625	0.1650	0.1512
	(0.1280)	(0.1320)	(0.1291)	(0.1317)	(0.1317)	(0.1374)	(0.1331)
World Bank	-0.0028	0.0197	-0.0045	-0.0394	-0.0383	-0.0179	-0.0388
	(0.0957)	(0.0933)	(0.0903)	(0.0919)	(0.0971)	(0.0971)	(0.0937)
Foreign firm or JV	0.2419**	0.2781**	0.2677**	0.3599***	0.3263***	0.3522***	0.3357***
	(0.1194)	(0.1207)	(0.1210)	(0.1233)	(0.1238)	(0.1225)	(0.1228)
Log of GDP pc (1985)	-0.0201	-0.0253	-0.0411	-0.0530	-0.0313	-0.0393	-0.0609
	(0.0440)	(0.0457)	(0.0437)	(0.0440)	(0.0425)	(0.0450)	(0.0419)
Contract	-0.0946	-0.0799	-0.0919	-0.0703	-0.0708	-0.0604	-0.0697
	(0.0711)	(0.0712)	(0.0708)	(0.0696)	(0.0684)	(0.0686)	(0.0687)
Estimate	-0.0272	-0.0312	-0.0314	-0.0223	-0.0178	-0.0230	-0.0233
	(0.0517)	(0.0544)	(0.0540)	(0.0545)	(0.0511)	(0.0538)	(0.0533)
ACD Conflict	0.3253***				0.3366***		
	(0.0588)				(0.0571)		
ACD Post-Conflict	0.0525				0.0935*		
	(0.0549)				(0.0535)		
WGI Instability		0.1067**				0.1038**	
		(0.0424)				(0.0419)	
WGI Instability >Median			0.1370**				0.1502***
			(0.0577)				(0.0521)
Public investment/GDP				-0.0434**	-0.0382**	-0.0322*	-0.0406**
				(0.0214)	(0.0172)	(0.0189)	(0.0196)
(Public investment/GDP) ^{2}				0.0018*	0.0020**	0.0016*	0.0020**
				(0.0010)	(0.0009)	(0.0009)	(0.0010)
Observations	3,306	3,306	3,306	3,229	3,229	3,229	3,229
R^2	0.9000	0.8983	0.8982	0.9016	0.9040	0.9022	0.9023
Work activity FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5-year period×work-type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Min U-curve	-	-	-	12.08	9.529	10.33	10.08
U-test($P > \|t\|$)	-	-	-	0.038	0.033	0.05	0.035

Notes: The dependent variable is the log of cost per km. See annex table A.1 for definition of variables. Minor differences in number of the observations and estimated coefficients between columns 1 - 3 and (Collier et al., 2016, table 4) are due to a different treatment of fixed effects. Standard errors (in parentheses) are clustered at the country level. $*, **, ***$ denote significance at 10%, 5% and 1% levels, respectively. The null hypothesis for U-test ($P > |t|$) is that the relationship is increasing at the left-hand side of the interval and/or is decreasing at the right-hand side (Lind and Mehlum, 2010). Thus H_0: inverted U or monotonic vis-à-vis H_1: U-shaped.

types of projects each requiring a unique set of optimal management practices. In other cases, it may be rational for politicians to either deliberately leave projects unfinished to increase voters' incentives to reelect them (Robinson and Torvik, 2005) or paralyze them altogether when political power shifts (Keefer and Vlaicu, 2007; Burgess et al., 2015).

As robustness checks, we first replicate our baseline analysis using only estimated and contracted unit road costs—excluding the actual cost—for two reasons. First, to focus on the role of absorptive capacity constraint on costs at the time of decision making. Second, as the actual cost is spread over a long period of time, it may be difficult to link costs with episodes of rapid public investment scaling up. The results reported in table 2 hold up even after observations with actual unit costs are dropped from the sample (see annex table A.2), or as corruption and an income group fixed effect are introduced (see annex table A.3). In the second exercise, we re-estimate the baseline model using non-parametric methods. Specifically, we create four equally spaced splines from the marginal distribution of the public investment series to allow for non-linear relationships between investment and costs.[10] The results—shown in table A.4—confirm our core findings. While the segment representing 35^{th} - 65^{th} percentile of the distribution shows unit costs falling, the trend reverses with a sharp increase in unit costs once public investment goes beyond the 65^{th} percentile of the distribution.

5.2 The role of investment efficiency

Investing in social and physical infrastructure can invigorate both short and long-term growth. The benefits of efficient public investment is especially higher in developing countries when efficient public investment targets clearly identified infrastructure needs. As policymakers explore the best ways to remove these bottlenecks, they should keep alert to the risk of time and cost overruns associated with ambitious public investment plans.

One way to think about the relationship between investment efficiency and absorptive capacity constraints is suggested by Berg, Portillo, Yang and Zanna (2013). They model absorptive capacity constraints in developing countries as lower public investment efficiency when investment is scaled up. This idea is consistent with indirect empirical evidence showing lower investment returns as investment accelerates (Arestoff and Hurlin,

[10] See Wegman and Wright (1983) and Dierckx (1995).

2006; Shi et al., 2017). Another way to think about the same relationship is to consider efficiency as an exogenous feature of economies and not one that arises when investment is scaled-up. Absorptive capacity constraints could manifest in investment cost hikes due to thinly spread planning capacity during investment drives or when public investment reaches some threshold (Collier et al., 2010; Buffie et al., 2012).

Following the second line of thought, we divided the sample into two country groups based on public investment efficiency scores to determine if the public investment threshold identified in section 5.1 varies across efficiency levels. To do this, we first construct an efficiency index using non-parametric techniques for a global sample of countries (see table A.7 for a distribution of countries). The index is developed using inputs (*public investment as a share of GDP, and GDP per-capita*) and output (*the quality of infrastructure*) from WEF's Global Competitiveness ranking. An output efficiency score of 0.8 indicates that the inefficient producer attains 80% of infrastructure quality score attained by the most efficient producers with the same input intake. Then, we define three efficiency quantiles and compare the bottom efficiency quantile against the other two higher efficiency quantiles (table 3).

Next, we test whether more efficient countries have greater scope for public investment vis-à-vis less efficient ones (those in the bottom quintile of the efficiency score). If this is indeed true, then all other factors equal, efficient countries have a higher absorptive capacity and, therefore, more room for public infrastructure investment without running into unit cost inflation. Columns 1 - 4 and 5 - 8 of table 3 report the results for the low- and high-efficiency groups, respectively. In both cases, the coefficients on public investment and its square term are highly significant. Also, the inflection point of public investment is lower at 7% of GDP for the lower efficiency group than the 10% for the higher efficiency group. The extreme points for both groups of countries are significant at standard confidence levels indicating the existence of a U-shaped relationship between unit costs and public investment levels.[11]

While these efficiency scores are time invariant—like others in the literature (see Dabla-Norris et al., 2012)—institutions and processes underpinning public investment manage-

[11]Each extremum is inside the data range, a necessary condition or the test of a U shape in finite samples. While it is possible to generate confidence intervals around each extremum, we cannot statistically test inequality of the extrema.

Table 3: Public investment and project unit costs, low versus high efficiency countries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Lowest efficiency quantile				Higher efficiency quantiles			
ACD Conflict		0.2106**				0.2574***		
		(0.0938)				(0.0690)		
ACD Post-conflict		-0.0284				0.0982		
		(0.1403)				(0.0882)		
WGI Instability			0.1151				0.1189**	
			(0.0890)				(0.0541)	
WGI Instability> Median				0.1867***				0.1132
				(0.0640)				(0.0897)
Public Investment/GDP	-0.1275**	-0.1141**	-0.1046*	-0.1073**	-0.0593*	-0.0645**	-0.0498*	-0.0576*
	(0.0503)	(0.0521)	(0.0518)	(0.0492)	(0.0330)	(0.0313)	(0.0297)	(0.0317)
(Public Investment/GDP)^2	0.0083*	0.0077*	0.0068*	0.0073*	0.0027*	0.0031**	0.0027**	0.0029**
	(0.0040)	(0.0040)	(0.0038)	(0.0039)	(0.0015)	(0.0014)	(0.0013)	(0.0014)
Observations	1,125	1,125	1,125	1,125	1,825	1,825	1,825	1,825
R^2	0.9160	0.9164	0.9162	0.9164	0.9069	0.9082	0.9076	0.9072
Project-level controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Macro-level controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Work-activity FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5-year period×work-type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Min U-curve	7.717	7.433	7.706	7.363	10.89	10.27	9.356	10.04
U-test ($P > \|t\|$)	0.045	0.050	0.064	0.058	0.051	0.030	0.064	0.047

Notes: The dependent variable is the log of cost per km. The table replicates columns 4-7 of table 2 for bottom and two higher efficiency quantiles. See table A.7 for the classification of countries in efficiency quintiles. Project- and Macro-level control variables are included as in table 2, but not shown. See annex table A.1 for definition of variables. Standard errors (in parentheses) are clustered at country level. $*, **, ***$ denote significance at 10%, 5% and 1% levels, respectively. The null hypothesis for U-test ($P > |t|$) is that the relationship is increasing at the left-hand side of the interval and/or is decreasing at the right-hand side. The null and alternative are H_0: inverted U or monotonic vis-à-vis H_1: U-shaped.

ment only gradually change. Assuming efficiency scores are indeed slow moving, the marginal effects from table 3 can help us put the above thresholds into perspective. On average, 15% of low-income developing countries devoted more than 10% of GDP to public investment between 2013 and 2015 (the most recent available data, see annex figure A.1) and nearly 32% invested above 7% of GDP. Columns 2 and 6 show us that scaling up public investment from 8% to 15% of GDP is associated with a 38% increase in unit costs in the lowest efficiency quantile vis-á-vis a 3% increase for those in the higher efficiency quantiles. Moreover, unit costs are disproportionately higher at higher shares of investment for both efficiency groups. An increase in public investment to 20% of GDP from 15% is associated with a 73% and 21% increase in unit costs for the lower and higher efficiency quantiles, respectively (see table A.5). The relationship is robust to different definitions of the efficiency buckets.

These results also broadly mirror findings from earlier studies in the literature, such as Isham and Kaufmann (1999) and Fosu et al. (2016). However, while that literature relies on total public investment and is likely to include non-infrastructure investment (because data on public infrastructure investment are not widely available), our analysis sheds light on the effect of absorptive capacity constraints on unit costs when looking explicitly at infrastructure projects.

5.3 Unit costs during public investment drives

Despite widespread anecdotal evidence of time and cost overruns in transport infrastructure worldwide, robust empirical analyses of the effects of 'big-push' public investment on unit costs of infrastructure delivery is sparse. The focus so far in the literature has been on the growth impact of public investment drives (IMF, 2014; Warner, 2014; Presbitero, 2016) or the political economy behind these investment accelerations (Gupta et al., 2016). While the evidence presented in these studies is mixed, there is consensus that many public investment drives falter after some early successes. In addition, the effect of public investment drives on unit cost is likely to depend on the efficiency of investment. Here too the focus has been the link or lack thereof between inefficiency and growth (Abiad et al., 2016; Berg et al., 2019).

In this section, we examine the effect of investment accelerations on unit costs. We begin by identifying investment drives in our sample using a 'threshold method' customarily used in the credit boom literature (Mendoza and Terrones, 2008, 2012). This approach allows us to identify investment drives as episodes where public investment (as a share of GDP) $p^i_{j,t}$ exceeded its long-run, country specific trend by more than a given 'drive' threshold, defined in terms of a tail probability event. The duration of these investment drives is set by "starting" and "ending" thresholds proportional to each country's standard deviation of $\sigma(p^i_j)$ and reflect country specific events.

Public investment drives are formally defined as follows. Suppose the deviation of public investment from its historical average share of GDP in country j, year t is denoted $D^i_{j,t} = p^i_{j,t} - \bar{p}^i_j$, and the corresponding standard deviation is $\sigma(p^i_j)$.[12] Country j is defined to have experienced an investment drive when one or more adjacent years are identified for which the 'investment drive' condition $D^i_{j,t} \geq \phi\sigma(p^i_j)$ holds, where ϕ is the 'drive' threshold factor. During investment drives, deviations from trend exceed typical expan-

[12]Trend and cycle components are not separated when identifying investment drives unlike in Mendoza and Terrones (2008, 2012) largely because, though volatile, historical public investment shares are stable in emerging and developing countries

sions of public investment by a factor of ϕ or more. The peak of the investment drive $\hat{t}$ is the date that shows the maximum difference $D^i_{j,t}$ compared to adjacent dates.

The starting date of the investment drive is a date t^s such that $t^s < \hat{t}$ and t^s yields the smallest difference $|D^i_{j,t} - \phi^s \sigma(D_j)|$. The ending date t^e is a date $t^e > \hat{t}$ that satisfies $\phi^e \ni (p^i_{j,s} \leq p^i_{j,e} < p^i_{j,t} + \phi\sigma(p^i_j))$[13] where ϕ^s and ϕ^e are the start and end thresholds. The baseline value of $\phi = 1$ or roughly at 16% of the standard normal distribution $\mathsf{P}\left(\frac{D^i_{j,t}}{\sigma(p_j)} \geq 1\right) = 0.16$. We conducted sensitivity analysis by setting $\phi = 1$ to confirm robustness of results to the value of ϕ. The two thresholds $\phi = 1$ and $\phi = 0.5$ are then labelled *booms* and *surges* and the baseline values of ϕ^s for these episodes are, respectively, set at 0.5 and 0.25. Using this approach, *surge* and *boom* episodes accounted for 25% and 12% of the sample. While broadly representative of every region and spread out across time, investment *surges* were more persistent in Africa and Asia, notably in Ethiopia, Indonesia, Laos, and Philippines.[14] Figure A.1 provides an example of public investment surge episodes in Vietnam, which resulted in a rapid expansion of the stock of infrastructure, but, at the same time, showed how investment inefficiencies could lead to critical weaknesses in infrastructure. Thanh and Dapice (2009) note that "[t]he apparent inability of heavy investment to solve infrastructure constraints is explained by the fact that a disproportionate number of infrastructure projects, particularly those in the transport sector, are economically non-viable but approved under political pressure with *inflated costs*."

In table 4, we extend the specification reported in table 2 by adding interactions of these investment accelerations (*booms* and *surges*) with the public investment-to-GDP ratio and its squared term. These interactions capture the relationship between investment accelerations and unit costs when the size of the public investment programs vary. The six columns feature interactions between surge and boom episodes and public investment shares for the full sample (columns 1, 2, 4, 5) and lower efficiency quantiles (columns 3 and 6). As in table 3, only the bottom half of the table is displayed to highlight the focus variables. Columns 1 and 4 are base specifications where investment accelerations are interacted with the share of public investment. These specifications assume uniform changes in unit cost changes from investment accelerations and irrespective of the size of

[13]The threshold value of ϕ^e is set so that the share of public investment at the end of the drive is either greater or equal to the starting level, but lower than the threshold.

[14]Some of these public investment drives are extensively discussed in World Bank (2016) (Ethiopia), IMF (2009) (Laos), and Warner (2014) (Philippines).

investment programs. Squared shares of public investment are added in columns 2, 3, 5, and 6 to highlight variations in unit cost change as the size of PIP changes.

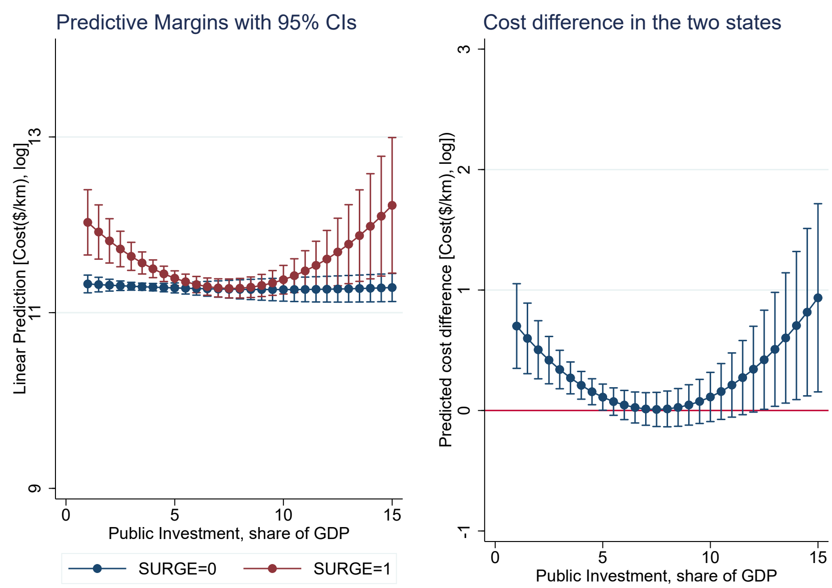
Table 4: Public investment drives and project unit costs

	(1) Full	(2) Full	(3) Low Efficiency	(4) Full	(5) Full	(6) Low Efficiency
WGI Instability > Median	0.1553**	0.1368**	0.0506	0.1523**	0.1386**	0.0546
	(0.0676)	(0.0635)	(0.0618)	(0.0652)	(0.0640)	(0.0638)
Public Investment/GDP	0.0010	-0.0078	0.0052	-0.0021	-0.0226	0.0061
	(0.0075)	(0.0215)	(0.0554)	(0.0071)	(0.0227)	(0.0529)
(Public Investment/GDP)^2		0.0004	-0.0010		0.0010	-0.0021
		(0.0010)	(0.0047)		(0.0011)	(0.0051)
SURGE	0.1396	0.7593***	0.9822**			
	(0.1034)	(0.2125)	(0.3690)			
Public Investment/GDP×SURGE	-0.0333*	-0.2531***	-0.3039**			
	(0.0189)	(0.0744)	(0.1122)			
(Public Investment/GDP)^2×SURGE		0.0169***	0.0209**			
		(0.0054)	(0.0084)			
BOOM				0.1259	0.7516***	1.0560***
				(0.1446)	(0.2673)	(0.2862)
Public Investment/GDP×BOOM				-0.0267	-0.2341***	-0.3126***
				(0.0216)	(0.0809)	(0.0863)
(Public Investment/GDP)^2×BOOM					0.0153***	0.0221***
					(0.0056)	(0.0067)
Observations	2,968	2,968	1,578	2,968	2,968	1,578
R^2	0.9018	0.9024	0.9034	0.9016	0.9020	0.9033
Project-level controls	Yes	Yes	Yes	Yes	Yes	Yes
Macro-level controls	Yes	Yes	Yes	Yes	Yes	Yes
Work activity FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes
5-year period×work-type FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The dependent variable is the log of cost per km. Project- and Macro-level control variables are included as in table 2, but not shown. See annex table A.1 for the definition of the variables. See table A.7 for the classification of low efficiency countries. Standard errors (in parentheses) are clustered at the country level. Only the bottom half of the table is displayed to highlight the focus variables. $*, **, ***$ denote significance at 10%, 5% and 1% levels, respectively.

Coefficients on the *Surge* and *Boom* dummies and their interactions are either weakly or not statistically significant in the base specifications. By contrast, specifications with squared investment are statistically significant in all four other columns and show a strong positive relationship between public investment drives and unit costs relative to normal investment episodes. These results imply two type of effects. First, project unit costs are larger with surges when investment programs are relatively moderate (less than 5% of GDP). Unit cost differences at these levels of investment could signify absorptive capacity constraints associated with investment acceleration vis-à-vis gradual scaling up of investment. Second, unit cost differences due to investment acceleration are not clearly visible as public investment programs become moderately bigger (5 - 10% of GDP). Differences are masked by two forces that drive up costs (a) a velocity effect $-$ *investment acceleration* and (b) the mass effect $-$ *PIP size*. The latter effect is discussed in section 5.1.

Figure 1: The absorptive capacity cost of public investment *surges*

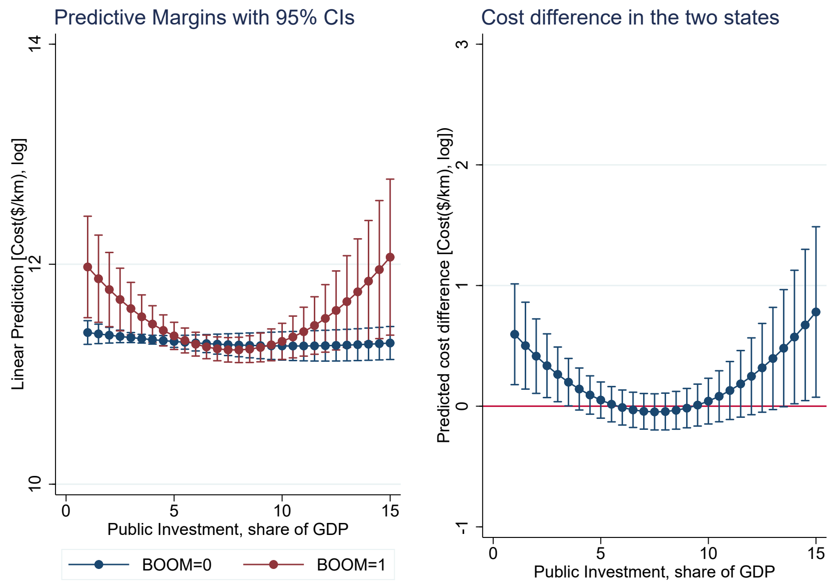


Note: Marginal effects from columns 1. The y-axis represent linear predictions of log unit costs. The right panel maps $\ln(\frac{c_s}{c})$ to the share of public investment in GDP, where c_s and c are unit costs with investment surges and gradual scaling up.

Table A.6 further elucidates these results by summarizing marginal effects from table 4. It shows that unit costs are 22 - 40% higher during investment surges, on average, than during periods of gradual scaling up, when these accelerations occur at public investment levels in the range of 5 - 7% of GDP. These results are robust to sample variations and alternative definitions of public investment drives. Unit costs are 48 - 73% higher over the same public investment range when the sample is restricted to countries in lower efficiency quantiles. Overall, our results suggest that unit costs are much higher when countries lack the institutional capacity to effectively manage investment drives.

Figures 1 and 2 provide a useful illustration of unit cost changes both during identified *boom* and *surge* episodes, also at varying sizes of public investment programs. The left and right panels plot unit costs during *surges* (figure 1) and *booms* (figure 2), vis-á-vis gradual scaling up, for given sizes of public investment programs and unit cost differences between investment drives and gradual scaling up. As both figures show, unit costs are much higher during *surges* and *booms* vis-á-vis gradual scaling up. These results are strongest when investment drives are initiated when public investment programs are small (e.g. below 5% of GDP). Unit costs are practically indistinguishable when investment drives and gradual scaling up take place on the back of already large public

Figure 2: The absorptive capacity cost of public investment *booms*



Note: Marginal effects from columns 3. The y-axis represent linear predictions of log unit costs. The right panel maps $\ln(\frac{c_s}{c})$ to the share of public investment in GDP, where c_s and c are unit costs with investment booms and gradual scaling up.

investment programs.[15]

6 Conclusion

Infrastructure bottlenecks are considered impediments to sustained growth in most developing countries. While public investment is necessary to stem these gaps, sustain growth and expand access to public services, little is said about the rate with which such investment can expand to deliver maximum benefit to these economies. Our analysis contributes to this debate showing that scaling up public investment too much and too fast can lead to inefficient outcomes, as countries are constrained in their ability to absorb investment. We use the World Bank's ROCKS dataset to show how unit costs change as public investment grows, especially during investment drives, and the extent to which absorptive capacity constraints vary with investment efficiency.

Three results stand out after controlling for a range of project characteristics, geographic features, financing instruments and a large set of granular fixed effects. First, there is

[15]While it is conceivable that booms might encourage governments to examine broader financing options (including private investment and public-private partnerships) which ostensibly minimize time and cost overruns, forging such partnerships or managing them may be difficult for many developing countries. On balance, how well cost savings from favorable financing arrangements dampen cost inflation during booms is an empirical question left for future research.

a U-shaped relationship between public investment and project unit costs, with an inflection point close to 10% of GDP. Second, the estimated threshold beyond which unit costs sharply increases is lower (close to 7% of GDP) for countries with low investment efficiency. Countries at lower efficiency quantiles are less likely to absorb large public investment projects without running into cost inflation compared to their high efficiency peers. Finally, we find evidence suggesting that unit cost increases in response to public investment surges, especially at low level of investment. Overall, both the velocity and the acceleration effects seems to be at play and the effects on unit costs are economically large. For instance, scaling up public investment from 8% to 15% of GDP is associated with a 38% increase in unit costs in the lowest efficiency quantile vis-á-vis a 3% increase for those in the higher efficiency quantiles. In interpreting our results it is important to keep in mind that the effects captured in the analysis are likely to be short term adjustment costs associated with large public investment and/or its rapid scaling up as fixed effects filter out unobserved country specific effects like market organization (rules governing an often-oligopolistic construction industry or technology) that cause persistent unit cost differences.

The relationship between unit costs and investment budgets is characterized by two forces. The evidence presented indicates the marginal cost of public investment governance is high when public investment is particularly large. At the opposing extreme, it shows the existence of a minimum efficient scale for public investment management. Investment portfolio mix are particularly inefficient when investment budgets are small. Such budgets are likely to target portfolios dominated by 'prestige projects' with limited social value and comparatively higher unit costs. As budgets and investment portfolio expand, the mix of projects likely becomes more balanced, including both affordable and sustainable projects. These changes and the availability of some investment evaluation and prioritization capacity in Finance Ministries are likely to lower unit costs. However, as investment budgets expand further, appraisal capacity does not grow commensurate with the pool of projects, and as phase, size and specificity disproportionately grow.

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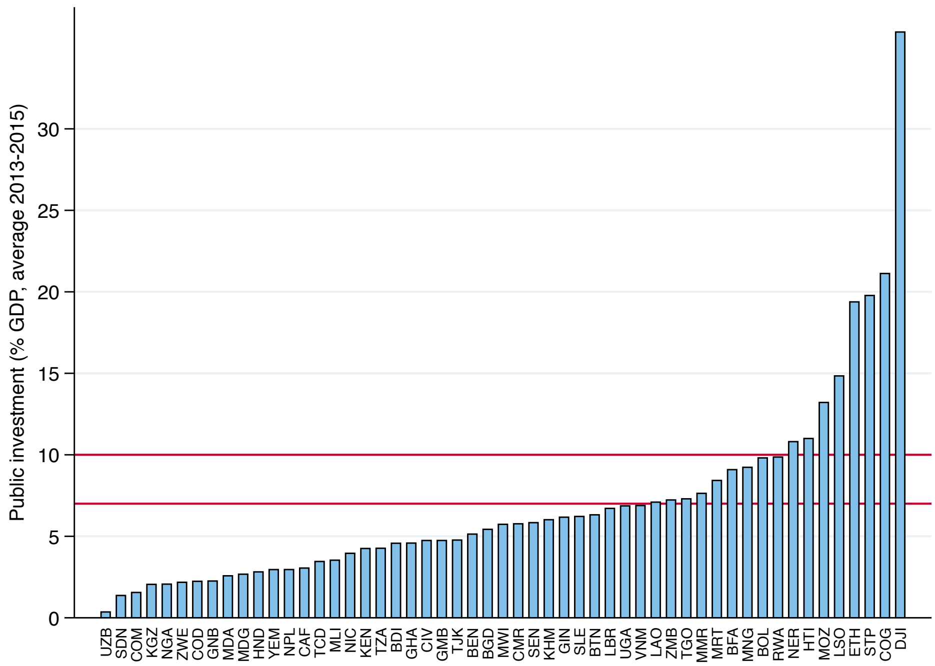
A.1 Appendix

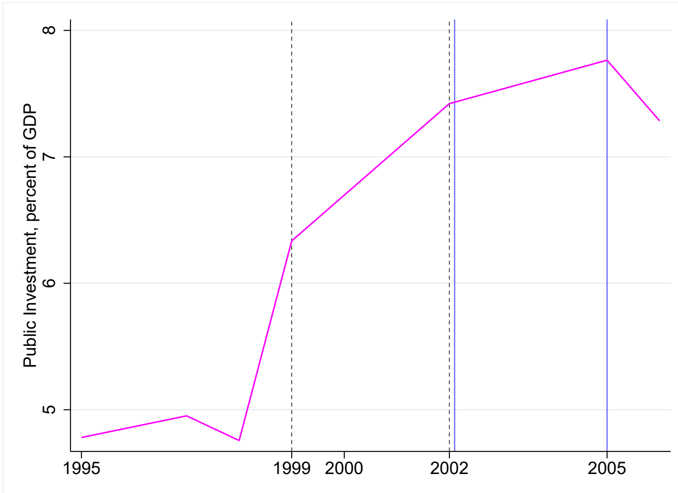
Additional Figures

Figure A.1: The distribution of public investment in developing countries, 2013-2015



Note: Data are from the Investment and Capital Stock Dataset, 1960-2015, published by the International Monetary Fund. Public investment to GDP ratios are averages over the period 2013-2015.

Figure A.2: Public investment surge episodes in Vietnam



Source: Authors using data from International Monetary Fund.
Note: The chart plots two distinct public investment surges in Vietnam (1999-2002), (2002-2005). Each episode – identified with vertical lines – represents periods where public investment was 0.5 percentage points above the average investment level (*surges*). The latter episode also qualifies as an investment *boom* episode since a surge begun in 1999 and public investment is a full standard deviation above the historical average.

Additional Tables

Table A.1: Data definition and source

Variable	Description	Source
Log unit cost	Log of unit cost of a particular road work activity (1984-2008)	ROCKS, World Bank
Estimate	= 1 if estimated costs	ROCKS, World Bank
Contract	= 1 if contracted costs	ROCKS , World Bank
Actual	= 1 if actual costs	ROCKS, World Bank
Flat	= 1 if terrain is Flat	ROCKS, World Bank
Hilly	= 1 if terrain is hilly	ROCKS, World Bank
Mountainous	= 1 if terrain is mountainous	ROCKS, World Bank
Rolling	= 1 if terrain is rolling	ROCKS, World Bank
Foreign firm or JV	= 1 if the work activity was carried out by a foreign firm or joint venture	ROCKS, World Bank
World Bank	= 1 if the work activity was financed by the World Bank	ROCKS, World Bank
Bilateral Donor	= 1 if the work activity was Financed by a bilateral donors	ROCKS, World Bank
Log of Ruggedness	Log of Terrain Ruggedness Index, representing the average ruggedness of a country measured as hundred of meters of elevation difference for grid points 926 meters apart	Nunn and Puga (2012)
Log of Distance to Coast	Log of average distance to nearest ice-free coast (1000 km)	Nunn and Puga (2012)
Log of Rainfall	Log of yearly precipitation in 100s mm, 2000-2008	Dell et al. (2012)
Population Density	Population Density (100 people per square km), 1960-2012	World Development Indicators
Log of Surface Area	Log of Surface Area (1,000 square km)	World Development Indicators
Log of GDP (1985)	Log of GDP per capita 1985, constant 2000 US$ (*initial GDP proxy*)	World Development Indicators
ACD Conflict	=1 if country is in a conflict	Armed Conflict Dataset
WGI Instability	Index of political instability and violence from World Governance Indicators (1996-2012), redefined to: -1.26 (lowest) to 2.21(highest)	World Governance Indicators
WGI Corruption	Index of corruption from World Governance Indicators (1996-2012), redefined to: -1.45 (lowest corruption) to 1.6 (highest corruption)	World Governance Indicators
PIMI	Public Investment Management Index, 2011, measured on scale from 0 (worst) to 4(best)	Dabla-Norris et al. (2012)
Public investment	Estimates of public investment flows between (1960-2017)	Capital Stock Dataset, IMF

Source: Collier et al. (2016); IMF (2019)

Table A.2: Public investment and project unit (estimated and contracted) costs

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Collier et al. (2016), table 4			Including Public Investment-GDP			
Length$>50km$	-0.1338***	-0.1165**	-0.1207***	-0.1209***	-0.1428***	-0.1220**	-0.1270***
	(0.0435)	(0.0459)	(0.0444)	(0.0451)	(0.0436)	(0.0463)	(0.0445)
Log Ruggedness	0.1015***	0.1266***	0.1362***	0.1443***	0.0589*	0.1009**	0.1073***
	(0.0309)	(0.0342)	(0.0333)	(0.0363)	(0.0349)	(0.0387)	(0.0371)
Log Rainfall	-0.1664**	-0.1717**	-0.1582**	-0.1557**	-0.2013***	-0.2089***	-0.1980**
	(0.0696)	(0.0757)	(0.0788)	(0.0721)	(0.0632)	(0.0734)	(0.0776)
Log Surface Area	0.0590**	0.0758***	0.0918***	0.0585**	0.0100	0.0378	0.0534**
	(0.0248)	(0.0249)	(0.0223)	(0.0248)	(0.0268)	(0.0266)	(0.0251)
Log Distance to Coast	0.0002	-0.0252	-0.0324	-0.0072	0.0183	-0.0126	-0.0210
	(0.0426)	(0.0454)	(0.0473)	(0.0508)	(0.0410)	(0.0462)	(0.0479)
Population Density	0.1438***	0.1239***	0.1194***	0.1175***	0.1236***	0.1085***	0.1015***
	(0.0186)	(0.0175)	(0.0170)	(0.0221)	(0.0215)	(0.0214)	(0.0216)
Bilateral Donor	0.1454	0.1555	0.1340	0.1708	0.1966	0.1951	0.1740
	(0.1247)	(0.1306)	(0.1265)	(0.1305)	(0.1311)	(0.1373)	(0.1312)
World Bank	0.0551	0.0822	0.0614	0.0181	0.0090	0.0379	0.0145
	(0.1084)	(0.1073)	(0.1045)	(0.1104)	(0.1153)	(0.1150)	(0.1113)
Foreign firm or JV	0.1748	0.2015*	0.2017*	0.2833**	0.2461**	0.2713**	0.2685**
	(0.1101)	(0.1096)	(0.1131)	(0.1106)	(0.1118)	(0.1097)	(0.1138)
Log of GDP pc (1985)	0.0021	-0.0030	-0.0171	-0.0400	-0.0144	-0.0246	-0.0489
	(0.0503)	(0.0518)	(0.0517)	(0.0540)	(0.0475)	(0.0520)	(0.0500)
Contract	-0.1650***	-0.1549***	-0.1679***	-0.1637***	-0.1616***	-0.1518**	-0.1652***
	(0.0563)	(0.0576)	(0.0559)	(0.0580)	(0.0559)	(0.0576)	(0.0549)
ACD Conflict	0.2755***				0.3297***		
	(0.0777)				(0.0722)		
ACD Post-Conflict	0.0886				0.1496**		
	(0.0727)				(0.0685)		
WGI Instability		0.1291**				0.1425***	
		(0.0562)				(0.0526)	
WGI Instability>Median			0.1174				0.1409*
			(0.0792)				(0.0780)
Public Investment/GDP				-0.0626**	-0.0576**	-0.0514**	-0.0603**
				(0.0280)	(0.0225)	(0.0239)	(0.0260)
(Public Investment/GDP)^2				0.0030**	0.0034***	0.0029**	0.0032**
				(0.0014)	(0.0012)	(0.0012)	(0.0013)
Observations	2,357	2,357	2,357	2,291	2,291	2,291	2,291
R^2	0.9157	0.9150	0.9146	0.9183	0.9204	0.9191	0.9188
Work activity FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5-year×work-type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Min U-curve	-	-	-	10.32	8.55	9.00	9.33
U-test, $P>\mid t\mid$	-	-	-	0.019	0.007	0.018	0.012

Notes: The dependent variable is the log of cost per km, excluding actual costs and considering only estimated and contracted costs. Standard errors (in parentheses) are clustered at the country level. $*, **, ***$ denote significance at 10%, 5% and 1% levels, respectively. The null hypothesis for U-test($P>|t|$) is that the relationship is increasing at the left-hand side of the interval and/or is decreasing at the right-hand side. H_0: inverted U or monotonic vis-à-vis H_1: U-shaped.

Table A.3: Public investment and project unit (additional regressors)

	(1)	(2)	(3)	(4)	(5)
Length$> 50km$	-0.1429***	-0.1609***	-0.1419***	-0.1443***	-0.1442***
	(0.0441)	(0.0416)	(0.0444)	(0.0441)	(0.0441)
Log Ruggedness	0.1232***	0.0557**	0.1075***	0.1058***	0.1063***
	(0.0296)	(0.0278)	(0.0310)	(0.0317)	(0.0322)
Log Rainfall	-0.0950	-0.1375**	-0.1176*	-0.1199*	-0.1172*
	(0.0631)	(0.0555)	(0.0634)	(0.0672)	(0.0683)
Log Surface Area	0.0871***	0.0479**	0.0779***	0.0810***	0.0827***
	(0.0196)	(0.0213)	(0.0215)	(0.0201)	(0.0211)
Log Distance to Coast	-0.0252	-0.0017	-0.0300	-0.0332	-0.0364
	(0.0370)	(0.0366)	(0.0369)	(0.0372)	(0.0376)
Population Density	0.0851***	0.1069***	0.0817***	0.0776***	0.0745***
	(0.0231)	(0.0231)	(0.0230)	(0.0234)	(0.0240)
Bilateral Donor	0.1173	0.1372	0.1297	0.1240	0.1253
	(0.1267)	(0.1283)	(0.1298)	(0.1270)	(0.1270)
World Bank	-0.0722	-0.0629	-0.0599	-0.0688	-0.0711
	(0.0923)	(0.0960)	(0.0965)	(0.0934)	(0.0936)
Foreign firm or JV	0.2850**	0.2656**	0.2888**	0.2828**	0.2854**
	(0.1175)	(0.1171)	(0.1180)	(0.1176)	(0.1190)
Log of GDP pc (1985)	0.0231	0.0360	0.0208	0.0087	0.0123
	(0.0415)	(0.0407)	(0.0407)	(0.0397)	(0.0392)
Contract	-0.0570	-0.0594	-0.0537	-0.0584	-0.0574
	(0.0669)	(0.0658)	(0.0668)	(0.0665)	(0.0665)
Estimate	-0.0374	-0.0321	-0.0360	-0.0357	-0.0349
	(0.0547)	(0.0518)	(0.0543)	(0.0543)	(0.0543)
ACD Conflict		0.3061***			
		(0.0554)			
ACD Post-Conflict		0.0842*			
		(0.0500)			
WGI Instability			0.0486		
			(0.0422)		
WGI Instability>Median				0.0712	0.0641
				(0.0569)	(0.0607)
WGI Corruption>Median					0.0262
					(0.0549)
Public Investment/GDP	-0.0442**	-0.0379**	-0.0393**	-0.0432**	-0.0425**
	(0.0193)	(0.0158)	(0.0185)	(0.0186)	(0.0187)
$(\text{Public Investment/GDP})^2$	0.0025**	0.0025***	0.0023**	0.0025***	0.0025***
	(0.0010)	(0.0008)	(0.0009)	(0.0009)	(0.0009)
Observations	3,229	3,229	3,229	3,229	3,229
R^2	0.9032	0.9051	0.9033	0.9033	0.9033
Work activity FE	Yes	Yes	Yes	Yes	Yes
Income Group FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes
5-year×work-type FE	Yes	Yes	Yes	Yes	Yes
Min U-curve	8.895	7.562	8.454	8.564	8.405
U-test, $P >\mid t \mid$	0.013	0.011	0.019	0.012	0.014

Notes: The dependent variable is the log of cost per km, excluding actual costs and considering only estimated and contracted costs. Standard errors (in parentheses) are clustered at the country level. $*, **, ***$ denote significance at 10%, 5% and 1% levels, respectively. The null hypothesis for U-test($P > |t|$) is that the relationship is increasing at the left-hand side of the interval and/or is decreasing at the right-hand side. H_0: inverted U or monotonic vis-à-vis H_1: U-shaped.

Table A.4: Public investment and project unit costs (non-parametric regression)

	(1)	(2)	(3)	(4)
Length$>50km$	-0.1186***	-0.1379***	-0.1186***	-0.1224***
	(0.0390)	(0.0369)	(0.0397)	(0.0390)
Log Ruggedness	0.1145***	0.0453	0.0902***	0.0871***
	(0.0329)	(0.0276)	(0.0331)	(0.0311)
Log Rainfall	-0.1019*	-0.1456***	-0.1376**	-0.1409**
	(0.0591)	(0.0507)	(0.0554)	(0.0575)
Log Surface Area	0.0584***	0.0243	0.0474**	0.0536***
	(0.0192)	(0.0204)	(0.0205)	(0.0193)
Log Distance to Coast	-0.0105	0.0054	-0.0169	-0.0225
	(0.0403)	(0.0334)	(0.0381)	(0.0371)
Population Density	0.0924***	0.1055***	0.0882***	0.0811***
	(0.0192)	(0.0177)	(0.0184)	(0.0173)
Bilateral	0.1726	0.1852	0.1877	0.1757
	(0.1270)	(0.1258)	(0.1300)	(0.1275)
World Bank	-0.0273	-0.0299	-0.0108	-0.0293
	(0.0908)	(0.0950)	(0.0941)	(0.0915)
Foreign firm or JV	0.3541***	0.3234**	0.3482***	0.3336***
	(0.1250)	(0.1230)	(0.1236)	(0.1238)
Log of GDP pc (1985)	-0.0462	-0.0266	-0.0345	-0.0523
	(0.0417)	(0.0401)	(0.0432)	(0.0400)
Contract	-0.0424	-0.0441	-0.0348	-0.0428
	(0.0609)	(0.0605)	(0.0605)	(0.0606)
Estimate	-0.0154	-0.0123	-0.0160	-0.0169
	(0.0530)	(0.0501)	(0.0525)	(0.0521)
ACD Conflict		0.2945***		
		(0.0558)		
ACD Post-conflict		0.0830*		
		(0.0492)		
WGI Instability			0.0829**	
			(0.0407)	
WGI Instability>Median				0.1211**
				(0.0515)
(Public Investment/GDP)$_{5-35\%}$	0.0361*	0.0344*	0.0440**	0.0343*
	(0.0194)	(0.0195)	(0.0193)	(0.0197)
(Public Investment/GDP)$_{35-65\%}$	-1.2032***	-1.0359***	-1.1908***	-1.0856***
	(0.3329)	(0.3072)	(0.3331)	(0.3317)
(Public Investment/GDP)$_{65-95\%}$	2.1989***	1.9059***	2.1639***	1.9951***
	(0.6032)	(0.5466)	(0.6002)	(0.5971)
Observations	3,229	3,229	3,229	3,229
R^2	0.8930	0.8952	0.8934	0.8935
Work activity FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
5-year period$\times$Work-type FE	Yes	Yes	Yes	Yes

Notes: The dependent variable is the log of cost per km, excluding actual costs and considering only estimated and contracted costs. See annex for definition of variables and sources. Standard errors (in parentheses) are clustered at the country level. $*, **, ***$ denote significance at 10%, 5% and 1% levels, respectively. (Public Investment/GDP)$_j$ represents the j^{th} spline between knots j and $j+1$. The splines are equally spaced with knots set at percentiles 5, 35, 65, and 95.

Table A.5: Project unit costs by efficiency levels

	Lowest Efficiency quantile				Higher efficiency quantiles			
Pub Inv/GDP	Margin	Std. Err.	z	$P>z$	Margin	Std. Err.	z	$P>z$
1	11.26	0.13	88.21	0.00	11.73	0.08	142.03	0.00
2	11.16	0.08	131.89	0.00	11.67	0.06	211.75	0.00
3	11.07	0.05	222.97	0.00	11.62	0.03	367.76	0.00
4	11.01	0.02	455.73	0.00	11.57	0.02	664.00	0.00
5	10.95	0.02	684.73	0.00	11.53	0.02	469.84	0.00
6	10.92	0.02	441.05	0.00	11.5	0.04	288.68	0.00
7	10.89	0.03	319.87	0.00	11.47	0.05	209.68	0.00
8	10.89	0.04	257.8	0.00	11.45	0.07	168.76	0.00
9	10.90	0.05	207.88	0.00	11.44	0.08	144.72	0.00
10	10.92	0.07	159.38	0.00	11.43	0.09	129.51	0.00
11	10.96	0.09	117.86	0.00	11.43	0.1	119.48	0.00
12	11.01	0.13	87.07	0.00	11.43	0.1	112.74	0.00
13	11.08	0.17	65.61	0.00	11.44	0.11	108.14	0.00
14	11.17	0.22	50.76	0.00	11.46	0.11	104.87	0.00
15	11.27	0.28	40.31	0.00	11.48	0.11	102.27	0.00
16	11.39	0.35	32.77	0.00	11.51	0.12	99.71	0.00
17	11.52	0.42	27.19	0.00	11.55	0.12	96.57	0.00
18	11.67	0.51	22.97	0.00	11.59	0.13	92.39	0.00
19	11.83	0.60	19.71	0.00	11.64	0.13	86.95	0.00
20	12.00	0.70	17.14	0.00	11.69	0.15	80.40	0.00

Notes: The table reports marginal Effects from table 3 showing variations in unit costs as public investment shares change. The margins columns report predicted unit costs from columns 2 and 6 of table 3. Within column margin differences are percentage cost differences since predicted unit costs are expressed in log points.

Table A.6: Project unit costs during investment drives vis-á-vis gradual scaling-up

	SURGE						BOOM					
	Full Sample			Lower efficiency quantiles			Full Sample			Lower efficiency quantiles		
Pub Inv/GDP	Cost Diff	Std. Err.	P> χ^2	Cost Diff	Std. Err.	P> χ^2	Cost diff	Std. Err.	P> χ^2	Cost diff	Std. Err.	P> χ^2
1	0.71	0.17	0.00	0.99	0.31	0.00	0.62	0.21	0.00	0.93	0.22	0.00
2	0.60	0.15	0.00	0.86	0.27	0.00	0.52	0.18	0.00	0.8	0.19	0.00
3	0.50	0.12	0.00	0.75	0.23	0.00	0.43	0.16	0.01	0.68	0.17	0.00
4	0.42	0.10	0.00	0.64	0.19	0.00	0.35	0.13	0.01	0.57	0.14	0.00
5	0.34	0.08	0.00	0.55	0.16	0.00	0.27	0.11	0.02	0.48	0.12	0.00
6	0.26	0.06	0.00	0.47	0.14	0.00	0.20	0.10	0.04	0.39	0.11	0.00
7	0.20	0.06	0.00	0.39	0.12	0.00	0.14	0.08	0.09	0.32	0.09	0.00
8	0.15	0.05	0.00	0.33	0.11	0.00	0.09	0.08	0.23	0.26	0.08	0.00
9	0.10	0.05	0.05	0.28	0.10	0.00	0.05	0.07	0.50	0.21	0.08	0.01
10	0.06	0.05	0.25	0.23	0.09	0.01	0.01	0.07	0.87	0.17	0.07	0.02
11	0.03	0.06	0.58	0.20	0.09	0.02	-0.02	0.07	0.80	0.14	0.07	0.06
12	0.01	0.06	0.87	0.18	0.09	0.05	-0.04	0.07	0.58	0.12	0.07	0.10
13	0.00	0.06	0.96	0.17	0.09	0.07	-0.05	0.07	0.47	0.11	0.07	0.12
14	-0.01	0.07	0.91	0.17	0.10	0.08	-0.06	0.07	0.43	0.12	0.08	0.13
15	0.00	0.07	0.96	0.18	0.11	0.09	-0.06	0.07	0.45	0.13	0.08	0.11
16	0.01	0.08	0.91	0.20	0.12	0.08	-0.05	0.08	0.54	0.16	0.09	0.08
17	0.03	0.08	0.71	0.23	0.13	0.08	-0.03	0.08	0.71	0.19	0.10	0.06
18	0.06	0.09	0.51	0.27	0.15	0.07	0.00	0.09	0.95	0.24	0.12	0.05
19	0.10	0.10	0.33	0.33	0.17	0.06	0.03	0.09	0.77	0.30	0.14	0.03
20	0.14	0.11	0.21	0.39	0.20	0.05	0.07	0.11	0.52	0.37	0.17	0.03

Notes: The table reports unit cost differences at different public investment shares from columns 1 and 3 of table 4. The significance of cost differences is tested using the χ^2 test. Under the null hypothesis, there are no cost differences during surges and booms vis-á-vis normal times.

Table A.7: Efficiency scores

Lowest efficiency Quantile		Higher Efficiency Quantiles					
Angola	0.29	Albania	0.46	Argentina	0.53	Panama	0.68
Bangladesh	0.35	Botswana	0.55	Armenia	0.79	Russia	0.65
Burkina Faso	0.34	Bulgaria	0.53	Azerbaijan	0.59	South Africa	0.64
Cameroon	0.36	China	0.66	Brazil	0.58	Sri Lanka	0.58
Ethiopia	0.39	Colombia	0.51	Chile	0.72	Thailand	0.70
Guinea	0.26	Dominican Republic	0.47	Costa Rica	0.54	Tunisia	0.64
Malawi	0.34	Ecuador	0.50	El Salvador	0.72	Turkey	0.63
Mongolia	0.39	Ghana	0.45	Guatemala	0.57		
Mozambique	0.36	Honduras	0.48	Indonesia	0.55		
Nigeria	0.35	India	0.54	Jordan	0.65		
Paraguay	0.37	Iran	0.62	Kazakhstan	0.58		
Senegal	0.41	Kenya	0.46	Lebanon	0.47		
Sierra Leone	0.33	Uruguay	0.62	Lithuania	0.69		
Tanzania	0.36	Mali	0.43	Malaysia	0.79		
Uganda	0.36	Pakistan	0.44	Mexico	0.59		
Venezuela	0.40	Peru	0.49	Moldova	0.55		
Yemen	0.31	Philippines	0.48	Morocco	0.60		
Zambia	0.40	Vietnam	0.50	Namibia	0.65		
Zimbabwe	0.41						

Source: Authors' computations. These scores are generated using data envelopment analysis using inputs (*public investment as a share of GDP, GDP per-capita*) and output (*the quality of infrastructure*) from WEF's Global Competitiveness ranking. An output efficiency score of 0.8 indicates that the inefficient producer attains 80% of infrastructure quality score attained by the most efficient producers with the same input intake. Three efficiency quantiles are defined. Upper quantiles are collapsed into one.