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The role and impact of infrastructure in middle-income countries: Anything special?

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THE ROLE AND IMPACT OF INFRASTRUCTURE IN MIDDLE-INCOME COUNTRIES: ANYTHING SPECIAL?

Abdul Abiad, Margarita Debuque-Gonzales, and Andrea Loren Sy

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and Andrea Loren Sy

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CONTENTS

TABLES AND FIGURES	iv
ABSTRACT	v
I. INTRODUCTION	1
II. PRIMER: INFRASTRUCTURE AND THE ECONOMY	2
III. TAKING STOCK: THE STYLIZED FACTS	4
IV. INFRASTRUCTURE PROVISION AND INVESTMENT: GOING DEEPER	8
V. THE MACROECONOMIC EFFECTS OF PUBLIC INVESTMENT	16
VI. CONCLUSION	19
APPENDIXES	21
REFERENCES	25

TABLES AND FIGURES

TABLES

1.a	Sectoral Infrastructure Regressions, Without Fixed Effects	10
1.b	Sectoral Infrastructure Regressions, With Fixed Effects	11
2	Sectoral Infrastructure Regressions Using Lagged GDP per Capita, Level, and Quadratic Terms	12
3.a	Sectoral Infrastructure Regressions for the Developing Country Subsample	13
3.b	Sectoral Infrastructure Regressions for the Middle-Income Country Subsample	13
4	Using the Composite Infrastructure Index of Donaubauer, Meyer, and Nunnenkamp	14
5	Public Investment Regressions	15
A1	Data Sources	21
A2	List of Countries	22
A3	Summary Statistics	23
A4	Sectoral Infrastructure Regressions for the Middle-Income Country Subsample Using Lagged GDP per Capita	24

FIGURES

1	Infrastructure, Income, and Growth Performance	6
2	Shares of Different Types of Infrastructure in Total Infrastructure Stock	7
3	Total Infrastructure Investment	8
4	Effects of Public Investment on Output	18

ABSTRACT

We examine the evolution of infrastructure, and the impact of infrastructure investment, in middle-income countries (MICs). We document how different types of infrastructure stocks, as well as infrastructure investment, vary with the level of development and growth performance. We then use the two-stage approach of Corsetti, Meier, and Müller (2012) to identify exogenous public investment shocks and investigate the macroeconomic impact of these shocks. We find that the provision of infrastructure varies across development stages; there is a focus on basic infrastructure, such as transport, water, and sanitation, during early stages, and an emphasis on “advanced” infrastructure, such as power and especially information and communication technology, in later stages. Better-performing MICs tend to invest more in infrastructure. They also have more information and communication technology infrastructure. Finally, we find a more significant and sustained impact of exogenous public investment shocks on output in MICs than in low-income countries.

Keywords: economic development, infrastructure, middle income

JEL codes: H54, O18, O40, Q40

I. INTRODUCTION

The provision of infrastructure has long been considered a crucial element of economic development—a widespread view not only in the academic setting but also in policy circles (Calderón and Servén 2008). Although related empirical studies dating back to the late 1980s (beginning with Aschauer in 1989) have not always been in complete agreement, a majority finds a strong positive link between infrastructure and development outcomes (see Straub 2008 for a survey).

Middle-income countries (MICs) often face challenges in sustaining growth, and hence could potentially benefit from increased infrastructure investment. As they develop, countries often experience substantial slowdowns in growth when they reach middle-income status, preventing many of them from making a quick transition to high-income status.¹ Eichengreen, Park, and Shin (2014) find that growth decelerations usually occur at per capita income levels of about \$10,000–\$11,000 and again at \$15,000–\$16,000 a year in 2005 international purchasing power parity (PPP) dollars. Historically, it takes about 55 years for a country to graduate from lower-middle-income to upper-middle-income status, and another 15 years to graduate to high-income status, with only a few economies, mostly in Asia, able to do so significantly faster (Felipe, Kumar, and Galope 2017). By raising productive capacity, infrastructure investment could play a critical role in sustaining growth in MICs. In a theoretical treatment of the phenomenon, Agénor and Canuto (2015) hypothesize that investing in advanced infrastructure, such as information and communication technology (ICT), can raise potential growth in MICs. But the type of investment undertaken is important, as an economy’s infrastructure needs may change as it develops. While the transition from low income to middle income corresponds to a basic shift from sectors with low to higher productivity, the transition to high-income status is more complex, requiring countries to diversify into a wider set of products, innovate rather than just imitate, and upgrade to more complex products with higher value added.

The empirical literature to date is sparse on whether infrastructure plays a special role in overcoming the development challenges faced by MICs. The few studies that have examined the issue simply include a few indicators of infrastructure as one of many right-hand-side controls, in the search for correlates of growth. The results are unsurprisingly diverse. Using probit analysis, Aiyar et al. (2013) find that better infrastructure (measured by roads and telephone lines) lowers the risk of a growth slowdown in MICs. Examining differences in group means, Vandenberg, Poot, and Miyamoto (2015) find that middle-income economies tend to be weak in infrastructure (measured by roads, electricity, and phone lines) relative to high-income countries (HICs). And Han and Wei (2017), applying newly developed nonparametric classification techniques (conditional tree and random forest analysis), do not find any special role for infrastructure (measured by electricity, roads, and rail) in MICs in terms of separating fast-growing and slow-growing economies, although they do find that good transport infrastructure matters for low-income countries (LICs).

The goal of the paper is to better understand the evolution and nature of infrastructure in MICs. We begin by investigating whether the level and sector compositions of infrastructure, as well as patterns of infrastructure investment, change as countries attain middle-income status and, further, if these vary with growth performance within an income group.

¹ While this has often been referred to in the literature as a “middle-income trap” (a term first used by Gill and Kharas in 2007), other authors argue that this label is not accurate, as the data do not support the notion that MICs are more likely than other income groups to be stuck, or that they have a high probability of being caught in such a trap (see for example, Han and Wei 2017; and Felipe, Kumar, and Galope 2017).

We then examine whether the macroeconomic impact of infrastructure investment differs for MICs. The direction of expectations here is less clear. We expect middle-income economies to have smaller infrastructure shortfalls than LICs, which would lower the marginal productivity of infrastructure investment. However, investment efficiency and absorptive capacity could also be higher in MICs because of stronger institutions, resulting in better selection and execution of infrastructure projects.

To address these questions, this paper presents stylized facts on the provision of infrastructure across the different country income groups and the different levels of performance within these groups, where the latter is measured in terms of growth in gross domestic product (GDP) per capita. Physical measures of different types of infrastructure capital are used, supplemented by an overall measure of infrastructure investment that combines public investment and private infrastructure investment data. Using the data on infrastructure stocks, we probe the robustness of the stylized facts by estimating panel regressions that formally test the relationship between a country's income level and growth performance on the one hand, and infrastructure stocks and infrastructure investment on the other. Finally, an empirical method based on Corsetti, Meier, and Müller (2012) is adopted to identify exogenous public investment shocks and examine whether the effects of infrastructure investment on economic output are different for MICs.

The study reveals several interesting results regarding MICs. First, there is a clear pattern in the sectoral provision of infrastructure across development stages, with basic infrastructure such as transport and water and sanitation emphasized more during the early stages, and more advanced infrastructure such as power and ICT becoming more important during later stages. Second, faster-growing MICs invest more in infrastructure than slower-growing countries. They also tend to have a greater share of infrastructure in ICT than other MICs. Finally, there is a more significant and sustained impact of public infrastructure investment on output in MICs relative to LICs.

The rest of the paper is organized as follows. Section II provides a primer on infrastructure that outlines our conceptual framework. Section III discusses the stylized facts regarding infrastructure provision across development stages and levels of growth performance, with section IV providing more solid econometric backing to the findings. Section V presents the analysis on the macroeconomic effects of infrastructure investment, while section VI concludes.

II. PRIMER: INFRASTRUCTURE AND THE ECONOMY

Infrastructure typically refers to the basic structures that facilitate and support economic activity. In this paper, we use the term to denote network infrastructure—transport by roads and rails, electricity, water and sanitation, and telecommunication by landlines, mobile phones, and internet systems. By providing essential services and connecting markets, infrastructure is essential for the smooth functioning of the economy. It is highly complementary to labor and other types of capital. Therefore, its contribution to output gains can be potentially large.

Infrastructure differs from other types of capital in a few important ways. Infrastructure projects are often big and capital intensive, making them natural monopolies. They have large upfront costs, but benefits accumulate over very long periods. They also tend to generate positive externalities, as social returns can exceed the private gains that can be generated. Because of these peculiarities, which make private financing and provision of infrastructure difficult, infrastructure is still commonly provided or regulated by the public sector. For example, ADB (2017a) finds that over 90% of infrastructure

investment in developing Asia is done by the public sector. Given the budget constraints faced by many low- and middle-income economies, much-needed infrastructure often remains underprovided.

Like other government spending, public investment in infrastructure provides a short-term boost to the economy via the impact of the short-term fiscal multiplier on aggregate demand. It also has a longer-term supply-side effect as a higher infrastructure capital stock raises the productive capacity of the economy. The strength of this latter effect naturally depends on absorptive capacity and the strength of the investment process, which affect how competently projects are selected, implemented, and monitored. If inefficiencies abound, then only a fraction of the amount invested in infrastructure goes toward the actual buildup of the country's infrastructure base.²

In thinking about the role of infrastructure at different stages of a country's economic development, it is useful to provide a sketch of how a country transitions from one income group to another. In a standard Lewis-type development model, LICs can achieve middle-income status through sectoral shifts—primarily by moving workers out of low-productivity agriculture to higher-productivity manufacturing—and by adopting or imitating foreign technology. These sources of high growth tend to dissipate, however, once middle-income (and especially upper-middle-income) status is reached, as the pool of underemployed labor shrinks, thereby causing wages to rise and the country's competitiveness to decline.

Maintaining growth becomes increasingly difficult at this stage, unless it finds other ways to raise productivity. This would require, for instance, strong investment that supports innovation and generates new ideas, processes, and technologies; and a shift to higher value-added products and services. Infrastructure could be central to this process. Agénor and Canuto (2015), for example, developed a two-sector model where the design-innovation sector is the source of endogenous growth. Agents' occupational choice is endogenous; there is a cost to investing in education, and agents will pursue it only if wages in the design-innovation sector are high enough. In their model, sufficiently large investments in advanced infrastructure (such as ICT) improve knowledge spillovers and learning-by-doing, leading to increased human capital accumulation. The authors argue that such a mechanism could help a developing country escape a “middle-income trap” by helping to promote innovation.

A few hypotheses about the role of infrastructure in development can be drawn from this discussion. One is that infrastructure requirements of a country may evolve as a country develops, with more rudimentary infrastructure (such as water and sanitation and basic transport) likely to be critical during the earlier stages of development, and more sophisticated infrastructure required for industrialization and subsequently innovation (such as power and ICT) in the later stages, particularly when a country reaches middle-income levels.³ Another hypothesis is that countries that are better at providing the necessary infrastructure would tend to also perform better.

The macroeconomic impact of infrastructure may likewise change at different stages of development. There are two forces working in offsetting directions here. First, infrastructure shortfalls

² Previous research on the macroeconomic effects of public investment (e.g., Abiad, Furceri, and Topalova 2016) confirms the role that efficiency plays in shaping the macroeconomic impact of such investment. However, that study focused only on public investment in advanced (Organisation for Economic Co-operation and Development [OECD]) economies. One difficulty is that measures of the efficiency of public investment are available only for a limited number of countries, and these measures are only cross sectional.

³ Because of congestion, pollution, and other problems associated with urbanization that takes place in the middle-income phase, urban infrastructure is also likely to become more important for MICs. However, lack of comprehensive data on such urban infrastructure (such as mass transit) prevents us from analyzing this further, and we leave this for future research.

tend to be more pronounced in LICs, and less so in MICs, suggesting that the marginal productivity of infrastructure investment may be larger in less developed countries. However, LICs tend to share certain features such as poor absorptive capacity, making it hard for them to ramp up investment; a more limited supply of complementary factors of production such as human capital or private physical capital, weakening the return on infrastructure investment; and generally lower investment efficiency (Presbitero 2016). These factors suggest that infrastructure investment may have a larger macroeconomic impact in middle-income economies. Considering this theoretical ambiguity, the question of how the macroeconomic impact of infrastructure investment varies with stages of development should be resolved by empirical analysis.

III. TAKING STOCK: THE STYLIZED FACTS

This section documents the stylized facts on infrastructure provision in the various country income groups, allowing us to compare MICs with other economies.⁴ We classify all country-year observations in our sample into three income groups: low-income countries (LICs), lower-middle-income countries (LMICs), and upper-middle-income countries (UMICs). These are based on income thresholds defined by the World Bank, which are applied to GDP data from Penn World Table 9.0, following Han and Wei (2017).⁵ We exclude from the analysis countries whose behavior tends to be atypical—this includes fuel exporters (countries for whom fuel commodities comprise more than 50% of export earnings), small states (which tend to experience much sharper output fluctuations), conflict countries, and former members of the Union of Soviet Socialist Republics.⁶ Movements in GDP per capita in these countries tend to be much larger and driven by idiosyncratic factors, such as oil price swings in the case of oil exporters, weather or even large infrastructure projects in the case of small states, war and postwar reconstruction and recovery in the case of conflict countries, and the post-transition collapse and recovery in the case of the states of the former Soviet Union.

Within each country income group, we classify economies further based on geometric mean per capita GDP growth while in that income group—with “top25” representing the fastest-growing quartile of economies in an income group, “mid50” representing the middle 50%, and “low25” comprising the slowest-growing quartile. This is done to see if differences in infrastructure provision are associated with differences in growth performance within each income group.

⁴ The list of data sources used in this section and the rest of the paper is provided in Appendix Table A1. The sample comprises the 99 countries listed in Appendix Table A2, and is an unbalanced panel with some data starting from 1960, subject to data availability.

⁵ Specifically, the thresholds were derived from the World Bank country income thresholds for fiscal year 2017 (1 July 2016–30 June 2017), which use gross national income per capita to classify countries. To identify corresponding thresholds in Penn World Tables 9.0, which uses GDP per capita in constant 2011 PPP dollars, we calculate the 2015 ratios of average gross national income per capita to GDP per capita in constant PPP per income group (i.e., LIC, LMIC, UMIC, and HIC), and use these ratios to derive the equivalent thresholds in GDP per capita in constant 2011 PPP dollars. United States GDP per capita in 1960 is used to identify the threshold for HICs. The resulting thresholds are: GDP per capita (year 2011 PPP) \leq \$2,585 for LIC; $2,585 < \text{GDP per capita (year 2011 PPP)} \leq 5,351$ for LMIC; and $5,351 < \text{GDP per capita (year 2011 PPP)} \leq 17,600$ for UMIC.

⁶ Small states are defined as countries with populations of less than one million. Conflict countries are those with conflict intensity equal to 2 or “war” based on the UCDP/PRIO Armed Conflict Dataset (see Gleditsch et al. 2002, and Pettersson and Wallensteen 2015), and that also experienced a decline in GDP per capita of more than 10%. Two other countries excluded from the analysis were Bosnia and Herzegovina (a conflict country) and Zimbabwe (hyperinflation and macroeconomic instability).

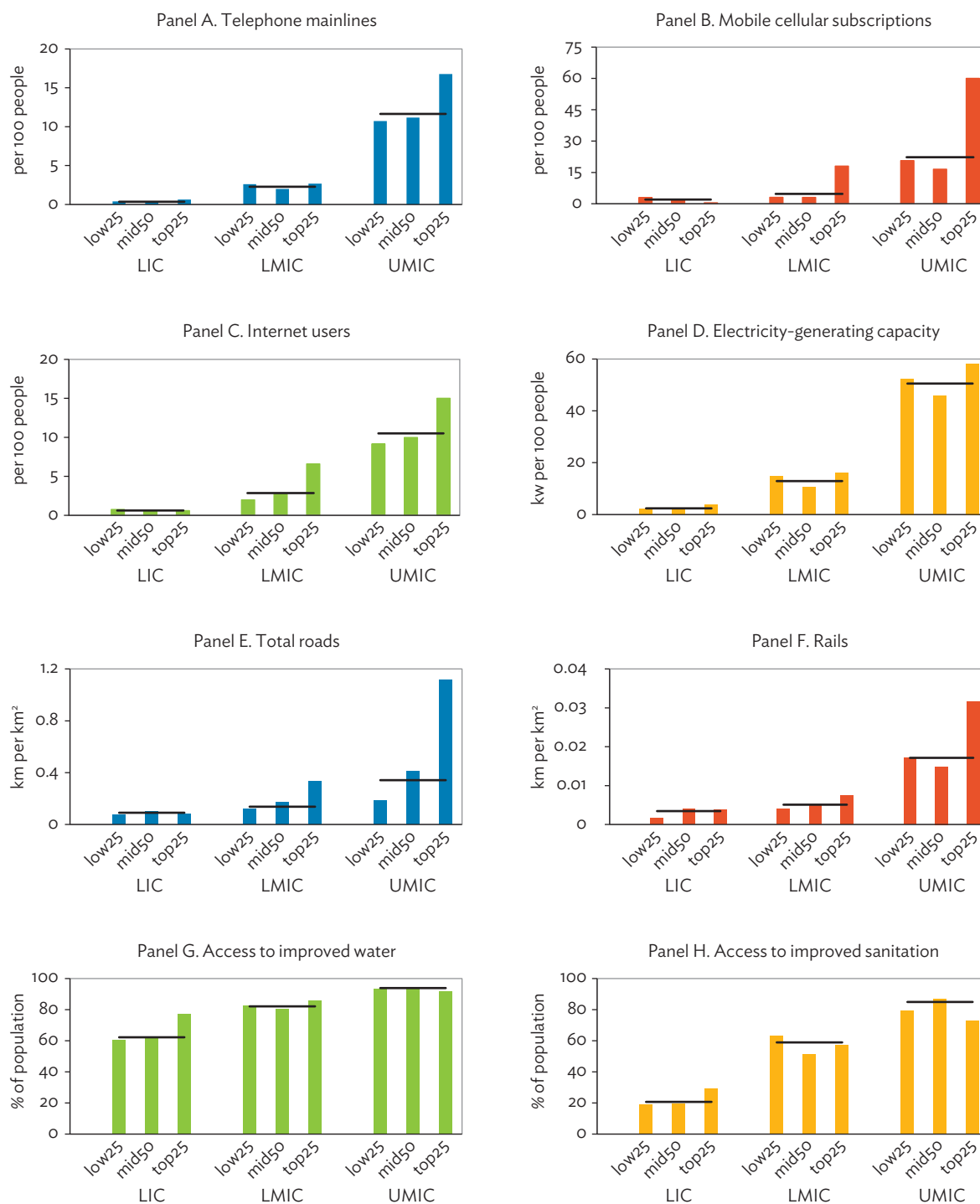
For each country, we use eight measures of the extent of infrastructure provision. For the power sector, we look at electricity-generating capacity in kilowatts per 100 people, taken from Calderón, Moral-Benito, and Servén (2015) and extended to 2011 by the International Monetary Fund (IMF) (2014) using data from Canning (2007) and the US Energy Information Administration. For ICT, we use three indicators—telephone mainlines per 100 people, mobile cellular subscriptions per 100 people, and internet users per 100 people from the World Bank’s World Development Indicators (WDI) dataset. For transport infrastructure, we use two indicators—total road kilometers per square kilometer of land area and total rail kilometers per square kilometer of land area—from Calderón, Moral-Benito, and Servén (2015), extended to 2011 by IMF (2014) using data from the WDI. And for water and sanitation, we take the percentage of the population with access to improved water and improved sanitation, from the WDI. Summary statistics for these and other variables included in the analysis are in Appendix Table A3. For each growth performance group (top25, mid50, low25) within each income group (LIC, LMIC, UMIC), we take the median value of each of the eight infrastructure indicators. The results are similar if the mean value is used.

We find a strong positive correlation between a country’s level of development and measures of infrastructure provision (Figure 1, horizontal black lines). LMICs generally have more infrastructure than LICs, and UMICs have more than the other two income groups. There tends to be a bigger difference in infrastructure provision between UMICs and LMICs than there is between LMICs and LICs, except for water and sanitation where much of the infrastructure provision seems to take place at earlier stages of development. The finding that infrastructure provision increases with development is not surprising or novel, and has been widely documented elsewhere (e.g., IMF 2014).

The more novel finding is that countries that grow faster than their peers in the same income group tend to have more of certain types of infrastructure (Figure 1, vertical bars corresponding to “top25”). This is most evident in ICT (panels A–C) and in transport (panels E and F). For electricity, water, and sanitation, there seems to be little or no association between growth performance and infrastructure provision in these bivariate charts.

While all types of infrastructure tend to increase as countries develop, it is possible that their relative importance changes, as measured by their shares in the overall stock of infrastructure. To explore this conjecture, the different types of infrastructure are aggregated using unit costs of production drawn from Fay and Yepes (2003).⁷ We see that, as countries move from LIC to LMIC to UMIC status, the share of ICT and electricity in the total infrastructure stock rises, while that of transport declines (Figure 2, horizontal black lines). The share of ICT infrastructure is particularly high for the fastest-growing MICs (Figure 2, “top25” bar in the top left panel). The share of electricity climbs steadily as a country progresses, which may reflect industrialization as industry is more energy intensive than agriculture, but it may also reflect higher energy consumption by households as per capita incomes rise. The same figure also shows a drop in the share of water and sanitation as a country reaches the upper-middle-income phase, which is not surprising since providing water and sanitation is a priority in early rather than later stages of development.

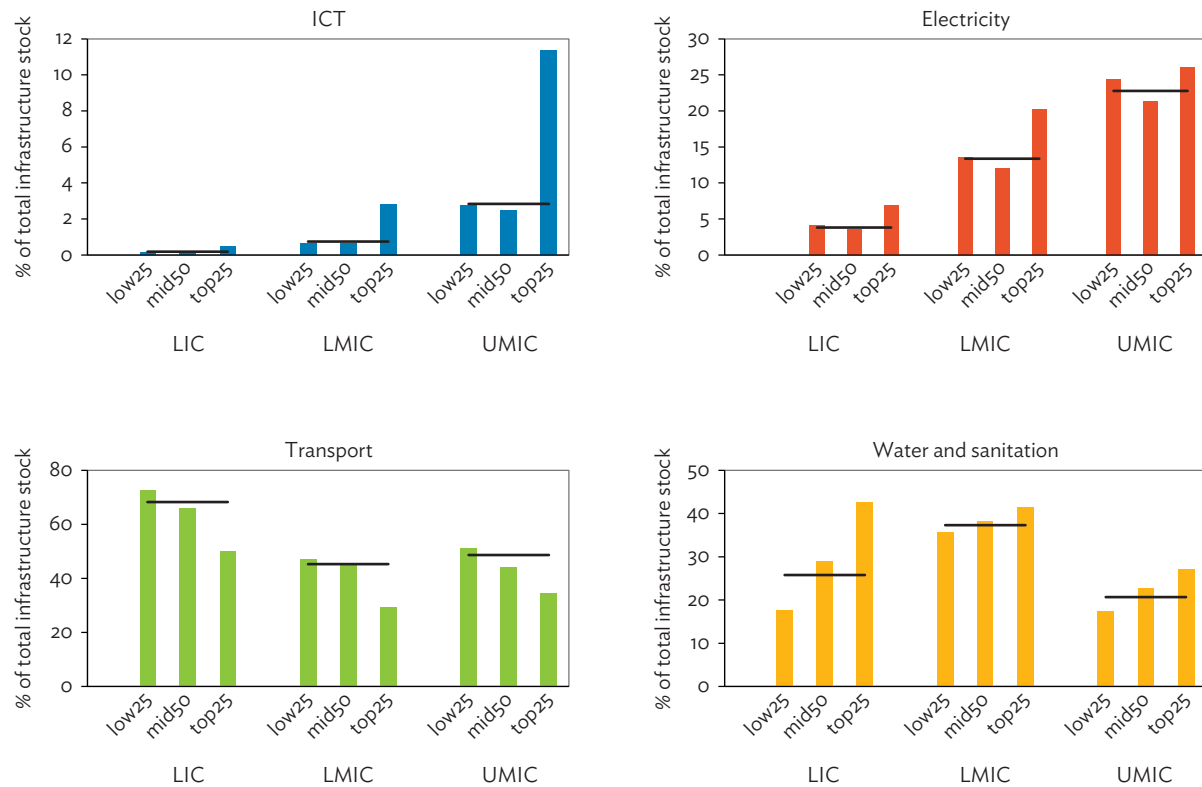
⁷ Physical quantities of infrastructure (e.g., road and rail kilometers, kilowatts of power generation capacity) are multiplied by unit costs and aggregated; the shares of various types of infrastructure in the total can then be calculated. Fay and Yepes (2003, 10) provide such unit costs for telephone landlines, mobile lines, roads, rail, electricity, water supply, and sanitation. Costs of internet provision are omitted in the calculations for Figure 2 because unit costs are not available for internet infrastructure provision; inclusion would raise the share of ICT in overall infrastructure. Using unit costs from ADB (2017a) produces a similar picture.

Figure 1: Infrastructure, Income, and Growth Performance

km = kilometer, km² = square kilometer, kw = kilowatt, LIC = low-income country, LMIC = lower-middle-income country, UMIC = upper-middle-income country.

Note: The bars represent the median level of infrastructure stock for different levels of growth performance (top25, mid50, low25) within each income group, while the horizontal lines represent the median level of infrastructure stock per income group.

Source: Authors' estimates.

Figure 2: Shares of Different Types of Infrastructure in Total Infrastructure Stock

ICT = information and communication technology, LIC = low-income country, LMIC = lower-middle-income country, UMIC = upper-middle-income country.

Note: The bars represent the median level of shares for different levels of growth performance (top25, mid50, low25) within each income group, while the horizontal lines represent the median level of shares per income group.

Source: Authors' estimates.

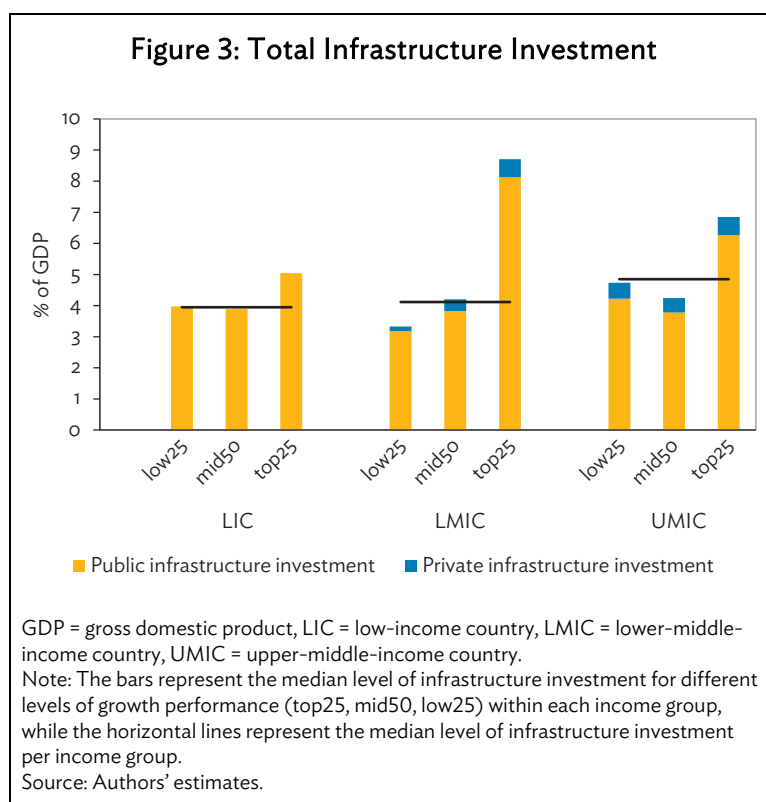
We now turn from comparing infrastructure stocks to examining differences in infrastructure investment. To come up with a measure of total infrastructure investment, we sum the ratios of public investment (the best available proxy for public infrastructure investment) and private infrastructure investment as a share of GDP.⁸ We obtain data on public investment from the Investment and Capital Stock Dataset of the IMF's Fiscal Affairs Department, and private infrastructure investment from the World Bank's Private Provision in Infrastructure database.

From this overall measure of infrastructure investment, we see that infrastructure spending does not differ substantially across income groups (Figure 3, horizontal lines). Median infrastructure investment ranges from 4.1% of GDP in LICs to 4.9% of GDP in UMICs. Interestingly though, one finds that faster-growing countries (especially among MICs) invest relatively more in their infrastructure. Median investment was close to 7% of GDP in the top quartile of UMICs, and above 8% of GDP in the top quartile of LMICs. The higher infrastructure investment is not being driven by higher incomes, as the comparison is between countries within the same income group (median income per capita is similar across the low25, mid50, and top25 groups within each income group). There are two possible

⁸ Public investment can include investment in noninfrastructure items such as machinery and equipment, inventories, valuables, and land.

explanations for the positive association between infrastructure investment and growth performance: it could be that infrastructure investment is enabling or causing higher growth, or that infrastructure investment is simply responding to higher growth. We investigate the issue of causality more systematically in section V.

Finally, Figure 3 shows that infrastructure investment in developing countries is dominated by the public sector; private infrastructure investment is less than one-tenth of overall investment. For this reason, we will focus our attention on public investment in the following sections.



IV. INFRASTRUCTURE PROVISION AND INVESTMENT: GOING DEEPER

While the bivariate approach used in the previous section can be informative about the empirical regularities regarding infrastructure provision (in the form of normalized physical stocks) and infrastructure investment across country income groups and growth performance, it does not take into account the role of other factors affecting infrastructure provision and investment, nor does it make any formal inferences about the observed empirical relationships. To deal with these shortcomings, we adopt more rigorous methods that allow us to control for other correlates and assess the strength of these stylized facts.

In this section, we run panel regressions that control for factors other than level of development and growth performance, which may influence infrastructure provision in a country. In the various specifications, the dependent variables used are the different types of infrastructure stocks, which are defined in the previous section. We use the panel unit root test of Maddala and Wu (1999), with maximum lag length selected based on the Schwartz information criteria, to test for the stationarity of

the infrastructure stocks and find no unit root, except in the case of water access, which could not be tested due to the insufficient number of observations per cross section.

The key explanatory variables enter the regressions as dummy variables, representing income groups (with low-income economies serving as the omitted group) and growth performance (with the slowest-growing countries serving as the omitted group).⁹ Using a standard set of controls, we estimate the following equation:

$$\text{infra}_{i,t} = \beta_0 + \gamma_1 \text{LMIC}_{i,t} + \gamma_2 \text{UMIC}_{i,t} + \gamma_3 \text{HIC}_{i,t} + \delta_1 \text{mid50}_{i,t} + \delta_2 \text{top25}_{i,t} + \beta_1 A_{i,t} + \beta_2 P_{i,t} + \beta_3 U_{i,t} + \beta_4 D_i + \beta_5 D_t + \varepsilon_{i,t} \quad (1)$$

where $\text{infra}_{i,t}$ is the log of the level of infrastructure stock in country i at time t (except for water and sanitation, where access is measured in percent of population); $\text{LMIC}_{i,t}$, $\text{UMIC}_{i,t}$, and $\text{HIC}_{i,t}$ are the income group dummies; $\text{mid50}_{i,t}$ and $\text{top25}_{i,t}$ are the growth performance dummies; $A_{i,t}$ is the percent share of agriculture in GDP; $P_{i,t}$ is the log of population density; $U_{i,t}$ is the degree of urbanization, defined as urban population as a percent of total population; and D_i and D_t are the country and time fixed effects, respectively. The auxiliary controls used are similar to those used in Fay and Yepes (2003) and Ruiz-Núñez and Wei (2015), among others. Measures of economic structure (percent share of agriculture in GDP), population density, and degree of urbanization are included as more industrialized and more densely populated and urbanized countries can be expected to have more infrastructure. We present the results both without and with country and year fixed effects, with the latter being the baseline specification as it controls for systematic unobserved heterogeneities across countries and over time.

The regressions confirm that LMICs tend to have greater infrastructure stocks than LICs, and that UMICs tend to have higher infrastructure stocks than both groups (Tables 1.a and 1.b, first two rows; formal tests of differences in coefficients are presented at the bottom of each table). This is true for most types of infrastructure. The link between countries' level of development and infrastructure provision is strong; regressions with only the income group dummies as explanatory variables and without fixed effects can already explain 15%–45% of the variation in advanced ICT (mobile and internet) and transport infrastructure, and 70% or more of the variation in telephone, energy, water, and sanitation infrastructure.

A few results stand out that add nuance to our previous observations on infrastructure provision across development stages. One is the continued accumulation of mobile, internet, and energy infrastructure throughout and beyond the middle-income stage, as evidenced by the increasing size of the country income dummy coefficients (Table 1.b, first three rows). The other, also based on these coefficients, is the tendency for road and telephone line provision, as well as water and sanitation, to level off following a run-up during the upper-middle-income phase. A formal test of differences in coefficients between the HIC dummy and UMIC dummy confirms these results, as reported at the bottom of Table 1.b. For roads, a possible explanation is that, during early stages of development, the focus is on expanding the road network—building new roads where none existed. But at later stages of development, the focus shifts to increasing the quality and capacity of existing roads (e.g., upgrading from two lanes to four, or from provincial roads to national roads and highways), and this is not captured in the indicator we use, which measures the length of the road network. Water and sanitation access also tends to rise during the early middle-income stages, but provision of these services naturally tapers as

⁹ For completeness, we also introduce dummies for HICs with GDP per capita (year 2011 PPP) $\geq \$17,600$. Results are similar when regressions are estimated on a sample that excludes HICs (see Table 3.a.).

access becomes practically universal by the time a country reaches high-income or even upper-middle-income status.

The regressions also confirm the positive association between growth performance and some types of infrastructure stocks. Most notably, better performers (the top 25%) tend to have more ICT infrastructure (Table 1.b, columns 1–3). Countries in the top quartile of growth performance tend to have about 25%–50% more telephone mainlines, mobile subscriptions, and internet usage than those in the bottom quartile of growth performance. Good growth performers also seem to have slightly greater (2%–4% more) access to water and sanitation. Exceptions to the positive relationship are rail provision, which seems unrelated to growth performance, and energy and roads, where good growth performers seem to have slightly less (8%–14%) provision. Coefficients on the auxiliary control variables generally have the correct signs, with higher population density and urbanization associated with more infrastructure, and a larger agriculture sector associated with less infrastructure.

Table 1.a: Sectoral Infrastructure Regressions, Without Fixed Effects

Variables	(1) Telephone Mainlines	(2) Mobile Subscriptions (per 100 people)	(3) Internet Users	(4) Electricity	(5) Total Roads (per km ²)	(6) Rails	(7) Water Access (% of population)	(8) Sanitation Access
Lower-middle income	0.875*** (0.050)	–0.049 (0.287)	0.338 (0.250)	0.928*** (0.046)	0.271*** (0.039)	0.160*** (0.047)	10.527*** (1.942)	24.877*** (1.466)
Upper-middle income	1.764*** (0.052)	0.668** (0.306)	0.826*** (0.263)	1.498*** (0.053)	0.741*** (0.049)	0.936*** (0.058)	16.076*** (2.298)	36.785*** (1.484)
High income	2.479*** (0.063)	1.056*** (0.366)	1.650*** (0.309)	2.404*** (0.064)	1.625*** (0.056)	1.598*** (0.068)	17.423*** (2.663)	46.718*** (1.737)
Mid50	0.089*** (0.027)	–0.216 (0.135)	0.179 (0.116)	–0.042 (0.027)	–0.072*** (0.023)	–0.008 (0.027)	1.676* (0.917)	1.261** (0.582)
Top25	0.182*** (0.044)	0.601*** (0.211)	0.599*** (0.188)	0.263*** (0.042)	–0.524*** (0.054)	–0.302*** (0.055)	1.718 (1.404)	–0.942 (1.076)
Agriculture, share of GDP	–0.037*** (0.002)	–0.053*** (0.010)	–0.057*** (0.008)	–0.028*** (0.002)	–0.011*** (0.002)	–0.012*** (0.002)	–0.338*** (0.075)	–0.298*** (0.044)
Population density	0.089*** (0.009)	–0.012 (0.041)	0.057* (0.035)	–0.024** (0.009)	0.672*** (0.009)	0.503*** (0.010)	2.617*** (0.350)	3.571*** (0.246)
Urbanization	0.020*** (0.001)	0.010** (0.004)	0.017*** (0.004)	0.021*** (0.001)	0.001 (0.001)	0.003** (0.001)	0.183*** (0.044)	0.324*** (0.026)
Constant	–0.540*** (0.086)	1.373*** (0.471)	–0.413 (0.390)	1.386*** (0.091)	–4.576*** (0.090)	–7.169*** (0.103)	56.321*** (4.097)	11.239*** (2.530)
Observations	3,249	2,016	1,779	3,713	3,291	3,225	525	2,045
R-squared	0.897	0.185	0.374	0.870	0.810	0.703	0.766	0.859
Formal test of differences in coefficients								
UMIC > LMIC	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HIC > UMIC	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Top25 > Mid50	Yes	Yes	Yes	Yes	No	Yes	No	No

GDP = gross domestic product, HIC = high-income country, km² = square kilometer, LMIC = lower-middle-income country, UMIC = upper-middle-income country.

Notes: Robust standard errors are in parentheses below the coefficients. *** p<0.01, ** p<0.05, * p<0.1.

Source: Authors' estimates.

Table 1.b: Sectoral Infrastructure Regressions, With Fixed Effects
(baseline)

Variables	(1) Telephone Mainlines	(2) Mobile Subscriptions (per 100 people)	(3) Internet Users	(4) Electricity	(5) Total Roads (per km ²)	(6) Rails	(7) Water Access (% of population)	(8) Sanitation Access
Lower-middle income	0.518*** (0.049)	0.892*** (0.125)	0.760*** (0.162)	0.327*** (0.031)	0.300*** (0.024)	-0.013 (0.016)	3.540*** (1.363)	5.007*** (0.798)
Upper-middle income	0.900*** (0.064)	1.390*** (0.164)	1.602*** (0.212)	0.485*** (0.046)	0.339*** (0.042)	0.067** (0.028)	4.917*** (1.753)	7.665*** (0.885)
High income	0.817*** (0.072)	1.845*** (0.245)	1.880*** (0.268)	0.600*** (0.054)	0.277*** (0.046)	0.069** (0.031)	4.027* (2.163)	6.390*** (1.011)
Mid50	0.030 (0.039)	0.017 (0.129)	0.336*** (0.124)	-0.079*** (0.026)	-0.037* (0.020)	0.033* (0.017)	1.994 (1.470)	1.498** (0.684)
Top25	0.231*** (0.053)	0.500*** (0.184)	0.268* (0.161)	-0.080** (0.040)	-0.138*** (0.033)	-0.011 (0.020)	3.861** (1.578)	1.953*** (0.632)
Agriculture, share of GDP	-0.033*** (0.002)	-0.081*** (0.009)	-0.071*** (0.009)	-0.012*** (0.002)	-0.011*** (0.001)	0.000 (0.001)	-0.095 (0.081)	-0.148*** (0.027)
Population density	0.164** (0.076)	6.941*** (0.515)	5.482*** (0.447)	-0.302*** (0.049)	0.274*** (0.042)	0.045 (0.038)	21.519*** (3.094)	6.401*** (1.017)
Urbanization	0.027*** (0.003)	-0.003 (0.012)	0.044*** (0.014)	0.020*** (0.002)	0.005*** (0.002)	0.002* (0.001)	0.308*** (0.102)	0.440*** (0.043)
Constant	-1.161*** (0.320)	-35.147*** (2.480)	-32.377*** (2.166)	3.009*** (0.270)	-2.219*** (0.197)	-4.120*** (0.127)	-24.508* (13.818)	31.082*** (4.790)
Observations	3,249	2,016	1,779	3,713	3,291	3,225	525	2,045
R-squared	0.968	0.915	0.931	0.978	0.978	0.981	0.965	0.993
Formal test of differences in coefficients								
UMIC > LMIC	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
HIC > UMIC	No	Yes	Yes	Yes	No	No	No	No
Top25 > Mid50	Yes	Yes	No	No	No	No	Yes	No

GDP = gross domestic product, HIC = high-income country, km² = square kilometer, LMIC = lower-middle-income country, UMIC = upper-middle-income country.

Notes: Robust standard errors are in parentheses below the coefficients. *** p<0.01, ** p<0.05, * p<0.1.

Source: Authors' estimates.

These results are robust to various changes in specification. First, we estimate an alternative regression that replaces the country income group dummies with a continuous variable, the lagged value of the log of GDP per capita; we include linear and quadratic terms to allow for possible nonlinearities (Table 2). In line with our original regressions, infrastructure stocks tend to rise with per capita income, which represents the level of economic development. The negative and significant coefficient on the quadratic term suggests that infrastructure increases at a declining rate as countries develop. The coefficients on the growth performance dummies and auxiliary controls remain similar as in the baseline regression. Second, we restrict the estimation sample to the developing country subsample, and further to just the MIC subsample (Tables 3.a and 3.b). These shrink the estimation sample size substantially—by between one-half and two-thirds of observations in the case of the MIC subsample—and so it is not surprising that the results are generally weaker than in the baseline. They are nonetheless similar to the results in the baseline regression, and confirm that the documented relationships hold in developing countries in general, and in the MICs in particular.¹⁰

¹⁰ In ADB (2017b), the specification uses the lagged value of the log of GDP per capita (instead of a UMIC dummy) in the MIC subsample regression. The results are robust to this change, and that regression is presented in Appendix Table A4.

Third, we run the same set of regressions using a composite infrastructure index constructed by Donaubaauer, Meyer, and Nunnenkamp (2016), which combines a large number of indicators of both the quantity and quality of different types of infrastructure using an unobserved components model. One disadvantage is that this composite measure is substantially shorter than our original time series (starting only in 1990 or later), and the data has substantially less time variation and is, thus, much more cross sectional in nature; country dummies alone can explain 96% of the overall variation in the composite index. For this reason, we do not include fixed effects in the specification. The results (Table 4) are similar to those in the baseline regression; infrastructure as measured by this overall composite index tends to be positively associated with both level of development and with growth performance.

Table 2: Sectoral Infrastructure Regressions Using Lagged GDP per Capita, Level, and Quadratic Terms

Variables	(1) Telephone Mainlines	(2) Mobile Subscriptions (per 100 people)	(3) Internet Users	(4) Electricity	(5) Total Roads (per km ²)	(6) Rails	(7) Water Access (% of population)	(8) Sanitation Access
Lagged GDP per capita	5.314*** (0.281)	15.861*** (0.973)	13.307*** (1.250)	0.809*** (0.155)	1.464*** (0.148)	-0.061 (0.113)	48.796*** (5.957)	37.284*** (3.289)
(Lagged GDP per capita) ²	-0.286*** (0.015)	-0.950*** (0.055)	-0.782*** (0.067)	-0.020** (0.009)	-0.080*** (0.009)	0.006 (0.007)	-2.903*** (0.341)	-2.103*** (0.179)
Mid50	0.028 (0.035)	-0.070 (0.144)	0.427*** (0.128)	-0.046* (0.025)	-0.000 (0.021)	0.036** (0.016)	1.934 (1.484)	1.445** (0.600)
Top25	0.283*** (0.052)	0.809*** (0.176)	0.685*** (0.150)	-0.006 (0.038)	-0.109*** (0.033)	-0.004 (0.019)	4.136*** (1.489)	2.574*** (0.595)
Agriculture, share of GDP	-0.017*** (0.002)	-0.056*** (0.009)	-0.052*** (0.009)	-0.006*** (0.002)	-0.010*** (0.001)	0.000 (0.001)	0.009 (0.072)	-0.089*** (0.030)
Population density	0.068 (0.080)	4.582*** (0.468)	3.534*** (0.464)	0.111* (0.062)	0.246*** (0.051)	0.090* (0.049)	14.913*** (2.963)	3.698*** (1.206)
Urbanization	0.021*** (0.003)	-0.020* (0.011)	0.044*** (0.014)	0.014*** (0.002)	0.004*** (0.002)	0.002** (0.001)	0.262*** (0.099)	0.411*** (0.045)
Constant	-25.089*** (1.303)	-91.243*** (4.174)	-80.291*** (5.308)	-3.621*** (0.707)	-8.506*** (0.662)	-4.221*** (0.379)	-198.038*** (29.957)	-117.140*** (15.631)
Observations	3,241	2,015	1,779	3,711	3,288	3,220	520	2,041
R-squared	0.973	0.929	0.939	0.979	0.978	0.981	0.969	0.993

GDP = gross domestic product, km² = square kilometer.

Notes: Robust standard errors are in parentheses below the coefficients. *** p<0.01, ** p<0.05, * p<0.1.

Source: Authors' estimates.

Table 3.a: Sectoral Infrastructure Regressions for the Developing Country Subsample

Variables	(1) Telephone Mainlines	(2) Mobile Subscriptions (per 100 people)	(3) Internet Users	(4) Electricity	(5) Total Roads (per km ²)	(6) Rails	(7) Water Access (% of population)	(8) Sanitation Access
Lower-middle income	0.431*** (0.045)	0.524*** (0.114)	0.675*** (0.156)	0.317*** (0.031)	0.284*** (0.024)	-0.013 (0.016)	3.007** (1.365)	4.412*** (0.772)
Upper-middle income	0.624*** (0.062)	0.100 (0.163)	1.145*** (0.212)	0.424*** (0.047)	0.277*** (0.041)	0.074** (0.030)	2.771 (1.869)	5.692*** (0.850)
Mid50	-0.023 (0.050)	-0.042 (0.125)	0.192 (0.149)	-0.090** (0.036)	-0.035 (0.026)	0.063*** (0.024)	3.125 (1.998)	1.843** (0.929)
Top25	0.182*** (0.070)	0.790*** (0.215)	-0.066 (0.221)	-0.117** (0.058)	-0.186*** (0.055)	0.026 (0.030)	5.352** (2.286)	1.008 (0.885)
Agriculture, share of GDP	-0.029*** (0.002)	-0.033*** (0.007)	-0.037*** (0.008)	-0.011*** (0.002)	-0.010*** (0.001)	0.000 (0.001)	-0.036 (0.086)	-0.091*** (0.027)
Population density	-0.931*** (0.108)	3.645*** (0.524)	2.534*** (0.462)	-0.587*** (0.080)	0.014 (0.065)	0.042 (0.058)	15.539*** (3.994)	-4.575*** (1.460)
Urbanization	0.029*** (0.003)	-0.044*** (0.014)	0.021 (0.016)	0.018*** (0.003)	0.003 (0.002)	0.001 (0.001)	0.259** (0.129)	0.426*** (0.052)
Constant	3.063*** (0.439)	-21.451*** (2.365)	-20.535*** (2.194)	4.135*** (0.373)	-1.225*** (0.264)	-4.121*** (0.187)	1.853 (18.392)	80.479*** (7.170)
Observations	2,472	1,349	1,208	2,929	2,545	2,486	375	1,496
R-squared	0.956	0.945	0.939	0.962	0.968	0.972	0.955	0.991

GDP = gross domestic product, km² = square kilometer.

Notes: Robust standard errors are in parentheses below the coefficients. *** p<0.01, ** p<0.05, * p<0.1.

Source: Authors' estimates.

Table 3.b: Sectoral Infrastructure Regressions for the Middle-Income Country Subsample

Variables	(1) Telephone Mainlines	(2) Mobile Subscriptions (per 100 people)	(3) Internet Users	(4) Electricity	(5) Total Roads (per km ²)	(6) Rails	(7) Water Access (% of population)	(8) Sanitation Access
Upper-middle income	0.280*** (0.035)	0.124 (0.116)	0.713*** (0.139)	0.035 (0.026)	-0.049* (0.028)	0.067** (0.031)	2.251 (1.367)	0.264 (0.465)
Mid50	0.188*** (0.053)	0.307* (0.167)	0.500*** (0.187)	0.093** (0.037)	0.082** (0.032)	0.046* (0.024)	-0.345 (2.228)	2.350*** (0.657)
Top25	0.316*** (0.090)	0.722*** (0.253)	0.259 (0.210)	-0.037 (0.074)	-0.388*** (0.133)	-0.125*** (0.035)	1.704 (2.331)	3.657*** (0.797)
Agriculture, share of GDP	-0.037*** (0.003)	-0.014 (0.014)	-0.025* (0.014)	-0.016*** (0.003)	-0.019*** (0.002)	0.005*** (0.001)	0.051 (0.116)	-0.070** (0.035)
Population density	-0.574*** (0.141)	-2.588*** (0.668)	-0.828 (0.858)	0.163 (0.112)	0.088 (0.096)	0.111** (0.050)	9.994 (6.612)	14.948*** (2.805)
Urbanization	0.014*** (0.004)	-0.027* (0.014)	0.042** (0.018)	0.008** (0.003)	0.020*** (0.003)	0.001 (0.001)	-0.018 (0.159)	0.285*** (0.051)
Constant	2.728*** (0.574)	5.566* (2.849)	-5.730 (3.742)	1.970*** (0.451)	-1.166*** (0.375)	-4.515*** (0.183)	40.977 (27.575)	-1.439 (12.359)
Observations	1,355	861	755	1,497	1,316	1,330	221	865
R-squared	0.940	0.954	0.940	0.946	0.966	0.969	0.928	0.987

GDP = gross domestic product, km² = square kilometer.

Notes: Robust standard errors are in parentheses below the coefficients. *** p<0.01, ** p<0.05, * p<0.1.

Source: Authors' estimates.

Table 4: Using the Composite Infrastructure Index of Donaubauer, Meyer, and Nunnenkamp (2016)

Variables	Total Infrastructure Index
Lower-middle income	0.135*** (0.033)
Upper-middle income	0.165*** (0.040)
High income	1.826*** (0.060)
Mid50	0.195*** (0.023)
Top25	0.196*** (0.051)
Agriculture, share of GDP	-0.011*** (0.001)
Population density	0.050*** (0.008)
Urbanization	0.007*** (0.001)
Constant	-1.029*** (0.073)
Observations	1,733
R-squared	0.825

GDP = gross domestic product.

Notes: Robust standard errors are in parentheses below the coefficients. *** $p < 0.01$, ** $p < 0.05$,

* $p < 0.1$.

Source: Authors' estimates.

We now turn to an examination of the correlates of infrastructure investment, focusing on public investment which, as noted above, comprises more than 90% of overall infrastructure investment. Our regression specification draws on the literature on fiscal policy reaction functions, beginning with Bohn (1998). In this literature, public spending is a function of the state of public finances (typically proxied by the lagged level of public debt) and cyclical macroeconomic conditions (often measured by the output gap), and various other controls. Here, we adopt a parsimonious specification which includes the income group and growth performance dummies used in Section II, the lagged level of public debt as a percent of GDP, and controls for macroeconomic conditions. Given the difficulty of measuring the output gap in developing countries—see, for example, Aguiar and Gopinath (2007)—we proxy cyclical macroeconomic conditions using lagged GDP growth, as well as expectations for contemporaneous growth. We also include the lag of investment to account for persistence, and country and time fixed effects to account for systematic unobserved heterogeneities across countries and over time. The specification is:

$$\begin{aligned}
 inv_{i,t} = & \beta i_{i,t-1} + \sigma d_{i,t-1} + \theta g_{i,t-1} + \mu g_fcast_{i,t-1}^t + \gamma_1 LMIC_{i,t} + \gamma_2 UMIC_{i,t} + \gamma_3 HIC_{i,t} \\
 & + \delta_1 mid50_{i,t} + \delta_2 top25_{i,t} + \alpha_i + \varphi_t + e_{i,t}
 \end{aligned} \tag{2}$$

where $inv_{i,t}$ refers to public investment as a share of GDP; d_t is the debt-to-GDP ratio; g_t denotes output growth; $g_fcast_{i,t-1}^t$ is the expectation about current economic activity, proxied by GDP growth forecasts for the current year made in October of the prior year, from the IMF's World Economic Outlook; and α_i and φ_t are the country and time fixed effects, respectively.

The investment regression results are in Table 5. We begin with column 1, which presents the regressions without lagged investment and the fixed effects; the subsequent columns add these in sequence. The coefficient on the lagged level of public debt is negative; higher public debt in the previous period is associated with lower levels of public investment, other things being equal. This is consistent with the findings in most of the fiscal reaction function literature, which finds that, as public debt rises, government spending declines and the primary balance improves. Public investment is also positively associated with lagged GDP growth and with expectations of contemporaneous growth. Turning to our variables of interest, we find no association between income group levels and public investment, consistent with the finding in Figure 3 that investment levels do not vary much across income groups. Finally, we find that the top25 growth performance dummy is positively associated with public investment, which is also consistent with what was observed in Figure 3. The inclusion of lagged public investment as a control (column 2) does not qualitatively affect these results. When country and year fixed effects are included (columns 3 and 4), lagged GDP growth continues to be significantly associated with public investment; lagged public debt and the top25 growth performance dummy retain the same sign, but are no longer statistically significant. This suggests that the higher infrastructure investment we observed in fast-growing countries relative to other countries, which was documented in Figure 3, is mainly driven by differences across countries, rather than by within-country variations in growth performance.

Table 5: Public Investment Regressions

Variables	No Fixed Effects		With Fixed Effects	
	(1) Public Investment	(2) Public Investment	(3) Public Investment	(4) Public Investment
Lagged public investment (% of GDP)		0.909*** (0.020)		0.773*** (0.045)
Lagged public debt (% of GDP)	-0.009** (0.004)	-0.001*** (0.000)	-0.006 (0.004)	-0.002 (0.001)
Lagged GDP growth (%)	0.046** (0.022)	0.014* (0.008)	0.032*** (0.012)	0.016* (0.008)
Forecast of current GDP growth made in previous period	0.137* (0.074)	0.022 (0.018)	0.111** (0.051)	0.032 (0.022)
Lower-middle income	-0.656 (0.619)	-0.035 (0.092)	0.337 (0.552)	0.236 (0.204)
Upper-middle income	-0.319 (0.601)	-0.052 (0.070)	0.115 (0.661)	0.014 (0.272)
High income	-0.762 (0.586)	-0.082 (0.069)	0.476 (0.851)	-0.088 (0.310)
Mid50	-0.365 (0.359)	-0.023 (0.045)	-0.361 (0.392)	0.050 (0.137)
Top25	2.728** (1.187)	0.199* (0.101)	0.111 (0.452)	0.272 (0.170)
Constant	4.690*** (0.681)	0.406*** (0.123)	4.386*** (0.874)	1.162*** (0.279)
Observations	2,263	2,263	2,263	2,263
R-squared	0.176	0.881	0.719	0.894

GDP = gross domestic product.

Notes: Robust standard errors are in parentheses below the coefficients. *** p<0.01, ** p<0.05, * p<0.1.

Source: Authors' estimates.

To sum up our findings to this point, the stylized facts and regression results on infrastructure provision suggest a hierarchy of needs where countries are more likely to invest in basic infrastructure such as water and sanitation, roads, power, and telephone mainlines during early stages of development. Countries then seem to turn their attention to advanced infrastructure, such as mobile cellular and internet connections, when they reach the upper middle-income stage, with power also continuing to be a priority. Moreover, fast-growing economies within each income group generally invest more and tend to have higher infrastructure stocks than their weaker counterparts for certain types of infrastructure, notably ICT.

V. THE MACROECONOMIC EFFECTS OF PUBLIC INVESTMENT

The previous sections have established an association between infrastructure provision and investment, on the one hand, and level of development and growth performance on the other. But the bivariate charts and multivariate regressions cannot shed light on the direction of causality between infrastructure and output. The positive relationship can arise because output responds to infrastructure investment, with the latter boosting short-run demand and increasing the productivity of existing factors of production. It can also arise from infrastructure responding to output—either because higher output growth in the past makes it easier to pay for infrastructure, or because expectations of higher growth induce greater investment in infrastructure. This is a problem that has long plagued the literature on the macroeconomic effects of infrastructure investment.

The challenge is to identify changes in infrastructure investment that are not driven by contemporaneous or lagged output, nor by expectations of future output growth. To tackle this issue, we follow the empirical strategy of Corsetti, Meier, and Müller (2012), which in turn builds on Perotti (1999). The idea is to employ a two-stage strategy, relying on the fact that significant parts of government spending are likely to be determined by past information and cannot easily respond to current economic conditions. This is especially true of public investment, which operates with substantial lags and is more difficult to adjust quickly than current spending. Based on this assumption, one can first estimate a fiscal policy rule where public investment is a function of past information on macroeconomic conditions (lagged growth and past expectations of contemporaneous growth), and from this obtain a series of exogenous shocks to public investment.¹¹ The estimated policy shocks can then be used to trace the dynamic effects of public investment on output.

In principle, the assumption that public investment cannot easily respond to current economic conditions can be violated for two reasons. First, public spending can automatically respond to cyclical conditions. This should not pose a problem for public investment because these expenditures are discretionary; automatic stabilizers operate mostly via revenues and social spending. Second, discretionary public investment spending could be in response to output conditions. As discussed in Corsetti, Meier, and Müller (2012), the relevance of this concern relates to the precise definition of contemporaneous feedback effects. Although it is typically assumed in the literature that government spending does not react to changes in economic activity within a given quarter (Blanchard and Perotti 2002), whether it may respond in a period longer than a quarter is an open question. Recent evidence suggests that the restriction that government spending does not respond to economic conditions within a year cannot be rejected (Beetsma, Giuliadori, and Klaassen 2009; Born and Müller 2012).

¹¹ This identification strategy is very similar to the structure embedded in fiscal policy vector autoregressions. The fiscal policy rule links the change in government spending to its lags, lagged growth, current and lagged public indebtedness, and expectations of next year's growth.

To implement this two-step approach, in the first step an annual time series of public investment shocks is derived by estimating a fiscal policy reaction function, where public investment as a share of GDP is a function of its own lag, lagged public debt, previous period output growth, and expectations about current economic activity. But this is precisely the specification adopted in Table 5, column 4, of Section IV. Thus, the residuals from that regression provide estimates of the public investment shocks, which by construction do not contain the response of public investment to macroeconomic conditions.

In the second step, following the “local projections” approach proposed by Jordà (2005) in estimating impulse response functions, the impact of public investment innovations on output is estimated through the equation

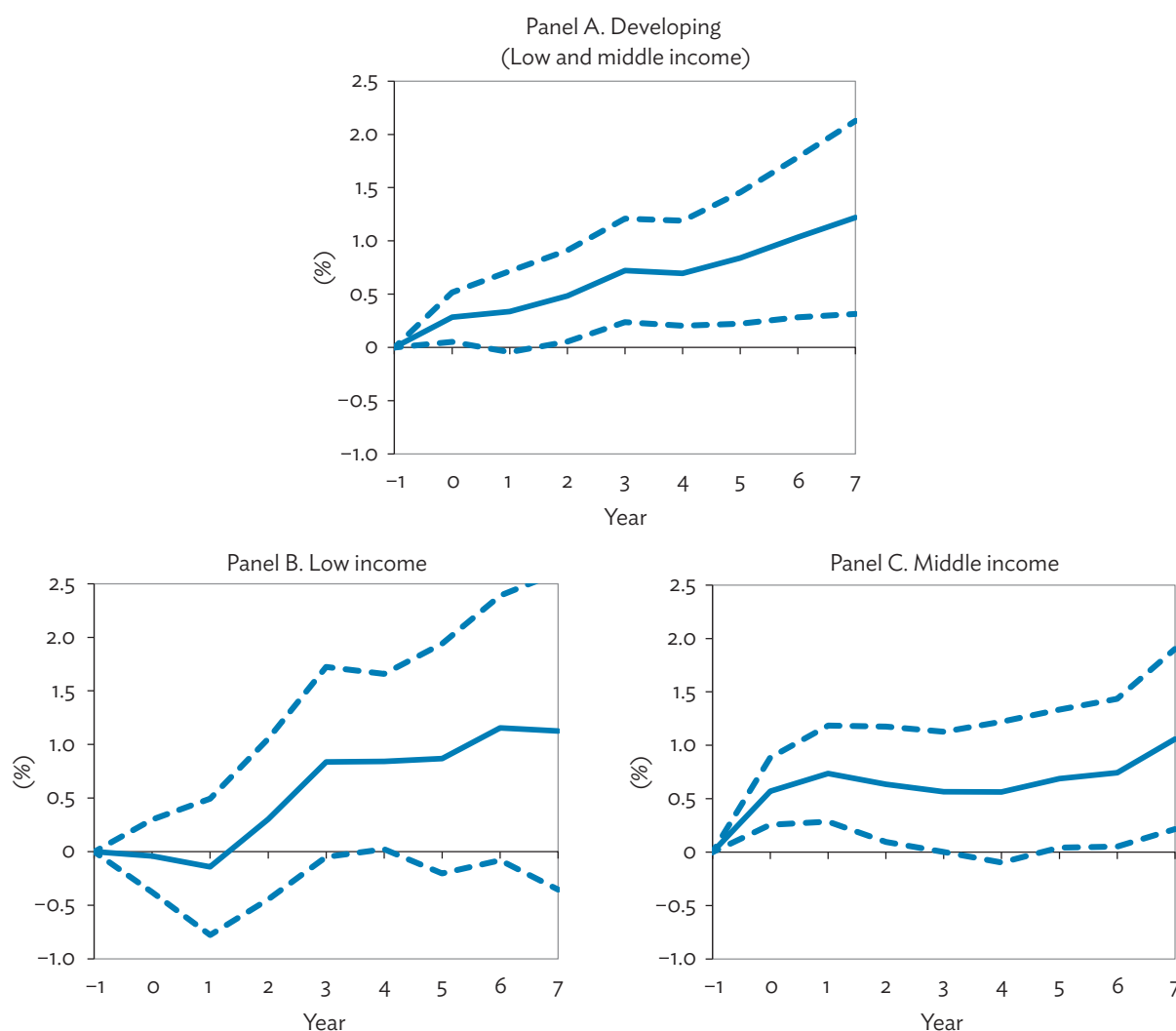
$$y_{i,t+k} - y_{i,t} = \alpha_i^k + \gamma_t^k + \beta^k INV_{i,t} + \varepsilon_i^k \quad (3)$$

where y is the log of output; α_i and γ_t are the country and time fixed effects, respectively; and $INV_{i,t}$ represents the exogenous public investment shocks derived from the fiscal policy reaction function. This approach has been advocated by Stock and Watson (2007) and Auerbach and Gorodnichenko (2013), among others, as a flexible alternative that does not impose the dynamic restrictions embedded in vector autoregression (autoregressive–distributed lag) specifications. The equation is estimated for each k ($= 0, 1, 2, 3, 4, 5, 6, 7$) representing the time horizon in years after a shock. Impulse response functions are computed using the estimated coefficients β^k , and the confidence bands associated with the impulse response functions are generated using the estimated standard errors of the coefficients β^k , based on clustered robust standard errors.

We apply this approach specifically to explore the macroeconomic effects of infrastructure investment in developing economies and, more specifically, to examine whether macroeconomic effects are different in middle-income economies relative to low-income economies.¹² To compare the country income groups, we generate the impulse response functions for each income group separately.

The results suggest that public investment has a positive and persistent impact on output in developing countries (Figure 4, Panel A). The contemporaneous effect of a 1 percentage point of GDP increase in public investment is a 0.3% increase in output. Using the sample average of government investment as a percentage of output, this implies short-term investment spending multipliers of about 0.3, consistent with other estimates of the overall government spending multiplier reported in the literature (see Coenen et al. 2012 and literature cited therein). This gradually increases to just above 1.2% 7 years after the shock, with the impact being significantly different from zero in both the short and long run, suggesting an expansion of the productive capacity of the economy as public investment augments the physical infrastructure stock.

¹² Abiad, Furceri, and Topalova (2016) examine the macroeconomic effects of public investment using a more precise measure of shocks to public investment, namely forecast errors in public investment derived from OECD Economic Reports. This approach is not feasible for our investigation of developing economies due to lack of similar forecast data.

Figure 4: Effects of Public Investment on Output

Notes: $t = 0$ is the year of the shock; dashed lines denote 90% confidence bands. Shock represents an exogenous 1 percentage point of gross domestic product increase in public investment spending.

Source: Authors' estimates.

When splitting the developing economy sample into LICs and MICs, one sees a slight difference in effects (Figure 4, Panel B versus Panel C). For LICs, public investment shocks do not raise output on impact. There is an increase in long-term output of 1.1% after 7 years, but with the substantially larger standard errors in the LIC subsample, the estimated impact is not significantly different from zero. In MICs, public investment shocks raise output by 0.6% on impact, and the effect is significantly different from zero. Over time, the impact increases to 1.1% by the 7th year after the shock, and this long run effect is also significantly different from zero.

The greater variance (and consequent statistical insignificance) of the impact of public investment in LICs is consistent with evidence from existing studies. Warner (2014), for instance, finds only a weak and fleeting relationship between public investment spending and growth in LICs, noting in his paper how past investment drives were typically weighed down by incentive and agency problems

and the lack of information and data needed to make rational investment choices. Kraay (2012) observes a significant and positive output effect of government spending in LICs (instrumented using official creditor loan disbursements), but the estimated multipliers tend to lie at the low end of the spectrum in the literature.

Failure of public investment to lead to sustained output growth in LICs is often attributed to poor investment efficiency in many of these countries, which inhibits their ability to convert dollar spending into productive capital stock. Another cited reason for weak output gains is the limited absorptive capacity of certain countries, with marginal returns likely to decline as investment outlays are scaled up, not only because of a smaller number of high-return projects available, but also because of institutional and human and infrastructure capital constraints (Presbitero 2016). Such absorptive capacity constraints, which occur with a rapid acceleration and ratcheting up of public investment, are likely to be more acute in low-income economies. Finally, the marginal productivity of infrastructure investment may not be that high in LICs despite the larger shortfall of infrastructure because complementary factors of production—human capital, private capital, and the right institutions—are in similar short supply.

VI. CONCLUSION

So how does infrastructure evolve and what impact does it have in MICs? Our analysis has uncovered several noteworthy results. We find that the stock of different types of infrastructure tends to rise with country income, and with growth performance. The mix of infrastructure varies with a country's stage of development, reflecting a clear hierarchy of requirements. Transport, basic communications, water, and sanitation are relatively more important at early stages of development for instance, while energy and ICT (mobile and internet connections) become more important as countries advance.

Better-performing economies, especially among the MICs, differ from peers in the same income group in two important ways. Faster-growing countries tend to have more of certain types of infrastructure—especially ICT—than their peers. They also seem to invest proportionately more overall in infrastructure as a share of GDP. The paper addresses the issue of causality, and shows how exogenous shocks to public investment have significant positive and persistent effects on output, particularly in MICs.

The strong and sustained impact of infrastructure investment on output in MICs suggests that increased infrastructure investment is a potential policy lever for governments grappling with the MIC challenge of sustaining growth. But it is not enough to simply raise the level of infrastructure investment; one needs to invest in specific types of infrastructure, depending on a country's level of development. While it may be beneficial for an LIC to focus initially on basic infrastructure such as water and sanitation, for instance, this paper's findings suggest that one should shift attention to more advanced infrastructure such as ICT when one becomes an MIC.

The Republic of Korea's experience during its upper-middle-income phase is potentially illustrative. The country was on the cusp of transitioning to high income in the mid-1990s; by some measures, it crossed the threshold in 1995. But shortly thereafter, the country was hit hard by the Asian financial crisis, imperiling its newfound status as an HIC. Several studies, including Lee (2003), Oh and Larson (2011), Bae (2011), Yeo et al. (2014), and Lee (2015), document how the government of the Republic of Korea deliberately targeted the rapid development of ICT infrastructure in the late 1990s.

Broadband services were launched in the Republic of Korea in 1998, and from 2000 to 2005, the Republic of Korea's broadband penetration rate was the highest in the world (Bae 2011). As a result, Oh and Larson (2011) noted that "in 1997 the ICT sector contributed only about 12% to the nation's GDP growth. By 2003, that percentage had risen to about 40% and it remained substantial through 2009." The Republic of Korea's world-leading ICT infrastructure likely contributes to the country being ranked the most innovative country in the world (Bloomberg 2015).

The analysis also has two implications for further research on infrastructure. First, the results highlight the importance of ICT infrastructure, which tends to be higher in faster-growing countries. Establishing that the causality runs from ICT infrastructure provision to growth will be important. Röller and Waverman (2001) use a simultaneous equations approach that jointly estimates a micromodel for telecommunication investment with a macroeconomic production function, and they find a significant positive causal link from telecommunication provision to output, especially once a critical mass of telecommunication infrastructure is reached. They do this only for advanced (OECD) countries, however. A similar analysis for developing countries is needed, but is hampered by a lack of data on ICT infrastructure investment.

Second, the paper's findings suggest that any analyses of the macroeconomic effects of infrastructure provision and investment, and on the links between infrastructure and development, need to account for the multifaceted nature of infrastructure. Different types of infrastructure matter at different stages of development. Studies that ignore this risk muddying the picture of the role infrastructure plays in development.

APPENDIXES

Table A1: Data Sources

Indicator	Source
Electricity-generating capacity	Calderón, Moral-Benito, and Servén 2015; Canning 2007; US Energy Information Administration; IMF (2014)
Total roads	Calderón, Moral-Benito, and Servén 2015; World Bank, World Development Indicators Database; International Road Federation, World Road Statistics; IMF (2014)
Rails	Calderón, Moral-Benito, and Servén 2015; World Bank, World Development Indicators Database; IMF (2014)
Telephone lines	World Bank, World Development Indicators Database
Mobile cellular subscriptions	World Bank, World Development Indicators Database
Internet users	World Bank, World Development Indicators Database
Improved water access (% of population)	World Bank, World Development Indicators Database
Improved sanitation access (% of population)	World Bank, World Development Indicators Database
Public debt (% of GDP)	IMF, Fiscal Affairs Department
Real public investment (PPP-adjusted 2005 US dollars)	IMF, Investment and Capital Stock Dataset, 2017
Total investment (private)	World Bank, Private Participation in Infrastructure Database
Expenditure-side real GDP at chained PPPs (2011 US dollars)	Penn World Table (PWT) 9.0 (see Feenstra, Inklaar, and Timmer 2015)
Real GDP at constant 2011 national prices (2011 US dollars)	PWT 9.0
GDP (current prices)	IMF, World Development Outlook Database; World Bank, World Development Indicators Database
GDP growth forecast	IMF, World Economic Outlook, October 2014
Population	IMF, World Development Outlook Database; World Bank, World Development Indicators Database; PWT 9.0
Land area	World Bank, World Development Indicators Database
Population density	World Bank, World Development Indicators Database
Agriculture (% of GDP)	World Bank, World Development Indicators Database
Urban population (% of total population)	World Bank, World Development Indicators Database

GDP = gross domestic product, IMF = International Monetary Fund, PPP = purchasing power parity, PWT = Penn World Tables, US = United States.

Source: Authors' compilation.

Table A2: List of Countries

Albania	Egypt	Lao People's Democratic	Senegal
Argentina	El Salvador	Republic	Sierra Leone
Australia	Finland	Lesotho	Singapore
Austria	France	Macedonia (former	Slovak Republic
Bangladesh	Gambia, The	Yugoslav Republic)	Slovenia
Belgium	Germany	Madagascar	South Africa
Benin	Ghana	Malawi	Spain
Botswana	Greece	Malaysia	Sri Lanka
Brazil	Guatemala	Mali	Sudan
Bulgaria	Guinea	Mauritania	Swaziland
Burkina Faso	Guinea-Bissau	Mauritius	Sweden
Burundi	Haiti	Mexico	Switzerland
Cameroon	Honduras	Mongolia	Taipei, China
Canada	Hong Kong, China	Morocco	Tanzania
Central African Republic	Hungary	Namibia	Thailand
Chile	India	Nepal	Togo
China, People's Republic of	Indonesia	The Netherlands	Tunisia
Colombia	Ireland	New Zealand	Turkey
Congo, Democratic	Israel	Niger	Uganda
Republic of the	Italy	Norway	United Kingdom
Costa Rica	Jamaica	Pakistan	United States
Croatia	Japan	Panama	Uruguay
Côte d'Ivoire	Jordan	Paraguay	Viet Nam
Czech Republic	Kenya	Philippines	Zambia
Denmark	Korea, Republic of	Poland	
Dominican Republic		Portugal	
		Romania	

Source: Authors' compilation.

Table A3: Summary Statistics

Variables	Mean	Std Dev	Min	Max	Median	Obs	Number of Countries
Telephone mainlines (per 100 people)	15.449	19.058	0.006	74.762	5.266	3,790	98
Mobile subscriptions (per 100 people)	20.788	37.952	0.000	229.245	0.059	3,865	98
Internet users (per 100 people)	19.063	26.365	0.000	96.300	4.356	2,274	98
Electricity-generating capacity (per 100 people)	60.349	91.630	0.063	647.420	18.334	4,784	99
Total roads (km per km ²)	0.544	0.799	0.003	5.086	0.164	4,027	98
Rails (km per km ²)	0.020	0.025	0.000	0.124	0.009	4,260	98
Water access (% of population)	83.571	18.489	28.087	100.000	91.174	571	96
Sanitation access (% of population)	65.779	32.526	3.900	100.000	75.600	2,368	96
Public investment (% of GDP)	5.143	4.621	0.001	52.066	4.022	5,144	98
Public debt (% of GDP)	56.513	43.079	0.971	454.864	45.928	4,304	99
GDP per capita	9,604.767	11,316.100	336.805	72,743.530	4,697.327	5,742	99
GDP growth (%)	3.750	4.307	-44.702	33.418	3.933	5,102	99
GDP growth forecast (% of GDP)	4.119	2.296	-9.015	51.420	4.007	2,346	99
Agriculture (% of GDP)	20.215	16.468	0.034	94.846	16.318	3,893	96
Urban population (% of total population)	47.880	25.082	2.038	100.000	46.139	4,953	98
Population density	202.760	732.016	0.750	7,589.143	59.809	4,831	98

GDP = gross domestic product, km = kilometer, km² = square kilometer.

Source: Authors' estimates.

Table A4: Sectoral Infrastructure Regressions for the Middle-Income Country Subsample Using Lagged GDP per Capita

Variables	(1) Telephone Mainlines	(2) Mobile Subscriptions (per 100 people)	(3) Internet Users (per 100 people)	(4) Electricity	(5) Total Roads (per km ²)	(6) Rails (per km ²)	(7) Water Access (% of population)	(8) Sanitation Access (% of population)
Lagged GDP per capita	0.599*** (0.063)	0.125 (0.253)	0.761** (0.307)	0.234*** (0.047)	-0.151*** (0.047)	-0.012 (0.027)	3.242 (2.398)	0.912 (0.946)
Mid50	0.244*** (0.055)	0.353** (0.162)	0.745*** (0.220)	0.119*** (0.039)	0.081** (0.033)	0.038 (0.024)	1.031 (2.294)	2.505*** (0.675)
Top25	0.491*** (0.094)	0.810*** (0.226)	0.953*** (0.209)	0.026 (0.071)	-0.414*** (0.130)	-0.134*** (0.035)	3.765* (2.160)	3.901*** (0.749)
Agriculture, share of GDP	-0.033*** (0.003)	-0.014 (0.014)	-0.019 (0.013)	-0.014*** (0.003)	-0.020*** (0.002)	0.004*** (0.001)	0.090 (0.109)	-0.063* (0.036)
Population density	-0.230* (0.135)	-2.300*** (0.705)	-0.060 (0.896)	0.330*** (0.108)	-0.045 (0.113)	0.084 (0.056)	9.356 (6.606)	15.143*** (2.825)
Urbanization	0.009** (0.004)	-0.028* (0.015)	0.034* (0.020)	0.004 (0.003)	0.022*** (0.003)	0.003** (0.001)	-0.065 (0.165)	0.270*** (0.056)
Constant	-3.511*** (0.826)	3.317 (4.124)	-15.304*** (5.024)	-0.552 (0.605)	0.536 (0.688)	-4.356*** (0.361)	16.815 (33.990)	-9.639 (14.853)
Observations	1,351	860	755	1,496	1,314	1,327	218	863
R-squared	0.943	0.954	0.938	0.947	0.966	0.969	0.928	0.987

GDP = gross domestic product, km² = square kilometer.

Notes: Robust standard errors are in parentheses below the coefficients. *** p<0.01, ** p<0.05, * p<0.1.

Source: Authors' estimates.

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* ADB recognizes "Korea" and "South Korea" as the Republic of Korea.

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The Role and Impact of Infrastructure in Middle-Income Countries: Anything Special?

This paper finds that the provision of infrastructure varies across different levels of development and growth performance. Basic infrastructure, such as transport, water, and sanitation, are emphasized more during early stages of development, while “advanced” infrastructure, such as power and especially information and communication technology, become more important during later stages. In addition, better-performing middle-income countries tend to have more information and communication technology infrastructure than their peers, and tend to invest more in infrastructure. Finally, public investment is shown to have a more significant and sustained impact on output in middle-income countries than in low-income countries.

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