Infrastructure and Growth in Developing Asia

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This paper applies two distinct approaches—growth regressions and growth accounting—to analyze the link between infrastructure, growth, and productivity in developing Asian countries. The main conclusion is that a number of countries in developing Asia have significantly improved their basic infrastructure endowments in the recent past. This improvement appears to correlate significantly with good growth performances. However, the evidence seems to indicate that this is mostly the result of factor accumulation, a direct effect, and that the impact on productivity is rather inconclusive.

JEL classification: H54, N15, O4

I. INFRASTRUCTURE: A REVIEW OF ISSUES

The relevance of infrastructure for development outcomes comes from the fact that it provides both final consumption services to households and key intermediate consumption items for production. Crude estimates from the literature indicate that between one third and one half of infrastructure services are used by households (Prud'Homme 2005, Fay and Morrison 2007), while the rest are utilized by firms.

Infrastructure thus plays an important role in supporting growth and poverty reduction. On the supply side, it supports growth and poverty reduction directly when infrastructure capital stock serves as a production factor, and indirectly, when improved infrastructure promotes technological progress. An increase in the stock of infrastructure capital is argued to have a direct, increasing effect on the productivity of the other factors. It is also believed to generate important externalities across a range of economic activities, which could possibly have a larger net effect than what is expected from a simple factor accumulation effect. These indirect effects could operate through various channels. Among others, these include labor productivity gains resulting from

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improved information and communication technologies, reductions in time wasted and stress incurred when commuting to work, improvements in health and education, and improvements in economies of scale and scope throughout the economy.

On the demand side, infrastructure facilitates the delivery of services that people need and want—water and sanitation; power for heat, cooking, and light; telephone lines and internet access; and transport. The absence of some of the most basic infrastructure services is an important dimension of what we often mean when we talk about poverty. Increasing the level of infrastructure stock has therefore a direct implication on poverty reduction.

Infrastructure appears significantly related to per capita gross domestic product (GDP) growth in the past decades, mainly through accumulating infrastructure capital stock as a production factor. Yet, the assumed link between infrastructure and growth relies mostly on the assumption that variations of infrastructure services are one of the main drivers of differences in firms' productivity across regions and countries. The link between the two, however, is not particularly clear from the data. Linking infrastructure services with economic growth or productivity is, therefore, still subject to considerable debate and uncertainty.

There are many ways infrastructure shortcomings translate into productive efficiency losses. For example, access to markets and interactions with potential clients rely on the existence and reliability of the transport and telecommunication networks, and when these fail, firms may suffer from lack of access to market opportunities, higher logistic costs and inventory levels, or information losses (Guasch and Kogan 2001, Li and Li 2008, and Jensen 2007). Similarly, investment and technological choices may be affected by the poor quality of electricity networks, in the sense that frequent power outages and unstable voltage induce high costs and greater risk of machinery breakdown. Growing evidence shows that firms respond by making suboptimal technological choices, by investing in remedial equipment such as power generators, or by deferring other types of investments (Alby, Dethier, and Straub 2011).

The objective of the present paper is twofold. First, it presents a brief update on the state of infrastructure in developing Asian countries. Then it applies two distinct approaches—growth regressions and growth accounting—to analyze the link between infrastructure, growth, and productivity. The paper is organized as follows. Section II provides an overview of past developments in infrastructure capital accumulation in developing Asia. Section III reviews the underlying theory, as well as the existing empirical literature, on the link between infrastructure and growth.[1] Section IV presents the results of an empirical

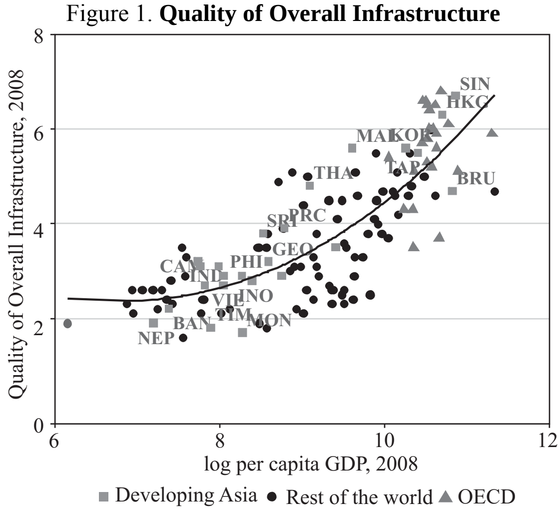
[1]This is by no means an exhaustive review of empirical contributions. For surveys of empirical literature, see Gramlich (1994); Sturm, Kuper, and de Haan (1998); Romp and de Haan (2005); and Straub (2008 and 2011).

investigation of the theoretical effects discussed in Section III. Section V concludes.

II. WHERE DOES DEVELOPING ASIA STAND?

While some developing Asian countries have far better infrastructure than others, overall, the infrastructure in the region remains below the world average. Except for the five relatively advanced economies—Hong Kong, China; the Republic of Korea; Malaysia; Singapore; and Taipei,China (or Asia-5)—the overall quality of infrastructure in developing Asia is largely lagging behind that of industrialized economies (see Figure 1).

Figure 1. **Quality of Overall Infrastructure**



BAN = Bangladesh; BRU = Brunei Darussalam; CAM = Cambodia; GEO = Georgia; HKG = Hong Kong, China; IND = India; INO = Indonesia; KOR = Korea, Rep. of; MAL = Malaysia; MON = Mongolia; NEP = Nepal; PHI = Philippines; PRC = China, People's Rep. of; SIN = Singapore; SRI = Sri Lanka; TAP = Taipei,China; THA = Thailand; TIM = Democratic Rep. of Timor-Leste; and VIE = Viet Nam. GDP = gross domestic product.

Note: Per capita GDP is based on purchasing power parity in current international dollars. Quality of overall infrastructure refers to assessments of the quality of general infrastructure (e.g., transport, telephony, and energy) in an economy. 1 indicates extremely underdeveloped, while 7 indicates extensive and efficient by international standards. Data cover 132 economies.

Sources: Authors' calculation using data from World Economic Forum (2005) and International Monetary Fund (2010).

A closer look at different types of infrastructure capital over a longer period reveals a robust but uneven growth across countries and regions over the past years. Electricity generation capacity in developing Asia grew by 4.3 percent annually or more than doubled between 1990 and 2007. But there is a divergence within developing Asia. Central Asia and the Pacific economies were an exception to the rapid growth trend and achieved only marginal growth, if not contraction, during this period. Among the good performers, particularly the Asia-5, capacity growth slowed down by 2000, as the economies matured. Meanwhile some countries with lower per capita income such as Cambodia (since 1995), the People's Republic of China (PRC), and Viet Nam continued with a robust expansion in generation capacity in the 2000s.

Increase in other infrastructure stocks such as in telecommunication and internet connections has also been significant. Internet users, for example, more than tripled since 2000 or from five users per 100 persons in 2000 to 16 users per 100 persons by 2008. This growth has been largely driven by the Asia-5. However, the current level lags far behind that of Latin American economies with 28 internet users per 100 persons in 2008, a level comparable to the world average.

In the transport sector, the share of paved road to total roads increased from less than half in 1990 to almost 60 percent by mid-2000, though total railroad lines (in kilometers [km]) have shown only modest growth over the same period. But, again, the dispersion is huge across economies with a rapidly growing road subsector. Many of developing Asia's roads such as in Bangladesh, Cambodia, Mongolia, and Papua New Guinea are hardly paved while almost all roads are paved in Singapore; Hong Kong, China; as well as some economies of the former Soviet Union countries such as Armenia and Kazakhstan.

The rural–urban divide, in terms of access to clean and reliable water supply, is significant. The proportion of the population using an improved drinking water source in 2006, for example, is 90 percent for those living in urban areas as opposed to only 68 percent for those in rural areas. The gap is particularly significant in economies such as the Lao People's Democratic Republic, Mongolia, Papua New Guinea, and Vanuatu.

Are these developments sufficient to improve productivity? The World Economic Forum (2009) finds that the inadequate supply of infrastructure is a problem for doing business in countries such as Bangladesh, Nepal, and Viet Nam. A closer look at the various types of infrastructure indexes in developing Asia reveals that overall, the improvement has not been enough to catch up with developed economies, and is not sufficient to translate into an important productivity-enhancing factor in many developing Asian countries.

III. THEORY AND EXISTING EVIDENCE

This section reviews theory underlying the link between the infrastructure capital stock and growth and productivity. It also discusses the existing empirical literature.

A. Theory[2]

In a standard production function where factors are gross complements, an increase in the stock of infrastructure capital would have a direct, increasing effect on the productivity of the other factors. This is particularly clear if one thinks of cases of strong complementarities,[3] for example, if roads or bridges investment provide access to previously inaccessible areas, thereby enabling productive investment there, or if improvements of the electricity or telecommunication networks make the use of certain types of machineries possible. But because infrastructure capital is also believed to generate important externalities across a range of economic activities, it is possible that its net effect is larger than expected from a simple factor accumulation effect. The theoretical literature has discussed a number of channels for these indirect effects.

The first one is related to maintenance, private capital durability, and adjustment costs. There is growing evidence that infrastructure policy is biased toward the realization of new investments, to the detriment of maintenance of the existing stock. The main reasons appear to be political economy ones (Rioja 2003, Maskin and Tirole 2008, and Dewatripont and Seabright 2006, among others).[4] As a consequence, the life span of the stock of both the infrastructure itself and of private capital that makes use of it, such as trucks operating on low-quality roads, or machines connected to unstable voltage lines, is reduced and operating costs increase.[5] The case of palliative private investments in devices such as electricity generators is an extreme example of this.

Second, infrastructure appears to have a microeconomic impact through a number of channels, including labor productivity gains resulting from improved information and communication technologies, reductions in time wasted and stress incurred when commuting to work, and improvements in health and education among others. Moreover, such improvements are likely to induce additional investment in human capital in the medium and long term.

Finally, infrastructure may be the source of economies of scale and scope throughout the economy. For example, as roads and railroads improve, lowering transport costs, private firms benefit from economies of scale and more efficient inventory management.[6] Similarly, enhanced access to communication devices, as was the case across the developing world in the last 2 decades with the growth of mobile telephony, is likely to result in improved information flows, which in turn could result in efficient market clearing and enhanced competition.[7] Economic

[2] See Straub (2011) for a detailed review.

[3] See theoretical formulation in Kremer's O-ring production function (1995).

[4] Either on the financing side or linked to pork-barrel arguments.

[5] See Engel, Fischer, and Galetovic (2009) for a detailed analysis of the case of roads.

[6] See Li and Li (2009) for evidence in the case of the PRC.

[7] See Jensen (2007) for a striking example in the case of Indian fishermen.

geography tells us that, as a result, we should expect different patterns of agglomeration, as well as changes in the pattern of specialization of agents and in their incentives to innovate (e.g., Baldwin et al. 2003). In other words, changes in the nature and availability of key types of infrastructure are likely to have profound structural effects on the whole economy through the agents' and firms' decisions.

Infrastructure investments, however, do not occur in isolation from other economic constraints. Unlocking some of the direct and indirect effects mentioned above may be conditioned by a number of practical issues, which are at present less well understood. First of all, infrastructure investments are often at least partly publicly financed, either through taxation or borrowing on financial markets, with the consequent risk of crowding out private investments. Another key question refers to sequencing. Which type of infrastructure is more effective in supporting growth and should be prioritized? Which type of reforms supporting these investments, such as privatization, restructuring measures, regulation, and introduction of competition, should be pursued and how? Because of their obvious context dependence, the answers to these questions have to be based on empirical literature.

The next subsection reviews the existing empirical literature, with a special emphasis on contributions focusing on Asian countries.[8] It discusses the theoretical effects identified above, including practical issues of financing and investment sequencing, showing that on all these aspects, empirical evidence is somewhat lacking.

B. Empirics

1. Macroeconomic Level

The first generation of studies applying a production function approach to state-level data in the United States (US), and augmented with some measures of infrastructure capital, provided estimates of output elasticity of infrastructure capital varying between 0.3 and 0.5.[9] Because these numbers imply a marginal product of around 100 percent, they have often been dismissed and deemed unrealistic.

Recent studies point out a number of weaknesses in the econometric analysis by the earlier studies.[10] These weaknesses include the existence of state-

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[8]This is by no means an exhaustive review of empirical contributions. For surveys of the empirical literature, see Gramlich (1994); Sturm, Kuper, and de Haan (1998); Romp and de Haan (2005); and Straub (2008 and 2011).

[9]The most widely quoted paper is Aschauer (1989). Gramlich (1994) provides a review of this early empirical literature.

[10]See Straub (2011) for a detailed analysis of these aspects.

or region-level unobserved effects and potential reverse causality between output and infrastructure investment, which may generate an upward bias in the estimated coefficients. Unsurprisingly, a second generation of studies taking these concerns into account came up with significantly smaller estimates. For example, the survey by Romp and de Haan (2005) reports elasticities between 0.1 and 0.2; in Bom and Ligthart (2008), a meta-analysis of 67 studies using public capital measures reports an unconditional output elasticity of public capital of around 0.15. A more recent paper by Calderón et al. (2009) estimate the output elasticity of a synthetic infrastructure index to be between 0.07 and 0.10.[11]

In this strand of literature, specific evidence on East Asia can be found in both Seethepalli et al. (2008) and Straub et al. (2008). Seethepalli et al. (2008) find a positive effect of all dimensions of infrastructure stocks on growth, using standard growth regressions in a panel of 16 East Asian countries at 5-year intervals. They also conclude that these significant effects vary with a number of country-level characteristics. For example, telecommunication and sanitation are found to have a greater effect in countries with better governance, higher income level, and low inequality in the access to infrastructure. In contrast, Straub et al. (2008) find much weaker results in their cross-country growth regressions, when using a sample of 93 developing or emerging countries, including 16 East Asian countries. The number of phone lines has a positive effect on growth, and this positive effect is stronger for East Asia and high-income countries. However, most results are not robust to using panel techniques or to controlling for an endogenous response of infrastructure to growth. As a matter of fact, while Seethepalli, Bramati, and Veredas (2008) argue that the use of infrastructure stocks rather than flows alleviates the problem of reverse causation; fails to control for the potential endogeneity of infrastructure stocks due to countries' unobserved characteristics, leading them to have both higher infrastructure stocks and higher growth; and does not include country fixed effects (see Holtz-Eakin 1994).

The existence and magnitude of indirect effects is a more complex issue at the empirical level, as a result it has been rarely addressed. Most of the existing contributions have used a growth accounting framework, as for example Hulten et al. (2005), Hulten and Schwab (2000), and La Ferrara and Marcelino (2000). Assuming that the share of output of intermediate inputs is constant over time, Hulten and Schwab (2000) conclude that absence of infrastructure externalities on growth in the US case, while Hulten et al. (2005) find highways and electricity to account for about half of total factor productivity (TFP) growth across Indian states in the period 1972–1992. Straub et al.'s (2008) growth accounting exercise on five East Asian countries yields few significant results. They found that telecommunication investment has significantly contributed to TFP growth more

[11] Note that such estimates still imply high rates of return, between 25 and 50 percent.

than other types of capital in Indonesia and the Philippines, while roads have had a positive influence only in Thailand. No significant effect is found in the Republic of Korea and Singapore.

2. Microeconomic Level

A growing amount of microeconometric evidence is providing insights into a number of specific channels linking infrastructure investment and development outcomes, such as household income and poverty, welfare, health issues such as child mortality, and gender empowerment, for example in the labor market.

Examples include Gibson and Rozelle (2003) and Donaldson (2010) on transportation infrastructure development; Dinkelman (2009) on the effect of rural electrification in South Africa on women employment; Galiani, Gertler and Schargrodsky (2005) on the impact of increased household access to the water network following privatization on the incidence of water-borne diseases related child mortality; and Duflo and Pande (2007) on the link between irrigation dams and agricultural production and poverty in India. Finally, a few papers, such as the study by Alby, Dethier, and Straub (2010) on the impact of electricity deficiencies, have used enterprise survey data to assess the impact of infrastructure constraints on firms' choices and performance.[12]

3. Geographic Evidence

It is difficult to underestimate the importance of the spatial nature of infrastructure investment. First, investment decisions imply rival choices on the geographical areas to be served. Second, spatial variations in the availability and quality of infrastructure are likely to have an impact on individuals' and firms' decisions, such as migration, location of new firms, etc.

Recently, empirical contributions directly inspired by the new economic geography literature have explicitly included spatial variables. They are based on the use of an accessibility indicator, which measures, for households and firms at each location in a given geographic area, the opportunities available at other locations in terms of employment opportunities or market potential by inversely weighting the sum of some destinations' indicators (GDP or employment for example) by a proxy of the costs involved in reaching them.

Examples for developing countries include Deichman et al. (2004) for Southern Mexico; Lall, Funderburg, and Yepes (2004) for Brazil; Lall, Shalizi, and Deichman (2004) for India; Deichmann et al. (2005) for Indonesia; and Lall, Sandefur, and Wang (2009) for Ghana. All these studies find that accessibility is a major determinant of firm productivity.

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[12] A review of this literature is available in Dethier, Hirn, and Straub (2011).

IV. EMPIRICAL ANALYSIS

This section extends the analysis in Straub et al. (2008) along several lines. The first part presents a growth regression analysis to specifically examine the effect of interactions with several subgroups of Asian countries. The second part presents a growth accounting analysis, including longer TFP time series, and observations from 14 countries. The description of the theoretical framework used in both sections is in Straub and Terada-Hagiwara (2010, Appendix).

A. Cross-country Regressions

We test a specification of the form:

$$g_i = \alpha y_{i0} + \beta K_i^I + Z_i \gamma + v_i \quad (1)$$

where g_i is the growth rate of real per capita GDP for country *I;* y_{i0} is initial income (possibly in log form); K^I_i is a measure of infrastructure capital; and Z_i is a vector of controls (i.e., initial per capita GDP, proxies for educational attainment, investment as a share of GDP).[13]

1. Data

We use physical infrastructure indicators that have been used extensively in recent the literature. This allows direct comparisons with the results from the growth accounting exercise below. Physical indicators for four different sectors (telecommunication, energy, transport, and water) are taken from the World Development Indicators (WDI) database, unless specified otherwise, covering the 1971–2006 period. Specifically, we use the following series:

(i) Telecommunication
  - (a) Number of main telephone lines, 1975–2006
  - (b) Number of mobile phones, 1980–2006
  - (c) Internet users per 100 persons, 1999–2006 (from the International Telecommunication Union website accessed 13 August 2010)

[13] See Straub (2011) for a discussion of the limitations of such estimations in the context of infrastructure.

(ii) Energy
   (a) A "quality proxy" is computed using electricity-generating capacity (in million kilowatts) and electric power transmission and distribution losses (percent of output)

(iii) Transport
   (a) Road total network (in kilometers), 1990–2006
   (b) Paved roads (percent of total network), as a quality proxy, 1990–2006
   (c) Rail route length (in kilometers), 1980–2006

(iv) Water
   (a) Improved water source (percent of population with access), 1990–2006

Additional variables used include GDP per capita, gross fixed capital formation (investment/GDP), and primary and secondary school enrolment ratios (all from the WDI).

2. Sample

We rely on a sample of 102 developing economies, of which 17 belong to the East Asia and Pacific region (the PRC; Fiji; Hong Kong, China; Indonesia; the Republic of Korea; Democratic People's Republic of Korea; the Lao People's Democratic Republic; Malaysia; Mongolia; Myanmar; Papua New Guinea; the Philippines; Singapore; Thailand; Tonga; Vanuatu; and Viet Nam). Five belong to South Asia (Bhutan, India, Nepal, Pakistan, and Sri Lanka).

3. Results

In what follows we present the results from cross-country estimations based on the collapsed data set, obtained by averaging the data over the period where data is available.

The infrastructure proxies are introduced in two ways: (i) using the average levels and (ii) using the average growth rates of these variables over the relevant period. In each case, after testing simple ordinary least square (OLS) specifications, we instrument potentially endogenous infrastructure indicators and perform related tests. In all cases, the instruments are beginning of the period indicators for the relevant infrastructure variable, the share of agriculture over GDP, population density, and total population.

We also test specifications with interactions between an infrastructure indicator and an East Asia and Pacific (EAP) dummy or a South Asia (SA) dummy. Results for each infrastructure dimension are presented in a separate table: Table 1 for electricity, Table 2 for telecommunication (both fixed + mobile phone lines and mobile phones alone), Table 3 for internet, Table 5 for railroads, Table 6 for roads, and Table 7 for water.[14]

Note first that the control variables yield results consistent with the empirical growth literature present: initial per capita GDP is negative and significant, which denotes convergence conditional on the other variables, while education and investment variables are positive and generally significant throughout Tables 1–3 and 5–7.

The per capita electricity-generating capacity appears to have no significant effect on growth as shown in column 1 of Table 1, while its growth rate has a positive and significant effect (column 2), such that an additional point in the average growth rate of electricity-generating capacity net of losses results in 0.22 additional average per capita growth over the period in our sample of developing countries. The introduction of investment–EAP and investment–SA interaction terms (columns 3 and 4) show that positive and significant effects arise for both groups of countries. As for electricity-generating capacity in level, the effects are 0.008 for EAP and 0.05 for SA.

The effects when variables are expressed in growth rates are 0.2 for EAP and 0.197 for SA.[15] These numbers mean that an additional point in the average growth rate of electricity generating capacity net of losses results in 0.18 additional average per capita growth over the period in our sample of developing countries, but this effect is about 11 percent stronger among Asian countries, indicating that investment in electricity across the region has been effective in relieving infrastructure bottlenecks and complementing productive investment.

As shown in columns 5 and 6, a Wu-Hausman endogeneity test rejects exogeneity for the electricity variable in level, which probably corresponds to the fact that countries have characteristics unobserved to the econometrician such that they have both faster growth and higher electricity generation. When instrumented, electricity in level loses significance. On the other hand, exogeneity is accepted for the growth rate, suggesting that these results are more robust than those in levels.

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[14] Note that results from panel regressions on 5-year subperiod averages, using alternatively fixed and random effects, as well as instrumental variable estimations, yield not significant results overall. These results are omitted for the sake of space.

[15] Marginal effects are computed as follows: for example, the effect in growth rates for EAP = 0.181 + 0.0198 ≈ 0.2)

Table 1. **Cross-section Regression Results, Electricity**
(dependent variable: per capita GDP growth)

Explanatory Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
1971 per capita GDP	–1.57e-06***	–1.24e-06***	–1.16e-06***	–1.07e-06***	2.48e-06	–9.96e-07*
	(4.91e-07)	(1.85e-07)	(4.21e-07)	(1.90e-07)	(4.87e-06)	(5.59e-07)
Secondary enrollment ratio	0.000577***	0.000485***	0.000482***	0.000420***	0.00119	0.000215
	(0.000149)	(0.000138)	(0.000165)	(0.000121)	(0.000799)	(0.000296)
Primary enrollment ratio	–0.000293	–0.000154	–0.000168	–0.000115	–0.000293	–7.43e-05
	(0.000186)	(0.000188)	(0.000200)	(0.000151)	(0.000580)	(0.000371)
Investment–GDP ratio	0.149***	0.110**	0.120**	0.0687*	0.149	0.00608
	(0.0523)	(0.0482)	(0.0520)	(0.0390)	(0.122)	(0.107)
Pcegc	0.00121		–5.49e-05		–0.0170	
	(0.00187)		(0.00164)		(0.0209)	
Pcegc_gr		0.222***		0.181***		0.245
		(0.0646)		(0.0444)		(0.203)
Pcegc* EAP dummy			0.00765***		-0.0220	
			(0.00258)		(0.0361)	
Pcegc* SA dummy			0.0476***		0.281	
			(0.0132)		(0.251)	
Pcegc_gr*EAP dummy				0.0198***		0.0475
				(0.00664)		(0.0563)
Pcegc_gr*SA dummy				0.0155***		–0.00262
				(0.00403)		(0.0562)
Constant	–0.0149	–0.248***	–0.0177	–0.201***	–0.0353	–0.252
	(0.0162)	(0.0713)	(0.0170)	(0.0528)	(0.0430)	(0.234)
Observations	48	46	48	46	38	37
R-squared	0.509	0.635	0.582	0.763		
Wu-Hausman F test, p-value					0.001	0.377

*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

EAP = East Asia and Pacific, GDP = gross domestic product; Pcegc = per capita electricity generation capacity, net of transmission and distribution losses; Pcegc_gr = rate of Pcegc growth; SA = South Asia.

Note: Robust standard errors in parentheses.

Source: Authors' calculations.

Table 2 presents the results when using telecommunication variables, which are respectively the sum of fixed and mobile phone lines in columns 1–6, and the number of mobile phones lines alone in columns 7–9.[16] The coefficient of the total telecommunication variable is positive and significant, both when introduced in level (column 1) and in growth rate (column 2), but with a marginal effect indicating that one additional point in the average growth rate of the number of per capita phone lines generates 0.23 additional average per capita growth over the period. Its interaction with the regional dummies show that these effects are stronger and more significant for Asian countries, both in levels and in growth rates. Focusing on these last ones, the overall effect is 0.213 for EAP countries and 0.209 for SA countries, compared with only 0.197 for the overall sample. These results are supported by the outcome of the estimations focusing on mobile phones in columns 7 and 8. The positive and significant effect on growth remains, and again is much stronger in the EAP and SA subsamples (0.125 and 0.961, respectively, versus 0.055 in the overall sample). Together, these results support the idea that telecommunication development was instrumental in boosting growth in the Asian region, and especially the rapid spread of mobile telephony, probably facilitated by well-designed regulatory frameworks.[17]

The introduction of internet services in the 1990s is an additional aspect that is often thought to have been instrumental for private sector development. To test this hypothesis, we perform a similar analysis using as independent variable the average growth rate of number of internet users, as provided by the International Telecommunication Union.[18] Table 3 shows that while the effect across the whole sample is negative, the net effect for the two groups of Asian countries under study is positive and significant. Specifically, an additional point in the average growth rate of internet coverage implied an additional 0.01 average per capita growth over the period for EAP countries, and 0.003 for SA countries, respectively. Given that the average annual growth of the number of internet users over this period was 18 percent worldwide, and close to 35 percent for the subsample of available Asia and Pacific economies (see Table 4), these elasticities are far from negligible. Exogeneity of the internet usage growth rate is not rejected.

[16]The series of mobiles phones growth rates are characterized by very high rates in the first years as they start from very low levels, so we do not use it. The growth effect resulting from the introduction of mobile phones in the 1980s is however reflected in the growth of the total number of fixed and mobile phones.

[17]Exogeneity is rejected by the Wu-Hausman test for both the variables in level and in growth rate, although only marginally in this last case. However, when instrumented, they are no longer significant, which may indicate that our instruments are weak.

[18]Other indicators, such as the number of broadband subscriptions, were not available for a long enough period to perform this analysis.

Table 2. **Cross-section Regression Results, Telecommunication**
(dependent variable: per capita GDP growth)

Explanatory Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
1975 per capita GDP	–1.56e-06***	–1.11e-06***	–1.27e-06***	–9.37e-07**	–2.27e-06	–3.99e-07			
	(2.75e-07)	(3.81e-07)	(2.19e-07)	(3.90e-07)	(8.01e-06)	(5.28e-06)			
Secondary enrollment ratio	0.000304**	0.000605***	0.000313**	0.000533***	0.00135	–3.66e-05	0.000205*	0.000200**	–0.00240
	(0.000133)	(0.000110)	(0.000122)	(9.87e-05)	(0.00287)	(0.00204)	(0.000108)	(9.93e-05)	(0.00641)
Primary enrollment ratio	–0.000186	–0.000243*	–0.000158	–0.000210*	–0.000880	–0.000264	-0.000159	–0.000128	0.000403
	(0.000134)	(0.000136)	(0.000130)	(0.000111)	(0.00220)	(0.00127)	(0.000129)	(0.000126)	(0.00152)
Investment–GDP ratio	0.110***	0.109***	0.0986***	0.0907***	0.285	–0.101	0.135***	0.120***	0.119
	(0.0293)	(0.0310)	(0.0285)	(0.0297)	(0.539)	(0.583)	(0.0231)	(0.0228)	(0.209)
Pctel	0.0367**		0.0173		0.0694				
	(0.0172)		(0.0127)		(0.702)				
Pctel*EAP dummy			0.0418***		–0.869				
			(0.0145)		(2.411)				
Pctel*SA dummy			0.533***		8.928				
			(0.197)		(19.95)				
Pctel_gr		0.231***		0.197***		0.000425			
		(0.0775)		(0.0520)		(1.172)			
Pctel_gr*EAP dummy				0.0157***		0.197			
				(0.00568)		(0.546)			
Pctel_gr*SA dummy				0.0120**		-0.157			
				(0.00500)		(0.513)			
1980 Per capita GDP							–1.46e-06***	–1.25e-06***	–1.47e-05
							(3.33e-07)	(2.98e-07)	(3.60e-05)
Pcmob							0.0824**	0.0550**	2.467
							(0.0311)	(0.0237)	(6.058)
Pcmob*EAP dummy								0.0697**	–1.475

continued.

Table 2—*Continued*

Explanatory Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
								(0.0275)	(3.805)
Pcmob*SA dummy								0.906**	23.25
								(0.387)	(45.92)
Constant	-0.00926	-0.276***	-0.00994	-0.236***	-0.0331	0.0423	-0.0136	-0.0133	-0.0503
	(0.0114)	(0.0953)	(0.0113)	(0.0630)	(0.102)	(1.459)	(0.0121)	(0.0119)	(0.113)
Observations	66	57	66	57	48	46	72	72	60
R-squared	0.469	0.545	0.531	0.640			0.500	0.552	
Wu-Hausman F test, p-value					0.001	0.08			0.000

*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

EAP = East Asia and Pacific, GDP = gross domestic product, pctel = per capita number of fixed plus mobile phones lines, pctel_gr = rate of growth, Pcmob = per capita number of mobile phones lines, SA = South Asia.

Note: Robust standard errors in parentheses.

Source: Authors' calculations.

Table 3. **Cross-section Regression Results, Internet**
(dependent variable: per capita GDP growth)

Explanatory Variables	**(1)**	**(2)**	**(3)**
1999 per capita GDP	–5.56e-08	–9.63e-08	–1.03e-07
	(5.17e-07)	(4.04e-07)	(1.12e-06)
Secondary enrollment ratio	9.34e-05	8.44e-05	–1.07e-05
	(0.000116)	(0.000112)	(0.000193)
Primary enrollment ratio	–0.000187	–0.000218	–0.000143
	(0.000150)	(0.000151)	(0.000277)
Investment–GDP ratio	0.150***	0.117***	0.0820
	(0.0368)	(0.0334)	(0.0689)
Pcinternet_gr	–0.00271	–0.00420	–0.0458
	(0.0117)	(0.0116)	(0.0568)
Pcinternet_gr*EAP dummy		0.0154***	0.0119
		(0.00317)	(0.0204)
Pcinternet_gr*SA dummy		0.00706*	0.0625
		(0.00421)	(0.0488)
Constant	0.00570	0.0161	0.0784
	(0.0202)	(0.0199)	(0.0882)
Observations	77	77	75
R-squared	0.272	0.372	
Wu-Hausman F test, p-value			0.12

*** $p<0.01$, ** $p<0.05$, * $p<0.1$.
EAP = East Asia and Pacific, GDP = gross domestic product, pcinternet_gr = rate of growth (percent) of number of users per 100 inhabitants between 1999 and 2006, SA = South Asia.
Note: Robust standard errors in parentheses.
Source: Authors' calculations.

Table 4. **Average Growth of Internet Usage, 1999-2006**

Economy	**Growth of Internet Users**
China, People's Rep. of	40.1
Fiji	33.7
Hong Kong, China	15.0
India	34.0
Indonesia	34.7
Iran	58.8
Korea, Rep. of	15.4
Lao People's Democratic Rep.	52.5
Malaysia	19.6
Nepal	28.9
Pakistan	81.5
Papua New Guinea	12.8
Philippines	19.0
Singapore	12.0
Thailand	27.7
Tonga	24.4
Vanuatu	34.7
Viet Nam	84.2
EAP Average	**34.9**
World	18.0

Source: International Telecommunication Union (2010).

In Table 5, we introduce the railroads variable. While its coefficient is not significant in the overall sample, the interaction terms with the regional dummies show again that the effect of railroad infrastructure on growth is strong and significant for Asian countries, both in terms of levels and growth rates. For example, an additional point in the average growth rate of railroad lines results in 0.25 additional average per capita growth over the period in our sample of developing countries (see Table 5, column 4), but this effect is about 10–12 percent stronger among Asian countries (0.283 and 0.276 for EAP and SA respectively, versus 0.248 in the overall sample). Note that exogeneity is not rejected by the Wu-Hausman test instrumented for the railroads variables in levels and in growth rates.

As shown in Table 6, most of the coefficients of kilometers of roads per capita fail to be significant, with two exceptions. In column 4, the interaction between the road quality proxy, "percent of the road network that is paved", with the regional dummies (EAP and SA) indicates that the quality of the road network has a positive effect on growth in the Asian region. The implied marginal effects are that an increase of 10 percent in the proportion of paved roads corresponds to an additional average per capita growth over the period of 0.3 percent in EAP and 0.4 percent in SA. In column 5, an additional point in the average growth rate of roads results in a significantly higher average per capita growth over the period for EAP and SA than in the overall sample of developing countries (0.071, versus 0.056 in the overall sample).[19]

Finally, Table 7 reports the results using percentage of the population with access to an improved water source. While overall results are not significant, interactions with the EAP and the SA dummies are again positive and significant, supporting the idea of a positive link between the number of connections and growth in the Asian region. In levels, the results indicate that an additional 10 percent in the rate of population coverage translates into 0.06 percent additional per capita growth in the EAP region and 0.04 percent in SA. In growth rates, an additional point in the average growth rate of water coverage results in significantly higher average per capita growth over the period for SA than in the overall sample of developing countries (0.172 versus 0.158 in the overall sample). This is in line with some previous studies that found that countries with a well-functioning water sector also experimented stronger growth. Possible channels include an indirect impact through external effects such as better health and better productivity of workers.

[19]Note that exogeneity is rejected by the Wu-Hausman test for roads, when considering either level and growth rate, but instrumental estimations fail to be significant for growth rates.

Table 5. **Cross-section Regression Results, Railroads**
(dependent variable: per capita GDP growth)

Explanatory Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
1980 per capita GDP	–1.65e-06**	–2.54e-06***	–1.08e-06	–1.91e-06**	1.53e-06	–1.03e-06
	(6.22e-07)	(7.07e-07)	(6.67e-07)	(8.43e-07)	(2.06e-05)	(1.72e-06)
Secondary enrollment ratio	0.000393*	0.000246	0.000282	0.000332	0.00126	0.000337
	(0.000230)	(0.000279)	(0.000179)	(0.000222)	(0.00610)	(0.000357)
Primary enrollment ratio	–0.000128	–0.000260	–2.32e-05	–0.000113	–0.000194	0.000204
	(0.000239)	(0.000318)	(0.000203)	(0.000327)	(0.00263)	(0.000574)
Investment–GDP ratio	0.155**	0.161**	0.0954*	0.0694	0.778	0.0312
	(0.0613)	(0.0738)	(0.0509)	(0.0614)	(4.105)	(0.100)
Pcrail	3.968		9.105		–36.46	
	(7.129)		(6.600)		(320.1)	
pcrail*EAP dummy			443.8***		–5,175	
			(146.4)		(33,066)	
pcrail_sa			306.8***		3,457	
			(87.71)		(17,518)	
pcrail_gr		0.397		0.248		–0.199
		(0.272)		(0.259)		(0.674)
pcrail_gr*EAP dummy				0.0346***		0.0489
				(0.0114)		(0.0379)
pcrail_grsa				0.0281***		0.0390
				(0.00763)		(0.0435)
Constant	–0.0257	–0.391	–0.0243	–0.253	–0.183	0.159
	(0.0217)	(0.258)	(0.0204)	(0.237)	(0.933)	(0.623)
Observations	39	26	39	26	32	24
R-squared	0.456	0.508	0.650	0.726		
Wu-Hausman F test, p-value					0.13	0.58

*** p<0.01, ** p<0.05, * p<0.1.
EAP = East Asia and Pacific, GDP = gross domestic product, pcrail = per capita kilometer of railroad lines, pcrail_gr = per capita rate of growth of railroad lines, pcrail_eap = interaction with East Asian and Pacific dummy, pcrail_sa = interaction with South Asia dummy, SA = South Asia.
Note: Robust standard errors in parentheses.
Source: Authors' calculations.

Table 6. **Cross-section Regression Results, Roads**
(dependent variable: per capita GDP growth)

Explanatory Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
1990 per capita GDP	–6.44e-07*	–7.03e-07*	–5.54e-07	–7.61e-07**	–5.82e-07	9.91e-07	–1.64e-06
	(3.66e-07)	(3.98e-07)	(6.86e-07)	(3.78e-07)	(5.83e-07)	(3.97e-06)	(2.08e-06)
Secondary enrollment ratio	0.000213*	0.000198*	0.000188	0.000233**	0.000175	–4.55e-05	0.000312
	(0.000108)	(0.000113)	(0.000122)	(0.000114)	(0.000126)	(0.000897)	(0.000231)
Primary enrollment ratio	2.69e-05	3.24e-05	–5.99e-05	1.41e-05	–3.71e-05	0.000690	–8.71e-06
	(0.000130)	(0.000132)	(0.000143)	(0.000135)	(0.000145)	(0.00159)	(0.000188)
Investment–GDP ratio	0.144***	0.140***	0.154***	0.116***	0.113***	–0.0904	0.0806
	(0.0258)	(0.0272)	(0.0368)	(0.0306)	(0.0301)	(0.369)	(0.0934)
Pcroad	–0.570	–0.518		–0.357		–4.587	
	(0.568)	(0.561)		(0.552)		(7.252)	
Pcroad*EAP dummy				–0.847		–34.80	
				(1.742)		(110.3)	
Pcroad*SA dummy				–1.797		61.08	
				(2.598)		(107.4)	
Roadqual		3.29e-05		–3.98e-05	3.93e-05		
		(6.66e-05)		(6.60e-05)	(7.09e-05)		
Roadqual*EAP dummy				0.000241**			
				(0.000106)			
Roadqual*SA dummy				0.000345*			
				(0.000184)			
Pcroad_gr			0.0956		0.0562		–0.217
			(0.0775)		(0.0631)		(0.421)
Pcroad_gr*EAP dummy					0.0149**		0.0296
					(0.00649)		(0.0377)
Pcroad_gr*SA dummy					0.0145**		0.0645

continued.

Table 6—*Continued*

					(0.00605)		(0.0407)
Constant	–0.0233**	–0.0236**	–0.113	–0.0181	–0.0708	-0.00981	0.197
	(0.0116)	(0.0116)	(0.0774)	(0.0128)	(0.0631)	(0.0596)	(0.412)
Observations	79	79	59	79	59	67	56
R-squared	0.468	0.469	0.448	0.523	0.532		
Wu-Hausman F test, p-value						0.001	0.033

*** p<0.01, ** p<0.05, * p<0.1.

EAP = East Asia and Pacific, GDP = gross domestic product, pcroad = per capita kilometer of road lines, pcroad_gr = per capita rate of growth of road lines; roadqual = paved roads as a percentage of the total network, SA = South Asia.

Note: Robust standard errors in parentheses.

Source: Authors' calculations.

Table 7. **Cross-section Regression Results, Water**
(dependent variable: per capita GDP growth)

Explanatory Variables	**(1) Pcgdpgrowth**	**(2) pcgdpgrowth**	**(3) pcgdpgrowth**	**(4) pcgdpgrowth**	**(5) pcgdpgrowth**	**(6) pcgdpgrowth**
1990 per capita GDP	–7.57e-07*	–5.99e-07*	–5.30e-07	–3.79e-07	3.75e-07	4.85e-07
	(4.12e-07)	(3.54e-07)	(3.82e-07)	(4.05e-07)	(1.21e-06)	(2.12e-06)
School enrollment secondary	0.000213*	0.000217*	0.000233**	0.000211	0.000406	0.000271
	(0.000117)	(0.000122)	(0.000111)	(0.000127)	(0.000338)	(0.000337)
School enrollment primary	3.10e-05	–2.32e-05	2.95e-05	–4.23e-06	–8.94e-05	–1.47e-05
	(0.000132)	(0.000159)	(0.000128)	(0.000159)	(0.000263)	(0.000327)
Inv/gdp	0.149***	0.213***	0.120***	0.183***	0.0663	-0.0595
	(0.0276)	(0.0363)	(0.0283)	(0.0416)	(0.224)	(0.518)
Pcwater	–5.74e-05		–0.000122		–0.000390	
	(0.000126)		(0.000132)		(0.000420)	
pcwater_eap			0.000179**		0.000716	
			(7.07e-05)		(0.00117)	
pcwater_sa			0.000164***		0.000366	
			(5.92e-05)		(0.000675)	
pcwater_gr		0.111		0.158		0.319
		(0.141)		(0.143)		(0.531)
pcwater_gr*EAP dummy				0.00897		0.0975
				(0.00674)		(0.193)
pcwater_grsa				0.0142***		0.00458
				(0.00363)		(0.105)
Constant	–0.0226*	–0.146	–0.0150	–0.192	0.0120	–0.319
	(0.0129)	(0.149)	(0.0140)	(0.150)	(0.0662)	(0.497)
Observations	77	60	77	60	61	57
R-squared	0.461	0.550	0.518	0.580		
Wu-Hausman F test, p-value					0.094	0.202

*** p<0.01, ** p<0.05, * p<0.1.
EAP = East Asia and Pacific, GDP = gross domestic product, pcwater = percentage of population with access to an improved water source; pcwater_gr = per capita rate of growth of access to an improved water source.
Note: Robust standard errors in parentheses.
Source: Authors' calculations.

One possibility that is often mentioned is that infrastructure would require a suitable institutional environment to generate sizable growth dividends (e.g., see De 2010). To test this hypothesis in the context of Asian countries, we augment our standard specifications by introducing several indices capturing institutional quality. The first one is an index of regulatory quality, taken from Kaufmann, Kraay, and Mastruzzi (2009). We focus on this index because the overall quality of the regulatory environment should matter for infrastructure development. We use 2006 values.[20]

We also experiment with an index of infrastructure performance taken from the Logistics Performance Index of the World Bank.[21] The specific infrastructure subcomponent of this index measures the "quality of trade and transport related infrastructure (e.g., ports, railroads, roads, information technology)". Consistent with its definition, this index is used only for estimation including transportation indicators (i.e., railroads and roads). The scores are from 1 to 5, 1 being the worst performance.

Table 8 presents results, where the standard specifications have been extended to include our institutional indices of interest, as well as additional interactions with our Asian country groups, i.e., we introduce, on top of the standard interactions of previous tables, triple interactions between infrastructure indices, regional dummies, and institutional indices. A significant coefficient would therefore indicate that the additional effect of infrastructure in the Asian subgroups, as implied by the significant interactions found in most previous regressions, can be partly attributed to institutional quality in the sense that within EAP or SA country groups, countries with better environment would experience stronger links between infrastructure investment and growth.

Note that the Kaufmann Kraay and Mastruzzi (2009) indices are commonly used in cross-country applications and are built by aggregating most of the existing country-level institutional indicators along each dimension (corruption, regulatory quality, government effectiveness, etc.). As such, the results obtained here can be considered pretty reliable, in the sense that using alternative indicators would most probably produce very consistent outcomes.[22]

We focus on interactions with growth rates of infrastructure indicators, as these have shown consistently significant results and are also much less subject to endogeneity problems than indicators in levels.

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[20] Unfortunately, these indices are only available from 1996, preventing us from using similar period-average values as for other variables.

[21] Available: info.worldbank.org/etools/tradesurvey/mode1b.asp, downloaded 3 August 2010.

[22] Note that alternative estimations using an index computed as the average of government effectiveness, rule of law, and control of corruption from the same source to capture the overall institutional quality prevailing in a given country yield very similar results. Results, not shown here to save space, are available from the authors.

Table 8. **Regression Results with Institutional indicators**
(dependent variable: per capita GDP growth)

Infrastructure Indicator Institutional Index	**(1) Electricity Regulatory Quality**	**(2) Phones Regulatory Quality**	**(3) Railroads Regulatory Quality**	**(4) Railroads Infrastructure Performance**	**(5) Roads Regulatory Quality**	**(6) Roads Infrastructure Performance**	**(7) Water Regulatory Quality**
pcgdp71	–1.06e-06***						
	(2.17e-07)						
pcgdp75		–1.10e-06***					
		(3.37e-07)					
pcgdp80			–2.39e-06**	–1.88e-06			
			(8.05e-07)	(1.20e-06)			
pcgdp90					–1.41e-06**	–1.07e-06	–7.95e-07**
					(6.07e-07)	(7.80e-07)	(3.28e-07)
School enrollment secondary	0.000230	0.000372***	0.000242	0.000114	0.000122	6.96e-05	8.49e-05
	(0.000156)	(0.000112)	(0.000226)	(0.000326)	(0.000144)	(0.000163)	(0.000148)
School enrollment primary	–5.01e-05	–0.000149	–0.000348	5.88e-05	–0.000131	–5.23e-05	2.12e-05
	(0.000204)	(0.000134)	(0.000292)	(0.000345)	(0.000164)	(0.000189)	(0.000163)
Inv/gdp	0.0830**	0.0924***	0.0375	0.0470	0.116***	0.144***	0.159***
	(0.0374)	(0.0239)	(0.0481)	(0.0706)	(0.0306)	(0.0388)	(0.0401)
Regulatory quality	0.0379	-0.0902	0.551		0.259**		–0.166
	(0.0600)	(0.0770)	(0.324)		(0.122)		(0.329)
Infrastructure performance				0.831		0.113	
				(0.706)		(0.101)	
pcinfra_gr	0.163***	0.195***	0.287	2.696	0.112	0.407	0.253
	(0.0458)	(0.0486)	(0.227)	(2.156)	(0.0719)	(0.331)	(0.298)
pcinfra_gr*EAP dummy	0.0171**	0.0120*	0.0456***	–0.117	0.0132**	-0.0231	0.00916
	(0.00809)	(0.00625)	(0.00898)	(0.145)	(0.00580)	(0.0197)	(0.00651)
pcinfra_gr*sa	0.0104**	0.00518	0.0332***	0.0392	0.0250***	-0.0118	0.0150**
	(0.00446)	(0.00713)	(0.00615)	(0.0382)	(0.00544)	(0.0225)	(0.00648)

continued.

Table 4—*Continued*

Infrastructure Indicator Institutional Index	**(1) Electricity Regulatory Quality**	**(2) Phones Regulatory Quality**	**(3) Railroads Regulatory Quality**	**(4) Railroads Infrastructure Performance**	**(5) Roads Regulatory Quality**	**(6) Roads Infrastructure Performance**	**(7) Water Regulatory Quality**
pcinfra_gr*inst_index	-0.0288	0.0890	–0.551	–0.846	–0.251**	–0.106	0.176
	(0.0597)	(0.0707)	(0.331)	(0.718)	(0.124)	(0.1000)	(0.327)
pcinfra_gr*EAP dummy *inst_index	-0.00350	0.00206	–0.0430**	0.0450	0.00195	0.0114	–0.00559
	(0.00706)	(0.00542)	(0.0179)	(0.0441)	(0.00738)	(0.00805)	(0.00783)
pcinfra_gr*sa*inst_index	-0.0150	-0.0268	0.0346	–0.00481	0.0490***	0.00851	0.00589
	(0.0181)	(0.0188)	(0.0230)	(0.0149)	(0.0146)	(0.00934)	(0.0203)
Constant	-0.179***	-0.229***	–0.251	–2.656	–0.109	–0.434	–0.274
	(0.0551)	(0.0622)	(0.209)	(2.104)	(0.0692)	(0.325)	(0.304)
Observations	46	57	26	25	59	52	60
R-squared	0.813	0.716	0.862	0.761	0.604	0.622	0.637

*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

EAP = East Asia and Pacific, GDP = gross domestic product, pcinfra _gr = rate of growth of per capita infrastructure indicator, pcinfra_gr*inst_index = interaction of pcinfra _gr with institutional indicator, pcinfra_gr*eap*inst_index.

Note: For each column, the infrastructure and institutional indicators used are indicated above. Robust standard errors in parentheses.

Source: Authors' calculations.

The results are disappointing, as almost no significant effects are found. The interpretation is that the comparatively higher impact of infrastructure on per capita growth in the EAP and SA groups is not particularly driven by the subset of countries in these regions that have better institutional environment. The only exception is the case of roads in SA, which therefore indicates that the growth of the roads network having a stronger effect on per capita growth in this group of countries than in the whole sample is driven by the countries in the group with a better institutional environment, i.e., Bhutan, India, and Sri Lanka. The interpretation cannot be pushed too far, however, as only five South Asian countries are included in the analysis.

B. Growth Accounting

1. Data and Estimation

We now turn to growth accounting analysis to delve further into the interpretation of the results. There are two main options for estimating the impact of infrastructure on TFP growth.[23] One uses regional panel data, while the other applies a country-per-country approach using time series data.

We first perform individual country estimation, which more realistically does not assume that there is a common underlying technology for all countries. This has been the approach used by most noninfrastructure growth accounting studies (see for example, Barro and Sala-i-Martin 2005). The panel estimation technique, on the other hand, rests on the assumption that a common production function exists for the countries under analysis, with individual country effects to be controlled for. While this approach has been extensively used with state or provincial panel data for India (Hulten et al. 2005), Italy (La Ferrara and Marcellino 2000), and the US (Holtz-Eakin 1994), it remains to be seen whether it can work when applied to a set of countries, albeit in the same region. We report below panel estimations suggesting that indeed this modeling of growth accounting runs into the problem of country-level heterogeneity and adds little to individual country estimations.

Concerning possible simultaneity issues, we cannot rule out a priori an influence of TFP growth on investment in infrastructure. Possible causes of simultaneity include endogenous responses of infrastructure policies to TFP growth, making it necessary to test the presence of reverse causation in the data. Country-specific estimations, as opposed to panel estimations, call for longer time series in order to produce efficient estimators. We concentrate again on physical indicators of infrastructure that allow for longer time coverage.

[23] See Straub et al. (2008) for technical details on the growth accounting framework.

With respect to explanatory variables, we use the same data from WDI. Note that roads data could only be used for two countries, while water data could not be used as the corresponding time series are too short for all Asian countries. The TFP growth rates, to be used as the dependent variable, were collected from two sources:

(i) The Asian Productivity Organization (APO 2010) provides TFP growth rates for six Asian and Pacific countries (the PRC, Fiji, Indonesia, the Republic of Korea, the Philippines, and Thailand) over the period 1970–2007. These are calculated TFP growth rates following the standard methodology described in Straub et al. (2008) and, in addition, taking into account changes in labor quality.
(ii) Additionally, the World Productivity Database (WPD) of the United Nations Industrial Development Organization (UNIDO 2010) provides information on levels and growth of aggregate TFP for eight other Asian and Pacific countries between 1960 and 2000 (see Isaksson 2008). We use TFP growth estimated with a nonparametric technique using data envelopment analysis with long memory (3).[24]

Crossing available infrastructure data series, which in general are good for telephones (fixed and mobiles) and electricity (production), mediocre to bad for railroads and roads, and inexistent for water, with TFP data, we get the following coverage:

(i) APO data for the period 1970–2007:
    (a) PRC (telecommunication, electricity, railroads)
    (b) Fiji (telecommunication)
    (c) Indonesia (telecommunication, electricity)
    (d) Republic of Korea (telecommunication, electricity, railroads, roads)
    (e) Philippines (telecommunication, electricity)
    (f) Thailand (telecommunication, electricity, railroads)

(ii) UNIDO data for the period 1961–2000:
    (a) Hong Kong, China (telecommunication, electricity)
    (b) India (telecommunication, electricity, railroads)
    (c) Malaysia (telecommunication, electricity, railroads)
    (d) Nepal (telecommunication, electricity)
    (e) Pakistan (telecommunication, electricity, railroads, roads)
    (f) Papua New Guinea (telecommunication)

[24]See Isaksson (2008) and Um, Straub, and Vellutini (2009) for details. Essentially, the data envelopment analysis with long memory method relies on linear programming estimators.

(f) Papua New Guinea (telecommunication)
(g) Sri Lanka (telecommunication, electricity)
(h) Singapore (telecommunication, electricity)

2. Results

Tables 9–11 report the results from individual growth accounting regressions. The results of regressions including only the electricity and telecommunication variables for the 14 countries included in our sample are in Tables 9 and 10, while Table 11 adds railroads and roads when available.

First, note that in 11 out of 14 countries, we cannot reject the hypothesis that the coefficients of both electricity and telecommunication are zero. Again, recall that the interpretation for this result is not that infrastructure is not productive but rather that there is no evidence that it is more productive than other types of capital. This conclusion is not modified for the two countries of this group also included in Table 11, where neither railroads nor roads are significant.

As for the significant results, they concern the PRC, the Republic of Korea, and Thailand. For the PRC, the total number of telephones (fixed plus mobiles) has a positive coefficient of 0.02, significant at the 1 percent level, while electricity-generating capacity adjusted for losses also appears to be more productive than standard capital, with a 5 percent level of significance. This can be interpreted as an externality effect expressed as an output elasticity of 0.12 for telecommunication and 0.35 for electricity.

In the Republic of Korea and Thailand, the electricity variable also has a positive coefficient of 0.28 and 0.50 respectively, significant at the 5 percent level, again supporting externalities from this variable. Finally, note that in the PRC, the Republic of Korea, and Thailand, the growth of infrastructure indicators explains close to one fourth of the TFP growth (R^2 of 0.23 for the PRC, 0.23 for the Republic of Korea, and 0.25 for Thailand).

In Table 11, the results on electricity are robust to including the railroads variable in the specifications, while the telecommunication variable becomes insignificant for the PRC and negative for the Republic of Korea. However, this could be due to the fact that including railroads (and roads in the case of the Republic of Korea) reduces the number of available observations from 31 to 25 for the PRC, and from 28 to 12 for the Republic of Korea.

Table 9. **Individual Country Regression Results**
(dependent variable: TFP growth rate)

Variables	**(1) China, People's Rep. of**	**(2) Fiji**	**(3) Hong Kong, China**	**(4) India**	**(5) Indonesia**	**(6) Korea, Rep. of**	**(7) Malaysia**
Growth rate of mobile and fixed-line telephony per capita	0.0497*	0.0913	–0.280	0.0230	0.0750	-0.0757	-0.00822
	(0.0272)	(0.107)	(0.234)	(0.0818)	(0.0537)	(0.0820)	(0.101)
Growth rate of per capita electricity production net of losses	0.346**		0.113	0.288	0.0491	0.279**	0.0311
	(0.152)		(0.0827)	(0.367)	(0.111)	(0.126)	(0.123)
Constant	–0.00374	–0.00860	0.0344*	–0.00144	–0.0181	-0.00622	0.0131
	(0.0182)	(0.0138)	(0.0197)	(0.0314)	(0.0265)	(0.0153)	(0.0176)
Observations	31	31	25	25	31	28	23
R-squared	0.234	0.030	0.175	0.077	0.053	0.228	0.003

*** p<0.01, ** p<0.05, * p<0.1.
TFP = total factor productivity.
Note: Robust standard errors in parentheses.
Source: Authors' calculations.

Table 10. **Individual Country Regression Results**
(dependent variable: TFP growth rate)

Variables	**(8) Nepal**	**(9) Pakistan**	**(10) Papua New Guinea**	**(11) Philippines**	**(12) Singapore**	**(13) Sri Lanka**	**(14) Thailand**
Growth rate of mobile and fixed-line telephony per capita	–0.00635	–0.0515	–0.0395	0.0675	–0.0666	0.000378	0.0238
	(0.0347)	(0.0536)	(0.212)	(0.0485)	(0.104)	(0.0405)	(0.0435)
Growth rate of per capita electricity production net of losses	0.00182	0.0719		0.107	0.314	–0.151	0.498**
	(0.0277)	(0.106)		(0.192)	(0.243)	(0.121)	(0.197)
Constant	0.00543	0.0160	–0.00398	–0.0193	0.0104	0.00894	–0.0285
	(0.0109)	(0.00954)	(0.0126)	(0.0125)	(0.0158)	(0.00880)	(0.0253)
Observations	25	25	25	31	20	25	31
R-squared	0.001	0.043	0.001	0.118	0.074	0.051	0.253

*** p<0.01, ** p<0.05, * p<0.1.
Note: Robust standard errors in parentheses.
Source: Authors' calculations.

Table 11. **Individual Country Regression Results with Railroads and Roads**
(dependent variable: TFP growth rate)

Variables	**(1) China, People's Rep. of**	**(2) India**	**(3) Korea, Rep. of**	**(4) Malaysia**	**(5) Pakistan**	**(6) Thailand**
Growth rate of mobile and fixed-line telephony per capita	0.0395	–0.0452	–0.211***	–0.123	0.00528	0.0228
	(0.0282)	(0.0545)	(0.0525)	(0.111)	(0.0806)	(0.0496)
Growth rate of per capita electricity production net of losses	0.274**	0.0356	0.216*	0.0956	0.0175	0.461**
	(0.123)	(0.249)	(0.111)	(0.113)	(0.0710)	(0.221)
Growth rate of per capita rail (kilometers)	–0.906	0.196	0.0460	–0.614	–0.0809	–0.170
	(0.539)	(0.473)	(0.0617)	(0.939)	(0.0947)	(0.418)
Growth rate of per capita roads (kilometers)			0.00146		0.0346	
			(0.0293)		(0.104)	
Constant	0.00498	0.0290	0.0118	0.00477	–0.00242	–0.0263
	(0.0170)	(0.0202)	(0.00882)	(0.0335)	(0.0169)	(0.0291)
Observations	26	20	12	16	10	26
R-squared	0.191	0.044	0.758	0.160	0.058	0.233

*** p<0.01, ** p<0.05, * p<0.1.
Note: Robust standard errors in parentheses.
Source: Authors' calculations.

These individual country regressions could be missing cross-country variations explaining differences in TFP growth. Table 12 reports the results from panel regressions. The electricity variable comes out positive and significant in columns 1–3, i.e., when per capita growth rate of the infrastructure indicators are used. Additionally, in column 2 the telecommunication variable is also positive and significant. In columns 4–6, similar albeit slightly weaker results are obtained when using aggregate rather than per capita growth rates. Note that a Hausman specification test supports the random effect specification in all but the last column, which is not surprising considering that the countries included (between 9 and 12) are drawn from a larger population of countries. However, the fixed effect estimation of the specification in column 6 yields very similar results and is not reported. Also, the overall R^2, which measures goodness-of fit for both between- and within-sample variations, is rather small in all specifications.

Overall, the rho-statistic and the results from a between-effect version of the panel regressions in Table 12, not shown here to save space, indicate that most of the significant results are driven by the "within" (i.e., individual country-level) variation. The panel analysis does not add anything to the results in Tables 9–11, probably because the assumption needed to run such estimations, i.e., that countries in the sample share some common technology, is not warranted in our sample, which contains very heterogenous countries, from large emerging Asian countries such as the PRC, to small Pacific island economies.

Finally, because TFP series are by construction noisy, in Table 13 we turn to 5-year averages to smooth them out. The resulting panel size is reduced to between 38 and 77 observations. The results corresponding to the total number of phone lines are maintained, while electricity is no longer significant. However, the small panel size (N between 9 and 12, t between 3 and 7) makes these results obviously fragile.

Table 12. **Panel Regression Results**
(dependent variable: TFP growth)

Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Growth rate of per capita electricity production net of losses	0.0910**	0.0924**	0.228***			
	(0.0462)	(0.0471)	(0.0722)			
Growth rate of mobile and fixed-line telephony per capita		0.0283*	0.00663			
		(0.0160)	(0.0186)			
Growth rate of per capita rail (kilometers)			–0.0460			
			(0.0500)			
Growth rate of electricity production, net of losses				0.0653	0.0643	0.220***
				(0.0458)	(0.0522)	(0.0556)
Growth rate of mobile and fixed-line telephony					0.0293*	0.0102
					(0.0161)	(0.0189)
Growth rate of rail (kilometers)						–0.0281
						(0.0590)
Constant	0.00468*	0.00134	–0.00410	0.00514	0.00116	–0.00765
	(0.00283)	(0.00426)	(0.00889)	(0.00383)	(0.00594)	(0.00811)
Observations	378	320	178	378	320	178
Number of id_country	12	12	9	12	12	9
R-squared (overall)	0.0266	0.0362	0.0730	0.0183	0.0259	0.0654
Rho	0.0454	0.0734	0.152	0.0461	0.0727	0.128
Hausman test (FE vs RE) p-value	0.85	0.86	0.52	0.78	0.84	0.00*

*** p<0.01, ** p<0.05, * p<0.1.
FE = fixed effects model, RE = random effects model, TFP = total factor productivity.
Note: Full set of period dummies included. Robust standard errors in parentheses.
Source: Authors' calculations.

Table 13. **Panel Regression Results, 5-year Averages**
(dependent variable: TFP growth)

Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(5)**
Growth rate of per capita electricity production net of losses	0.0734	0.0122	0.0279			
	(0.0655)	(0.0772)	(0.137)			
Growth rate of mobile and fixed-line telephony per capita		0.0609*	0.0582			
		(0.0318)	(0.0393)			
Growth rate of per capita rail (kilometers)			0.167			
			(0.358)			
Growth rate of electricity production, net of losses				0.0699	0.00902	0.0327
				(0.0646)	(0.0882)	(0.134)
Growth rate of mobile and fixed-line telephony					0.0613**	0.0571
					(0.0309)	(0.0414)
Growth rate of rail (kilometers)						0.139
						(0.462)
Constant	0.0182***	0.00836	0.00894	0.0175***	0.00738	0.00603
	(0.00271)	(0.00959)	(0.00782)	(0.00356)	(0.0108)	(0.00932)
Observations	77	65	38	77	65	38
Period dummies	Yes	Yes	Yes	Yes	Yes	Yes
Number of id_country	12	12	9	12	12	9
R-squared (overall)	0.180	0.222	0.329	0.181	0.221	0.310
Rho	0.0998	0.217	0.172	0.104	0.218	0.161

*** $p<0.01$, ** $p<0.05$, * $p<0.1$.
TFP = total factor productivity.
Note: Full set of period dummies included. Robust standard errors in parentheses.
Source: Authors' calculations.

V. CONCLUSION

Infrastructure stocks in developing Asia have been growing at a significant pace. We find, however, that their levels remain well below corresponding world averages, in terms of both quantity and quality. A massive buildup of infrastructure stock in electricity, telecommunication, transport, and water supply is needed for it to have a positive impact on economic growth.

After reviewing the state of infrastructure development in developing Asia and the literature on infrastructure and development, a number of empirical exercises are performed to assess the contribution of infrastructure to growth and productivity across a number of dimensions (electricity, telecommunication, railroads, roads, and water).

Cross-country estimations show that for most infrastructure indicators, the growth rate of stocks has a positive and significant impact on per capita GDP average growth rate in the subgroups of EAP and SA countries. The growth accounting exercise, on the other hand, shows that positive and significant effects of infrastructure on TFP growth are only observed in a few countries (the PRC, the Republic of Korea, Thailand), for telecommunication and electricity indicators. Given these results, the most plausible interpretation to be derived from the analysis is that in most Asian countries, the observed effect on growth was simply the results of higher than average infrastructure capital accumulation (a “direct effect”), but that additional productivity enhancing (“indirect”) effects were rather rare.

East Asia’s economic history seems to give credit to that claim. As discussed in Straub, Vellutini, and Warlters (2008), between 1975 and 1995, East Asia accumulated infrastructure at a rate that outpaced other regions (see Table 14). The PRC and Viet Nam, the two fastest-growing economies in the region, invest around 10 percent of GDP in infrastructure, and other countries, for example those in the Greater Mekong countries (the PRC, Cambodia, Indonesia, the Lao People’s Democratic Republic, Myanmar, Thailand, and Viet Nam) are planning to reach investment levels above 5–6 percent.

Table 14. **1995 Infrastructure Stocks as Multiples of 1975 Levels**

Region	**Electricity (generating capacity in megawatts)**	**Roads (paved roads in kilometers)**	**Telecommunication (number of main lines)**
East Asia	5.9	2.9	15.5
South Asia	4.4	2.5	8.2
Middle East and North Africa	6.1	2.1	7.2
Latin America and Caribbean	3.0	1.9	5.1
OECD	1.6	1.4	2.2
Pacific	2.0		4.3
Sub-Saharan Africa	2.6	1.7	3.9
Eastern Europe	1.6	1.2	6.9

OECD = Organisation for Economic Co-operation and Development.
Source: Straub, Vellutini, and Warlters (2008).

One must be cautious however, because due to the limited availability of data, there is no perfect match between the samples and the indicators used in both exercises. In particular, not all countries have long enough TFP data, and not all infrastructure series are long enough to be included in the growth accounting estimations.

One final comment can be made regarding convergence in the region. As shown by the cross-country regressions, initial values of per capita GDP are consistently negative and significant, indicating indeed the existence of convergence in our sample. Furthermore, specific results regarding the interaction between income levels and infrastructure endowments from Straub et al. (2008) are relevant. As shown there, infrastructure indicators appear to have a significantly lower impact among low- and middle-income countries, compared to high-income ones. That means that when we interact the specific infrastructure indicators with dummy variables for low-, middle-, and high-income countries, the results show that the net effect of infrastructure is lower in the low- and middle-income groups than in the high-income one (being actually negative in some cases for low-income countries).

The first possibility, consistent with some of the existing literature on telecommunication, for example Röller and Waverman (2001), is simply a network effect type of explanation. In the case of roads, a similar argument could be made referring to the importance of regional integration to potentiate physical infrastructure investments among the fastest growing countries, for example in the Greater Mekong subregion (see Stone and Strutt 2009). Another line of explanation is that more developed countries also have a more favorable institutional environment, e.g., better property rights, which boosts the impact of infrastructure investments or facilitates their implementation. Although our data does not allow us to isolate such an effect, a more microeconomic approach to institution and infrastructure measurement may help to illustrate such channels. Such an approach would also be useful to analyze the impact of impediments to productivity, such as congestion and environmental degradation, which are associated with urban agglomeration and may slow down the productivity-enhancing effect of infrastructure investment in cities.

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