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How Relevant Is Infrastructure to Growth in East Asia?

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Abstract

This paper seeks to shed some light on the extent to which infrastructure sub-sectors – energy, telecommunications, water supply, sanitation, and transport – contributed to growth in East Asia during 1985-2004. It also attempts to provide additional insights on whether the relationship between infrastructure and growth depends on five additional variables: the degree of private participation in infrastructure, the quality of governance, the extent of rural-urban inequality in access to infrastructure services, country income levels, as well as geography.

The findings show that greater stocks of infrastructure were indeed associated with higher growth. However, a more nuanced look at the sensitivity of infrastructure impacts on the five additional variables yields different results, with some sectors supporting conventional expectations and others yielding mixed or counter-intuitive results. In particular, the telecom and sanitation sectors yield statistically significant results supporting the a priori hypotheses; electricity and water infrastructure provide mixed results; and road infrastructure consistently contradicts a priori expectations. The results are consistent with the widely-accepted idea in policy research that infrastructure plays an important role in promoting growth, as well as with the viewpoint that certain countries' endowments influence the growth-related impacts of infrastructure.

This paper—a product of the Operations and Policy Division, East Asia & Pacific Sustainable Development (EASSD) Department—is part of a larger effort in the department to better understand the extent to which infrastructure sub-sectors have contributed to growth in East Asia. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at kseethepalli@worldbank.org.

How Relevant Is Infrastructure to Growth in East Asia?*

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1. Infrastructure and Growth in East Asia

Despite the financial crisis of 1997, East Asia[1] has seen strong growth and poverty reduction outcomes. Output has increased by a yearly average of more than 7% over the last 15 years, and investment levels have generally been high, averaging more than 30% of GDP since the 1990s. Infrastructure has played a central part in the East Asian development model; it may be no coincidence that China and Vietnam, with average annual per capita growth rates of 8.7% and 5.8% respectively over the 1990-2005 period (among the highest in developing East Asia), had made investments in infrastructure of 7% and 9% of GDP respectively over the same period.

Infrastructure works to reduce poverty by supporting economic growth and providing access to key services (ADB, JCIB, World Bank, 2005). Infrastructure can, in addition, lower income inequality and help raise the income of the poor more than proportionately (Calderon & Serven, 2005), suggesting that infrastructure development in an essential ingredient for poverty reduction. This paper examines the first part of the infrastructure-growth-poverty reduction equation. It seeks to understand the extent to which different infrastructure sub-sectors – i.e. energy, telecommunications, water supply, sanitation, and transport - have contributed to growth in East Asia[2] over the period 1985-2004, and presents a similar analysis to that conducted for 41 countries in Sub-Saharan Africa by Estache, Speciale, & Veredas (2005) to the East Asian context. As in the Estache et al (2005) paper, we use an augmented Solow growth model to compare the significance of infrastructure to growth after taking into account the effect of other sectoral expenditures such as those pertaining to education and capital formation.

In order to anchor this analysis in the context of ongoing policy debates, we attempt to provide for additional insights on the importance of infrastructure subsectors to growth depending on the quality of governance, degree of private participation in infrastructure (PPI), country income levels, extent of rural-urban inequality in access to infrastructure services, as well as geography (island vs. non-island countries):

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[1] Reference to East Asia throughout the paper includes the 9 Pacific Islands Countries (PICs), and corresponds to the Bank's definition of East Asia and Pacific Region.

[2] For a comprehensive review of the empirical literature on infrastructure's impact on growth, see Straub & Vellutini (2006).

- *Governance.*[3] Good governance is associated with better provision of infrastructure services. It acts by reducing corruption and incentives of political actors to capture monopoly rents, increasing transparency of public and private transactions and regulatory structures while guaranteeing investors an adequate rate of return and protecting them from arbitrary action by government as well as protecting consumers from abuse by firms with substantial market power (Lovei and McKechnie, 2000; Jacobs, 2004; World Development Report, 2005). Additionally, better governance quality in a country helps to define its business environment and is associated with higher investment flows (Globerman and Shapiro, 2002), thereby creating favorable conditions for economic growth (Kaufmann and Kraay, 2002; Mauro, 1995; Kaufmann, Kraay and Zoido-Lobaton, 1999; Wei, 1997). Taken together, we expect good governance to enhance the growth enhancing effects of infrastructure. More specifically, we hypothesize that good governance contributes to growth by supporting better provision of infrastructure services, and a priori, expect to find evidence of differential impact of infrastructure investments on a country's growth depending upon its quality of governance.

- *Private Participation in Infrastructure.* The move towards private provision of infrastructure services across developing countries has been motivated by disenchantment with the inefficiency and poor performance of state-owned monopolies, the need for new investments and modernization to meet rapid growth in demand, and fiscal constraints, along with the desire to extend service access to the poor (Besant-Jones, 2006). In the East Asian context, rapid growth continues to place a strain on existing infrastructure stocks, and many governments in the region are looking to increase the role that Public Private Partnerships (PPPs) play in meeting critical infrastructure needs (ADB, JBIC, World Bank, 2005). Evidence suggests that the introduction of the private sector has led to improvements in efficiency and, very often, an expansion in, and quality of, services, with the poor benefiting from private participation compared to the situation prevailing under public provision; moreover, improvements in efficiency that occur can also lead to reductions in prices (Harris, 2003). Overall, PPI can expand access and quality of infrastructure services, with attendant increases in labor and service productivity (Ramamurti, 1996; Agénor and Moreno-Dodson, 2006; ILO, 2002), support efficiency

[3] We follow Kaufmann, Kraay and Zoido-Lobaton's (1999) definition of governance that includes (i) the process by which governments are selected, monitored and replaced; (ii) the capacity to effectively formulate and implement sound policies; and (iii) the respect of the citizens and the state for the institutions that govern economic and social interactions among them.

improvements and deployment of new technology in utilities, introduce alternative mechanisms to finance infrastructure and free scare resources to channel towards growth and other development policy priorities – all of which may positively impact growth. We therefore expect to find evidence of differential impact of infrastructure investments on a country's growth depending upon prevalence of PPI.

- *Income levels*. Countries with higher income levels have better rates of access to infrastructure services. Moreover, rich countries have higher levels of accumulated capital stock and savings rates (Cass, 1965; Koopmans, 1965), technology (Romer, 1986), and human capital (Lucas, 1988) to channel towards better provision of infrastructure services. Additionally, richer countries tend to use resources spent on infrastructure more effectively (Hulten, 1996) to deliver better infrastructure service quality (Calderon and Serven, 2004) that is closely related to higher competitiveness (Global Competitiveness Report, various years) and higher rates of economic growth. Based on this intuition, we investigate whether the contribution of infrastructure to growth is systematically greater in richer countries than in poorer ones. We therefore expect to find evidence of differential impact of infrastructure investments on a country's growth depending upon countries' income levels.

- *Inequality of access to infrastructure.* A priori, one could argue that greater inequality of access to infrastructure services would lead to lower growth by systematically excluding groups of individuals who, with better access to infrastructure, could have made a greater contribution to growth. Indeed, several studies have argued that access to infrastructure services helps poorer individuals and underdeveloped areas to get connected to core economic activities, allowing them to access additional productive opportunities (Estache, 2003), enhancing their human capital and therefore income prospects (Leipziger, Fay and Yepes, 2003), as well as reducing production and transaction costs (Gannon and Liu, 1997). Together, these benefits of equitable access to infrastructure services can play a key role not only in helping reduce income inequality (Calderon and Serven, 2004; Estache, Foster and Wodon, 2002; Lopez, 2004), but also in fostering economic growth (Alesina and Rodrick, 1994; Alesina and Perotti, 1996; Galor and Zeira, 1993). We therefore expect to find evidence of differential impact of infrastructure investments on a country's growth depending upon inequality in access to infrastructure services.

- *Geography:* The goal here is to investigate whether infrastructure provision in Pacific Island countries (PICs) is predisposed to yield systematically different results than could be expected in non-PIC settings.

In addition, this paper serves as a benchmark against which to re-examine, at a future date, the relationship between infrastructure and growth in the context of the sweeping changes in East Asia's political economy[4]. Among the principal elements influencing contemporary East Asia, and which no doubt will shape its future, are decentralization, rapid urbanization and regional integration (ADB, JBIC, World Bank, 2005). Despite their relevance to East Asia's growth, we could not examine the differential impact of infrastructure depending on the extent of decentralization, urbanization and regional integration, since these trends are still nascent, with little variation over the 1985-2004 interval on which we focus, to make for meaningful econometric analysis. The present paper provides an estimate of the impact of infrastructure on growth implicitly[5] taking as a given present levels of decentralization, urbanization and regional integration. Such an estimate provides a benchmark against which to judge, through future analysis using a larger number of independent variables, the extent to which variations in levels of decentralization, urbanization and regional integration (for example) influence the magnitude of infrastructure's impact on growth.

Limitations of growth theory. Before proceeding any further, a restatement of some of the well documented limitations of the research into economic growth is called for[6]. The new growth literature, using both neoclassical (Solow, 1956; Swan, 1956) and endogenous growth (Romer, 1985; Lucas, 1988) models, has intensively studied physical and human capital, technological change, and national economic policies (such as those relating to macroeconomics and trade), as key factors influencing long run growth. Yet, there are few policies about which we can say with certainty that they deeply and positively affect growth (Harberger, 2003; Rodrik, 2004[7]; Easterly,

[4] See "Connecting East Asia: A New Framework for Infrastructure" for a discussion of the economic, spatial and demographic, environmental, political and funding dimensions of infrastructure service provision.
[5] Lack of sufficient (variation in) data on decentralization, urbanization and regional integration prevented us from explicitly including these as control variables in the econometric specifications examined in this paper.
[6] For an excellent review of the history of modern growth theory, see Barro and Sala-i-Martin (2004).
[7] A related issue is that igniting economic growth and sustaining it are somewhat different enterprises. The former generally requires a limited range of (often unconventional) reforms that need not overly tax the institutional capacity of the economy. The latter challenge is in many ways harder, as it requires

2004). For instance, although extremely bad policy can probably destroy any chance of growth, it does not follow that good macroeconomic or trade policy alone can create the conditions for high steady-state growth. Second, research into the effects of economic policies on growth usually focus on the years following 1960, for which national accounts data started to become available for a large group of countries[8]. However, given that the correlation of per capita income in 1960 with per capita income in 1999 is 0.87 (Easterly, 2004), countries' relative performance may largely be explained by the point they had already reached by 1960, suggesting that the role of post-1960 policies in determining development outcomes can only be limited. The role of policies in explaining post-1960 growth is further constrained once we realize that policy variables are much more stable over time than are growth rates (Easterly, Kremer and Pritchett, 1993). Third, research devoted to economic growth does not always take into account the role of externalities, which would otherwise explain why many countries appear to share a common long run growth rate despite persistently different rates of investment in physical and human capital (Klenow and Rodriguez-Clare, 2004). Finally, growth regressions require large samples to address issues such as the identification of empirically salient determinants of growth when the range of potential factors is large relative to the number of observations (Durlauf, 2004), and the requirements of panel data methods to detect growth patterns in a dataset comprised of heterogeneous countries (Islam, 1995; Durlauf, 2004). Similarly, some methods for addressing other problems, such as measurement error, are only useful in samples larger than those that are usually available to growth researchers. It follows that conclusions derived from empirical growth research based on small samples would rightly be regarded as questionable.

Despite the many difficulties that arise in empirical growth research, researchers have uncovered stylized facts – such as the massive divergence in living standards that has occurred over the last several centuries, the lack of sustained productivity growth in the poorer regions of the world, the unprecedented growth rates in some developing countries after the 1960s – and linked them to substantive economic arguments. This paper attempts to contribute in a small way to the understanding of the contribution of one set of factors, namely infrastructure stocks, to economic growth, in one region of the world, namely East Asia. It should be stated at the outset that the dataset constructed for the analysis is small given the relatively low number of countries and the

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constructing a sound institutional underpinning to maintain productive dynamism and endow the economy with resilience to shocks over the longer term. Ignoring the distinction between these two tasks leaves reformers saddled with impossibly ambitious, undifferentiated, and impractical policy agendas (Rodrik, 2004).

[8] Another reason for this starting point is that many colonies did not gain independence until the 1960s (Durlauf, 2004; Easterly, 2004).

relatively short time interval of 1985-2004. This could dilute the veracity of the results presented in this paper. In order to address this issue, we conducted a robustness check of the estimation results using the bootstrapping technique (Cameron & Trivedi, 2005), and found evidence confirming our results.

The paper is organized as follows. Section 2 lays out the theoretical framework underlying the analysis of the impact of infrastructure on growth. Section 3 discusses the data underlying this analysis; it includes a description of dependent and independent variables as well as a discussion of data limitations. Section 4 presents the results of the econometric exercise stemming from the theoretical framework. Section 5 presents concluding remarks and draws on Estache et al (2005) to provide a brief comparison of the extent to, and manner in which infrastructure has contributed to growth across the East Asia and Sub-Saharan Africa regions.

2. A Theoretical Framework: An Augmented Solow Model with Infrastructure[9]

As mentioned above, we employ an augmented Solow growth model, developed in Estache et al (2005), as the theoretical framework to organize our analysis of the relative importance of different infrastructure sub-sectors to growth in the East Asian context. The model builds on that proposed by Solow (1956) and further developed by Mankiw, Romer and Weil (1992), and includes the accumulation of human as well as physical capital to explain the international variation in growth rates across East Asian countries. In addition, the model introduces an infrastructure index (Inf Inx hereafter) in the production function. As in the Estache et al (2005) paper, the Solow growth model used here relies on a Cobb-Douglas production function with labor augmenting technological progress, human capital and the infrastructure index.

$$Y(t) = IK(t)^{\alpha} H(t)^{\beta} (A(t)L(t))^{1-\alpha-\beta}, 0 < \alpha + \beta < 1 \qquad \ldots(1)$$

where Y is the income, I is the Inf Inx, K is the stock of physical capital, H is the stock of human capital, A is technology and L is labour. α and β are the physical and human capital shares of income respectively. The parameter constraint $0 < \alpha + \beta < 1$ ensures decreasing returns to capital. We define $y = Y / AL$, $k = K / AL$ and $h = H / AL$ to be the income-, and stocks of

[9] For more details about the development of the Augmented Solow Model with Infrastructure, see Estache et al (2005).

human and physical capital, per effective unit of labour. Further, s_k and s_h are the fractions invested in human and physical capital. Labour and technological progress are assumed to grow exogenously at rates *n* and *g*: $L(t)=L(0)e^{nt}$ and $A(t)=A(0)e^{gt}$. Therefore the number of effective units of labour, $L(t)A(t)$ grows at rate *g+n*. Capital depreciates at rate *δ*. The growth rate of technology and depreciation rates are assumed to be constant and both sum 0.05, i.e. $g+\delta=0.05$[10]. *I*, the Inf Inx, represents the influence of an economy's infrastructure. Inf Inx is measured by infrastructure indicators, denoted by *ω*, such as kilometres of paved roads, number of phone lines, percentage of population with access to improved water and sanitation facilities, etc. The index is $I=\varpi^{\gamma}$ where γ reflects the elasticity of GDP with respect to infrastructure. To a large extent, the exercise conducted in this paper consists in demonstrating that γ is statistically significant as evidence that infrastructure matters to growth. In per capita terms,

$$\frac{Y(t)}{A(t)L(t)}=I\left(\frac{K(t)}{A(t)L(t)}\right)^{\alpha}\left(\frac{H(t)}{A(t)L(t)}\right)^{\beta}\Rightarrow y(t)=Ik(t)^{\alpha}h(t)^{\beta}$$

The evolution of *k* and *h* is governed by

$$\begin{aligned}\dot{k}&=s_k y(t)-(n+g+\delta)k(t)\\ \dot{h}&=s_h y(t)-(n+g+\delta)h(t)\end{aligned}$$

Equating the right hand side to zero to arrive at steady states, substituting *y* and solving we get

$$k^{*}=\left(\frac{s_k^{1-\beta}Is_h^{\beta}}{n+g+\delta}\right)^{1/(1-\alpha-\beta)}\quad\text{and}\quad h^{*}=\left(\frac{s_k^{\alpha}Is_h^{1-\alpha}}{n+g+\delta}\right)^{1/(1-\alpha-\beta)},$$

Introducing these steady states in $y(t)=Ik(t)^{\alpha}h(t)^{\beta}$ and taking logs we get

[10] This assumption is consistent with that adopted in Mankiw, Romer and Weil (1992, pp. 413, Footnote 6) and Islam (1995, pp. 1139) for all countries analyzed (although it is important to point out that this value is only valid for countries comparable to the United States) and is similar to the value 0.03-0.04 used in Romer (1990). Furthermore, the assumption $g+\delta=0.05$ has been used in Estache et al (2005) for the Sub-Saharan Africa dataset. Given that this assumption has been made in the context of diverse datasets, we feel comfortable doing the same for the East Asian sample.

$$y^* = \ln\left(\frac{Y(t)}{L(t)}\right) = \ln A(0) + gt + \frac{1}{1-\alpha-\beta}\ln I$$
$$-\frac{\alpha+\beta}{1-\alpha-\beta}\ln(n+g+\delta) + \frac{\alpha}{1-\alpha-\beta}\ln(s_k) + \frac{\beta}{1-\alpha-\beta}\ln(s_h)$$

This equation shows how income per capita depends on labour growth, accumulation of physical and human capital, technology and Inf Inx. Following Mankiw, Romer and Weil (1992), this equation may be rewritten in terms of the steady state of human capital

$$y^* = \ln A(0) + gt + \frac{1}{1-\alpha}\gamma \ln \omega_j + \frac{\alpha}{1-\alpha}\left[\ln(s_k) - \ln(n+g+\delta)\right] + \frac{\beta}{1-\alpha}\ln(h^*) \qquad (2)$$

This model nests the augmented Solow model developed by Mankiw, Romer and Weil (1992), in which Inf Inx equals one. In their augmented Solow model, only effective labour, and physical and human capital affect income:

$$Y(t) = K(t)^{\alpha} H(t)^{\beta} (A(t)L(t))^{1-\alpha-\beta}, 0 < \alpha + \beta < 1$$

The steady states of this model is

$$y^* = \ln A(0) + gt + \frac{\alpha}{1-\alpha}\left[\ln(s_k) - \ln(n+g+\delta)\right] + \frac{\beta}{1-\alpha}\ln(h^*) \qquad (3)$$

In our estimations we will consider this augmented version as the benchmark model.

There are several possible econometric techniques to estimate the benchmark model, namely panel data, pooled regression and cross-section regression (over long time spans). With respect to panel data, we can choose the appropriate estimator from random and fixed effect methodologies. Panel estimators relying on the random effects assumption do not seem to be appropriate since it is difficult to argue that individual (country) effects are uncorrelated with the exogenous variables (Greene, 2003). Another option is to consider the Least Squares Dummy Variable (LSDV) estimator, which is based on the fixed effects assumption. Country (fixed) effects would then be included in the regression and treated as parameters to be estimated together with those of the exogenous variables. However, while the LSDV estimator has the advantage to control for unobserved heterogeneity, it is not a suitable estimator for our model for two main reasons. First, a simple ANOVA analysis showed how within-country variation is negligible. There are more differences between countries than within countries, with between country differences representing 98% of the source of total variance. A fixed effects estimator would thus be of little use in studying differences between countries because it uses only the time variation within each cross-section. And the severe unbalanced nature of our panel due to missing data reduces the number of time periods to very few, as a result of which the within cross-section variation becomes unimportant. Second, fixed effects estimates would exacerbate measurement errors problems (Wooldridge, 2002).

We therefore rely on the pooled regression technique. Pooled regression results are very similar to single cross-section results (Islam 1995, pp. 1141). Since our study focuses on East Asian economies, for which little data is available, a further advantage of a pooled regression over a single cross-section is the increased sample size it affords. We therefore specify the following econometric model for our benchmark model:

$$\ln GDP_{it} = b_0 + \delta_t + b_1 \left[\ln Total\ Investment - \ln \left(Population\ growth - 0.05 \right) \right]_{it} + b_2 \ln Education_{it} + \varepsilon_{it} \quad \ldots(4)$$

and the following econometric model for our Infrastructure model:

$$\begin{aligned} &\ln GDP_{it} = b_0 + \delta_t + b_1 \ln Infrastructure_{it} \\ &+ b_2 \left[\ln Total\ Investment - \ln \left(Population\ growth - 0.05 \right) \right]_{it} + b_3 \ln Education_{it} + \varepsilon_{it}, \end{aligned} \quad \ldots(5)$$

where $i = 1,..., N$, $t = 1,..., T$, *N* is the number of countries, *T* the number of periods and δ_t is a set of time dummies.

It is important to clarify that the parameters that are estimated are those of the econometric model needed to generate the implicit parameters of the economic model – in particular γ (the elasticity of GDP with respect to infrastructure), and α and β (the physical and human capital shares of income respectively). The total investment parameter, the education parameter and the infrastructure parameter can be computed from the estimated model using $\alpha = b_2 (1 + b_2)^{-1}$, $\beta = b_3 (1 - \alpha)$ and $\gamma = b_1 (1 - \alpha)$ respectively. This means that the statistical significance of the various parameters of the econometric model will tell us whether infrastructure matters or not. If b_1 is not statistically significant, infrastructure does not matter. If, by contrast, b_2 is not statistically significant, $\alpha = 0$ and hence the implied parameters for education and infrastructure can be read directly from the estimated econometric model, i.e. $\beta = b_3$ and $\gamma = b_1$ (Estache et al, 2007).

3. Data and Estimation

Data. In order to conduct the econometric analysis discussed, we constructed a database of all East Asian countries drawing on multiple data sources including, World Development Indicators (WDI), PPI database and the database of Governance Indicators maintained by the World Bank. The database allowed us to cover 16 countries in East Asia: Australia, Cambodia, China, Fiji, Indonesia, South Korea, Laos, Malaysia, Mongolia, Papua New Guinea, Philippines, Singapore, Thailand, Tonga, Vanuatu, and Vietnam. Owing to limitations of data availability, we had to drop Kiribati, Marshall Islands, Micronesia, Myanmar, Palau, Solomon Islands, and Timor-Leste from the analysis.

Variables. The time horizon considered in the paper covers 20 years from 1985 to 2004[11]. The *dependent variable* is growth in the East Asian countries studied, as measured by the evolution of GDP per capita in constant 2000 prices. We consider a set of infrastructure stocks as *explanatory variables*. Specifically, our analysis takes into account the following measures of infrastructure in 5 key sectors:

(i) Telecommunications – telephone mainlines per 1000 people; mobile subscribers per 1000 people;
(ii) Electricity – electric power consumption per capita (kwh);
(iii) Roads – kilometres of paved roads per capita; percentage of road network paved;
(iv) Water – percentage of population with access to an improved water source;
(v) Sanitation – percentage of population with access to improved sanitation facilities.

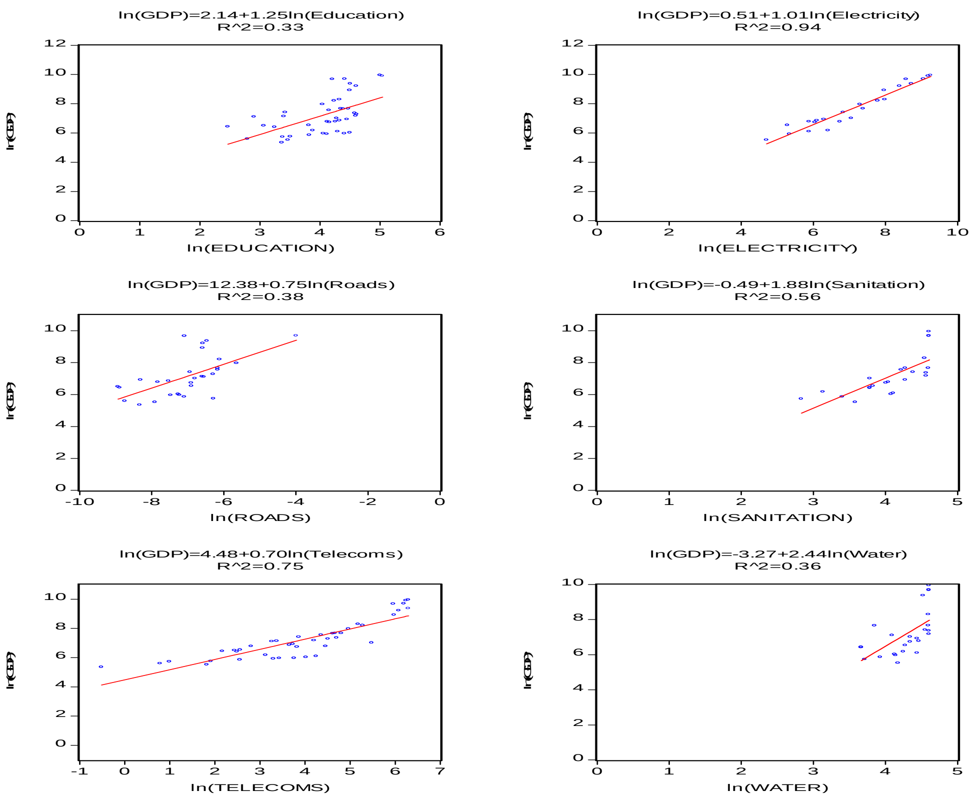
As discussed in the econometric model developed above, we *control* for the level of investment and of human capital, proxied by Gross Fixed Capital Formation (% of GDP) and secondary school enrolment (% gross)[12], respectively. Natural logarithms are taken for both infrastructure and control variables. Additionally, we consider the five variables mentioned above (i.e. PPI; governance; inequality in infrastructure access; country income levels; and Pacific Island[13] vs.

[11] Although data were available for the year 2005 for a few variables, our time series spanned the years 1985-2004 in the interest of consistency across all variables.
[12] Gross (secondary) enrollment ratio is the ratio of total (secondary) enrollment, regardless of age, to the population of the age group that officially corresponds to the level of education shown.
[13] The 9 Pacific Island Countries (PICs) include Fiji, Federated States of Micronesia (FSM), Kiribati, Marshall Islands, Palau, Samoa, Solomon Islands, Tonga, and Vanuatu.

non island countries). Each variable is incorporated into the econometric model as a dummy variable. Details of variable definitions, sources and dummy variable construction are provided in Appendix 1.

By way of illustration, Figure 1 shows the scatter plots between per capita growth and the various infrastructure sub-sectors as well as education from the estimation of a linear trend in East Asia over the period 1985-2004.

Figure 1. Scatter Plots: The Impact of Education and Infrastructure on Growth



The simplistic univariate linear regression estimation above allows for visualizing the possible links between growth and infrastructure, and suggests that the impact of any infrastructure sub-sector on GDP per capita is clearly positive (reported in row 1 of Table 2).

Missing data. Several variables in our dataset suffered from moderate to sever missing data problems. Compounding the missing data problem is the fact that East Asia as a region comprises a smaller number of countries than other regions resulting in a rather modest number of potential observations per variable to begin with. Table 1 summarizes the size of the database for all of the variables used in the paper. It shows the number of annual observations and the proportion of missing values. Two facts emerge from the table. First, all the variables have missing values. Second, and most important, for five out of the eight variables more than half of the data cells are empty.

Table 1: Observations and missing values

	5 years interval		Annual	
	Number of obs available	**% missing obs**	**Number of obs available**	**% missing obs**
GDP per capita	63	2%	310	3%
Education	44	31%	113	65%
Investment	62	3%	278	13%
Telecoms	64	0%	313	2%
Mobile Phones	57	11%	302	6%
Electricity	36	44%	171	47%
Roads	46	28%	205	36%
Water	28	56%	28	91%
Sanitation	25	61%	26	92%

In order to address this problem, at least partially, we aggregated the observations over intervals of five years. The number of observations and the proportion of missing values for each sector are provided in Table 1. The manner in which such an aggregation is made (i.e., average, sum of observations, or usage of the last available observation) depends on the nature of the variable. For the variables measured as a stock (investments, education and all infrastructure variables except electricity) the last observation over the 5-year period was taken. For the variables measured as a flow (per capita GDP and electricity), averages over the 5-year periods were taken. In all, we considered four intervals of time: 1985− 1989, 1990−1994, 1995− 1999, 2000 − 2004.

Table 1 shows that if data is aggregated to capture 5 years intervals, only two variables have more than half observations missing. While the missing data problem is not entirely circumvented, data aggregation is a definite improvement over the use of annual data. The use of data aggregation over five years is standard practice in the literature, e.g. Islam (1995), in particular when there is a concern that annual observations are too noisy. Additionally, the five-year time-span can mitigate the impact of business cycles on observations in the dataset.

Multicollinearity. Table 2 provides a correlation matrix between dependent and explanatory variables used in the analysis. It is also useful to get a sense of the simple correlation between the various subsectors since it would provide an early hint of any possible multicollinearity problems for the econometric work presented later in the paper. A few observations are called for on the basis of the analysis in Table 2. First, the first row of Table 2 suggests that there is a high and statistically significant correlation between growth and infrastructure. Second, education is highly correlated with all the infrastructure subsectors except roads[14]. The final observation is that the various infrastructure subsectors are highly correlated among themselves.

Overall, these results suggest that there is a strong likelihood of multicollinearity, which if confirmed, needs to be addressed as part of our econometric work. In particular, multicollinearity has the effect of significantly increasing standard errors resulting in low t-statistics. In other words, including all independent variables in the model at the same time could result in many of them not being significant, even though their respective relationships with the dependent variable may be significant when considered individually. To avoid this problem, we regress the infrastructure variables one by one in model (5)[15]. We may then compare model (5)'s goodness of fit with that of the benchmark model (4).

Table 2: Sample pair-wise correlations between dependent and explanatory variables (p-values in parenthesis)

	GDPpc	Education	Telecom	Electricity	Roads	Water	Sanitation
GDPpc	1	0.63	0.93	0.98	0.58	0.51	0.60
		(.0000)	(.0000)	(.0000)	(.0000)	(.0056)	(.0015)
Education		1	0.68	0.80	0.23	0.61	0.67
			(.0000)	(.0000)	(.1331)	(.0006)	(.0002)
Telecoms			1	0.93	0.46	0.56	0.67
				(.0000)	(.0013)	(.0019)	(.0002)
Electricity				1	0.59	0.64	0.73
					(.0002)	(.0002)	(.0000)
Roads					1	0.36	0.45
						(.0599)	(.0240)
Water						1	0.81
							(.0000)
Sanitation							1

We formally assess the presence of multicollinearity by examining tolerance and its inverse, variance inflation factors (VIFs), which give a sense of the magnitude by which the standard error of an independent variable is "inflated" when it is predicted by other independent variables in the

[14] One would expect a superior endowment of roads to be associated with ease of access to education by facilitating an individual's travel to school. The statistically insignificant pairwise correlation coefficient between education and roads (correlation coefficient of 0.23, with a *p*-value of 0.1331) is therefore somewhat counter-intuitive. A possible reason for this could lie in the definition of our roads infrastructure variable as kilometers per capita of paved roads. In other words, roads that are not paved are not accounted for in the analysis, which in turn could lower the correlation between education and roads infrastructure.

[15] An alternative is to rely on a synthetic index of the various infrastructure services as done by Calderon and Serven (2004). This is a useful solution when the focus is on the aggregate level of infrastructure. Here the emphasis in on the relative relevance of the various infrastructure sub-sectors and hence we discarded the synthetic index approach.

model[16]. As a rule of thumb, a tolerance value of 0.10, which corresponds to a VIF value above 10 suggests that multicollinearity among independent variables is a serious problem (Hair, Anderson, Tatham, and Black, 1998, pp. 193). Table 3 below shows that every infrastructure variable, with the exception of per capita availability of paved roads, is associated with VIFs that far exceed the widely accepted cutoff of 10, confirming that the infrastructure (i.e., independent variables in our analysis) are multicollinear. As mentioned above, we address this problem by regressing the infrastructure variables one at a time rather than incorporating them together in our empirical model.

Table 3: Tolerance and Variance Inflation Factor for infrastructure variables

	Telecoms	Electricity	Roads	Water	Sanitation
Tolerance	.01	.01	.14	.02	.03
Variance Inflation Factor	185.19	200.00	7.02	41.15	36.10

Endogeneity. Another concern to deal with is the possible presence of endogeneity. In our paper, endogeneity would be present when both our variables of interest, GDP per capita and its infrastructure variables are flows. However, endogeneity does not arise when the explanatory variables are stocks, as it mitigates the possibility of reverse causality. For instance, the accumulated stock of roads today dates back a few decades. While it may be reasonable to say that roads constructed 20 years ago are still causing growth, it would be difficult to argue the reverse, i.e., roads constructed 20 years ago could not have been “caused” by today’s growth. All the infrastructure variables in our paper are measured as stocks, except electricity. We conducted a Hausman test for endogeneity, which did not reject the null hypothesis of exogeneity of electricity[17].

[16] The tolerance and its inverse, the variance inflation factor (VIF), are among the most common measures for assessing multicollinearity. Tolerance is the amount of variability of the selected independent variable not explained by other independent variables. Small tolerance values, and therefore large VIFs, denote high multicollinearity (Hair, Anderson, Tatham, and Black, 1998).

[17] In order to test for endogeneity of electricity, we conduct a Hausman test (Wooldridge, 2002) that involves the two stage Least Squares procedure. In the first stage, we introduce total investment and education, at both current and lagged values, as additional regressors on electricity. The first stage F statistic is equal to 5.87. In the second stage, we introduce the residuals of the first stage as an additional variable to the Solow regression for electricity. The regression coefficient for the first stage residuals is -0.18 with t-statistic equal to -1.03. Therefore, the test does not reject the exogeneity of electricity. Additionally, we conducted a Hausman test for endogeneity of country income levels (for results displayed in Table 7) in the infrastructure model for electricity. The regression coefficient for the first stage residuals is 0.01, with a t-statistic equal to 0.03. We therefore conclude that the null hypothesis of exogeneity of electricity when dummies on income are added to the infrastructure model is not rejected.

Limitations. A note on the limitations of the analysis is called for. First, while missing data issues have been addressed in the manner described above, the overall dataset available for the analysis is small, which could affect the robustness of our results. In order to assess the robustness of our estimation results, we computed standard errors across all specification reported using the bootstrapping technique with replacement (Cameron & Trivedi, 2005) and 100 replications, and found evidence confirming the results. Second, as pointed out above, in order to address the issue of endogeneity, we defined our dependent variable as per capita GDP and regressed this dependent variable on the stocks of infrastructure at different points in time, rather than regressing change in GDP per capita to a change in infrastructure stocks. Had we been able to use dependent and independent variables defined in terms of "changes"/"increases", we could have conducted a more sophisticated analysis of how growth responds to increments in infrastructure, including an investigation of the lags with which growth responds to expansions of infrastructure stocks.[18] Third, in addition to being directly consumed by households and firms, infrastructure services have efficiency-enhancing externalities – higher quality electricity supply makes possible the use of more sophisticated machines; better transport infrastructure, by lowering transport costs, promotes access to markets, economies of scale, and different patterns of agglomeration. Interesting and important as the issue may be, our analysis does not separate the direct and efficiency-enhancing effects of infrastructure. Finally, while our analysis attempts to tell a preliminary story about the comparative influence of infrastructure sectors on per capita growth across East Asian countries (and in different contexts regarding governance, PPI, inequality in access to infrastructure, income levels and geographic characteristics), it does not address the specific priorities of individual countries. Country-specific assessments would be required to formulate country-specific policy priorities.

[18] The usage of these metrics of growth would have required us to address endogeneity by employing instrumental variables (IVs), i.e., variables that are correlated with the endogenous independent variable (infrastructure, in our analysis), but uncorrelated with the dependent variable (growth) and the error term. However, this approach is not without its limitations. For instance, the IV-estimator is highly biased if a slight correlation exists between the IV and the error term (Bartels, 1991) and, since the error term is unobservable, there is no effective test to reveal such correlation. In addition, large finite sample biases can occur when instrumental variables are weak (i.e., weakly correlated with the included endogenous variables). In particular, when the number of time series observations is small as is the case in our sample, lagged levels of the variables are only weak instruments for subsequent first-differences (Nelson and Startz, 1990a, 1990b; Staiger and Stock, 1997). Overall, it is advisable to select reliable instrumental variables based on subjective judgment about cause-effect relationships in the domain. On balance we favored using infrastructure stocks as explanatory variables to address the endogeneity problem over the use of IVs.

4. Results

In this section we provide the results of our econometric analysis. We begin by discussing the augmented Solow model with education and total investment, which serves as a benchmark. Against this benchmark model, we include each infrastructure subsector, one at a time, to assess the additional variance in growth that is now captured by each of the infrastructure variables, respectively. We then estimate how variations in each one of the five factors mentioned above (governance, PPI, inequality in access to infrastructure, income levels and geographic characteristics) influence the relationship between infrastructure and growth.

Estimation results of models (4) and (5) are shown in Tables 4-9, in which the rows report on the explanatory variables: education, total investment and infrastructure; subsectors are specified in the columns of these tables. Table 9 summarizes the results.

How relevant is infrastructure to growth?

Table 4 compares estimation results of the augmented Solow model accounting for human capital exclusively (our benchmark model) with the augmented model including infrastructure variables. As explained in Section 3, our dataset suffers from missing observations; additionally, each infrastructure variable has different missing observations. In order to address this problem, we estimated the benchmark and infrastructure models using five sets of observations corresponding to the five infrastructure subsectors. This allowed us to compute the fraction of the total variance explained by each infrastructure variable, separately. It also allowed us to show the size of the bias of the estimates for the models that did not include the infrastructure variables.

All the infrastructure variables significantly affect GDP per capita, after controlling for education and total investment[19]. The adjusted R^2 also tells us that growth can be better explained when infrastructure is included in the model; indeed, the adjusted R^2 increases in all cases. The magnitude of increase is greatest for telecoms and electricity, with these two infrastructure subsectors explaining 54% and 53%, respectively, of the total variance after accounting for the contribution of education and total investment to growth. Among the other infrastructure

[19] As a robustness check of the estimation results we computed the standard errors using the bootstrapping technique with replacement and 100 replications. Results, available upon request, do not change qualitatively and confirm the significance of the estimated parameters.

subsectors, sanitation explained 31%, water 17% and roads 14%, of the variance in growth over and above the benchmark model.

Table 4: Augmented Solow model with infrastructure variables

	Telecoms		Electricity		Roads		Sanitation		Water	
	Bench	Infrast	Bench	Infrast	Bench	Infrast	Bench	Infrast	Bench	Infrast
Education	1.24	−.31	2.49	−.04	.73	.38	1.23	.28	1.02	.31
t-stat	3.65	−1.35	4.14	−.16	1.40	.92	2.73	.63	2.21	.62
Elast(β)	1.24	.00	2.49	.00	.73	.00	1.23	.00	1.02	.00
Total Invst	.03	−.83	.36	−.35	.72	.43	−.39	−.22	−.11	−.67
t-stat	.08	−3.64	.61	−1.72	1.40	.89	−.65	−.46	−.16	−1.08
Elast(α)	.00	−4.88	.00	.00	.00	.00	.00	.00	.00	.00
Infrast		.94		1.04		.55		1.72		2.53
t-stat		10.39		12.72		2.53		3.64		2.57
Elast (γ)		5.50		1.04		.55		1.72		2.53
R^2	.29	.83	.41	.94	.24	.38	.20	.51	.14	.31
No. Obs	42	42	23	23	28	28	23	23	25	25

Note: This Table shows the human capital augmented Solow models (denoted by Benchmark) and the infrastructure and human capital augmented Solow models (denoted by Infrast). Constants are not reported. In order to compare the Benchmark and the Infrast and avoid the effect of missing observations, Bechmark is estimated for the 5 different set of observations (each infrastructure variable has different missing observations). Total Invst stands for Total Investment minus population growth minus depreciation. Infrast stands for the infrastructure variable. Elast stands for the implied estimated elasticities of the economic model. Parameters are estimated by pooled OLS and standard errors estimators are heteroskedastic-consistent. R^2 stands for the adjusted goodness of fit.

Education has a positive and significant impact on growth across all subsectors in the benchmark model. However, education loses significance across all models once we include the infrastructure variables, implying that the omission of these infrastructure variables biases upward the impact of education on growth. Also noteworthy is the fact that total investment seems statistically unrelated to growth in the electricity, roads, sanitation and water subsectors (for both the benchmark and infrastructure models). It gains significance only when telecom is incorporated in the regression model, although somewhat counter-intuitively, it is then negatively associated with growth. In other words, Table 4 suggests that when considered alongside telecom infrastructure (which has a significant and positive impact on growth), non-telecom investments are negatively associated with growth. A possible reason for this finding could be that the configuration of telecom infrastructure and non-telecom investments is sub-optimal. To the extent that key infrastructure services, such as transport, energy and telecom, enter as complementary inputs in production and/or consumption processes, a bottleneck and negative elasticities may arise if one or more of these complementary inputs is (are) under-provided.

An important policy implication that emerges from Table 4 is that infrastructure subsectors across the board have a positive and significant impact on growth in East Asia, and are shown to be statistically significant engines of growth. Notably, education loses relevance to growth once infrastructure is taken into account. The mechanics underlying the relationship between education and infrastructure would clearly be of interest to policy makers, and as such call for further research.

While Table 4 shows that infrastructure matters to East Asia's growth, it does not specify whether the relationship is affected by the countries' institutional or physical endowments. This sub-section and those that follow incorporate the five "variables of interest" discussed above in the infrastructure model. Doing so allows us to comment on how the relevance of infrastructure to growth is affected by explicitly accounting for each of these variables.

Quality of governance

Good governance tends to be associated with better provision of infrastructure services. It acts by reducing corruption and incentives of political actors to capture monopoly rents, increasing transparency of public and private transactions and regulatory structures while guaranteeing investors an adequate rate of return and protecting them from arbitrary action by government, improving a country's business environment, as well as protecting consumers from abuse by firms with substantial market power (Lovei and McKechnie, 2000; Jacobs, 2004; World Development Report, 2005; Globerman and Shapiro, 2002), thereby creating favorable conditions for economic growth (Kaufmann and Kraay, 2002; Mauro, 1995; Kaufmann, Kraay and Zoido-Lobaton, 1999. Poor governance and corruption on the other hand, whether through grand corruption in the allocation of lucrative monopolies, or petty corruption in meter reading and billing contributes to weak operational and financial performance and, for the poor in particular, declining service quality or reduced chances of ever accessing network services (Lovei and McKechnie, 2000). We therefore expect to find evidence of differential impact of infrastructure investments on a country's growth depending upon its quality of governance.

In order to test for the relevance of this dimension, we include a dummy variable in the model to account for differences between high, medium and low quality of governance. Table 5 displays the estimation results of the augmented Solow model. In three of the five infrastructure subsectors (telecom, electricity and sanitation), investments in infrastructure have a significantly higher payoff in countries with high quality of governance than in countries with medium or low quality of governance. The results are particularly striking for sanitation with the elasticity of GDP with respect to sanitation climbing from 0.90 in low and medium governance settings to 1.38 in high governance settings. In telecom and electricity, elasticity figures rise from 0.60 and 0.63 in low and medium governance settings to 0.83 and 0.75 in high governance settings respectively.

Table 5: Augmented Solow model with infrastructure variables and the effect of the quality of governance: low, medium or high quality governance

	Telecoms		Electricity		Roads		Sanitation		Water	
	Bench	Infrast	Bench	Infrast	Bench	Infrast	Bench	Infrast	Bench	Infrast
Education	1.24	−0.18	2.49	0.26	0.73	0.15	1.23	0.09	1.02	−0.02
t-stat	3.65	−1.03	4.14	0.85	1.40	0.55	2.73	0.33	2.21	−0.05
Elast(β)	1.24	0.00	2.49	0.00	0.73	0.00	1.23	0.00	1.02	0.00
Total Invst	0.03	−0.54	0.36	−0.15	0.72	0.01	−0.39	0.05	−0.11	−0.15
t-stat	0.08	−3.06	0.61	−0.78	1.40	0.01	−0.65	0.16	−0.16	−0.38
Elast(α)	0.00	−1.17	0.00	0.00	0.00	0.45	0.00	0.00	0.00	0.00
Low										
Infrast		0.60		0.63		0.35		0.90		1.04
t-stat		6.48		3.53		2.33		2.80		1.65
Elast (γ)		1.30		0.63		0.35		0.90		.00
Medium										
Infrast		0.60		0.63		0.35		0.90		1.04
t-stat		6.48		3.53		2.33		2.80		1.65
Elast (γ)		1.30		0.63		0.35		0.90		0.00
High										
Infrast		0.83		0.75		0.03		1.38		0.55
t-stat		5.28		2.58		−4.77		6.13		6.54
Elast (γ)		1.80		0.75		0.03		1.38		0.55
R^2	0.29	0.90	0.41	0.95	0.24	0.72	0.20	0.84	0.14	0.77
No. Obs	42	42	23	23	28	28	23	23	25	25
Difference		YES		YES		YES		YES		YES

Somewhat counter-intuitively, the elasticity of GDP with respect to roads decreases from 0.35 in countries with low and medium governance to 0.03 in countries with high governance quality. This interpretation must however be treated with caution since there is a risk of encountering an omitted variable bias in comparing the results across countries with different levels of governance. For instance, there could be a variable correlated with high quality of governance such as better air transportation, which could potentially decrease the sensitivity of GDP to road infrastructure. Note that in this table and in those that follow, when the coefficients for the dummies are not significant (i.e. when there are no differences with respect to the coefficients associated with different levels of the variable of interest, such as “low” and “medium” quality of governance), we leave identical coefficients and t-values.

Private participation in infrastructure

PPI can expand access and quality of infrastructure services, with attendant increases in labor and service productivity (Ramamurti, 1996; Agénor and Moreno-Dodson, 2006; ILO, 2002), support efficiency improvements and deployment of new technology in utilities, introduce alternative mechanisms to finance infrastructure and free scare resources to channel towards growth and other development policy priorities (Besant-Jones, 2006; ADB, JBIC, World Bank, 2005; Harris, 2003) – all of which may positively impact growth. We therefore expect to find evidence of differential impact of infrastructure investments on a country's growth depending upon prevalence of PPI. In this paper, the dummy variable "private" summarizes the information on the timing of private participation in specific infrastructure subsectors in a country. The variable takes the value 0 before the first year of private entry and the value 1 from that year on. Overall, private investors have invested approximately US$ 224 billion since 1990 (World Bank PPI Database) in East Asia's infrastructure subsectors across 18 countries[20].

Table 6: Augmented Solow model with infrastructure variables and the effect of privatization

	Telecoms		Electricity		Roads		Sanitation		Water	
	Bench	Infrast	Bench	Infrast	Bench	Infrast	Bench	Infrast	Bench	Infrast
Education	1.24	.53	2.49	.26	.73	.55	1.23	.33	1.02	.37
t-stat	3.65	1.68	4.14	1.17	1.40	1.33	2.73	.83	2.21	.79
Elast(β)	1.24	.00	2.49	.00	.73	.00	1.23	.00	1.02	.00
Total Invst	.03	.62	.36	−.07	.72	1.08	−.39	−.20	−.11	−.70
t-stat	.08	2.99	.61	−.53	1.40	2.85	−.65	−.75	−.16	−1.27
Elast(α)	.00	.38	.00	.00	.00	.52	.00	.00	.00	.00
No private										
Infrast		.29		.99		.13		1.59		2.16
t-stat		1.89		12.29		.92		3.96		2.62
Elast (γ)		.18		.99		.00		1.59		2.16
Private										
Infrast		.48		.99		.13		1.75		2.16
t-stat		2.17		12.29		.92		1.86		2.62
Elast (γ)		.30		.99		.00		1.75		2.16
R^2	.29	.57	.41	.93	.24	.33	.20	.58	.14	.33
No. Obs	42	42	23	23	28	28	23	23	25	25
Difference		YES		NO		NO		YES*		NO

Note: "*" means result significant only at 10% probability level.

Table 6 shows that PPI, when measured as a dummy variable, did not influence East Asia's growth, except for telecom and sanitation infrastructure. Specifically, the elasticity of GDP with

[20] Electricity, roads, water supply and sanitation, and telecom accounted, respectively, for 34%, 18%, 16% and 7% of the number of PPI projects in the region. However, the distribution of projects has been skewed across East Asian countries, with over 77% of water and sanitation, 68% of roads, and 42% of electricity projects located in China alone.

respect to telecom investments increased from 0.29 in countries without private participation in telecom to 0.48 in countries where private participation was allowed in the telecom sector. Similar results were obtained for sanitation, albeit at a lower level of significance. However, there seems to be no impact of PPI in the other three sectors, despite a relatively large proportion of PPI projects devoted to these subsectors.

Income level

Countries with higher income levels have better rates of access to infrastructure services. Moreover, rich countries have higher levels of accumulated capital stock and savings rates (Cass, 1965; Koopmans, 1965), technology (Romer, 1986), and human capital (Lucas, 1988) to channel towards better provision of infrastructure services. Additionally, richer countries tend use resources spent on infrastructure more effectively (Hulten, 1996) to deliver better infrastructure service quality (Calderon and Serven, 2004) that is closely related to higher competitiveness (Global Competitiveness Report, various years) and higher rates of economic growth. Based on this intuition, we investigate whether the contribution of infrastructure to growth is systematically greater in richer countries than in poorer ones. We therefore expect to find evidence of differential impact of infrastructure investments on a country's growth depending upon countries' income levels.

Table 7 shows that an increase in countries' income levels (i.e., from low to medium to high levels) is associated with a greater positive and significant impact of telecom, sanitation and water infrastructure on growth. Specifically, the elasticity of per capita GDP with respect to telecom increases from 0.37 for low-income countries to 0.54 in medium incomes countries and 0.91 in high-income countries. Similar results are obtained for sanitation. There was no significant growth effect associated with water infrastructure in low-income countries. However, the growth effect of water infrastructure differed between medium and high income countries, with an elasticity of growth with respect to water of 0.94 in high income countries, more than four times time higher than the elasticity in medium income countries (0.23). The policy implication emerging from these results is that growth-related results arising from expansion of stocks of telecom and sanitation infrastructure may be expected to increase as the country's income level rises. In the water sector however, it appears that a certain threshold of income needs to be crossed (i.e., the transition from low to medium income) before the benefits of increasing water sector infrastructure begin to increase as the country's income level rises further.

However, the elasticity of GDP with respect to roads is higher in poor countries (0.29) than in medium income countries (0.15), which in turn is higher than in high-income level countries (-2.6). One possible reason could lie in the definition of the variable as kilometers of paved roads per capita. This means that roads that are not paved (see the Appendix for the precise meaning of "paved") are not taken into account. Poor countries have the lowest volume of paved roads per capita. In these countries with a limited supply of paved roads, the marginal contribution of a km of paved road to growth can be expected to be higher than in countries with a denser network of paved roads. Additionally, as discussed in the interpretation of the Governance model (Table 5), this result could perhaps be explained by an omitted variable bias: the widespread use of alternative modes of transportation such as air transport as countries' income level rises is not considered in our analysis and such alternative modes could potentially decrease the sensitivity of GDP to roads infrastructure in richer countries. Finally, while electricity is associated with a positive and significant influence on growth in East Asia, its impact does not differ by countries' income levels.

Table 7: Augmented Solow model with infrastructure variables and the effect of the income level: low, medium or high-income countries

	Telecoms		Electricity		Roads		Sanitation		Water	
	Bench	Infrast	Bench	Infrast	Bench	Infrast	Bench	Infrast	Bench	Infrast
Education	1.24	−.17	2.49	.00	.73	−.09	1.23	−.10	1.02	.09
t-stat	3.65	−1.18	4.14	−.01	1.40	−.39	2.73	.07	2.21	.38
Elast(β)	1.24	.00	2.49	.00	.73	.00	1.23	.00	1.02	.00
Total Invst	.03	−.40	.36	−.22	.72	.12	−.39	.02	−.11	.03
t-stat	.08	−2.73	.61	−1.01	1.40	.46	−.65	.07	−.16	.11
Elast(α)	.00	−.67	.00	.00	.00	.00	.00	.00	.00	.00
Low										
Infrast		.37		.89		.29		.68		−.12
t-stat		4.15		4.07		2.47		2.50		−.21
Elast (γ)		.62		.89		.29		.68		.00
Medium										
Infrast		.54		.89		.15		.86		.23
t-stat		4.29		4.07		−3.96		3.00		3.60
Elast (γ)		.90		.89		.15		.86		.23
High										
Infrast		.91		.89		−.26		1.46		.94
t-stat		7.80		4.07		−8.39		7.58		8.53
Elast (γ)		1.52		.89		−.26		1.46		.94
R^2	.29	.93	.41	.94	.24	.84	.20	.88	.14	.85
No. Obs	42	42	23	23	28	28	23	23	25	25
Difference		YES		NO		YES		YES		YES

Inequality in access to infrastructure

A priori, one could argue that greater inequality of access to infrastructure services would lead to lower growth by systematically excluding groups of individuals who, with better access to infrastructure, could have made a greater contribution to growth. Indeed, several studies have argued that access to infrastructure services helps poorer individuals and underdeveloped areas to get connected to core economic activities, allowing them to access additional productive opportunities (Estache, 2003), enhancing their human capital and therefore income prospects (Leipziger, Fay and Yepes, 2003), as well as reducing production and transaction costs (Gannon and Liu, 1997). Together, these benefits of equitable access to infrastructure services play a key role in helping reduce income inequality (Calderon and Serven, 2004; Estache, Foster and Wodon, 2002; Lopez, 2004), with its positive impact on economic growth (Alesina and Rodrick, 1994; Alesina and Perotti, 1996; Galor and Zeira, 1993). We therefore expect to find evidence of differential impact of infrastructure investments on a country’s growth depending upon inequality in access to infrastructure services. We use a derived index of rural-urban inequality in access to infrastructure to test this hypothesis (see details of how the index was constructed in the Appendix).

Table 8 summarizes the estimation results, which partially support our hypothesis. There seems to be some inequality effect in the impact of telecom infrastructure on growth. Comparing elasticities of growth with respect to telecom, the figure for medium access inequality is somewhat higher (1.15) than that for high access inequality (1.05); there is no difference in telecom’s impact on growth between countries with low- and medium access inequality to telecom infrastructure. Similar results are obtained for sanitation, with a reduction in elasticity from 1.32 in environments of low and medium access inequality to 1.09 in high inequality settings, albeit at a weaker level of significance.

Table 8: Augmented Solow model with infrastructure variables and the effect of the level of inequality: low, medium or high inequality

	Telecoms		Electricity		Roads		Sanitation		Water	
	Bench	Infrast	Bench	Infrast	Bench	Infrast	Bench	Infrast	Bench	Infrast
Education	1.38	−.52	1.82	−2.25	−	−	1.25	.50	1.01	.21
t-stat	3.27	−2.18	1.61	−1.64	−	−	2.48	1.13	1.85	.34
Elast(β)	1.38	−3.25	.00	.00	−	−	1.25	.00	.00	.00
Total Invst	−.11	−.84	−.22	.50	−	−	−.27	−.14	.02	−.12
t-stat	−.23	−4.15	−.25	.65	−	−	−.42	−.30	.03	−.14
Elast(α)	.00	−5.25	.00	.00	−	−	.00	.00	.00	.00
Low										
Infrast		1.15		2.64		−		1.32		1.51
t-stat		11.56		2.81		−		2.39		.73
Elast (γ)		7.19		2.64		−		1.32		.00
Medium										
Infrast		1.15		2.64		−		1.32		1.51
t-stat		11.56		2.81		−		2.39		.73
Elast (γ)		7.19		2.64		−		1.32		.00
High										
Infrast		1.05		2.16		−		1.09		1.51
t-stat		−2.28		−2.37		−		−1.85		.73
Elast (γ)		6.56		2.16		−		1.09		.00
R^2	.24	.88	.13	.92	−	−	.19	.58	.11	.35
No. Obs	34	34	9	9	−	−	20	20	21	21
Difference		YES		YES		−		YES*		NO

Note: "*" means result significant only at 10% probability level.

In the case of electricity, results do suggest that growth is lower in countries with high inequality, than in countries with medium inequality. However, such a result should be interpreted with extreme caution, since only 9 observations were available on rural and urban access to electricity; moreover, the adjusted R^2 in the benchmark model is very low. There is no inequality effect in the impact of water on growth. Finally, we were not able to obtain regression estimates for roads infrastructure owing to the lack of data on rural and urban access to roads (see details of how the index was constructed in the Appendix).

The effect of geography – Pacific Island vs. non-island countries

The goal here was to investigate whether infrastructure provision in Pacific Island countries (PICs) was predisposed to yield systematically different results than could be expected in non-PIC settings. This exercise did not yield any significant findings. The results obtained suggest that a country's geographic status in East Asia measured as a dummy variable did not significantly influence its growth. A part of these results may be attributed to the severe limitations in the data underlying this specification. Although there are 9 PICs in the region, we included only Fiji, Tonga and Vanuatu in the dataset constructed for this study due to severe missing data problems encountered in the remaining PICs on a number of variables. Additionally, the electricity subsector could not be analyzed for lack of data on electricity for the PICs included in the sample.

5. Conclusions

Overall, the results of our analysis indicate that greater stocks of infrastructure were indeed associated with higher growth, proxied by GDP per capita, in East Asia over the interval 1985-2004 (benchmark model, Table 4). Moreover, consistently higher R^2 values suggest that growth can be better explained when infrastructure is included in the model. The magnitude of the increase in R^2 values is greatest in the telecom and electricity sectors.

In order to anchor this analysis in the context of ongoing policy debates, we attempt to provide for additional insights on the importance of infrastructure sub-sectors to growth depending on the degree of private participation in infrastructure (PPI), quality of governance, extent of rural-urban inequality in access to infrastructure services, country income levels, as well as geography. Among the various infrastructure sub-sectors, telecom and sanitation are those that conform most closely to our a priori hypotheses. For example, a given level of telecom and sanitation infrastructure may be expected to provide a greater boost to growth in East Asian countries with better governance, low inequality in access to infrastructure and higher income levels. Electricity and water infrastructure yield mixed results, while the impact of roads on GDP per capita consistently contradicts a priori expectations, for e.g., the impact of roads infrastructure on per capita growth decreases as the quality of governance improves. Taken together, our analysis indicates that while infrastructure matters to growth across the board, a more nuanced look at the sensitivity of growth to various institutional and physical endowments can yield starkly differing results, with some sectors supporting conventional expectations and others yielding mixed or counter-intuitive results.

Among the additional variables of interest, the quality of governance and country income level, by and large, consistently influence the sensitivity of growth to the level of infrastructure stocks. Better governance (country income level) seems to engender a greater impact of telecom, electricity and sanitation (telecom, sanitation and water) infrastructure on growth. Greater inequality in access to infrastructure for its part dampens the growth-related impact of infrastructure in the telecom sector. Similar results were found for water, albeit at a lower level of significance. While the same was observed for electricity, the very small number of observations compromises the reliability of the result. PPI in the telecom and sanitation sub-sectors had a high payoff in terms of growth. PPI in electricity and water on the other hand did not have any specific affect on growth. The result in the case of roads was not statistically significant. Finally, our analysis found no evidence suggesting that infrastructure provision in PICs was predisposed to yield systematically different results than could be expected in non-PIC settings.

Overall, our results are consistent with the widely-accepted idea in policy research that infrastructure plays an important role in promoting growth, as well as with the viewpoint that certain countries' endowments influence the growth-related impacts of infrastructure. These findings suggest that leveraging the benefits of infrastructure investments may be contingent on an optimal configuration of various factors, rather than on the undertaking of infrastructure investments in isolation. However, the results should be regarded as indicative and more analysis needs to be undertaken before translating these results into policy priorities.

It is instructive to compare these indicative results from our East Asia sample to those that were obtained, using the same methodological framework, in the context of Sub-Saharan Africa (Estache et al, 2005). Two specifications – the benchmark model and the model examining the impact of private participation in infrastructure on infrastructure's impact on growth – are common across the Sub-Saharan Africa and East Asia analyses[21]. As in East Asia, infrastructure significantly effects growth across various infrastructure sectors in Sub-Saharan Africa. In Sub-Saharan Africa the impact is largest for telecom, electricity and roads; it appears inexistent for sanitation however. In East Asia, as we have seen, the impact of telecom and electricity is large also, but the impact of roads is low while that of sanitation is significant. Private participation in infrastructure, on the other hand, did not matter at all to Sub-Saharan Africa's growth. Estache et al (2005) attribute this finding to the fact that little private investment took place in Africa's infrastructure, and that when it did take place it was highly concentrated. Consequently, the contribution of the private sector to growth was not sufficient to make any difference. In the East Asian sample, there was some evidence that growth-related benefits of infrastructure were significantly higher when PPI was adopted in telecom and, to a lesser extent, in sanitation.

[21] Other variables of interest in Estache et al (2005) were the legal inheritance of a country (i.e., whether or not a country was a former British colony), and geography (i.e., whether a country was a coastal or land-locked country).

In terms of empirical analysis, the Sub-Saharan Africa study may stand on firmer ground given the larger sample size with numbers of observations across specifications ranging from 83 to 176, compared to a corresponding range of 9 to 42 in East Asia. As mentioned earlier, our analysis tells a preliminary story about the comparative influence of infrastructure sectors on per capita growth across East Asian countries, and in different institutional and physical settings. Clearly, more detailed and better quality data would be useful to further test and confirm this preliminary story. Finally, as already pointed out, country-specific assessments are required to formulate country-specific policy priorities.

Table 9. How Relevant Is Infrastructure to Growth in East Asia: Summary of Results

	Telecom	Electricity	Roads	Sanitation	Water
Benchmark model – impact of infrastructure on growth	Hypothesis supported. Higher infrastructure stocks associated with significant growth in GDP per capita (GDPpc), after controlling for education and total investment. Consistently higher R^2 indicates that growth can be better explained when infrastructure is included in the model.				
Quality of governance	Hypo supported. Better the governance, greater the elasticity of GDPpc with respect to telecom.	Hypo supported. Better the governance, greater the elasticity of GDPpc with respect to electricity.	Hypothesis not supported. Better the governance, lower the elasticity of GDPpc with respect to roads.	Hypo supported. Better the governance, greater the elasticity of GDPpc with respect to sanitation.	Hypothesis not supported. Better the governance, lower the elasticity of GDPpc with respect to water.
Privatization	Hypo supported. Greater elasticity of GDPpc with respect to telecom when PPI in telecom (compared to no PPI).	Hypothesis not supported.	Results not significant.	Hypo supported. Greater elasticity of GDPpc with respect to sanitation when PPI in sanitation (compared to no PPI).	Hypothesis not supported.
Income level	Hypo supported. Greater the income level, greater the elasticity of GDPpc with respect to telecom.	Hypothesis not supported.	Hypothesis not supported. Greater the income level, lower the elasticity of GDPpc with respect to roads.	Hypo supported. Greater the income level, greater the elasticity of GDPpc with respect to sanitation.	Hypo supported. Greater the income level, greater the elasticity of GDPpc with respect to water.
Level of inequality of access to infrastructure	Hypo supported. Greater the level of inequality, lower elasticity of GDPpc with respect to telecom.	Hypo supported. Greater the level of inequality, lower elasticity of GDPpc with respect to electricity; *BUT only 9 observations.*	Data not available to analyze model.	Hypo supported. Greater the level of inequality, lower elasticity of GDPpc with respect to sanitation; *BUT result weakly significant.*	Result not significant.
Island vs. non-island	Hypothesis not supported. No significant impact of country's geography on the relationship between infrastructure and growth. Additionally, no analysis could be carried out for electricity due to lack of data.				
Overall	By and large, telecom found to have impact on infrastructure, supporting hypotheses - i.e., telecom infrastructure expected to have most impact on growth in countries with better governance, PPI in telecom, higher income level, and low levels of inequality of infra access.	Results indicate that better governance engenders higher growth-related benefits of electricity infrastructure. Other hypotheses not supported; poor data quality.	Results consistently contrary to hypotheses - i.e., better governance and higher income associated with lower impact of roads infrastructure on growth. Poor data quality.	By and large, sanitation found to have impact on infrastructure, supporting hypotheses – i.e., sanitation infrastructure expected to have most impact on growth in countries with better governance, PPI in sanitation, higher income level, and low levels of inequality of infra access.	Results indicate that greater income level engenders higher growth-related benefits of water infrastructure. Other hypotheses not supported; or result not significant.

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Appendix. Definitions of Variables Used in Analysis, Data Sources and Coverage

Annual data, time interval: 1985 – 2004

Countries included in the analysis: Australia, Cambodia, China, Fiji, Indonesia, South Korea, Laos, Malaysia, Mongolia, Papua New Guinea, Philippines, Singapore, Thailand, Tonga, Vanuatu, Vietnam.

Dependent variable – Growth: GDP per capita (constant 2000 US$). GDP per capita is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in constant U.S. dollars.

Source: World Development Indicators

Independent variables – Infrastructure stocks. We consider five measures of infrastructure that reflect 5 key sectors. For each of the 5 infrastructure sectors, we consider the following proxies:

(i) Telecommunications:

   a. Telephone mainlines (per 1,000 people). Telephone mainlines are telephone lines connecting a customer's equipment to the public switched telephone network. Data are presented per 1,000 people for the entire country;
   b. Mobile subscribers (per 1,000 people). Mobile telephone subscribers are subscribers to a public mobile telephone service using cellular technology. Data are presented per 1,000 people for the entire country.

(ii) Electricity: Electric power consumption per capita (kwh) measures the production of power plants and combined heat and power plants less transmission, distribution, and transformation losses and own use by heat and power plants plus imports less, per capita;

(iii) Roads: Roads, paved (kilometers of paved roads per capita). Paved roads are those surfaced with crushed stone (macadam) and hydrocarbon binder or bituminized agents, with concrete, or with cobblestones;

(iv) Water: Improved water source (% of population with access). Access to an improved water source refers to the percentage of the population with reasonable access to an adequate amount of water from an improved source, such as a household connection, public standpipe, borehole, protected well or spring, and rainwater collection. Unimproved sources include vendors, tanker trucks, and unprotected wells and springs. Reasonable access is defined as the availability of at least 20 liters a person a day from a source within one kilometer of the dwelling;

(v) Sanitation: Improved sanitation facilities (% of population with access). Access to improved sanitation facilities refers to the percentage of the population with at least adequate excreta disposal facilities (private or shared, but not public) that can effectively prevent human, animal, and insect contact with excreta. Improved facilities range from simple but protected pit latrines to flush toilets with a sewerage connection. To be effective, facilities must be correctly constructed and properly maintained.

Source: World Development Indicators

Control variables. As discussed in the econometric model developed above, we control for the level of investment and of human capital

(i) Gross fixed capital formation (% of GDP): Gross fixed capital formation (formerly gross domestic fixed investment) includes land improvements (fences, ditches, drains, and so on); plant, machinery, and equipment purchases; and the construction of roads, railways, and the like, including schools, offices, hospitals, private residential dwellings, and commercial and industrial buildings. According to the 1993 SNA, net acquisitions of valuables are also considered capital formation.

(ii) School enrolment, secondary (% gross): Gross enrollment ratio is the ratio of total enrollment, regardless of age, to the population of the age group that officially corresponds to the level of education shown. Secondary education completes the provision of basic education that began at the primary level, and aims at laying the foundations for lifelong learning and human development, by offering more subject- or skill-oriented instruction using more specialized teachers.

Source: World Development Indicators

Natural logarithms are taken for both infrastructure and control variables.

Additional variables. A number of additional variables of interest are incorporated into the econometric model as dummy variables:

(i) Quality of governance. Data for the 6 proposed indicators available from the Governance Indicators database on the quality of governance are available for a short time span (1996-2004, one observation for each 2 years). Therefore, we aggregated all the information contained in such indicators in 2 dummies representing medium quality of governance and high quality of governance. Since the governance indicators range from −2.5 to 2.5, with higher values corresponding to better governance outcome, we classified countries as having low quality of governance when the largest part of the indicators is strictly negative; medium quality whenever the indicators are all (or almost all) about 0; and high quality when they are strictly positive. Accordingly, we classified countries by quality of governance into the following categories:

- Low quality – Cambodia, China, Indonesia, Laos, Papua NG, Philippines, Tonga, Vanuatu, Vietnam;
- Medium quality – Fiji, Mongolia, Thailand;
- High quality – Australia, South Korea, Malaysia, Singapore.

Source: Governance Indicators by D. Kaufmann, A. Kraay and M. Mastruzzi, The World Bank. http://info.worldbank.org/governance/kkz2005/

(ii) Private participation in infrastructure. For each infrastructure equation a dummy variable is added, which takes values 1 from the time at which at least one private project in infrastructure (in telecom, roads, electricity and water supply) is closed, 0 otherwise. Since there are no data about the number of private sanitation projects closed, the same dummy as for water is used.

Source: Private Participation in Infrastructure (PPI) Database, The World Bank. http://ppi.worldbank.org.

(iii) Income level. We classified the countries analyzed into three income groups using standard World Bank norms, i.e., low income countries (with Gross National Income per capita lower than US$825), medium income countries (with Gross National Income per capita between US$825 and US$3255), and high income countries (with Gross National Income per capita greater than US$3256). We constructed two dummy variables for this purpose – one for medium income level and one for high. The medium (high) income dummy variable takes the value 1 in correspondence to medium (high) income countries, 0 otherwise. Accordingly, we classified countries by level of income into the following categories:

Low income – Cambodia, Indonesia, Laos, Mongolia, Papua NG, Vietnam;
Medium income – China, Fiji, Philippines, Thailand, Tonga, Vanuatu;
High income – Australia, South Korea, Malaysia, Singapore.

Source: Inequality indices derived from data available on World Development Indicators

(iv) Inequality in infrastructure. In order to classify countries by level of inequality in infrastructure, we devised an inequality criterion based on a derived inequality index ineqit.

The derived inequality index was calculated assuming that rural and urban populations have the same infrastructure needs. In order to address missing data problems, and be consistent with the other infrastructure analysis, we assigned dummies to reflect the degree of infrastructure inequality. These dummy variables for infrastructure inequality were constructed as follows:

- For telecom, the derived inequality index ineqit is computed as the difference between the percentage of urban main lines and the percentage of population that is urban. If the difference is positive, then we conclude that there is inequality in favour of the urban population. On the other hand, if the difference is negative, we conclude that there is inequality in favour of rural.

Low inequality: |ineqtel | =<15
Medium inequality: 15 < |ineqtel | =< 35
High inequality: |ineqtel | > 35

- For water (sanitation), we first constructed the variable "share of urban population as % of total population with access to improved water source (sanitation)". In order to construct this variable, we simply multiplied the urban population by the percentage of urban population with access to improved water source (sanitation) and divided this product by total population times percentage of population with access to improved water source (sanitation). We then multiplied this by 100 to obtain the percentage of urban population with access to improved water source (sanitation). Following this, we constructed the inequality index for water (sanitation) in a manner similar to telecom infrastructure explained above.

Water
Low inequality: |ineqwat | <=5
Medium inequality: 5 < |ineqwat | <= 10

High inequality: |ineqwat | > 10

Sanitation

Low inequality: |ineqsan | <= 5

Medium inequality: 5 < |ineqsan | <= 10

High inequality: |ineqsan | > 10

- For electricity we considered the relative difference between the population with electricity (Pw) and without electricity (Pwo) by using the simple algorithm:

$$\frac{Pw - Pwo}{Pw}$$

In order to be consistent with the other infrastructure analysis, we constructed dummy variables defined as:

Low inequality: 0.90 ≤ |ineq t|≤ 1

Medium inequality: 0.70 ≤|ineq t|< 0.90

High inequality: |ineqtt| < 0.70

(v) The impact of geography – PACs vs. non island countries. For each country in the dataset, we added a geography dummy which takes the value 1 if it is a PIC, and 0 otherwise. Island countries in the sample are Fiji, Tonga, Vanuatu.