

The Penalties of Inefficient Infrastructure

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Abstract

In most developing countries, irrigation, road, and power networks are not in good condition. In Latin America, for example, the effectiveness of such public infrastructure is only about 74% of that of industrialized countries. Low effectiveness imposes a cost on these countries in terms of forgone output. This paper develops a general-equilibrium model to study the long-run consequences of ineffective infrastructure. The model is solved numerically using parameters from seven Latin American countries. Results show that the long run penalty of ineffective infrastructure is about 40% of steady-state real GDP per capita. Raising effectiveness is shown to have sizable positive effects on income per capita, private investment, consumption, and welfare. Nevertheless, policymakers instead usually emphasize building new infrastructure. If effectiveness is low in the existing infrastructure network, new infrastructure investments can negatively affect per-capita income, private investment, consumption, and welfare.

1. Introduction

It is commonly agreed that a country's public infrastructure network (e.g., roads and water systems) is one of the foundations of economic activity. Cross-country empirical studies have generally found that public infrastructure has positive effects on a country's productive performance (e.g., Easterly and Rebelo, 1993; Canning and Fay, 1993; Canning, 1999). One of the implications from these results is that developing countries need additional public investment in order to grow. However, a considerable amount of resources has already been spent in new public infrastructure projects, which nevertheless have not served their purpose very effectively. The *World Development Report 1994* estimates that irrigation, road, and telecommunications networks in developing countries are not in good condition. An inefficient infrastructure network is costly to a country in terms of loss of potential output. This paper address the following questions:

1. How effective is infrastructure in Latin American countries?
2. What is the penalty, in terms of real gross domestic product (GDP) per capita, paid by these countries for not using their infrastructure as effectively as industrial countries?
3. How productive are new public investments, called for by most policymakers, when effectiveness is low?

Results show that these seven Latin American countries pay a long-run penalty for ineffectiveness of about 40% of steady-state real GDP per capita. In addition, the model shows that raising effectiveness has sizable positive effects on private investment, consumption, and welfare. Nevertheless, policymakers usually place a higher priority in getting new infrastructure built. This paper shows that the productivity of such new infrastructure critically depends on the level of effectiveness of the existing

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Table 1. Infrastructure Loss Indicators

	<i>Power</i> ^a	<i>Telecom.</i> ^b	<i>Paved roads</i> ^c	<i>Water</i> ^d
<i>Latin America:</i>				
Argentina	20	78	65	n/a
Brazil	14	4	70	30
Chile	22	6	58	n/a
Colombia	19	97	58	38
Mexico	13	n/a	15	n/a
Peru	18	n/a	76	n/a
Venezuela	18	6	60	n/a
<i>Industrialized countries:</i>				
USA	9	n/a	n/a	n/a
Germany	5	n/a	n/a	n/a
France	6	10	n/a	n/a
UK	8	16	n/a	n/a
Singapore	n/a	n/a	n/a	8

^aSystem losses (% of total output) 1990.

^bFaults (per 100 mainlines per year) 1990.

^cPercentage of roads not in good condition 1988.

^dLosses (% of total water provision) 1990.

Source: *World Development Report 1994*.

infrastructure network. In fact, new investments can have *negative* effects on the economy at very low levels of effectiveness.

While there are a number of studies on public infrastructure as a whole, the issue of the effectiveness of these networks has not received a lot of attention in the literature.¹ One notable exception is a paper by Hulten (1996). Using the World Bank's data for 42 low- and middle-income countries, he finds that the effectiveness of public infrastructure can partially explain differences in countries' growth rates. In this paper, I develop a micro-foundations general-equilibrium model that is consistent with Hulten's results and that can further address: (i) important dynamic interactions among macroeconomic variables, and (ii) out-of-sample infrastructure policy analysis. That is, the macroeconomic effects of various government policies regarding the effectiveness of infrastructure and the provision of new infrastructure can be evaluated. These policies are evaluated in an environment where economic agents optimize their objective function subject to constraints and policies. For example, given a policy that raises the effectiveness of infrastructure, agents in the model decide optimally on private capital investment, foreign bond holdings, work effort, and consumption. The framework is grounded on a neoclassical growth model of a small open economy where infrastructure is a publicly provided input in the production process. The model is solved numerically using historical data from seven Latin American countries.

Data compiled by the World Bank on effectiveness of several types of infrastructure provide a clear motivation to study the above issues. Table 1 lists loss indicators for power, telecommunications, paved roads, and water for Latin American countries and industrialized countries. The loss indicator for power reports the percentage of total energy output lost in the system. Latin American countries suffer about a 10% higher loss of power output than their industrialized counterparts. For telecommunications,

the indicator is the yearly number of telephone line faults per 100 mainlines. Compare 78 yearly faults per 100 mainlines in Argentina to only 16 in the UK. The loss indicator for paved roads is the percentage of the road network not in good condition, and for water systems it is the percentage of total water provided that is lost. Compare the 8% loss of water in Singapore to 38% in Colombia. Despite some indicators not being available (n/a) for certain countries, the contrast between the two groups is clear. Latin American infrastructure is clearly not effectively delivering the outputs it was designed for, and this is the case in most developing countries. This paper quantifies the long-run consequences of this neglect and the potential benefits of government policies raising effectiveness and/or increasing public investment.

2. The Model

The framework builds on the equilibrium models of infrastructure developed by Barro (1990), Glomm and Ravikumar (1994), Rioja (1999) and others. The model of a small open economy has three sectors: firms, households, and a government. The government provides new public infrastructure and maintains existing infrastructure; these expenditures are financed by taxing output at a flat rate. The government is required to balance its budget constraint every period. Firms use infrastructure as an externally given input and maximize profit. Households maximize utility subject to their budget constraint. The model is fully described below.

Households

The economy is populated by a large number of identical, infinitely lived households, a large number of firms, and a government. Households have preferences over consumption and leisure streams, $\{c_t, l_t\}$, given by the utility function

$$\sum_{t=0}^{\infty} \beta^t U(c_t, l_t), \quad (1)$$

where the discount factor is $0 < \beta < 1$, and $U(\cdot)$ is an instantaneous felicity function that is assumed to display standard properties (a specific functional form is given later). The amount of labor supplied by the household is n_t , and the total amount of time available to a person is normalized to unity so that $l_t + n_t = 1$.

The household's budget constraint can be written as

$$c_t + i_t + p_t b_{t+1} \leq w_t n_t + \bar{r}_t k_t + b_t. \quad (2)$$

The left-hand side of this budget constraint describes the uses of funds. Households can spend on consumption (c_t), on investment (i_t ; they own capital), or on purchasing foreign bonds that come due next period (b_{t+1}) at price p_t . Hence, p_t denotes the price of a bond that delivers one unit of consumption next period. The right-hand side of equation (2) describes how the household earns income. The household rents capital (k_t) to the firm earning a net return of \bar{r}_t and also earns a wage rate of w_t for its effort, n_t . In addition its net holdings of foreign bonds purchased last period, b_t , come due at time t . The return on capital, \bar{r}_t , is also the world interest rate, which is given from the small open economy's point of view. In equilibrium, the return on bonds and capital has to be equal so that both assets are held; this implies $\bar{r}_{t+1} = (1/p_t) - 1 - \delta_K$.

The evolution of private capital is standard:

$$k_{t+1} = i_t + (1 - \delta_K) k_t, \quad (3)$$

where δ_K is the depreciation rate of private capital. Finally a no-Ponzi game condition, $\lim_{t \rightarrow \infty} b_t / (1 + \bar{r}_t)^t = 0$, should be imposed on the household so that, basically, it cannot continuously borrow forever.

Firms

There are three factors of production in the economy: public infrastructure, private capital, and labor.² The final good is produced according to the technology

$$Y_t = f(\hat{K}_{Gt}, K_t, N_t). \quad (4)$$

The production function f satisfies standard properties and exhibits constant returns to scale (CRTS) over private inputs so that factor payments exhaust revenues.³ Given the CRTS assumption, the production function above is characterized as the technology for only one firm that uses the economywide per-capita levels of inputs (hence the upper-case letters in equation (4)). Consequently, K_t and N_t denote the economy-wide per-capita private capital and labor, respectively. Public infrastructure, K_{Gt} , is a government-provided input in production.⁴ However, only the *effective* measure of this stock, \hat{K}_{Gt} , is useful for private production. That is:

$$\hat{K}_{Gt} = \theta_t K_{Gt}, \quad (5)$$

following Hulten (1996), where $0 < \theta_t < 1$ is an infrastructure effectiveness index. The closer θ_t is to 1, the more effective the public capital stock, and the larger the benefit that firms get. Energy losses in power generation, telephone line faults, etc. would all reduce θ_t below 1.

At each date, the firm chooses levels of Y_t , K_t , N_t so as to maximize net-of-tax profit according to

$$(1 - \tau_t)Y_t - \bar{r}_t K_t - w_t N_t. \quad (6)$$

In equation (6), τ_t is the share of GDP that the government uses for infrastructure investment and maintenance.

Government

Effectively, the government taxes output at a flat rate, τ_t (which is equivalent to taxing factor incomes at a uniform rate).⁵ Tax revenues are, in turn, used to invest in new infrastructure (I_{Gt}) and to maintain the existing infrastructure (M_t). Thus the government balances its overall budget constraint as follows:

$$I_{Gt} + M_t = \tau_t Y_t. \quad (7)$$

A portion of tax revenues equaling $\lambda_t Y_t$ is used for new infrastructure investment, while the remainder $\mu_t Y_t$ is used for maintaining infrastructure. Hence, $\tau_t = \lambda_t + \mu_t$. Raising the overall effectiveness of the public capital stock, θ_t , is costly: maintenance expenditures must be increased by raising taxes. Therefore, the share of GDP devoted to maintenance, μ_t , must increase with a higher θ_t . This is formally characterized by $\mu_t = a\theta_t$, where $a > 0$ is a parameter.

Public capital evolves according to

$$K_{Gt+1} = I_{Gt} + (1 - \delta_G)K_{Gt}, \quad (8)$$

where δ_G is the depreciation rate of public capital. Tomorrow's stock of infrastructure (K_{Gt+1}) is equal to the amount invested today (I_{Gt}) plus the surviving stock $((1 - \delta_G)K_{Gt})$.

Market Clearing and the Foreign Sector

The goods market clearing condition is

$$C_t + I_t + I_{Gt} + M_t + TB_t = Y_t, \quad (9)$$

where TB_t is the trade balance at time t . The net holdings of foreign bonds evolves as follows:

$$p_t B_{t+1} = B_t + TB_t. \quad (10)$$

In a recursive competitive equilibrium of the whole model, the allocations and prices are a result of: (a) households maximizing their utility subject to their budget constraint; (b) firms maximizing profits; (c) the government balancing its budget constraint; and (d) markets clearing.

3. Solution Procedure*Optimality Conditions*

Obtaining a closed-form solution to the problem described in the previous section is not possible because of nonlinearities. However, it is possible to implement a numerical solution. The foundations for this solution are the first-order conditions of the system:

$$\begin{aligned} U_{c,t} - \beta U_{c,t+1} (\bar{r}_{t+1} + (1 - \delta_K)) &= 0, \\ U_{c,t} p_t - \beta U_{c,t+1} &= 0, \\ U_{l,t} - U_{c,t} w_t &= 0. \end{aligned}$$

The marginal utilities of consumption and leisure at time t are denoted $U_{c,t}$ and $U_{l,t}$, respectively. These three Euler equations plus the government budget constraint (equation (7)), the household's budget constraint (equation (2)), and the transversality condition ($\lim_{t \rightarrow \infty} \beta \Lambda_t k_{t+1} = 0$) characterize the basic unit of analysis for the model's solution. The variable Λ_t denotes the Lagrangian multiplier on the household's budget constraint (equation (2)) used when solving the maximization problem.

The Euler conditions above can be described intuitively. The first Euler equation describes the relevant margins that the household must consider when deciding on investment in private physical capital. Essentially the marginal rate of substitution (MRS) between consumption today and consumption tomorrow must equal their relative price: the return on the investment in terms of consumable output, $\bar{r}_{t+1} + (1 - \delta_K)$. The second Euler equation describes the relevant margin for investment in foreign assets. The interpretation is similar to the first equation: the household allocates consumption so that the MRS of consumption across time periods equals the relative price of foreign bonds to consumption. The third Euler equation describes the working decision. At the margin, the MRS between leisure and consumption must equal the ratio of the wage rate to the price of consumption (which is normalized to 1).

The Role of Effectiveness and Public Infrastructure

The effective stock of infrastructure plays a key role in the margins described above: it affects the marginal product of private factors. The interest rate and wage rate are simply the net-of-tax marginal products of private capital and labor, respectively. These can be written as

$$\bar{r} = (1 - \tau)f_K(\theta K_G, K, N), \quad (11)$$

$$w = (1 - \tau)f_N(\theta K_G, K, N), \quad (12)$$

where f_K and f_N denote the derivative of the production function with respect to private capital and labor, respectively. The effective stock of public capital, θK_G , is clearly a determinant of these net-of-tax marginal products. Raising θ —increasing the effectiveness of public capital—has two effects. On the one hand, a higher θ will tend to raise the marginal products f_K and f_N . On the other hand, this must be paid for by higher taxation (i.e., τ increases) which tends to decrease the net-of-tax marginal products. In fact, the wage rate is free to rise or fall with increases in θ . Recall, however, that the small open economy's interest rate is given by the world interest rate so an increase in θ cannot affect \bar{r} . Hence, private inputs will have to adjust to keep the net-of-tax marginal product of capital equal to \bar{r} .

With time subscripts removed, the Euler equations and constraints describe the steady state of the model. This steady state is computed numerically since the nonlinearities complicate a closed-form solution. Then the macroeconomic effects of policy experiments involving increasing or decreasing the effectiveness of infrastructure or changing public investment can be quantified.

4. Quantitative Evaluation of the Model

In order to evaluate the quantitative implications of the model, functional forms for utility and technology have to be specified. A standard constant relative risk-aversion form is used for the instantaneous utility function:

$$U(c_t, l_t) = \left[(c_t^\gamma l_t^{1-\gamma})^{1-\sigma} - 1 \right] / 1 - \sigma, \quad (13)$$

where the consumption share is $0 < \gamma < 1$, and the parameter σ is the inverse of the elasticity of intertemporal substitution between consumption in period t and $t + 1$.

The production function displays CRTS to private inputs:

$$Y_t = (\theta_t K_G)^{\phi(\theta_t)} K_t^\alpha N_t^{1-\alpha}. \quad (14)$$

The effective stock of public infrastructure, θK_G , is a publicly provided input in the production function. The coefficient of public capital in the production function, $\phi(\theta_t)$, is modeled as a function of effectiveness, θ (as in Hulten, 1996). The rationale is that new public investment is more productive the higher the degree of effectiveness in the whole system. If ϕ did not depend on θ , an increase in public investment would have the same impact whether effectiveness was low or high.

Table 2 describes the benchmark values for the model's parameters which must be specified to solve it. Most of the parameters come from various estimates of previous studies, but some are estimated here from data. The parameterization focuses on an average of seven Latin American countries: Argentina, Brazil, Chile, Colombia, Mexico, Peru, and Venezuela. When estimates for these seven countries are not available, estimates for samples of developing countries are used. The source of every parameter is discussed below, and the values are tabulated in Table 2.

The infrastructure-related parameter choices are described first. The benchmark effectiveness parameter, θ , is estimated here based on data from Table 1. An overall loss index across infrastructure types is calculated by taking a weighted average.⁶ The weighted-average loss in the Latin American countries is 34% (their infrastructure is 66% effective), while that in industrialized countries is 10% (90% effective). Suppose

Table 2. Benchmark Parameters

Parameter	Value	Description
θ	0.74	Infrastructure effectiveness parameter
τ	0.06	Fraction of GDP devoted to overall infrastructure spending
μ	0.012	Fraction of GDP devoted to maintenance
λ	0.048	Fraction of GDP devoted to new public investment
a	0.0168	Maintenance cost parameter
α	0.54	Capital share
ϕ	0.10	Infrastructure share
δ_K	0.025	Depreciation rate of private capital
δ_G	0.05	Depreciation rate of public capital
γ	0.35	Consumption share
σ	2.33	Utility curvature parameter
β	0.99	Discount factor

the effectiveness index θ is normalized to 1 for industrial countries: infrastructure is highly effective. Then this implies that θ for the seven Latin American countries is about 0.74 ($= 0.66/0.90$). This parameter is later varied to study its effects on the macroeconomy.

According to Easterly and Rebelo (1993), the share of GDP spent on public infrastructure in these seven countries is about 6%, so τ is set to 0.06. This goes to two uses: new investments and maintenance. Gyamfi et al. (1992) find that, in order to have a well-maintained infrastructure network (i.e., $\theta = 1$), these countries would have to spend about a yearly 1.4% of the replacement cost of their whole infrastructure network. Using this estimate to calibrate the parameter a yields a value of 0.0168. Hence, for the Latin American countries, which have a level of effectiveness of 74%, $\mu = a\theta = (0.0168)(0.74) = 0.012$ in the benchmark. This implies that these countries spend about 1.2% of GDP on maintenance. Finally, since $\tau = 0.06$, new public infrastructure investment gets $\lambda = \tau - \mu = 0.06 - 0.012 = 0.048$ or 4.8% of GDP.

The coefficient of public infrastructure in production, ϕ , is set to 0.10 following the average estimates for developing countries from Canning and Fay (1993), Easterly and Rebelo (1993), and Hulten (1996). The functional form of the public capital coefficient in production is simply assumed to follow $\phi = \theta/7.4$ (so when $\theta = 0.74$, ϕ is 0.10). Next, the depreciation rate of private capital, δ_K , is set to a standard value of 10% per year or 0.025 per quarter. The depreciation rate of public capital has been estimated to be about twice as high by the World Bank, so δ_G is set to 0.05.

The world interest rate is set to 0.01 per quarter following Rebelo and Vegh (1995). This choice for the world interest rate implies that the discount factor, β , equals 0.99. The remaining technology and preference parameters are set as described in Rioja (1999).

5. Results

Consequences of Low Effectiveness

This subsection analyzes the macroeconomic effects of increasing or decreasing the effectiveness of infrastructure, θ . The questions are: (i) What is the cost (in terms of

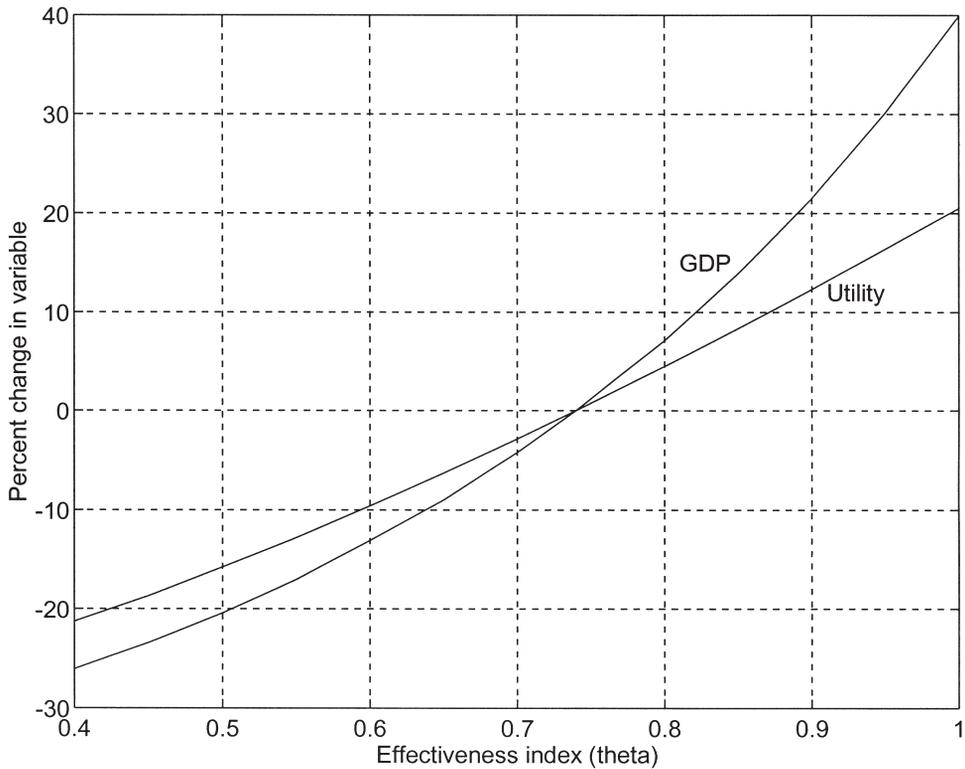


Figure 1. *Impact of Infrastructure Effectiveness Changes*

real GDP per capita and utility) of an ineffective infrastructure stock as in these seven Latin America countries? (ii) What are the potential gains or losses of raising or decreasing effectiveness?

In order to answer these questions, a number of experiments are conducted varying the size of θ between 0.40 and 1. Each experiment re-solves the model with a new value of θ and computes the resulting net steady-state change in GDP per capita and utility. Figure 1 graphically describes the effects on GDP per capita. The vertical axis measures the percentage change in GDP per capita from benchmark, and the horizontal axis measures θ . Hence, the starting point is the benchmark where $\theta = 0.74$. According to Figure 1, GDP per-capita changes are an increasing function of θ . For example, a country that raises the effectiveness of infrastructure by 10% (from 0.74 to 0.84) would have approximately a 12% larger GDP per capita in the long run. This result is consistent with Hulten's (1996) cross-country regressions.

Furthermore, suppose Latin American countries used their infrastructure as effectively as industrialized countries (i.e., $\theta = 1$). Figure 1 shows that per-capita GDP would be about 40% higher in the long run. Put differently, Latin America pays about a 40% of GDP "penalty" for not using their infrastructure effectively. In 1992, the US GDP per capita was about ten times that of the average of these seven Latin American countries. According to the numerical results, this ten-fold income disparity would be reduced to about seven if Latin Americans made more efficient use of their infrastructure.

The potential gains from raising effectiveness are clear. By the same token, if effectiveness diminishes, there are penalties as Figure 1 shows. For example, if effectiveness

Table 3. Long-Run Effects of a 1%-of-GDP Increase in Public Investment

θ	ϕ	% ΔY	% ΔC	% ΔI	% ΔU
0.20	0.03	-0.12	-1.19	-1.17	-1.40
0.30	0.04	0.48	-0.60	-0.58	-0.65
0.40	0.05	1.13	0.04	0.06	0.04
0.50	0.07	1.83	0.73	0.75	0.63
0.60	0.08	2.58	1.48	1.49	1.13
0.70	0.09	3.40	2.28	2.30	1.55
0.74	0.10	3.74	2.62	2.64	1.72
0.80	0.11	4.28	3.16	3.18	1.91
0.90	0.12	5.25	4.11	4.13	2.16
1.00	0.13	6.30	5.15	5.17	2.34

drops from 0.74 to 0.60, per-capita real GDP would be 14% lower in the long run, *ceteris paribus*, potentially adding to existing income disparities between Latin America and industrialized countries.

Figure 1 also describes the effects on utility, which are qualitatively similar: raising effectiveness has large positive effects and vice versa. Even though raising effectiveness requires higher taxes for better maintenance, the resulting productivity boost raises output which also raises consumption, and hence utility.

Raising Public Investment

The early empirical literature on infrastructure seemed to imply that more public investment was necessary for raising GDP in developing countries. In fact, many policymakers have advocated this position. However, the extent to which GDP rises with additional investment in public infrastructure depends on how effectively the whole network is being used. Table 3 computes the net effects of raising public investment by 1% of GDP (i.e., raising λ by 1%) under different degrees of effectiveness. Intuitively, there are two effects at work: the resource benefit and the resource cost. The resource benefit of more infrastructure raises productivity. The resource cost of providing more infrastructure arises because it must be financed by higher taxes. Under the benchmark level of effectiveness ($\theta = 0.74$), the resource benefit dominates: a 1%-of-GDP increase in infrastructure investment raises GDP (% ΔY) by 3.74% in the long run. If effectiveness was lower, say $\theta = 0.50$, increasing infrastructure investment in the exact same amount would raise GDP by only 1.83%. Conversely, if the effectiveness index was as high as an industrial country's ($\theta = 1$), GDP could increase by 6.30%. In summary, additional new public investment could be almost *twice* as productive if effectiveness was raised to industrialized standards.

The last three columns in Table 3 report the effects on private consumption (% ΔC), private investment (% ΔI), and utility (% ΔU). Under the benchmark scenario, the public investment increase raises all three of these variables as the resource benefit dominates. In general, the higher the degree of effectiveness, the higher the effect on these three variables. Notice, however, that at very low effectiveness indices more public investment could actually be *detrimental* to the economy. For example, if effectiveness is only 0.30, a 1%-of-GDP increase in infrastructure investment will *decrease* consumption by 0.60%, private investment by 0.58%, and utility by 0.65%. The result

seems at first surprising. Recall, however, that the increase in public investment is financed by raising taxes. When the effectiveness index is high, the productivity increase due to a larger stock of infrastructure more than pays for the tax raise. Conversely, if effectiveness is very low ($\theta \leq 0.30$), the resource cost of additional infrastructure exceeds the resource benefit. The implication is striking for policymakers: *more public investment can have negligible or negative consequences if effectiveness is not improved.* Many new infrastructure projects are built every year, but this could explain why they have not fully (or at all) boosted production in developing countries.

The results above show that there are payoffs to raising how effectively a country's infrastructure is used. But why is infrastructure in Latin America only 74% as effective as in the industrialized countries, and how might they raise this number? There may be a number of reasons. First, periodic maintenance of infrastructure has been neglected. This is one of the main reasons for low effectiveness, and it is incorporated in the model presented here. It is often the case that new public investments take precedence over maintaining existing roads or water systems, which deteriorate. Second, corruption at various levels of government may divert funds that should have been used to build highly efficient infrastructure. For example, government officials may contract to use lower-grade asphalt on highways, keeping part of the public funds for themselves (see Shleifer and Vishny, 1993; Tanzi and Davoodi, 1997). Finally, Isham and Kaufmann (1999) state that the country's overall policies and macro environment are crucial. They find that the economic rate of return to investment projects is higher when trade restrictions, exchange rate overvaluation, fiscal deficits, and price distortions are smaller.

6. Conclusions

This paper quantifies the long-run consequences of neglecting the effectiveness of public infrastructure in a general equilibrium context. The main results are as follows.

First, Latin American countries pay a steady-state penalty of about 40% of real GDP per capita for using their infrastructure only 74% as effectively as industrial countries do. Raising effectiveness to industrial country levels would reduce the income per-capita difference between the US and Latin America from 10-fold to about 7-fold.

Second, increasing public investment has often been advocated as a strategy of development. This paper shows that the effects of such increases critically depend on the effectiveness of the existing infrastructure network in the country. In fact, if effectiveness is sufficiently low, raising public investment actually *reduces* GDP per capita and welfare in the country. Hence, simply building new infrastructure projects may not be the panacea to attain development. The neglect of operations and maintenance in developing countries may be one of the causes of ineffective infrastructure. More research is needed to understand the reasons for low infrastructure effectiveness and how to raise it. As this paper shows, the payoffs can be large.

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Notes

1. Aschauer (1989) is a seminal paper on the importance of infrastructure for growth. Munnell (1992) offers a comprehensive survey of various empirical research on the topic. Also, Batina (1999) and Rioja (1999) are recent papers on this issue.
2. The infrastructure is not privately provided because private agents would be unable to exclude freeriders or to charge users competitive prices.
3. In a recursive competitive equilibrium framework, there is a distinction made between economy-wide per-capita variables (denoted by upper-case letters; e.g., K) and the variables that the individual household controls (lower-case letters; e.g., k). In equilibrium, the upper-case variables will be equal to the lower-case ones (i.e., $K = k$).
4. Feehan (1998) states that a consensus in the public inputs literature has emerged to model productive public inputs like infrastructure as factor augmenting. The production function in equation (4) follows this literature.
5. The costs of infrastructure are paid for by taxation in this model. Alternatively, they could be funded by borrowing. However, the funds would have to be repaid (by higher taxation) sooner or later in this equilibrium framework. Forward-looking infinitely lived agents would take this into account. Hence, for simplicity, the infrastructure is funded by contemporaneous taxation.
6. The weighted average is calculated using the following weights for power, telecommunications, paved roads, and water systems respectively: seven Latin American countries (0.40, 0.10, 0.25, 0.25); Industrialized countries (0.50, 0.09, 0.30, 0.11). The weights were obtained from the *World Development Report 1994*.

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