

Growth, Welfare, and Public Infrastructure: A General Equilibrium Analysis of Latin American Economies

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Empirical studies have found infrastructure investment important for a country's economic performance, but have not provided clear guidelines for infrastructure policy or its effects on other macroeconomic variables. This paper develops a general equilibrium model of a small open economy to study the effects of public infrastructure on output, private investment and welfare. The model is parameterized and solved for three Latin American countries: Brazil, Mexico, and Peru. Results show that infrastructure can have positive effects on output, private investment and welfare. However, raising public infrastructure investment past a certain threshold can be detrimental. All three countries are shown to have under-invested in infrastructure in the 1970s and 1980s. The gains from optimal infrastructure policy are greatest for Peru, the country with lowest infrastructure expenditure.

I. Introduction

Most economists agree that a country's public infrastructure is one of the pillars of economic growth. Publicly provided airports, highways, streets, and water systems contribute to output growth because they can increase productivity of private factors and decrease costs. Empirical studies of developing countries and cross-country regressions have found infrastructure important for a country's growth (e.g., Easterly and Rebelo (1993), Ford and Poret (1991), Canning and Fay (1993), among others). Papers in this literature have typically used regression analysis on either "growth accounting" or steady state equations. While these papers have been useful in pointing out the importance of infrastructure, their methodology does not allow for analyzing important general equilibrium feedback effects among variables or for out-of-sample policy experiments.

This paper develops a general equilibrium framework that yields quantitative predictions that can be used for policy analysis. In addition to studying the overall productiveness of infrastructure, this paper studies its effects on other macroeconomic variables such as private investment and welfare. Some of the questions addressed are: is private business investment encouraged or deterred with additional public investment, and in what proportion? How does additional infrastructure investment affect the population's welfare? Most previous studies of infrastructure have only focused on the implications for

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output.¹ This paper tries to offer infrastructure policy recommendations that are computed based on the largest welfare gains to the population.

In order to address these issues, a two-sector general equilibrium model of a small open economy is constructed. The model provides an internally consistent framework for policy analysis as suggested by Lucas (1987). The model is grounded in the equilibrium theoretical literature of Uzawa (1974), Barro (1990), and Glomm and Ravikumar (1994). However, their models are not quantitatively solved and do not emphasize welfare and private investment effects.

The model is parameterized to three Latin American countries: Brazil, Mexico, and Peru. Results show that infrastructure can have positive effects on output, private investment and welfare. However, raising public infrastructure investment past a certain threshold can be detrimental. All three countries are shown to have under-invested in infrastructure in the 1970s and 1980s. The gains from optimal infrastructure policy are greatest for Peru, the country with lowest infrastructure expenditure. The paper proceeds as follows: Section II describes the model. Section III describes the solution procedure and intuition. The quantitative evaluation of the model and policy implications are analyzed in Section IV, while Section V offers concluding remarks.

II. The Model

There are many households inhabiting the small open economy. Households have three sources of income. First, they earn wages by supplying their effort to firms. Second, they earn a return on physical capital that they own by renting it to firms. Third, they earn a return on their net holdings of foreign bonds, which they can buy and sell at the world interest rate. Households are utility maximizers, so they decide on their levels of consumption, investment, and foreign bond holdings. They also decide on their work effort and on how much capital to rent to firms in the economy. In the production sector, there is a representative firm that produces a final good using private capital and labor. In addition, there exists an external input in production, public infrastructure, which is provided by the government. The government finances infrastructure investment by taxing output at a flat rate, and it has to balance its budget constraint every period. A two-sector neoclassical general equilibrium model of a small open economy is formally described below.

1. Households

A large number of identical infinitely lived households, a representative firm, and a government populate the economy. Households have preferences over consumption and leisure streams $\{c_t, l_t\}_{t=0}^{\infty}$ given by the utility function

1. Among the exceptions are Looney and Frederiken (1997) and Blejer and Khan (1984) who study private investment effects.

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

where the discount factor is $0 < \mathbf{b} < 1$. $U(\cdot)$ is an instantaneous felicity function that is assumed to display standard properties. 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 $l_t + n_t \leq 1$. The household's budget constraint can be written as,

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

This budget constraint has a standard “uses cannot exceed sources” accounting interpretation. The left-hand side describes the uses of funds. Households can spend on consumption (c_t), investment (i_t) (they own capital), or purchase foreign bonds that come due next period (b_{t+1}) at price p_t . Thus p_t denotes the price of a bond that delivers one unit of consumption next period. The sources side of Equation (2) describes how the household earns income. The household rents capital (k_t) to the firm earning a net return of R_t . The household also earns a wage rate of w_t for its work effort, n_t , and has net holdings of foreign bonds, b_t , purchased last period which come due at time t . Since this is a small open economy, R_t is also the world interest rate. This is a standard assumption in small open economy models as these economies are too small to affect the world interest rate, but can borrow and lend internationally at that rate. This effectively ties their domestic interest rate to the world's rate.

Private capital evolves according to,

$$k_{t+1} = i_t + (1 - \mathbf{d}_k)k_t,$$

where \mathbf{d}_k is the depreciation rate of capital. The private capital stock tomorrow (k_{t+1}) is equal to the amount invested today (i_t) plus today's surviving capital stock, $(1 - \mathbf{d}_k)k_t$. Finally a no-Ponzi game condition, $\lim_{t \rightarrow \infty} b_t / (1 + R)^t = 0$, should be imposed on the household so that, basically, it cannot just continuously borrow forever.

2. Firm

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

$$y_t = f(K_{Gt}^*, k_t, n_t).$$

The production function f satisfies standard properties and exhibits constant returns to scale over *private* inputs so that factor payments exhaust revenues. The *effective* aggregate stock of public infrastructure, K_{Gt}^* , is a publicly provided input in production.² This effective public stock is related to the *raw* stock of infrastructure, K_{Gt} , by

$$K_{Gt}^* = \alpha K_{Gt}, \quad (3)$$

where $0 < \alpha < 1$ is a measure of effectiveness. Oftentimes in developing countries the stock of public infrastructure is not in perfect condition, hence the service derived from using it is diminished.

At each date, the firm chooses levels of y_t, k_t, n_t so as to maximize net-of-tax profit according to

$$(1 - \tau_t)y_t - R_t k_t - w_t n_t, \quad (4)$$

where τ_t is the tax rate on output. Alternatively, it will be useful to interpret τ_t as the share of GDP that the government uses for infrastructure investment.

3. Government

The revenue obtained from taxing output is used by the government to invest in infrastructure (I_{Gt}).³ The government balances its budget constraint as follows,

$$I_{Gt} = \tau_t y_t. \quad (5)$$

Public capital evolves according to,

$$K_{Gt+1} = I_{Gt} + (1 - d_G)K_{Gt}, \quad (6)$$

where d_G is the depreciation rate of public capital. Next period's stock of infrastructure, (K_{Gt+1}), is equal to the amount invested this period, (I_{Gt}), plus the surviving stock, $((1 - d_G)K_{Gt})$.

2. Public infrastructure is not privately provided because private agents are unwilling or unable to do so because it can be very hard to exclude free-riders or to charge users a competitive price.

3. In this model, borrowing from abroad is not used to finance infrastructure; only taxation can fund public investments. Even if agents were allowed to borrow, they would have to pay the loans by increased taxes sooner or later. In order to understand the full long run effects of infrastructure, the model should account that eventually taxpayers have to pay for it.

4. Market Clearing and Foreign Sector

The goods market clearing condition is:

$$c_t + i_t + I_{Gt} + TB_t = y_t, \quad (7)$$

where TB_t is the trade balance at time t . As in standard international finance models, the trade balance is the difference between output (y_t) and domestic absorption ($c_t + i_t + I_{Gt}$). The net holdings of foreign bonds evolves as follows,

$$p_t b_{t+1} = b_t + TB_t. \quad (8)$$

This equation is basically the country's balance of payments. In steady state, the trade balance simply becomes $(p-1)b$.⁴

III. Solution Procedure and Intuition

In general, an analytic solution for this economy is not possible due to nonlinearities. The model must be solved numerically. First, the Euler equations of the system are obtained. They are described by,

$$\mathbf{b}U_{c,t+1}/U_{c,t} = 1/(R_{t+1} + (1-\mathbf{d}_k)),$$

$$\mathbf{b}U_{c,t+1}/U_{c,t} = p_t,$$

$$U_{l,t}/U_{c,t} = w_t.$$

The subscripts c and l on U denote the marginal utilities of consumption and leisure, respectively, at time t . The basic unit of analysis for the model's solution is composed of these three Euler equations, the government budget constraint (Equation (5)), the household's budget constraint (Equation (2)), and the transversality condition, $\lim_{t \rightarrow \infty} \mathbf{b}\Lambda_t k_{t+1} = 0$, (where Λ_t is the lagrangian multiplier used for Equation (2) in the maximization procedure). The Euler equations can be described intuitively. The first equation describes the relevant margins that the household must consider when deciding on investment. Hence, the marginal rate of substitution between consumption today and consumption tomorrow ($\mathbf{b}U_{c,t+1}/U_{c,t}$) must be equal at the margin to the net return on investment in terms of consumable output, $1/(R_{t+1} + (1-\mathbf{d}_k))$. The second Euler equation describes the decision on the level of net foreign

4. The description of the international sector is similar to Rebelo and Vegh (1995) and Correia, Neves, and Rebelo (1993).

assets to be held. Basically, the marginal rate of substitution must equal the price of foreign bonds. The return on foreign bonds and capital has to be equal so that both assets are held. Hence, these two Euler equations can be combined yielding: $R_{t+1} = (1/p_t) - 1 - d_k$, where R_{t+1} is simply the world interest rate, which is exogenous from the small country's point of view.⁵ Finally, the third Euler equation describes the working decision. The marginal rate of substitution between consumption and leisure ($U_{l,t}/U_{c,t}$) must be equal at the margin to the real wage rate, w_t .

How does infrastructure affect the Euler equations? Infrastructure has a crucial effect on the marginal products of private factors. Any additional public investment is financed in the model by raising taxes (i.e., raising, I , the share of GDP that goes to infrastructure investment). The additional infrastructure has two effects on the net-of-tax rate of return, $R = (1 - I)f_k(k, K_G, n)$, and on the wage rate $w = (1 - I)f_N(k, K_G, n)$.⁶ The first effect (arising from a direct resource cost) obviously decreases the wage rate because of the higher tax necessary to fund more infrastructure (i.e., $I \uparrow \Rightarrow w \downarrow$). Conversely, this resource cost cannot affect the net return, R , which is fixed at the world rate of interest. This implies that, ceteris paribus, inputs need to adjust to keep the marginal product of capital equal to R . On the other hand, the second effect (a resource benefit) works opposite to the first effect since the additional infrastructure enhances the productivity of the existing private factors (i.e., $K_G \uparrow \Rightarrow w \uparrow$). This resource benefit also tends to raise the marginal product of capital, but cannot because it is fixed at R . Nevertheless, the resource benefit should partially (other inputs may also adjust) offset the increase in I (the resource cost) keeping the net-of-tax marginal product of capital constant at R .⁷

Consequently, public investment has both a resource cost and a resource benefit. This is why it should not be obvious that infrastructure investment (paid for by taxation) always increases GDP or private investment. The next section describes which of these effects dominates and under what conditions. With time subscripts removed, the Euler equations and constraints above describe the steady state of the model. This steady state is computed numerically since the non-linearities complicate a closed-form solution. Once it is calculated, the macroeconomic effects of policy experiments involving additional (or less) infrastructure investment can be quantified.

IV. Quantitative Evaluation of the Model

1. Parameterization

The model has to be solved, parameterized and simulated in order to evaluate its

5. Using the expression for the world interest rate, the steady state trade balance is $TB = (p - 1)b = [(-R - d_k)/(R + 1 - d_k)]b$. Given that R is the world interest rate and TB is a percentage of GDP, b can easily be determined.
6. The subscripts K and N denote the marginal products of capital and labor, respectively.
7. Baxter and King (1993) discuss these two effects in a closed economy setting.

quantitative implications. The specific functional forms for utility and technology are assumed to be:

$$U(c_t, l_t) = \frac{[c_t^g l_t^{1-g}]^{1-s} - 1}{1-s},$$

$$Y_t = K_G^{*f} k_t^a n_t^{1-a}.$$

The benchmark values for the parameters used in this paper are presented in Table 1. Individual estimates for Brazil, Mexico, and Peru are used when available. For example, Elias (1992) estimates the capital share of income, which corresponds to the parameter \forall , in these three countries as: 45%, 69%, and 66% in Brazil, Mexico, and Peru, respectively.

Table 1 Benchmark Parameters

Parameter	Description	Brazil	Mexico	Peru
a	Private capital coefficient	0.45	0.69	0.66
l	Infrastructure share (% of GDP)	6.3	7.6	5.6
a	Trade Balance (% of GDP)	0.42	0.64	-1.61

Rebelo and Vegh (1995) report the average share of GDP that was spent on infrastructure investment in the 1970s and 1980s. Mexico had the highest share with 7.6% of GDP spent of infrastructure investment. Brazil and Peru spent 6.3% and 5.6% respectively. Data from the World Development Indicators (1998) is used to compute the average trade balance (as percent of GDP) over this same time period. Brazil and Peru ran trade balance surpluses of 0.42% and 0.64%, while Peru had a deficit of 1.61%.

The rest of the parameters used are estimates for developing countries, since individual country estimates are not available. First, the coefficient of public capital in the production function, f , is set to 0.10 in the benchmark. This choice is an average of Hulten's (1996), Canning and Fay's (1993) and Easterly and Rebelo's (1993) estimates, which are all in the low end of estimates. Next, the depreciation rate of private capital, dK , is set to 10% per year or 2.5% per quarter. This figure is in Elias's (1992) estimated range for capital depreciation in Latin America. The depreciation rate of public capital, on the other hand, is estimated by the World Bank to be about twice that of private capital (*World Development Report 1994*). Hence, it is set to 5% per quarter in the benchmark.

Preference parameters are set as follows. A value of 0.35 is used for the consumption share g . Such value implies a leisure share of 0.65, which is consistent in the model with the allocation of roughly one-third of a household's time to market activities. Next, the curvature parameter, s , is set to 2.33, which comes from Ostry and Reinhart's (1992) estimates for developing countries. The world interest rate is set to 1% per quarter following Rebelo and Vegh (1995) which implies an annual return of 4%. This parameter choice for the interest rate implies that the discount rate, b , equals 0.99. Finally, the 1994 *World Development Report* estimates that the average effectiveness of public infrastructure in Latin America is about 75%,

so α is set to 0.75.

2. Results

The long-run effects of increasing infrastructure investment are presented in Table 2. The additional public investment is funded by taxation increases (i.e., by increasing the share of GDP devoted to infrastructure investment, I). Hence, I is alternatively raised by 1% of GDP, 5% of GDP, and 10% of GDP above the country's individual benchmark. Then, the resulting effects on GDP (Δy), private investment (Δi), and welfare (measured by Δw) are computed for each country.⁸

Table 2 Long-Run Effects of Raising Infrastructure Investment
(percent change from benchmark)

	ΔI	1.0	5.0	10.0
Brazil	Δy	2.23	7.82	10.4
	Δi	1.14	2.07	-1.37
	Δw	1.14	2.03	-1.45
Mexico	Δy	2.35	6.04	2.56
	Δi	1.25	0.32	-8.56
	Δw	1.23	0.31	-8.68
Peru	Δy	3.96	12.1	12.2
	Δi	2.86	6.18	0.30
	Δw	2.89	6.37	0.68

Consider, for example, the results for Brazil. A 1% -of-GDP increase in public infrastructure investment increases output by 2.23%. At the same time, private investment and welfare rise by 1.14%. Hence, the resource benefit of higher infrastructure investment exceeds the resource cost. Among the three countries, the 1% -of-GDP public investment increase has its largest positive effects for Peru. Output in Peru rises by 3.96% and welfare by 2.89%. These effects are twice the size of the ones in Brazil and Mexico. Considering that Brazil and Mexico have been investing larger shares of GDP in infrastructure, the result is not surprising. Peru has only been investing an average of 5.6% of GDP in infrastructure, while Brazil and Mexico have invested 6.3% and 7.6% of GDP, respectively. Hence, the gains of a 1% raise are larger in Peru which is the more infrastructure-deprived country of the three.

Overall, raising I by 1% above its benchmark has positive effects in all three countries. Table 2 also describes the effects of raising I by 5% and 10%. For example, in Brazil's case, raising I by 10% has a positive effect on GDP of 10.4%, but private investment and welfare are both *negatively* affected! The reason for this, however, follows from the intuition

8. As in Lucas (1987), the measure of welfare change is an equivalent change in aggregate consumption. It is a number w so that consumers are indifferent between: (i) a raise in I which provides more revenue to fund more infrastructure, and (ii) keeping I the same but reducing consumption by w percent.

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explained in Section III. Recall that a raise in I has both a resource cost and a resource benefit. Increasing I by 10% means that while infrastructure investment is being raised by that amount, this must be funded by an increase in taxes (the resource cost). Hence the resource cost has exceeded the resource benefit at this point. Private investment and welfare are both adversely affected due to the large increase in taxation. These adverse effects of a 10% raise in I can be seen in Brazil and Mexico's case. In Peru's case, however, the effects of such increase do not quite become negative. However, they do become very small: private investment only rises by 0.30% and welfare by 0.68%. Given Peru's low benchmark infrastructure expenditure, even with a 10% rise, the resource benefit is slightly larger than the resource cost.

Summarizing Table 2, additional infrastructure investment can be beneficial, but too much may be detrimental. In order to give concrete policy recommendations, the analysis can be extended even further. A government official may ask, how much should infrastructure investment be increased in order to get the maximum welfare gains? Figures 1 through 3 attempt to answer this question. These figures plot the change in welfare for different levels of infrastructure investment. Brazil's case is depicted in Figure 1.

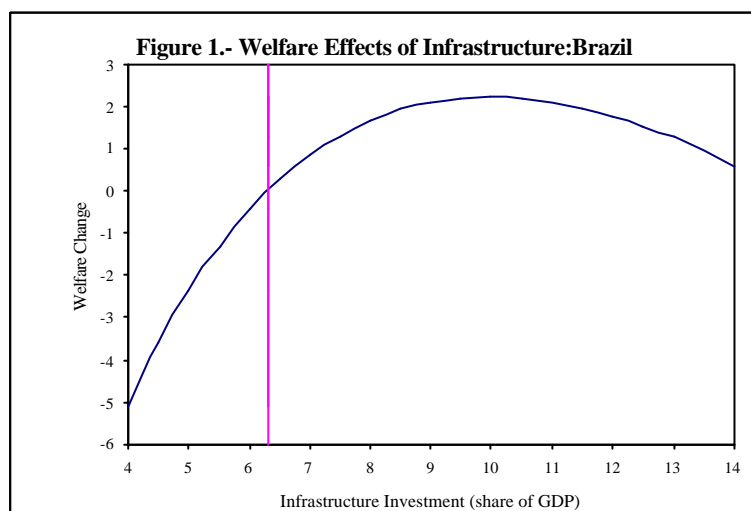


Figure 1 Welfare Effects of Infrastructure : Brazil

The horizontal axis measures the share of GDP devoted to infrastructure investment (I). Brazil's benchmark is $I = 6.3$, which is marked by a vertical line as a point of reference. Clearly, reducing public infrastructure investment (moving to the left of the benchmark) has adverse effects on welfare (measured on the vertical axis). Conversely, raising I has at first a positive effect, which later diminishes and eventually becomes negative (as Table 2 indicated). The peak of this curve is around $I = 10$. Therefore, the largest welfare gains can be obtained by devoting about 10% of GDP to public investment.

A corresponding plot for Mexico is described in Figure 2.

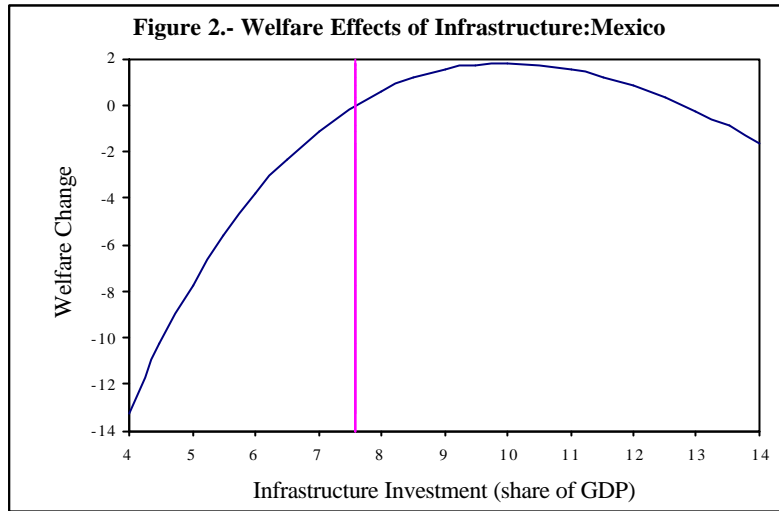


Figure 2 Welfare Effects of Infrastructure : Mexico

Note, however, that Mexico is much closer to optimal infrastructure investment than Brazil. Peru's case, shown on Figure 3, is much more striking since it starts from the lowest benchmark $I = 5.6$. Peru's plot shows the largest potential gains of optimal infrastructure policy, with a potential welfare increase of about 6% above benchmark.

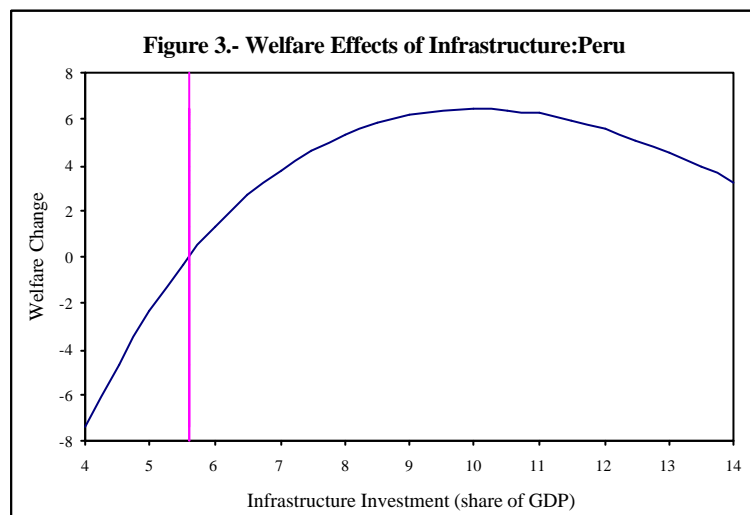


Figure 3 Welfare Effects of Infrastructure : Peru

Another interesting feature of the plots is that the optimal share of infrastructure investment is around 10% of GDP for all three countries. One of the most important determinants of this optimal share is the coefficient of public infrastructure in the production

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function, N (as shown in Barro's (1990) simpler model). This coefficient was parameterized to 0.10 using an average of fairly conservative estimates cited in Section IV, A. Good individual estimates for this parameter are unfortunately not available for these three countries, so a conservative average was used for all three. This yields an approximately equal optimal share of public infrastructure for all three countries. However, even using this a low, conservative estimate from the literature shows that these countries have all under-invested in infrastructure. Hence, the point remains that there are gains to raising infrastructure investment in these countries.

V. Conclusions

This paper quantifies the effects of infrastructure investment on GDP, private investment, and welfare using a calibrated general equilibrium model of a small open economy. The model is parameterized to data from Brazil, Mexico, and Peru, but could potentially be applied to other countries. For these three countries, results indicate that, devoting additional resources to infrastructure investment pays-off in terms of net increases in GDP. In addition, there exist sizable positive effects on private business investment. More highways and public communication networks encourage private companies to invest because using these public inputs can increase productivity of private factors.

This paper also contributes to the literature by studying the welfare effects of infrastructure policy, which can be very important in guiding policymakers' decisions. Results show that there is a range over which infrastructure investment in the three countries is welfare improving. However, very high levels of infrastructure investment can adversely affect welfare due to increased taxation necessary to fund it. In any event, all three countries under-invested in infrastructure in the 1970s and 1980s, so there is room for increased infrastructure investment that would be beneficial.

Potential extensions to this work would study the neglect of maintenance and repair of infrastructure networks in developing countries. Policymakers have often emphasized building brand new infrastructure over maintaining existing networks in optimal shape. The determinants of an optimal mix between these two expenditures should be studied.

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