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Infrastructure and Sectoral Output along the Road to Development

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ABSTRACT Public infrastructure is one of the foundations for economic growth. Empirical research has found that public infrastructure can have different effects in different sectors of the economy. The theoretical literature, however, has concentrated in one-sector growth models. This paper develops a three-sector model (agriculture, manufacturing and services) to study the effects of infrastructure. The model is calibrated and solved numerically using parameters from seven Latin American countries. Results show that the largest gains would have been obtained at an early stage of development in the decade of the 1960s. The seven Latin American countries would have also benefited from additional public investment in the 1990s, especially the service sector. This result also has implications for the early 2000s, as infrastructure expenditures have not increased from the 1990s levels.

JEL CLASSIFICATION: O4, H5

KEY WORDS: Public infrastructure, multi-sector model, Latin America

Introduction

Public infrastructure is generally believed to be one of the foundations for a country's economic development. Good networks of roads, water systems, power generating facilities, and communications are essential for the private sector's production activities to flourish. Such public infrastructure can decrease costs for businesses and increase the productivity of private factors of production. Cross-country empirical research has found infrastructure important for growth.[1] In the theoretical literature, Barro

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[1] For example, Canning & Fay (1993) study data from 95 developing countries. Easterly & Rebelo (1993) use data from a large worldwide sample. Hulten (1996) uses data

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(1990) used a one-sector growth model where productive public expenditures, a flow variable, was an input in production. Glomm & Ravikumar (1994) modelled public infrastructure as a stock variable that could be accumulated. Rioja (1999) extended this by calibrating a one-sector neoclassical growth model and studying the quantitative effects of public infrastructure policies on output, private investment, and welfare in developing countries. Hence, the theoretical literature has concentrated on studying infrastructure in one-sector models.

Empirical evidence, however, indicates that public infrastructure may have different effects in different sectors. For example, Feltenstein & Ha (1995) test the effects of infrastructure on costs in 16 sectors of the economy of Mexico. They find the effects can vary significantly among sectors. Sturm (2001) finds infrastructure had a higher positive effect in the service sector than in manufacturing and agriculture in the Netherlands after the Second World War. Morrison & Schwartz (1996) and Nadiri & Mamuneas (1994) find positive effects on manufacturing in the US. This empirical evidence provides the motivation to extend the theoretical literature to a multi-sector model. This paper extends the theoretical literature by studying the effects of public infrastructure in the three major sectors of the economy: agriculture, manufacturing, and services. A three-sector general equilibrium model is developed and calibrated to an average of seven Latin American countries: Argentina, Brazil, Colombia, Chile, Mexico, Peru and Venezuela. The first question is: how much did each sector benefit from infrastructure relative to the other sectors?

One important feature of sectoral shares in developing countries, however, is that they have changed over time. For example, in the decade of the 1960s, agriculture was, on average, 16% of the gross domestic product (GDP) in these seven Latin American countries. In the decade of the 1990s, conversely, agriculture had shrunk to only 9% of GDP. The service sector in the 1960s accounted for 48% of GDP, while in the 1990s it increased to 58% of GDP. This pattern is well known: as countries develop, the agricultural sector shrinks and the service sector grows. Hence, the second question the paper studies is: how has government infrastructure policy affected sectoral outputs in the 1960s versus the 1990s?

The basis of the model is a neoclassical growth model with three productive sectors: agriculture, manufacturing, and services.[2] The government provides infrastructure available to all sectors. Firms in all three sectors maximize profits. Households in the economy consume all three goods and rent private factors of production to firms. The model is calibrated to data from the seven Latin American countries. That is, parameters are chosen to generate sectoral shares actually observed in Latin America. Two alternative calibrations are implemented: one for the

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footnote continued

from 42 low and middle-income countries. Other related recent studies include Canning (1998, 1999) and Demetriades & Mamuneas (2000).

[2] In this paper, the industrial sector is included in 'manufacturing' in order to divide the economy into only three distinct private sectors.

1960s' decade and one for the 1990s'. Then, policy experiments on each calibrated benchmark are conducted.

Results show that additional infrastructure investment would have had a larger effect on sectoral outputs and overall GDP in the 1960s. This is because these countries were at an earlier stage of development at that time, and more infrastructure would have been very productive. Furthermore, results for the 1990s show that the service sector would get the largest benefits from additional infrastructure as its importance has increased.

The paper proceeds as follows. The economic model and solution procedure are specified in the next section. The third section describes the parameterization issues to evaluate the model quantitatively. The section after describes the results, and the final section makes concluding remarks.

The Model

The model has three productive sectors: agriculture, manufacturing, and services. There is a representative firm in each sector that hires private capital and labour as inputs.[3] In addition, all three sectors can use a publicly provided stock of infrastructure. The government provides this infrastructure, which is funded by taxing producers at a flat rate. Households in the model own the private inputs and rent them to the firms. Households maximize their utility function subject to a budget constraint. This three-sector neoclassical general equilibrium model is formally described below. Previous theoretical work studying productive public expenditures (such as infrastructure) includes Barro (1990), Glomm & Ravikumar (1994) and Rioja (1999). However, these papers only study one-sector models.

Firms

*Agriculture.*The representative agricultural firm rents private capital (K_{At}), land (T_t), and labour (n_{At}), and uses the effective stock of public infrastructure, $\hat{K}_{Gt}$, as an external input.[4] Production in this sector is described by,

$$y_{At} = f^A(\hat{K}_{Gt}, k_{At}, T_t, n_{At}) \tag{1}$$

[3] The agriculture sector also rents private land in order to grow crops.

[4] The rationale for public provision of infrastructure has been discussed in the public finance literature. Basically, private agents are unwilling or unable to provide this infrastructure because it can become very hard to exclude free-riders or to charge users a competitive price. In addition, government involvement may arise due to economies of scale inherent in the production of many types of infrastructure. In fact, as Aschauer (1989) notes, this last scenario is exactly consistent with the functional forms of the production functions described in this section and the next section.

where the production function, f^A, exhibits constant returns to scale (CRTS) to private inputs.[5] Infrastructures, such as roads, ports, power lines and water systems, are not pure public goods; they are subject to congestion with usage. Higher usage of private factors of production in all three sectors (which ‘crowds’ usage of the public factor) decreases the contribution of infrastructure to the firm’s productivity. Therefore, the effective stock of public infrastructure is defined as the raw stock deflated by usage:

$$\hat{K}_{Gt} = \frac{K_{Gt}}{k_t^{\zeta}}, \ \zeta > 0 \tag{2}$$

That is, the higher the use (captured by total private capital stock, k_t), the more congested the raw infrastructure stock K_{Gt} becomes. This specification has been previously used by Stiglitz (1988) and Glomm & Ravikumar (1994), and it is important in order truly to understand the contribution of infrastructure to each sector.

The government levies a flat tax rate of λ_t on the revenue of all firms. The representative agricultural firm maximizes net-of-tax profits (Π_A) according to:

$$\max_{\{k_{At}, n_{At}, T_t\}} \ \Pi_A = (1-\lambda_t) p_{At} y_{At} - r_{At} k_{At} - w_{At} n_{At} - r_{Tt} T_t$$

where p_{At} is the price of the agricultural good in terms on the numeraire (the manufactured good). Hence, $(1-\lambda_t) p_{At} y_{At}$ is the net-of-tax sales revenue of agricultural firms. The last three terms in the profit function above are the costs of hiring private factors of production. In this sector, the rental rate of capital, land, and the wage rate are given by r_{At}, r_{Tt} and w_{At}, respectively.

Manufacturing

The structure of the manufacturing sector is similar to the agriculture sector. The representative manufacturing firm produces output according to the following CRTS to private factors technology,

$$y_{Mt} = f^M(\hat{K}_{Gt}, k_{Mt}, n_{Mt}) \tag{3}$$

where k_{Mt} is private capital used in manufacturing production, n_{Mt} is labour used in manufacturing production, and $\hat{K}_{Gt}$ is the effective infrastructure stock defined in equation (2). Note that, unlike in the agricultural sector, land is not an input in manufacturing.

The manufacturing producer maximizes net-of-tax profits (Π_M) given by,

$$\max_{\{k_{Mt}, n_{Mt}\}} \ \Pi_M = (1-\lambda_t) y_{Mt} - r_{Mt} k_{Mt} - w_{Mt} n_{Mt} \tag{4}$$

where r_{Mt} and w_{Mt} are the rental rate of capital and the wage rate in manufacturing, respectively.

[5] According to Feehan (1998), there is a consensus in the public inputs literature to model productive public inputs having a direct effect on output in this fashion.

Services.The service sector also uses three inputs in production. Service output is produced with a CRTS to private factors technology:

$$y_{St} = f^S(\hat{K}_{Gt}, k_{St}, n_{St}) \tag{5}$$

The representative service producer hires private capital k_{St} and labour n_{St}. In addition, as in the other two sectors, the effective public infrastructure $\hat{K}_{Gt}$ is used as a public input. The service producer also maximizes net-of-tax profit:

$$\max_{\{k_{St}, n_{St}\}} \quad \Pi_S = (1 - \lambda_t)p_{St}y_{St} - r_{St}k_{St} - w_{St}n_{St} \tag{6}$$

where p_{St} is the price of the service good in terms of the numeraire (the manufacturing good), and where r_{St} and w_{St} are the rental rate of capital and wage rate in the service sector.

Government

Government authorities tax all firms' revenue at rate λ_t. These revenues are, in turn, used for public infrastructure investment, I_{Gt}.[6] The government's budget constraint is then given by:

$$I_{Gt} = \lambda_t(p_{At}y_{At} + y_{Mt} + p_{St}y_{St}) \tag{7}$$

Alternatively, one can interpret λ_t as the share of total output (i.e. GDP) used for public investment. This interpretation will be very useful later to compute λ_t from national income and product accounts for the countries of interest. The public infrastructure stock evolves according to:

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

where the rate of depreciation of public capital is denoted by δ_G. This expression says that next period's public capital stock, K_{Gt+1}, is equal to the amount invested by the government this period, I_{Gt}, plus the surviving public capital stock, $(1 - \delta_G)K_{Gt}$.

Households

Households have preferences over consumption and leisure streams given by the utility function,

$$\sum_{t=0}^{\infty} \beta_t U(c_{At}, c_{Mt}, c_{St}, l_t) \tag{9}$$

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6 Alternatively, borrowing could be used to finance public investment. In order to abstract from this, one can appeal to Ricardian equivalence (which holds in this type of general equilibrium model). Private agents do have to pay for public expenditures sooner or later. To understand the full effects of infrastructure, one must analyse both benefits and costs.

where $0 < \beta < 1$, c_{At} is consumption of agricultural goods, c_{Mt} denotes consumption of manufactured goods, and c_{St} denotes consumption of services. Leisure (l_t) is defined as the time endowment (normalized to unity) less labour supplied to the agricultural sector, n_{At}, labour supplied to the manufacturing sector, n_{Mt}, and labour supplied to the service sector, n_{St}. That is,

$$l_t + n_{At} + n_{Mt} + n_{St} = 1 \tag{10}$$

Households own the private capital stock (k_t), so they make the investment decision (i_t) and also decide on how much capital to rent to each sector. Households rent capital to all three types of firms earning returns r_{At}, r_{Mt} and r_{St}. They also earn wage rates of w_{At}, w_{Mt} and w_{St} for the effort they supply to each type of firm. Finally, they own land, T_t, which in this model is supplied inelastically to the agricultural sector and earns a return of rT_t.[7] This is all incorporated in the household's budget constraint:

$$\begin{aligned} &p_{At}c_{At} + c_{Mt} + p_{St}c_{St} + i_t \\ &\leq w_{At}n_{At} + w_{Mt}n_{Mt} + w_{St}n_{St} + r_{At}k_{At} + r_{Mt}k_{Mt} + r_{St}k_{St} + r_{Tt}T_t \end{aligned} \tag{11}$$

where every variable has been previously defined. This budget constraint can be easily interpreted using the standard accounting interpretation of 'uses' (the left-hand side) cannot exceed sources (the right-hand side).

Private capital is only produced in the manufacturing sector, but can be rented to any sector. Private capital evolves according to,

$$k_{t+1} = i_t + (1 - \delta_A)k_{At} + (1 - \delta_M)k_{Mt} + (1 - \delta_S)k_{St} \tag{12}$$

where δ_j, $j = A, M, S$ is the depreciation rate of capital in sector j.[8] This evolution equation has the standard interpretation: the capital stock next period is equal to the amount invested today plus today's surviving stock. Since the aggregate capital stock can be divided between the agriculture, manufacturing, and service sectors, then $k_t = k_{At} + k_{Mt} + k_{St}$.

Finally, the market clearing conditions for each sector are:

$$c_{At} + I_{GAt} = y_{At} \tag{13}$$

$$c_{Mt} + i_t + I_{GMt} = y_{Mt} \tag{14}$$

$$c_{St} + I_{GSt} = y_{St} \tag{15}$$

where $I_{Gt} = p_{At}I_{GAt} + I_{GMt} + p_{St}I_{GSt}$. That is, total public investment is the sum of what the government raises from each sector.[9] Aggregate output (GDP)

[7] As land is supplied inelastically, the government could raise funds more efficiently by only taxing land. However, we allow the government to raise funds from all three productive sectors as this is more realistic and incorporates benefits and costs to all producers. That is, a producer gets the benefit of using public capital, which he or she pays for indirectly by taxes.

[8] Private capital can be freely transformed between its three uses, but it may, in principle, depreciate at different rates.

[9] Alternatively, the revenue raised from each sector could be made into public capital using a production function. However, this would introduce the complication of

in the economy is defined by adding the value of production of every sector: $y_t = p_{At} y_{At} + y_{Mt} + p_{St} y_{St}$.

Infrastructure's Role

The role of public infrastructure in this model can be understood by examining factor payments. Profit maximization for firms implies that factor payments equal the value of their marginal product net of taxes. Hence,

$$\begin{aligned} r_{jt} &= (1 - \delta_t) p_{jt} f_k^j(t) \\ w_{jt} &= (1 - \delta_t) p_{jt} f_n^j(t), \text{ for } j = A, M, S \end{aligned} \tag{16}$$

The marginal product of private capital in sector j at time t is denoted by $f_k^j(t)$. Likewise, the marginal product of labour is $f_n^j(t)$.[10]

Public infrastructure plays an essential role in these factor payments and in the model's overall solution. Consider, for instance, a policy that raises public infrastructure investment increasing the public infrastructure stock K_{Gt}. Such a policy would have two effects on factor payments. First, an increase in K_{Gt} would tend to raise the marginal products of private capital and labour, $f_k(t)$ and $f_n(t)$, in all three sectors, and hence raise private factor payments r_{jt} and w_{jt} for $j = A$, M, S. This effect could be called the resource benefit of public infrastructure following Baxter & King (1993). However, public infrastructure also has a resource cost. The increase in public investment must be funded by raising taxes λ_t. But a rise in λ_t would tend to lower private factor payments, r_{jt} and w_{jt} for $j = A$, M, S as the expressions in equation (16) show. Consequently, the net effects of raising public infrastructure are not obvious and need to be studied with the numerical computations done in the following sections.

Solution Procedure

The solution to the model proceeds as follows. First, the first-order conditions of the maximization problem for households and firms in each sector are computed. Second, specific functional forms are given for the utility and production functions. Third, the model's parameters are determined based on estimates for seven Latin American countries; and fourth, experiments are conducted to study the implications of various infrastructure policies. This sub-section concentrates on the first step, presenting the first-order conditions and describing the intuition behind them.

The household's maximization problem yields the following first-order conditions:

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footnote continued
parameterizing such a non-standard function as estimates are not available. Hence, for simplicity, output from each sector is transformed at its marginal rate of transformation.

10 In addition, the factor payment to land is $r_{Tt} = (1 - \lambda_t) p_{At} f_T^A(t)$, where $f_T^A(t)$ is the marginal product of land in agricultural production. In addition, recall that $p_{Mt} = 1$ since the manufactured good is the numeraire.

$$U_{cM}(t) = \beta U_{cM}(t+1)[r_{Mt+1} + (1 - \delta_M)] \tag{17}$$

$$r_{At+1} = r_{Mt+1} = r_{St+1} \tag{18}$$

$$\frac{U_{cA}(t)}{U_{cM}(t)} = p_{At} \tag{19}$$

$$\frac{U_{cS}(t)}{U_{cM}(t)} = p_{St} \tag{20}$$

$$\frac{U_{l}(t)}{U_{cM}(t)} = w_{Mt} \tag{21}$$

$$w_{At} = w_{Mt} = w_{St} \tag{22}$$

The marginal utility of consumption of good j at time t is denoted by $U_{cj}(t)$, for $j = A$, M, S, while the marginal utility of leisure at time t is denoted $U_l(t)$. These first-order conditions can be interpreted intuitively. Equation (17) describes the decision to invest in private capital. The marginal utility of consuming a unit of manufactured good today must equal the discounted marginal utility of consuming a unit tomorrow times the net return from having invested it. Equation (18) simply states that the rate of return to capital must be equal across all three sectors of production since the household would not rent capital to any sector(s) that had lower return than other(s). Equations (19) and (20) state that the marginal rate of substitution between consumption of two types of goods equals their relative price. Equation (21) says that the marginal rate of substitution between leisure and consumption of manufactures equals their relative price: the wage rate in manufacturing divided by the numeraire price (i.e. 1). Finally, equation (22) states that wage rates in all three sectors must equalize otherwise the household would only work in the sector(s) where the wage rate is highest.

Quantitative Evaluation of the Model

In order to obtain quantitative implications from the model of the previous section, specific functional forms must be assumed and parameters must be determined. The utility function, U, is assumed to have a standard constant relative risk aversion (CRRA) formulation:

$$U(c_{At}, c_{Mt}, c_{St}, l_t) = \frac{\left[c_{At}^{\gamma A} c_{Mt}^{\gamma M} c_{St}^{\gamma S} l_t^{1-\gamma A-\gamma M-\gamma S}\right]^{1-\sigma} - 1}{1-\sigma}$$

The parameter σ is the inverse of the intertemporal elasticity of substitution.

Production functions in each sector are assumed to take a simple Cobb-Douglas form that has constant returns to scale to private factors of production.

$$y_{At} = \hat{K}_{Gt}^{\theta} k_{At}^{\varphi_1} T_t^{\varphi_2} n_{At}^{1-\varphi_1-\varphi_2}$$
$$y_{Mt} = \hat{K}_{Gt}^{\theta} k_{Mt}^{\alpha} n_{Mt}^{1-\alpha}$$
$$y_{St} = \hat{K}_{Gt}^{\theta} k_{St}^{\upsilon} n_{At}^{1-\upsilon}$$

Both these types of functional forms are commonly used in calibrated models. Next, parameters for the model must be specified. Parameter estimates for an average of seven Latin American countries are used: Argentina, Brazil, Chile, Colombia, Mexico, Peru and Venezuela. The model is solved for two alternative specifications: the decades of the 1960s and the 1990s. That is, the model is separately calibrated to the sectoral characteristics prevalent during each of those two decades. Table 1 describes data on the relative size of the three sectors in these countries.

Table 1. Sectoral shares in Latin America (percentage of GDP)

	Agriculture		Manufacturing		Services	
	1960s	1990s	1960s	1990s	1960s	1990s
Argentina	13	6	49	31	38	63
Brazil	21	14	37	36	42	50
Chile	9	8	34	37	57	55
Colombia	27	16	20	20	53	64
Mexico	14	5	41	26	45	68
Peru	21	7	32	37	47	56
Venezuela	5	4	41	47	54	49
Average	16	9	36	33	48	58

Source: World Development Indicators, World Bank.

The data reveal a well known trend: as countries develop, the agriculture sector shrinks and the service sector grows. The average of the seven countries shows that agriculture was 16% of GDP in the 1960s, but shrunk to 9% of GDP in the 1990s. Manufacturing went from being 36% of GDP to 33%. Finally, services accounted for 48% of GDP in the 1960s, but grew to 58% of GDP in the 1990s.

Table 2 describes the benchmark parameter choices. Preference parameters are described first. In order for the model to display the 1960s sectoral shares, the preference parameters γ_A γ_M and γ_S are set equal to 0.08, 0.04 and 0.24 respectively. Similarly for the 1990s, these are set to 0.05, 0.03 and 0.28 in order to generate the relative size of each sector as described in the data in Table 1. Next, the discount factor, β, is set to 0.962 so that in the steady state the interest rate is 4% per year following Rebelo & Vegh (1995). The utility curvature parameter, σ, is set to 2.33, which comes from Ostry & Reinhart's (1992) estimates for developing countries.

Technology related parameters are set based on estimates of the seminal growth accounting work for these seven countries—*Sources of Growth: A Study of Seven Latin American Economies* by Victor Elias

Table 2. Benchmark parameters

	Parameters	Value	Description
Preference	$\gamma_A(1960)$	0.08	Agriculture consumption share
	$\gamma_A(1990)$	0.05	
	$\gamma_M(1960)$	0.04	Manufacturing consumption share
	$\gamma_M(1990)$	0.03	
	$\gamma_S(1960)$	0.24	Service consumption share
	$\gamma_S(1990)$	0.28	
	β	0.962	Discount factor
	σ	2.33	Utility curvature
Technology	α	0.58	Capital share in manufacturing
	ϕ_1	0.45	Capital share in agriculture
	ϕ_2	0.13	Land share in agriculture
	υ	0.46	Capital share in services
	ζ	0.12	Congestion parameter
	θ	0.10	Infrastructure share
	δ_j, $j = A, M, S, G$	0.10	Depreciation rate
Government	λ (1960)	0.05	Public investment share
	λ (1990)	0.07	

(1992). The technology coefficient of private capital in manufacturing in the seven Latin American countries, α, is set to 0.58 according to Elias (1992). As expected, the manufacturing sector is fairly capital intensive. Conversely, the agricultural sector is less capital intensive; Elias (1992) estimates its capital share is $\phi_1 = 0.45$ and the coefficient on land is $\phi_2 = 0.13$. Unfortunately, Elias does not estimate the capital or labour share for the service sector. Estimates for these service sector parameters of the US by Jorgenson *et al.* (1987) and Horvath (2000) suggest that the capital share of service output—that is, υ—is in the neighbourhood of 0.46. This estimate makes intuitive sense since services are fairly labour intensive. Hence, in the absence of an estimate specific to these seven countries, we use an estimate from these two well-known works.

Next, the public capital coefficient in the production function, θ, is of key importance. As there are no specific estimates for these seven countries, we use an average of various estimates. This parameter has been estimated as large as 0.20 by Fay (2001) and Canning & Fay (1993) using large cross country data sets. Hulten (1996) estimates it around 0.10 using data from low- and middle-income countries, including six of the seven Latin American countries of interest. In the benchmark, θ is set to 0.10, on the conservative side of estimates. Note that the same value of θ is used for all three sectors. This parameter may vary by sector in principle, but estimates by sector are not available.

Next, a depreciation rate of capital of 10% per year is a figure that is commonly used in calibrated models. Hence, the depreciation rate for the capital stock in all sectors is set to $\delta_A = \delta_M = \delta_S = 0.10$, in the absence of

Table 3. Infrastructure Policy Effects

		1%		5%		10%	
		1960	1990	1960	1990	1960	1990
GDP	Δy	3.43	2.10	11.6	7.10	14.7	8.57
Agricultural Output	Δy_A	3.81	2.19	12.4	7.05	15.1	7.38
Manufacturing Output	Δy_M	2.78	1.87	10.0	7.33	14.0	11.2
Service Output	Δy_S	3.81	2.21	12.4	6.99	15.1	7.37
Agricultural Consumption	Δc_A	2.31	0.97	5.66	1.12	2.62	−3.66
Manufacturing Consumption	Δc_M	2.70	1.19	6.52	1.31	2.98	−4.77
Service Consumption	Δc_S	1.15	0.63	2.89	1.40	1.40	−0.45
Investment	Δi	1.41	0.66	3.57	1.64	1.68	0.09
Utility	ΔU	0.62	0.28	1.50	0.47	0.71	−0.60

sectoral depreciation rate data. The congestion parameter is set to $\zeta = 0.12$ so that, in the benchmark steady state, the effective infrastructure stock is about 85% of the raw stock. The *World Development Report 1994* estimates that the 'raw' stock of infrastructure is congested by about 10 to 20%. Consequently, ζ is set to generate an 'effective' stock of infrastructure that is only 85% of the 'raw' stock.

Finally, infrastructure investment as a share of GDP, λ, is obtained from Easterly & Rebelo (1993). These seven countries spent 5% of GDP on infrastructure in the 1960s versus 7% of GDP in the 1990s.

Results

This section seeks to quantify the effects of different infrastructure policies using the calibrated model described in the second and third sections above. The questions addressed are as follows. Would these seven countries have benefited from raising public investment in the 1960s? Would they have benefited from raising public investment in the 1990s? Incidentally, the answer to this latter question applies in the early 2000s as expenditures have not changed much from the 1990s levels. How would GDP, sectoral outputs, sectoral consumptions, investment, and utility be affected with different infrastructure policies?

The starting point to answer these questions is to compute a benchmark steady state for both time periods. In steady state, by definition, all variables are stationary (e.g. $k_{t+1} = k_t$). Hence, to calculate the steady state, time subscripts are dropped from equations (17) through (22) and constraints (7) and (13)–(15). In addition, the parameters described in the third section are substituted into these equations and constraints and fed to a non-linear equation solver that finds the benchmark steady states for the 1960s and for 1990s.

Results reported in Table 3 display long run effects of raising the share of GDP devoted to infrastructure investment (i.e. λ_t) by 1, 5 and 10 percentage points above the relevant benchmark. In the 1960s, for example, raising λ_t by 1 percentage point could have resulted in a net GDP increase (Δy) of 3.43%. That is, the resource benefit of higher public investment would have exceeded the resource cost of the tax increase necessary to fund it. The GDP increase originates when sectoral outputs increase across the board. Agriculture and service output rises by 3.81%, while manufacturing output rises by 2.78%. How would consumption be affected? Consumption of all three goods rises, and manufacturing consumption rises the most, 2.70%. Likewise, investment in private capital (Δi) would be positively affected by 1.41%. More infrastructure raises the real return to private capital, which leads to higher private investment. There is also a positive effect on the welfare of the population as utility rises by 0.62%. In summary, raising λ_t by 1 percentage point in the decade of the 1960s would have had sizeable positive effects on these economies.

What explains these results? The 1960s were an early stage in these countries' development paths, so the countries were in dire need of more infrastructure, such as roads connecting input and output markets. However, Latin America only spent 5% of GDP in infrastructure investment at that time. Even major cities within some countries were only connected by unpaved roads that were unreliable during the rainy season. Naturally, a 1 percentage point increase in infrastructure investment would have raised overall GDP and benefited the three sectors.

It should be noted that since taxes are distortionary in this model, there exists an associated deadweight loss (DWL) or excess burden. Auerbach & Hines (2002) define it as 'the additional revenue the government could collect without harming the consumer, were lump-sum taxes used instead of distortionary taxes'. Unfortunately, it is not possible to compute DWL in this setting.[11] The deadweight loss (incorporated in what is known as 'the marginal cost of public funds') has been estimated for only a couple of developing countries. Devarajan *et al.* (2002) estimate it as high as $0.20 for every $1 of revenue raised in Bangladesh, Cameroon and Indonesia. Those estimates are very carefully obtained using multi-sector models that account for idiosyncratic distortions of each country's economy. In the absence of specific estimates for Latin American countries, we are guided by Devarajan *et al.*'s (2002) upper bound of $0.20. The effects of a 1% of GDP increase in infrastructure investment shown on Table 3 yield output effects much larger than 1.20 (both for the whole economy and for sectoral outputs). Hence, the net effect of more infrastructure is positive and fairly large even after accounting for deadweight loss.

How do the effects of raising infrastructure investment by 1% of GDP in 1960s compare to an equal raise in the 1990s? The effects in the 1990s,

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[11] The non-linear solver takes in 10 equations and 10 unknowns and solves for the unknowns. To compute the DWL, two unknowns are removed as p_S and p_A would have to be fixed at the 'old' (before policy changes) values. In addition, there would be an additional equation imposing the constraint of utility equalling its 'new' (after policy change) level. Hence, there would be 11 equations and 8 unknowns, which could not be solved.

described in Table 3's second column of results, are similarly positive, for example, output (Δy) rises by 2.10%. However, this rise in GDP is smaller than that in the 1960s (3.43%). Similarly, production in the three sectors rises by less in the 1990s than in the 1960s. That is, infrastructure investment had higher potential payoffs at an earlier stage of development for these countries.

Agriculture and service output benefited more than manufacturing in both decades. For example, in the 1990s, agriculture and service production rises by about 2.20% while manufacturing rises by 1.87%. As the service sector becomes the largest in the 1990s, more communication networks, power generation, etc, would benefit this sector significantly. This result is consistent with Sturm (2001) who finds that the service sector benefited the most from infrastructure in the Netherlands after the Second World War. At that time, the Netherlands was already a country at an advanced stage of development, and services were a large part of the economy.

Table 3 also reports the effects of 5- and 10-percentage point increases in λ. For the 1960s, note that consumption in all three sectors rises with the 5-percentage point raise in λ. That is, consumption of agricultural goods (Δc_A) rises by 5.66%, consumption of manufactures (Δc_M) rises 6.52% and consumption of services (Δc_S) rises by 2.89%. However, increasing λ by an even higher 10 percentage points only increases these consumptions by 2.62%, 2.98% and 1.40%, respectively. That is, a 10 percentage point increase in λ may be excessive. The point is even clearer for the 1990's experiments: a 10% raise in λ would actually decrease consumption of goods and services! Consumption of agricultural goods, c_{At} falls by 3.66%, c_{Mt} falls by 4.77%, and c_{St} falls by 0.45%. Utility consequently also falls by 0.60%. This result can be interpreted as follows. As more resources are devoted to infrastructure, the costs start to exceed the benefits. Consequently, too much infrastructure can be detrimental to consumption and welfare due to the higher taxes needed to finance it.

In order to examine the robustness of these results to the choice of some key parameters, more policy experiments were conducted. Specifically, the congestion parameter ζ and the infrastructure coefficient in the production function, θ, are varied. The congestion parameter ζ was calibrated so that the 'effective' infrastructure stock was 85% of the 'raw' stock. This was in the range of *World Development Report 1994* estimates. We now consider reasonable values for ζ that are higher and lower than the benchmark: $\zeta = 0.17$ (80% effectiveness) and $\zeta = 0.08$ (90% effectiveness). Table 4 shows the results of a 1 percentage point raise in infrastructure (i.e. λ) under these specifications. These results can be compared with the benchmarks presented in the first two columns of Table 3. The results using the three different values of ζ are very similar. For example, the change in GDP is 3.39% ($\zeta = 0.17$), 3.45% ($\zeta = 0.08$) and 3.43% ($\zeta = 0.12$, benchmark). Naturally, the effect is slightly smaller when congestion is the highest ($\zeta = 0.17$ or infrastructure is only 80% 'effective').

Table 4. Robustness checks to 1 percentage point raise in infrastructure

		$\zeta = 0.17$		$\zeta = 0.08$		$\theta = 0.08$		$\theta = 0.15$	
		1960	1990	1960	1990	1960	1990	1960	1990
GDP	Δy	3.39	2.11	3.45	2.30	2.30	1.55	6.87	4.13
Agricultural Output	Δy_A	3.79	2.16	3.83	2.16	2.49	1.25	7.74	5.04
Manufacturing Output	Δy_M	2.68	1.93	2.80	2.52	1.98	2.21	5.32	2.23
Service Output	Δy_S	3.79	2.19	3.82	2.20	1.67	1.26	7.75	5.02
Agricultural Consumption	Δc_A	2.36	0.91	2.38	0.96	1.20	0.15	5.72	3.35
Manufacturing Consumption	Δc_M	2.66	1.09	2.66	1.06	1.36	0.12	6.62	3.78
Service Consumption	Δc_S	1.02	0.71	1.16	1.28	0.59	1.05	2.92	0.79
Investment	Δi	1.28	0.75	1.44	1.48	0.73	1.34	3.53	0.45
Utility	ΔU	0.60	0.29	0.65	0.42	0.32	0.27	1.63	1.00

Table 4 also shows the effects of changing θ. Recall that $\theta = 0.10$ was on the low end of estimates based on Hulten (1996). Other authors, such as Fay (2001) and Canning & Fay (1993) have estimated this parameter as high as 0.20. We choose values for θ that are lower and higher than the benchmark: 0.08 and 0.15. Table 4 shows that the size of the effects is smaller with 0.08 (e.g. in the 1960s the GDP effect is 2.30% versus 3.43% in the benchmark). When $\theta = 0.15$, the effects are larger: 6.87% versus 3.43% in the benchmark. This parameter is clearly very important for the size of the effects. As we chose a conservatively low estimate for the benchmark and still got sizeable effects, the potential effects could be even larger.

Conclusions

Public infrastructure can have important effects on a country's economy. This paper's contribution is to study these effects at a sectoral level taking into account that sectoral shares have changed over time. A three-sector general equilibrium model is constructed and calibrated to seven Latin American economies. The model can be adapted and parameterized for other regions or countries of the world. Results show that the greatest gains would have been obtained by raising infrastructure investment in the 1960s. This has important policy implications for countries that are presently in the early stages of development. The seven Latin American countries would have also benefited from additional public investment in the 1990s, especially the service sector. This result also has implications in the early 2000s as infrastructure expenditures have not increased from the 1990s levels. During 2000–2003, most of these countries were afflicted by a recession, which ruled out any increase in spending for public infrastructure.

Finally, some caveats should be pointed out. First, the paper abstracts from other forms of taxation and other public expenditures (such as schooling, defence, social security, etc). Since, the overall tax burden (and deadweight loss) is likely to be already high, increasing taxes for additional infrastructure may involve raising the deadweight loss in such a way that the gains are not as high as described in the paper. Given this, it may be better for those governments to shift expenditures from other uses to public infrastructure. Second, the overall policy environment is critical for public infrastructure to have the effects described in the paper. Isham & Kaufmann (1999) find that the economic rate of return of investment projects is higher when trade restrictions, exchange rate overvaluation, fiscal deficits, and price distortions are smaller. Hence, some of the policy regimes in Latin America in the 1960s and 1990s could have prevented realizing the potential gains described. In addition, corruption in public projects may divert funds from their intended allocation. For instance, government officials may contract to use lower-grade asphalt for a highway project, which may deteriorate prematurely (see Shleifer & Vishny, 1993; Tanzi & Davoodi, 1997).

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