Journal of Development Economics
Vol. 58 (1999) 387–404

JOURNAL OF Development ECONOMICS

Productiveness and welfare implications of public infrastructure: a dynamic two-sector general equilibrium analysis

Felix K. Rioja *

Department of Economics, Georgia State University, Atlanta, GA 30303, USA

Accepted 1 May 1998

Abstract

This paper develops a dynamic general equilibrium model that provides an internally consistent micro-foundations framework where various effects of infrastructure policy changes can be studied. Devoting additional resources to infrastructure investment can payoff in terms of sizable increases in GDP and private investment. In addition to this, the model also makes predictions concerning changes in the welfare of agents resulting from additional infrastructure investment. Specific policy recommendations that attain highest welfare gains are computed. The recommendation is that on average an additional 4% of GDP per year should be devoted to public investment in the Latin American countries in the sample. © 1999 Elsevier Science B.V. All rights reserved.

JEL classification: E62; O4; C61; C68

Keywords: Public infrastructure; Growth; Congestion; Public policy

1. Introduction

Despite common wisdom about its benefits, the importance of publicly provided airports, highways, streets, and water systems for the economic growth of a country is not well understood. Most economists believe that investment in such

* Tel.: +1-404-651-0417; fax: +1-404-651-3996; e-mail: prcfkr@langate.gsu.edu

PII: S0304-3878(98)00118-7

public infrastructure contributes to output growth since it increases productivity and decreases costs for the private sector. Increased attention to this topic can be found in recent issues of such publications like *The Economist*, as well as some academic journals (e.g., Morrison and Schwartz, 1996). Consider the following two examples.

- Seven South-American countries that comprise the common market MERCOSUR which was formed in 1991 have liberalized trade, fostering increased growth. To fully integrate this market, however, transport links like ports, roads, e.g., an unfinished key section of highway in Bolivia that would finally connect the continent's east and west coasts, and railways, need improvement. The Inter-American Development Bank IDB estimates that if these economies grow at 5%, their investment in infrastructure improving transport links needs to increase significantly.
- The former U.S. Navy base in Subic Bay, Philippines was closed in 1992. An organized effort from neighboring-town Olongapo's mayor to preserve the abandoned infrastructure, i.e., port facilities, a runaway capable of handling Jumbo-jet airplanes, and buildings successfully turned the base into a port. This attracted private investment of 200 companies worth US$1.2 billion. This was one of the factors contributing to the increase of Philippine GDP from about 0% in 1992 to about 6% in 1995. [1]

Both articles suggest that more infrastructure investment is needed in these countries. [2] Low levels of investment in infrastructure have been observed in recent years in regions like East Asia (about 5% of GDP), Latin America (about 6% of GDP), and even the U.S. (about 1% of GDP). In Latin America fiscal restraint in the mid-1980s (called for by stabilization plans) was in part responsible for the decline in public investment that has not yet recovered 1970s levels. Continuing low levels of public investment could stall economic growth. [3] This paper develops a general equilibrium model that can offer guidelines for infrastructure policy. In addition to studying the overall productiveness of infrastructure, this paper studies its effects on private investment. That is, is private business investment encouraged or deterred with additional public investment, and in what proportion? Furthermore, this paper studies how additional public infrastructure investment affects the population's welfare. A majority of previous studies of infrastructure have only focused on the implications for output. This paper attempts to quantify policy recommendations for public investment guided by

[1] These two examples are reported in *The Economist* in the 12 October 1996 and 11 May 1996 issues, respectively.

[2] Some of these issues were first brought to attention in the economic development classic of Hirschman (1958). He posited that social-overhead capital investment, i.e., infrastructure could attract more private investment serving as a development strategy.

[3] In this paper, 'public investment' is used synonymously to 'infrastructure investment' and to 'public capital investment.'

potential welfare gains for the citizenry. Specific quantitative policy recommendations concerning additions to infrastructure that result in the largest welfare gains to the population are computed.

In order to address the questions above, a dynamic two-sector general equilibrium model is solved and its quantitative predictions examined. Most types of infrastructures can potentially become congested with usage. The model in this paper accounts for that by using an 'effective' stock measure so different degrees of non-rivalry for the public input are possible. Equilibrium in the model is characterized by a system of difference equations which is solved using numerical techniques. The benchmark model is solved for an average of parameters estimated for a sample of seven Latin American countries (Argentina, Brasil, Chile, Colombia, Mexico, Peru, and Venezuela). Some of these parameter estimates come from Elias (1992) (a thorough growth accounting study of the seven countries) and Easterly and Rebelo (1993) (who construct series of infrastructure measures for a worldwide sample).

Empirical testing of the significance of public investment has been conducted among others by Aschauer (1989) (using U.S. states data), Canning and Fay (1993) (using data from 95 developing countries), Ford and Poret (1991) (using cross-section of OECD countries), and Hulten (1996) (using data from 42 low and middle-income countries), all of which find infrastructure important. [4] Most of the papers cited above use regression analysis of either 'growth accounting' or of steady-state equations. Unfortunately, this methodology does not allow for important general equilibrium feedback effects among variables. [5] That is, they are not fully articulated frameworks that can be used for policy analysis. A dynamic general equilibrium model that is explicitly solved, such as the one described in Section 2, provides such an internally consistent micro-foundations 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 effects on welfare and private investment. In this paper, measures of government investment in infrastructure are obtained from actual data from these

[4] However, there is disagreement among infrastructure studies of U.S. data. Some disaggregated studies find government spending on infrastructure not important for growth. These include Holtz-Eakin and Schwartz (1994) (using panel data from U.S. states) and Nadiri and Mamuneas (1994) (using data from various U.S. industry classifications). Other researchers using aggregate U.S. data like Aschauer (1989) and Flores de Frutos and Pereira (1993) find it very important. A conjecture that might explain this disagreement notes that studies finding public capital unimportant use data at the disaggregated level (e.g., state or industry) which may not reflect the full benefits of infrastructure as it accrues to the whole economy. In any event, the empirical disagreement over the importance of infrastructure is among studies of U.S. data which is not the focus of this paper. For a comparative summary discussion of these and other studies of infrastructure, see Munnell (1992).

[5] An exception is Baxter and King (1993) who do have a general equilibrium model. However, they study infrastructure in the U.S. and concentrate more on government consumption expenditures.

seven countries and used as a benchmark. Experiments deviating from this benchmark are then undertaken studying long-run and short-run effects on output, welfare, and other macroeconomic variables. It is found that infrastructure (even if funded by taxation) has sizable positive effects on GDP and private investment. For the countries studied, maximum welfare gains can be achieved by raising public investment by about 4% of GDP above present averages. Welfare–infrastructure trade-offs are also found; too much infrastructure investment is shown to be detrimental.

The paper proceeds as follows. The economic environment is specified in Section 2, and the recursive competitive equilibrium is characterized. Section 3 describes the solution procedure, while Section 4 discusses parameterization issues to be used in the solution. Section 5 describes the results, and Section 6 makes concluding remarks.

2. The model

The economy is first described intuitively; a more formal description follows. There are a large number of households that inhabit the economy. Households have two sources of income. First, they earn wages by supplying their effort to firms. Second, they earn a return on capital they own which is rented to firms. Households decide on their work effort, on the amount of capital to rent to firms, and on how much to consume and invest so as to maximize their utility. In the production sector, there is a large number of competitive firms that have identical technology used to produce a final good. Firms are profit maximizers and demand capital and labor as private inputs in the production process. 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 is formally described below. [6]

2.1. Households

The economy is populated by a large number of identical infinitely-lived households, a large number of firms, and a government. Households have prefer-

[6] Some remarks about the notation used in this section are in order at this stage to keep the presentation clear. First, given that the equilibrium concept used later in this section is that of a recursive competitive equilibrium (RCE), there is a distinction made between economywide per-capita variables (denoted by upper-case letters; e.g., K) and the variables that the household controls (lower-case letters; e.g., k). In equilibrium, the upper-case variables will be equal to the lower-case ones (i.e., $K = k$). Second, all starred variables have a growth component arising from a technology shock in the production function. The variables are later transformed to their non-starred counterparts, by removing the growth component, as will be described further into this section.

ences over stochastic consumptions and leisure streams $\{c_t*, l_t\}_{t=0}^{\infty}$ given by the utility function

$$E_0\left[\sum_{t=0}^{\infty}\beta*^t U(c_t*, l_t)\right], \tag{2.1}$$

where $0 < \beta* < 1$. E_0 denotes the mathematical expectation operator at time 0. The instantaneous felicity function, U is assumed to display standard properties a functional form is given further along. The amount of labor supplied by the household is n_t. [7] 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,

$$c_t* + i_t* \leq w_t* n_t + r_t* k_t*. \tag{2.2}$$

The interpretation of the budget constraint is the standard 'uses cannot exceed sources.' The left-hand side of expression (2.2) describes the uses of funds. Households can spend on consumption (c_t*) or investment (i_t*) (they own capital). The sources side of Eq. (2.2) describes how the household earns income. He rents capital (k_t*) to the firm earning a gross return of r_t*, and also earns a wage rate of w_t* for his effort, n_t. Private capital evolves according to,

$$k_{t+1}* = i_t* + (1-\delta_K*)k_t*, \tag{2.3}$$

where δ_K* is the depreciation rate of capital. The capital stock tomorrow $(k_{t+1}*)$ is equal to the amount invested today (i_t*) plus today's surviving capital stock, $(1-\delta_K*)k_t*$.

2.2. Firms

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

$$Y_t* = f\left(\hat{K}_{Gt}*, K_t*, z_t N_t\right). \tag{2.4}$$

The production function f satisfies standard properties and exhibits constant returns to scale over private inputs so that factor payments exhaust revenues. Given the constant returns to scale 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 Eq. (2.4)). The economywide stock of public infrastructure adjusted for congestion, $\hat{K}_{Gt}*$, is a publicly provided input in production that firms take as given. [8] Thus the measure

[7] The variables for leisure and labor are not starred since the time allocation is bounded between 0 and 1.

[8] The infrastructure is not privately provided because private agents are unwilling or unable to provide it because it can be very hard to exclude free-riders or to charge users competitive prices.

of public capital is adjusted for congestion similarly to Stiglitz (1988) and Glomm and Ravikumar (1994) according to,

$$\hat{K}_{Gt}* = \frac{K_{Gt}*}{K_t*^{\zeta}}, \tag{2.5}$$

where K_t* is the economywide per-capita private capital, and $\zeta > 0$ is a congestion parameter. Roads, airports, water systems are not pure public goods; they are subject to congestion with usage. Higher usage of private capital (which ‘crowds’ usage of public capital) decreases the contribution of infrastructure to the firm’s productivity. In Eq. (2.4), z_t is a labor augmenting shock described by $z_t = \exp(\mu t + \theta_t)$. This shock is composed of a deterministic trend, μt, and a stochastic component, θ_t, described by the following AR(1) representation,

$$\theta_t = (1-\rho_\theta)\tilde{\theta} + \rho_\theta \theta_{t-1} + \varepsilon_{\theta t}, \tag{2.6}$$

where $\tilde{\theta}$ is the mean of θ_t, $|\rho_\theta| \leq 1$ and innovations are serially independent with standard deviation σ_θ. At each date, firms choose levels of Y_t*, K_t*, N_t so as to maximize profit according to

$$(1-\lambda_t)Y_t* - r_t*K_t* - w_t N_t, \tag{2.7}$$

where λ_t is the share of GDP that the government uses for infrastructure investment.

2.3. Government

Effectively, the government taxes output at rate λ. [9] Revenues are, in turn, used to invest in infrastructure $(I_{Gt}*)$. Thus the government balances its budget constraint as follows,

$$I_{Gt}* = \lambda_t Y_t*. \tag{2.8}$$

Public capital evolves according to,

$$K_{Gt+1}* = I_{Gt}* + (1-\delta_G*)K_{Gt}*, \tag{2.9}$$

where δ_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 $((1-\delta_G*)K_{Gt}*)$. The share of output devoted to infrastructure, λ_t, is a policy variable, and as such it is subject to policy shocks. For

[9] Borrowing is not used to finance infrastructure here. Only taxation can fund public investments. This assumption is plausible given the Ricardian equivalence principle which holds in this model. Borrowing would just lead to higher taxation later in order to repay debt. Then to understand the full effects of infrastructure (i.e., costs as well as benefits), the model should account that eventually taxpayers have to pay for it.

example, upcoming elections or effective lobbying can alter policymakers preferences. Therefore this process can be described by

$$\lambda_t = (1-\rho_\lambda)\tilde{\lambda} + \rho_\lambda \lambda_{t-1} + \varepsilon_{\lambda t}. \qquad (2.10)$$

The mean value of λ_t is $\tilde{\lambda}$, $|\rho_\lambda| \le 1$, and innovations are serially independent with standard deviation σ_λ. [10]

The goods market clearing condition in the economy is

$$C_t * + I_t * + I_{Gt} * = Y_t *. \qquad (2.11)$$

Due to the deterministic trend in the production function, all starred variables grow over time. This trend is removed by dividing such variables by $\exp(\mu t)$. Consequently, all starred variables are transformed to their non-starred counterparts (e.g., consumption becomes $c_t = c_t * / \exp(\mu t)$. [11] Finally in order to define equilibrium concisely, let a vector $\boldsymbol{x}$ be composed of the exogenous shocks in the model, which were defined above. Further define the stationary transition density function as χ. [12]

2.4. Equilibrium

We can now define a recursive competitive equilibrium (RCE) for this economy. It consists of a set of decision rules $i(s)$, $c(s)$ and $n(s)$ for $s = (\theta, \lambda, k, K, K_G)$; a corresponding set of aggregate per-capita decision rules $I(S)$, $C(S)$, $N(S)$ for $S = (\theta, \lambda, K, K_G)$; factor price functions $w(S), r(S)$ and a value function $V(s)$ such that these functions satisfy: (i) the household's problem

$$V(s) = \max_{c,i,n} \left\{ U(c, 1-n) + \beta \int_{\boldsymbol{X}} V(s') \chi(x, \mathrm{d}x') \right\},$$

subject to

$$c + i \le r(S)k + w(S)n$$

$$k' = (1-\delta_K)k + i,$$

$$K' = (1-\delta_K)K + I,$$

$$\begin{bmatrix} \theta' \\ \lambda' \end{bmatrix} = \begin{bmatrix} (1-\rho_\theta)\tilde{\theta} \\ (1-\rho_\lambda)\tilde{\lambda} \end{bmatrix} + \begin{bmatrix} \rho_\theta & 0 \\ 0 & \rho_\lambda \end{bmatrix} \begin{bmatrix} \theta \\ \lambda \end{bmatrix} + \begin{bmatrix} \varepsilon_\theta \\ \varepsilon_\lambda \end{bmatrix}$$

---

[10] Taxes have been modelled in this fashion in McGrattan (1994), for instance. Using this specification, one can analyze dynamic effects on output and other macroeconomic variables in response to policy shocks that raise or lower public investment.

[11] After transforming the variables in such fashion, now $\beta = \beta * \exp(1-\sigma)\gamma\mu$ and $\delta_i = 1-(1-\delta_i *)\exp(-\mu)$, for $i = K, G$.

[12] Moreover, let $(\mathbf{X}, X, \chi)$ be a probability space. X are the Borel sets of $\boldsymbol{X}$, and χ be an X measurable function on subsets $A \subseteq X$. Assume $\mathbf{X}$ is compact and χ is monotone.

where ε_θ and ε_λ are uncorrelated; the covariance matrix is

$$\boldsymbol{\Sigma}=\begin{bmatrix}\sigma_\theta^2 & 0\\ 0 & \sigma_\lambda^2\end{bmatrix}.$$

(ii) Firms choose K, N to maximize their profit function,

$$(1-\lambda)f(\theta,K,K_G,N)-rK-wN$$

where $r=(1-\lambda)f_K(\theta,K,K_G,N)$ and $w=(1-\lambda)f_N(\theta,K,K_G,N)$. (iii) The government budget constraint is balanced every period

$$\lambda Y=K_G'+(1-\delta_G)K_G.$$

(iv) There is consistency of aggregate and individual decisions. That is, $c=C$, $k=K$, $i=I$, and $n=N$. (v) The aggregate resource constraint, Eq. (2.11), holds.

3. Solution procedure

Because of the nonlinearity of the above problem, an analytical solution cannot be implemented. Therefore the model has to be solved numerically. A number of solution techniques have been suggested in the literature (see Taylor and Uhlig, 1990). In this paper, a linear–quadratic approximation method is employed. First, a non-stochastic steady state is computed by eliminating time subscripts from the first-order conditions and constraints. A nonlinear equation solving procedure is applied to the resulting equations. Then, the original first-order conditions and constraints are linearized about the non-stochastic steady state yielding a system of linear expectational difference equations. At this stage, the decision rules are conjectured. The parameters of these decision rules are then computed using the gradient of the linearized equations with the method of undetermined coefficients. [13]

The first-order conditions of the system are: [14]

$$U_c-\beta\int_{\boldsymbol{X}}U_c'(r'+(1-\delta_K))\chi(x,\mathrm{d}x')=0$$

$$U_l-U_c w=0$$

U's subscripts c and l denote the marginal utility of consumption and leisure, respectively, at time t; primes denote next period's value. These two equations

[13] For a complete description of the method, see Christiano (1991) and Christiano and Schlagenhauf (1997).

[14] Given restrictions to the size of σ_λ, as well as the restrictions on preferences and technology, an interior solution to the problem is guaranteed.

plus the government budget constraint condition (2.8), the household's budget constraint (2.2), and the transversality conditions, $\lim_{t \to \infty} \beta^t \Lambda_t k_{t+1} = 0$ characterize the basic unit of analysis for the model's solution.

The above conditions can be intuitively described as follows. The first equation describes margins that the household must consider to optimally decide on his investment. At the margin, the utility of reducing consumption by one unit in period t, (U_c), should be equal to the expected discounted increase in utility from the consumption of that unit next period, ($\beta U_c'$), times the net return on the investment $(r' + (1 - \delta_K))$ in terms of consumable output due to the extra unit of capital.

The second equation describes the household's optimal work effort choice. It is basically the familiar condition that the marginal rate of substitution between leisure and consumption has to equal the ratio of their respective prices. Of course, the marginal products of private factors and hence the rate of return and wages are affected by the additional infrastructure and by the higher taxes required to fund it. These effects are fully described below.

Any additional public investment is financed in the model by raising, λ, the share of output devoted to infrastructure–effectively by raising taxes. The increased infrastructure has two effects on the net-of-tax rate of return, $r = (1 - \lambda) f_K(\theta, K_G, K, N)$ and on the wage rate $w = (1 - \lambda) f_N(\theta, K_G, K, N)$. On the one hand, a resource cost effect decreases the net-of-tax return and wage rate because of the tax increase necessary to fund more public capital (i.e., $\lambda \uparrow \ \Rightarrow \ r \downarrow, w \downarrow$). On the other hand, a resource benefit effect increases the net return and the wage rate because more infrastructure enhances the productivity of the existing private factors (i.e., $K_G \uparrow \ \Rightarrow \ r \uparrow, w \uparrow$). Public investment involves, then, both a resource cost and benefit. Section 5 describes which of the effects dominates. [15]

4. Quantitative evaluation of the model

The model has to be solved, parameterized and simulated in order to evaluate its quantitative implications. The specific functional forms for utility and technology are assumed to be:

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

$$Y_t = \hat{K}_{Gt}^{\phi} K_t^{\alpha} (z_t N_t)^{1-\alpha} \qquad (4.1)$$

The benchmark values for the parameters used in this paper are presented in Table 1. Most of the parameters come from various estimates of previous studies,

[15] Computer programs in MATLAB used to implement this solution are available from the author on request.

Table 1
Benchmark parameters

$\beta*$	0.9975	discount rate
$\delta_K * = \delta_G *$	0.025	depreciation rate
γ	0.35	consumption share
σ	2.33	utility curvature parameter
μ	0.0075	trend growth rate
α	0.54	capital share
ϕ	0.10	infrastructure share
$\tilde{\lambda}$	0.0624	fraction of GDP devoted to infrastructure
ζ	0.045	congestion parameter

but some are estimated here from data. The key of parameters are averages for seven Latin American countries: Argentina, Brazil, Chile, Colombia, Mexico, Peru, and Venezuela. The choice of countries is dictated by a thorough collection and analysis of their data (akin to Dale Jorgenson's work with U.S. data) by Victor Elias (1992) in his *Sources of Growth: A Study of Seven Latin American Countries*. However, not every parameter needed in this essay is computed in Elias (1992), so additional sources are used. The source of every parameter is discussed below and the values are tabulated in Table 1.

First, the coefficient of public capital in the production function, ϕ, is of crucial importance. It is set to 0.10 in the benchmark. This choice is supported by the estimate of Hulten (1996) of 0.11, the estimate of Canning and Fay (1993) of 0.07 for 95 developing countries, and the estimate of Easterly and Rebelo (1993) of 0.15 from a world sample. Sensitivity analysis varying this coefficient in this range will be shown to not significantly change the main conclusions.

The technology coefficient of private capital, α, is set to 0.54 according to Elias (1992) and Rebelo and Vegh (1995). [16] The depreciation rate, $\delta*$, is set to 10% per year or 0.025 per quarter. This figure is in the estimated range of Elias (1992) for capital depreciation in Latin America. Depreciation rates of public and private capital are set to be equal given that there are no known studies to the author that estimate them separately.

Preference parameters are set as follows. A value of 0.35 is used for the consumption share γ. Such value implies a leisure share of 0.65 which is consistent in the model with the allocation of roughly one-third of non-sleep time to market activities as estimated by Ghez and Becker (1975). Next, the curvature parameter, σ, is set to 2.33, which comes from the estimates for developing countries of Ostry and Reinhart (1992). The average growth of these countries from 1940 to 1992 was about 3% per year so the quarterly trend growth parameter

[16] For comparison, this figure is higher than the U.S. coefficient for capital, usually set at 0.33.

Table 2
Public investment in Latin America

Country	Public investment in the 1980s (as percentage of GDP)
Argentina	0.062
Brazil	0.063
Chile	0.060
Colombia	0.074
Mexico	0.076
Peru	0.056
Venezuela	0.122

μ is set to 0.075. The discount rate, $\beta*$, is set to 0.9975 so that in the steady state the interest rate is about 1% per quarter following Rebelo and Vegh (1995). The share of GDP that went into infrastructure investment in these countries in the 1980s is about 6.24% (i.e., $\tilde{\lambda} = 0.0624$). This figure is computed from the data of Easterly and Rebelo (1992) shown in Table 2.

Finally, to help determine the congestion parameter, ζ, information reported in the 1994 *World Development Report* is used. They estimate that the ‘raw’ stock of infrastructure is congested by about 20% to 30%. Consequently, the congestion parameter is set to 0.045 in the benchmark so that the ‘effective’ stock of infrastructure is only 75% of the ‘raw’ stock.

5. Results

5.1. Long-run effects and sensitivity analysis

The long-run consequences of additional public expenditures on infrastructure investment are given on Table 3. Table 3 basically describes results of a number of steady-state infrastructure experiments. Additional public investment is funded by taxation increases (i.e., by increasing the share of GDP devoted to infrastructure investment, $\tilde{\lambda}$, as shown in column (1)). Columns (2) and (3) describe how these changes in public investment affect output (Y) and welfare measured by ω, respectively. [17] Column (4) shows the effects on private investment (I). In the benchmark model, a 1%-of-GDP increase in public investment increases output by 2.53% with a welfare gain of 1.42%. The resource benefit of higher infrastructure

[17] Following Lucas (1987) and King and Rebelo (1990), the welfare measure is a number ω so that consumers are indifferent between: (i) a raise in $\tilde{\lambda}$ which provides more revenue to fund more K_G, and (ii) keeping $\tilde{\lambda}$ the same but reducing consumption by ω percent.

Table 3
Steady-state infrastructure experiments

(1)	(2)	(3)	(4)
$\%\Delta\tilde{\lambda}$	$\%\Delta Y$	$\%\Delta\omega$	$\%\Delta I$
Benchmark			
1.0	2.53	1.42	1.44
$\phi = 0.075$			
1.0	1.40	0.34	0.32
$\phi = 0.15$			
1.0	5.37	4.30	4.25
Higher congestion specification			
1.0	2.52	1.41	1.43
$\phi = 0.075$			
1.0	1.39	0.28	0.31
$\phi = 0.15$			
1.0	5.34	4.21	4.22

also positively affects private investment which rises by 1.44%. More publicly provided roads and water systems encourage private agents to invest more as in the Philippines example cited in the introduction. The preliminary conclusion from the benchmark is that infrastructure is important for GDP and private investment. This conclusion is tested below by performing sensitivity analysis which varies the value of ϕ (the coefficient of infrastructure in the production function).

Results from the sensitivity analysis are also reported on Table 3. The value of ϕ is alternatively set to 0.075 (the estimate of Canning and Fay (1993) which is lower than the benchmark) and 0.15 (the estimate of Easterly and Rebelo (1993) which is higher than the benchmark). For the first experiment, Table 3 shows that when $\phi = 0.075$, a 1%-of-GDP increase in public investment increases output by 1.40% and welfare by 0.34%. Thus, additional infrastructure investment has an important effect on output even with a fairly low infrastructure coefficient. Private investment is also positively affected rising by 0.32%. The second experiment sets ϕ to 0.15. This time, higher infrastructure investment raises output by 5.37%, private investment by 4.30%, and welfare by 4.25%. Consequently, both sensitivity experiments support the benchmark conclusion of a high importance of infrastructure.

5.2. Congestion

As highways and water systems become crowded with usage, benefits to users may diminish. How different are the quantitative effects of more infrastructure on macroeconomic variables when congestion levels are higher? This question is addressed in the lower portion of Table 3. The experiments performed above are repeated using a higher congestion parameter. The benchmark level (with

$\zeta = 0.045$) implied that the congestion-adjusted stock of infrastructure was only 75% of the raw stock. As cited, the World Development Report (1994) estimates effective levels between 70% and 80%. Then to understand the effects of higher congestion, ζ is raised to 0.057, which is consistent with a congestion adjusted stock of public capital only 70% as effective. Results from this specification indicate that the effects of a 1%-of-GDP raise in public investment are slightly lower than those computed for the benchmark. As expected, a higher congestion parameter precludes additional infrastructure from affecting GDP and private investment in the same proportion as in the lower-congestion scenario. However, output and private investment do still rise. In comparing effects among the alternative congestion scenarios, keep in mind that the results described follow an increase in congestion of only about 5% (i.e., from 75% effective to 70%). Much higher degrees of congestion have been observed on occasion for some types of infrastructure in developing countries. In that case, the positive effects of infrastructure on output and private investment can be significantly dampened—though more infrastructure should still alleviate the problem.

5.3. Welfare effects and policy recommendations

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 maximum welfare gains? This question is answered in Fig. 1. Fig. 1 describes an infrastructure–welfare trade-off curve. The horizontal axis measures the share of GDP devoted to public investment (above benchmark). The vertical axis measure welfare gains (losses) in percent from benchmark. The policymaker's question can be answered by identifying the

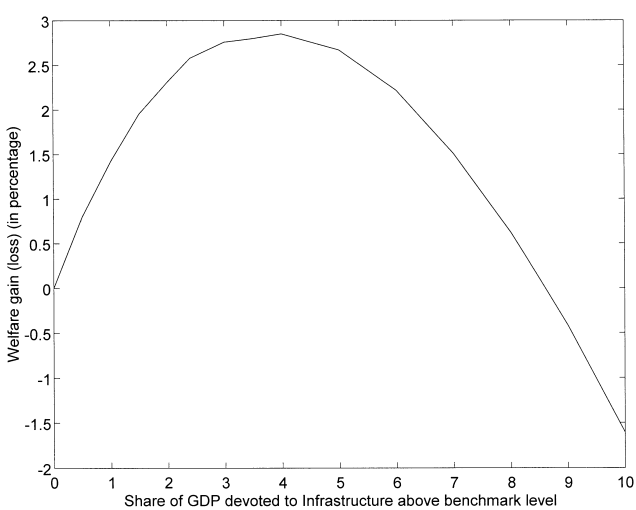

Fig. 1. Infrastructure–welfare trade-offs.

'highest peak' on the trade-off curve in Fig. 1. The highest welfare gain from additions to infrastructure is attained by increasing it by about 4% (i.e., devoting 10% of GDP to infrastructure). This implies a concrete policy recommendation for Latin American policymakers to increase infrastructure investment to this amount. The resulting welfare gains for the population are about 2.85% of aggregate consumption. With such potential benefits, why do these countries underinvest in infrastructure? The reasons are not discussed here in detail, but some conjectures should be mentioned. First, stabilization programs of the mid-1980s called for reduced public spending. Infrastructure was especially affected as described by Urrutia (1991) and Edwards (1995). Second, some like Tanzi and Davoodi (1997) believe corruption of public officials may play a role. Finally, it is also possible that policymakers in these countries do not fully understand potential payoffs of infrastructure investment in which case, the author would like to believe, this paper could offer some guidelines.

Are additions to infrastructure always welfare improving? Arrow and Kurz (1971) had noted that too much infrastructure could be detrimental to welfare in a theoretical framework. That is, there exists some threshold level beyond which more investment in public capital can decrease welfare. This threshold level is graphically depicted in Fig. 1 as the share of GDP devoted to infrastructure goes past 8% above benchmark (i.e., more than 14% of GDP). Hence, as Fig. 1 shows, devoting more than this to infrastructure can yield welfare losses. To make the point clearer, Table 4 tabulates how welfare gains turn into losses as more resources are devoted to infrastructure. The numbers in Table 4 correspond to the region of Fig. 1's trade-off curve where welfare gains turn into losses. The point, however, is that this threshold level does not come in until about 8% above present levels or (14% of GDP) is devoted to public capital investment. That means that for these countries there is large range where additional public capital investment is welfare improving.

In summary, results from the above steady-state experiments yield the following conclusions: (1) Infrastructure is very productive; (2) There is a wide range of additional investment in infrastructure (financed by more taxation) resulting in welfare improvements; (3) Congestion can reduce the positive effects of public

Table 4
Infrastructure–welfare trade-offs

$\%\Delta\tilde{\lambda}$	$\%\Delta\omega$
5.0	2.67
6.0	2.22
7.0	1.51
8.0	0.62
9.0	−0.42
10.0	−1.61

investment; (4) The largest welfare gains can be achieved by devoting overall about 10% of GDP to public investment.

5.4. Short-run dynamics

The model's dynamic implications are analyzed next. Studying tax policy, Judd (1987) points to the importance of adjustment paths, which over some time period can differ from the long-run effects. This section studies the effects of stochastic policy shocks in the share of GDP devoted to infrastructure that disturb the system by 1 standard deviation. Policy shocks arise as government officials priorities change due to approaching elections, lobbying, etc. More public capital available for firms' use affects relative returns. The dynamic decision rules obtained from the solution of the model describe how the variables respond to such disturbances. The experiment performed studies responses to a small persistent shock ($\rho_\lambda = 0.9$) to the share λ_t. Results for the benchmark model are pictured in impulse response functions (in percent change from steady-state values on the horizontal axis) in Fig. 2a–d. The vertical axis measures time in quarters with the shock taking place on the 21st quarter.

In order to intuitively understand these impulse responses, recall that there are two effects arising from additional infrastructure spending. The first effect (the

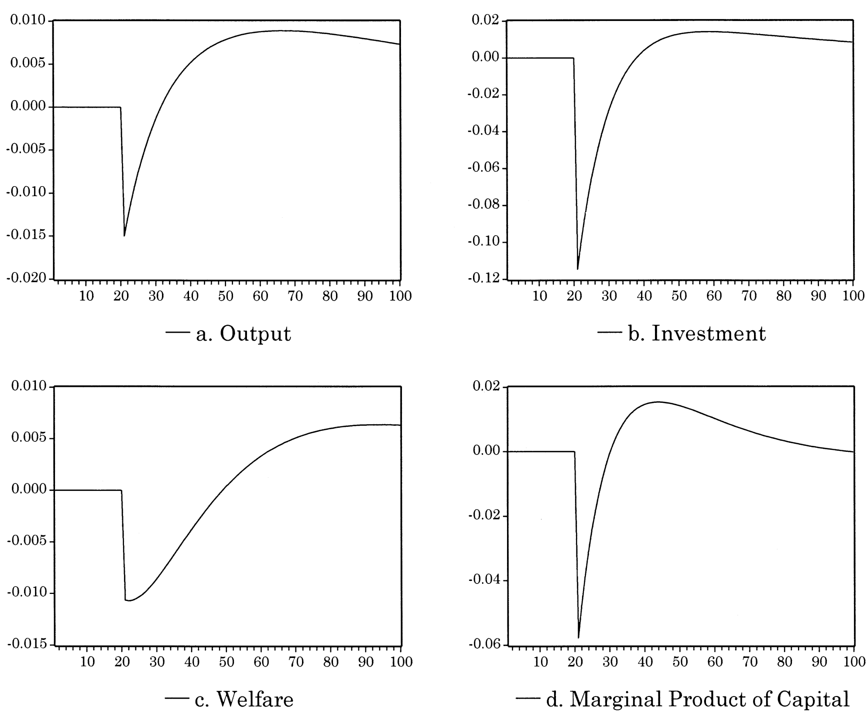

Fig. 2. Impulse responses to infrastructure-funding shock.

resource cost) decreases net-of-tax private marginal products (and, therefore, private investment) because of higher taxes. The second effect (the resource benefit) tends to raise these same private marginal products because a larger stock of public capital makes private factors more productive. Fig. 2d shows how these two effects impact on the marginal product of capital (MPK). The adverse tax effect dominates initially driving the MPK down. Consequently, private investment, output and welfare are also initially driven down by this same effect (Fig. 2b, a and c, respectively). However, the second effect (resource benefit) takes over shortly increasing the MPK. The paths of output, private investment, and welfare also rise reinforcing previous conclusions. The dynamic responses are useful in clearly depicting the paths of adjustment of macroeconomic variables when small shocks increase the amount of infrastructure by raising taxes and two opposing effects result. Higher public investment (financed by contemporary taxation) can initially have adverse effects. However, in a matter of one or two quarters the positive effects start to dominate yielding persistent benefits to the economy.

6. Conclusions

This paper develops a dynamic general equilibrium model that provides an internally consistent micro-foundations framework where various effects of infrastructure policy changes can be studied. Devoting additional resources to infrastructure investment can payoff in terms of sizable increases in GDP and private investment. More highways and public communication networks and facilities encourage private companies to invest because using these public inputs can increase productivity of private factors.

Little has been said in the recent literature about the welfare effects of infrastructure investment. This paper finds these effects can be very important in guiding policymakers' decisions. However, more infrastructure investment is found to be not always welfare improving. That is, very high levels of infrastructure can adversely affect welfare. A key contribution of this paper is providing specific quantitative recommendations for infrastructure policy that yield the largest welfare gains to citizens of seven Latin American countries. The paper identifies relevant margins to the decision of how much more to invest in public capital per year. For the seven Latin American countries in the sample, maximum welfare gains can be obtained by increasing infrastructure investment by about 4% of GDP (presently being about 6% of GDP).

Acknowledgements

The author gratefully acknowledges helpful comments from Art Blakemore, Thomas Cooley, Dennis Hoffman, Michael Melvin, Kevin Reffett, Don Schlagenhauf and two anonymous referees.

References

Arrow, K.J., Kurz, M., 1971. Public Investment, the Rate of Return, and Optimal Fiscal Policy. The Johns Hopkins Press, Baltimore, MD.

Aschauer, D., 1989. Is public expenditure productive?. Journal of Monetary Economics 23, 177–200.

Barro, R.J., 1990. Government spending in a simple model of endogenous growth. Journal of Political Economy 98, s103–s125.

Baxter, M., King, R., 1993. Fiscal policy in general equilibrium. American Economic Review 83 (3), 315–334.

Canning, D., Fay, M., 1993. The effect of transportation networks on economic growth. Columbia University Working Paper.

Christiano, L.J., 1991. Modelling the liquidity effect of a monetary shock. Federal Reserve of Minneapolis, Quarterly Review, pp. 3–34.

Christiano, L.J., Schlagenhauf, D., 1997. Solving dynamic models using a linearization method. Northwestern University Working Paper.

Easterly, W., Rebelo, S., 1993. Fiscal policy and economic growth: an empirical investigation. Journal of Monetary Economics 32, 417–458.

Edwards, S., 1995. Crisis and Reform in Latin America: From Despair to Hope. The World Bank. Oxford Univ. Press, New York.

Elias, V., 1992. Sources of Growth: A Study of Seven Latin American Economies. ICS Press, San Francisco, CA.

Flores de Frutos, R., Pereira, A., 1993. Public capital and aggregate growth in the U.S.: is public capital productive? University of California, San Diego Discussion Paper 93-31.

Ford, R., Poret, P., 1991. Infrastructure and private sector productivity. OECD Working Paper 91.

Ghez, G., Becker, G., 1975. The Allocation of Time and Goods Over the Life Cycle. National Bureau of Economic Research, New York.

Glomm, G., Ravikumar, B., 1994. Public investment in infrastructure in a simple growth model. Journal of Economic Dynamics and Control 18, 1173–1187.

Hirschman, A., 1958. The Strategy of Economic Development. Yale Univ. Press, New Haven and London.

Holtz-Eakin, D., Schwartz, A.E., 1994. Infrastructure in a structural model of economic growth. NBER Working Paper No. 4824.

Hulten, C., 1996. Infrastructure capital and economic growth: how well you use it may be more important than how much you have. NBER Working Paper No. 5847.

Judd, K.L., 1987. The welfare cost of factor taxation in a perfect-foresight model. Journal of Political Economy 95 (4), 675–709.

King, R., Rebelo, S., 1990. Public policy and economic growth: developing neoclassical implications. Journal of Political Economy 98 (5), s126–s150.

Lucas, R.E., Jr., 1987. Models of Business Cycles. Basil Blackwell, Oxford, UK.

McGrattan, E.R., 1994. The macroeconomic effects of distortionary taxation. Journal of Monetary Economics 33, 573–601.

Morrison, C.J., Schwartz, A.E., 1996. State infrastructure and productive performance. American Economic Review 86 (5), 1095–1111.

Munnell, A.H., 1992. Infrastructure investment and economic growth. Journal of Economic Perspectives 6, 189–198.

Nadiri, I.M., Mamuneas, T.P., 1994. Infrastructure and public RD investments and the growth of factor productivity in U.S. manufacturing industries. NBER Working Paper No. 4845, National Bureau of Economic Research.

Ostry, J.D., Reinhart, C.N., 1992. Private saving and terms of trade shocks. IMF Staff Papers 39, 495–517.

Rebelo, S., Vegh, C.A., 1995. Real effects of exchange rate-based stabilization: an analysis of competing theories. NBER Working Paper No. 5197, National Bureau of Economic Research.

Stiglitz, J.E., 1988. Economics of the Public Sector. W.W. Norton, New York.

Tanzi, V., Davoodi, H., 1997. Corruption, public investment and growth. IMF Working Paper 97/139.

Taylor, J.B., Uhlig, H., 1990. Solving nonlinear stochastic growth models: a comparison of alternative solution methods. Journal of Business and Economic Statistics 8 (1), 1–17.

Urrutia, M. (Ed.), 1991. Long Term Trends in Latin American Economic Development. Inter-American Development Bank, Washington, DC.

Uzawa, H., 1974. Sur la theorie economique du capital collectif social. Cahiers du Seminaire d'Econometrie, pp. 103–122.

1994 World Development Report. The World Bank, Washington, DC.