Macroeconomic and Welfare Effects of Public Infrastructure Investment in Five Latin American Countries*

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November 15, 2007

Abstract

It has been widely documented that investment in infrastructure is important for economic growth, but little work has been done in relation to the impact of infrastructure investment among other macroeconomic variables. This paper develops a Dynamic Stochastic General Equilibrium (DSGE) model of a small open economy to study the effects of public investment in infrastructure on output, consumption, private investment, trade balance and welfare. The model is parameterized and solved for five representative countries from The Initiative for the Integration of Regional Infrastructure in South America (IIRSA), which include: Bolivia, Chile, Brazil, Venezuela and Argentina. I also analyze the growth effects on GDP by increasing or decreasing the effectiveness index of infrastructure in each of these countries. Naturally output will grow at a larger rate, if infrastructure is handled with greater efficiency.

Keywords: Infrastructure, Economic Growth, Welfare.
JEL classification: H54, O40, D60.

*I would like to thank Luis Miguel Castilla, Jose Pineda, Pablo Sanguinetti, Felix Rioja, Paulo Regis and participants in the 2007 LACEA-LAMES annual meeting for useful comments and suggestions. I gratefully acknowledge financial support from the Corporación Andina de Fomento (CAF). I also thank Yesmina Andrade and Joaquin Morales, who provided able research assistance. The views expressed in this paper are only mine and do not represent those of the CAF or INESAD.

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1 Introduction

Although infrastructure was incorporated in the theory of growth literature by Arrow and Kurz (1970) and Weitzman (1970), people began to study the theme seriously after the seminal work of Barro (1990). Barro's model is well known, because he introduces government spending as a variable in the production function. The existence of constant returns to capital and government spending imply that the economy is capable of endogenous growth.

Coinciding with this new birth of the growth literature, empirical literature related to infrastructure is also showing up. Infrastructure becomes an important source of growth as shown by Aschauer (1989a) and Aschauer (1989b). These works concentrated in estimating production elasticities of government expenditure, using aggregated data for countries, mainly the U.S. There are also cross-country studies that emphasize the role of infrastructure for a country's growth.

Papers concerning this subject have typically used regressions 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 the analysis of important general equilibrium feedback effects among key macroeconomic variables and welfare.

This paper examines infrastructure as a platform for productive transformation in Latin America, using a Dynamic Stochastic General Equilibrium (DSGE) model for 5 Latin American countries. This type of new generation model will allow us to analyze the macroeconomic and welfare impact of public infrastructure. First, I analyze the macroeconomic impact of increasing public infrastructure investment as a share of GDP on output, consumption, private investment and trade balance. Second, I compute the welfare gains associated with an increase of infrastructure investment as a share of GDP. And finally I inspect how the GDP rate of growth of each country changes when the infrastructure effectiveness index varies. An important point is that the model is capable to yield accurate quantitative predictions that can be used for policy analysis.

I circumscribe the analysis to 5 Latin American countries that belong to the Initiative for the Integration of Regional Infrastructure in South America (IIRSA). The chosen countries are: Bolivia, Chile, Brazil, Venezuela and Argentina. These countries are representative for the integration and development hubs identified by the IIRSA. The case of Bolivia will be examined for three reasons. First, it has a strategic location in South America; second, it belongs to five hubs (Andean, Southern Andean, Paraguay-Paraná Waterway, Central Interoceanic and Peru-Brazil-Bolivia); and third, it is a country with very low levels of infrastructure. The case of Chile will be examined because it has demonstrated excellent economic performance in recent years. Brazil represents the biggest and most important country in South America. Finally, Argentina and Venezuela represent the two extremes of the IIRSA: Venezuela in the north taking part in the Andean and the Guianese Shield hubs, and Argentina in the south taking part in the Southern Andean, Capricorn, Southern, Paraguay-

Paraná and Mercosur-Chile hubs. Furthermore, Venezuela and Argentina have had the highest growth rates in 2006, with 10.5% and 8.8% respectively.[1]

Results show that the macroeconomic and welfare effects of an increase in public infrastructure investment as a share of GDP depend directly on the actual share of public investment in infrastructure. Countries with higher shares of public investment will enjoy higher welfare gains and higher rates of GDP growth.I am using different values for the two key parameters of the model, which are the effectiveness parameter and the share of public capital in the production function. Concretely, I calibrate different values for these parameters for each country, since my aim is to make comparisons between countries.[2]

Countries like Bolivia and Chile would be able to grow at rates higher than 6 percent only by raising their investment in public infrastructure by only 2 percent more. Argentina and Venezuela are the countries that assign a lower proportion of their GDP to public investment in infrastructure, which translates to smaller potential of reaching important rates of growth and welfare gains. Venezuela needs to invest 6 percent of its GDP in public infrastructure to grow at 5.75 percent.

Using the model I developed, we find that public infrastructure investment leads to a substitution and an income effect. These effects are visible over welfare, consumption, private investment and wages. The substitution effect appears because the new public infrastructure is financed by an income tax and this affects negatively the marginal product of labor, while the income effect appears because a larger stock of public infrastructure affects positively the marginal product of labor. If the first effect dominates the second effect, we should expect first, a reduction in wages. This reduction in wages affects consumption directly and therefore welfare, which is measured in terms of consumption.

There can be also a reduction in private investment which as Rioja (2001), I call a crowding out effect. Although, this crowding out effect emerges for very large shares of public infrastructure investment, except for Venezuela, where it emerges when the country invests 6 percent of GDP inpublic infrastructure, they have to be considered while making policy decisions, since they restrict private investment. It shows that in most cases it is better to have an investment in public infrastructure of 4 percent of GDP rather than a 6 percent since private investment continues to grow, but it does so at a decreasing rate. For instance Brazil has a change in private investment (as a share of GDP) of 4.05 percent at 4 percent increase in infrastructure investment, while it has a change of only 3.16 percent when infrastructure investment increases by 6 percent of GDP.[3]

The varying results in terms of magnitudes and effects, made me perform some policy experiments with the two key parameters, which are the effectiveness and public capital share parameters. Both parameters are related one to each other. I find that the results of changing the effectiveness of public infrastructure depend strongly on the actual levels of efficiency. Countries

[1] The model can be easily applied to any other Latin American country.

[2] Rioja (2001) and Rioja (2003) find the opposite: countries with lower stocks of public capital will enjoy higher growth and welfare gains.

[3] The crowding out effect was first discovered econometrically by Aschauer (1989c).

like, Bolivia which are inefficient in terms of infrastructure management could reach important rates of GDP growth just by increasing public investment in infrastructure by 1 percent, if efficiency could improve up to or close to the industrialized countries levels. Here, I have calibrated these parameters for each country. In the literature, there is no consensus about which is the exact value that these parameters should have, nevertheless, the results obtained with the model developed here, are consistent and feasible.

The paper is organized as follows. Section 2 presents the dynamic stochastic general equilibrium model used. Section 3 calibrates the model for each of the five countries selected. Section 4 reports the log-run macroeconomic and welfare effects, as well as the policy experiments with the key parameters of the model. Finally, Section 5 presents the conclusions.

2 The Model

In this section I develop a simple dynamic stochastic general equilibrium (DSGE) model of public infrastructure investment. It is a two-sector DSGE model of a small open economy. The model is based on Rioja (2001), but modified to be stochastic. This modification is significant as it allows for analysis and at the same time for growth and business cycles of the economy.

The model belongs to the neoclassical tradition. These RBC models are simpler since they do not incorporate imperfect competition and/or sticky prices as New-Keynesian models do. Furthermore, as I am not going to deal with monetary issues and my main goal is to develop quantitative implications in a simple framework, important factors are not lost by not using the more elaborated New-Keynesian models.

2.1 Households

There is an infinitely-lived representative household living in a single-good, stochastic economy.[4] Household's preferences are given by:

$$E_0 \sum_{t=0}^{\infty} \beta^t u(c_t, l_t) \tag{1}$$

where $\beta \in (0,1)$, $c_t \geq 0$ and $l_t \geq 0$ denote consumption and leisure at time t respectively; $u(\cdot)$ is an instantaneous felicity function, strictly concave and twice continuously differentiable.

With one unit of time per period, households divide it between leisure l_t and labor n_t.

$$1 = l_t + n_t \tag{2}$$

The household's budget constraint is given by:

$$c_t + i_t + q_t b_{t+1} \leq w_t n_t + R_t k_t + b_t \tag{3}$$

[4] The same as assuming that there is a large number of infinitely-lived households.

Households supply labor and earn wages (w_t). They own physical capital (k_t), from which they earn a return (R_t) by renting it to firms. They earn also, a return on their net holdings of foreign bonds (b_t), which they can buy and sell at the world interest rate R_t.[5] As they own the capital, they spend on investment (i_t). They consume (c_t) and purchase foreign bonds at a price q_t. The bond is a risk-free bond that delivers one unit of consumption next period.

Typically, private capital evolves according to,

$$k_{t+1} = i_t + (1 - \delta_k)k_t \tag{4}$$

where δ_k is the depreciation rate of capital.

As always, we have to impose a transversality condition or no-Ponzi game condition to foreign borrowing

$$\lim_{t\to\infty} \frac{b_t}{(1+R)^t} = 0$$

This condition prevents households to borrow forever.

2.2 Firms

The representative firm uses three factors of production to produce the final good. The production function is given by:

$$y_t = A_t f(G_t^*, k_t, n_t) \tag{5}$$

where G_t^* is the effective aggregate stock of public infrastructure (or public capital), k_t is private capital, n_t is labor and A_t is a technological shock, which I will assume follows an AR(1) process.

The effective public stock of infrastructure is provided publicly. I assume that private agents cannot provide this input, because it can be hard to exclude free-riders or to charge users a competitive price.[6] This effective stock is related to a raw stock of infrastructure G_t according to:

$$G_t^* = \theta G_t \tag{6}$$

where $\theta \in (0,1)$ is a measure of effectiveness. Raw infrastructure evolves according to the following equation:

$$G_{t+1} = I_t + (1 - \delta_g)G_t \tag{7}$$

where I_t is the amount invested in public infrastructure and δ_g is its depreciation rate.

In each period, the representative firm takes R_t and w_t as given and rents capital and labor from households to maximize net-of-tax profits

$$\max_{\{k_t, n_t\}} (1 - \lambda_t)y_t - R_t k_t - w_t n_t \tag{8}$$

where λ_t is the tax rate on output.

[5] As we are assuming that this is a small open economy, the interest rate R_t is given.

[6] Rioja (2001) uses the same assumption.

2.3 Government

The government only invests in public infrastructure I_t and finances this investment stream by taxing output. So, the government's budget constraint is given by:

$$I_t = \lambda_t y_t \tag{9}$$

Notice that λ_t can be interpreted also as the investment in public infrastructure share of GDP.

2.4 Foreign Sector

Finally, there is a foreign sector where the trade balance is the difference between output (y_t) and domestic absorption ($c_t + i_t + I_t$).[7] The trade balance in period t (TB_t) is given by the evolution of the net holdings of foreign bonds.

$$TB_t = q_t b_{t+1} - b_t \tag{10}$$

Equation (10) represents also the Balance of Payments of the country. To close the model it is necessary to also include a law of movement for bonds. I assume that bonds follow an AR(1) process. With this assumption there is no need to model the foreign sector in deep. Furthermore, as public infrastructure is totally financed by taxes, public infrastructure investment should not have any effects on the trade balance.

2.5 Market-Clearing Condition

The goods market-clearing condition is given by

$$c_t + i_t + I_t + TB_t = y_t \tag{11}$$

which states that the supply and demand must be equal.

2.6 Stochastic Competitive General Equilibrium

A *Stochastic Competitive General Equilibrium* (SCGE) for this economy is a set of allocation rules for $c_t(x)$, $l_t(x)$, $n_t(x)$, $i_t(x)$, $k_{t+1}(x)$, $I_t(x)$, $TB_t(x)$, $y_t(x)$, and $G_t(x)$, contingent prices $R_t(x)$, $w_t(x)$ and $q_t(x)$, numbers λ_t and θ_t, and law of motions of the exogenous state variables $x = A_t, b_t$ such that:

i) Given $k_0 > 0$, $R_t(x)$, $w_t(x)$, $q_t(x)$ and x, the contingent plans for $c_t(x)$, $l_t(x)$, $n_t(x)$, $i_t(x)$, $k_{t+1}(x)$ solve the households' optimization problem.

ii) For each history of x in each period t, given $R_t(x)$ and $w_t(x)$, the contingent plans for $n_t(x)$, $k_{t+1}(x)$, $y_t(x)$, and $G_t(x)$, solve the firms' optimization problem.

[7] Notice that, here, absorption includes investment in public capital (infrastructure) as well as investment in private capital.

iii) In each period t, the government satisfies its budget constraint given by equation (9).

iv) In each period t, markets clear, i.e. equation (11) holds.

3 Functional Forms and Calibration

The model just described is difficult to solve analytically. The alternative is to use numerical methods. Therefore, I will adopt functional forms for the utility and productions functions and give values to the parameters of the model to match exactly real data of each of the five countries. Bearing in mind that I will calibrate the model for Bolivia, Argentina, Brazil, Chile and Venezuela, one has to be very rigorous at this stage to simulate exactly these economies. Failure to exactly match the National Account ratios and standard deviations of key variables from these economies will result in the extraction of inadequate results and in the difficulty of giving precise policy implications.[8]

The functional form for the utility function is given by:

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

The production function is assumed to be of the Cobb-Douglas type, including the public capital as an input

$$y_t = A_t G_t^{*\phi(\theta)} k_t^{\alpha} n_t^{1-\alpha}$$

Notice that the coefficient of public capital ϕ is a function of θ, the effectiveness parameter, as in Hulten (1996). The reason for these relation is that new public investment is more productive the higher the degree of effectiveness in the economy. If ϕ did not depend on θ, an increase in public investment would have the same impact whether effectiveness was low or high.

The exogenous shocks A_t and b_t, follow AR(1) processes given by:

$$\ln(A_{t+1}) = A_0 + \rho^A \ln(A_t) + \sigma^A \varepsilon_{t+1}^A$$

$$\ln(b_{t+1}) = \xi_1 + \rho^b \ln(b_t) + \sigma^b \varepsilon_{t+1}^b$$

For the parameterizations, three parameters have been assumed constant and the same for the five countries. Those parameters are the utility curvature parameter σ, the depreciation rate of private capital δ_k and the depreciation rate of public capital δ_g. I assign a value of 2 to σ, which is a number consistent with the macro literature. The depreciation rate of private capital δ_k is set to a standard value of 10 percent per year or equivalently a 2.41 percent per quarter. According to the World Bank (World Development Report 1994), the

[8] Most authors avoid this stage.

depreciation rate of public capital δ_g has been estimated to be twice of the depreciation rate of private capital.

As my aim is to make comparisons between countries, I have computed the infrastructure effectiveness parameter θ for each country using the so called "Loss Indicators" of the World Bank. Table A1 in the appendix shows the calculations for each country, using the loss indicators for power, telecommunications, paved roads and water. Most of these loss indicators have been taken from the World Development Report 1994 which correspond to the year 1990. For Argentina and Brazil these indicators have been actualized using the data of Fay and Morrison (2005). The missing values have been completed using averages from 1990, in particular for the water provision. A country loss index across infrastructure types is calculated by taking a weighted loss for each country in the study and comparing it with the weighted average of industrialized countries.[9]

The weighted loss for Brazil is 21.15 percent which represents an infrastructure effectiveness of 78.85 percent, while the weighted average loss in industrialized countries is 10 percent, this means that they are 90 percent effective. Suppose the effectiveness index θ is normalized to 1 for industrial countries: infrastructure is highly effective. Then this implies that θ for Brazil is about 87.66 percent (=0.7885/0.9). This rationale is applied for each country to compute the values of θ shown in table 1.

Next, the infrastructure share parameter ϕ must be related to θ. I assume also that this relation should be different for each country, as different combinations of private capital, public capital and labor will configure the output. Unfortunately there are no country-specific regressions that estimate this parameter, so I have calibrated it using as benchmark, the computations performed by Rioja (2003). Considering the value of θ fixed, I look for the value of ϕ that increases GDP in the long run by 3.74 percent, when public investment in infrastructure is increased by 1 percent. The value of 3.74 percent is the average value found by Rioja (2003) for Latin American countries. Notice that, the values for ϕ range from 0.01457, the lowest value for Venezuela, to 0.0923, the highest value for Bolivia. The correlation between θ and ϕ is linear within a country, but not between countries. This means that, within a country a higher degree of effectiveness is associated with a larger value of public capital share. But, a country with a higher value of θ than another country would not have necessarily a higher value of ϕ than the other country. For example, Brazil which has the highest level of effectiveness, has a lower value of public capital share than Bolivia, which is the least efficient country.

I assume that the five countries are small open economies, so they take the international real interest rate as given. Using monthly data for the Libor rate, I obtain an average rate of 1 percent per quarter. This parameter choice for the interest rate implies that the discount rate, β, equals 0.99.

[9] I use the same weights as in Rioja (2003), this means 0.40, 0.10, 0.25, 0.25 for the Latin American countries and 0.50, 0.09, 0.30, 0.11 for industrialized countries, for power, telecom, paved roads and water systems respectively.

Table 1: Calibrated Parameters

Parameter	Countries' Parameter Values				
	Argentina	Bolivia	Brazil	Chile	Venezuela
σ	2	2	2	2	2
θ	0.8066	0.6865	0.8766	0.7793	0.7749
ϕ	0.02455	0.0923	0.0442	0.0564	0.01457
λ	0.0046	0.028	0.0114	0.0157	0.0013
α	0.2731	0.19	0.2674	0.2741	0.2398
δ_k	0.0241	0.0241	0.0241	0.0241	0.0241
δ_g	0.0482	0.0482	0.0482	0.0482	0.0482
γ	0.49	0.64	0.59	0.55	0.62
β	0.99	0.99	0.99	0.99	0.99
A_0	0.001075	-0.000154	0.007761	0.349	0.1054
ξ_1	0.194	0.1095	0.1592	-0.8989	-3.836
ρ^A	0.908405	0.30509	0.951991	0.395411	0.677768
ρ^b	0.580059	0.645147	0.812591	0.464554	0.089395
σ^A	0.01871	0.011228	0.150859	0.016599	0.03907
σ^b	0.126363	0.097912	0.120855	0.085431	0.310509

The value of the private capital share in the production function, α, has been calibrated for each country. Argentina, Chile and Brazil have values for α closer to 0.27, which is a reasonable value, since for developed countries this value is closer to 0.3. Venezuela and Bolivia have lower values, in particular it calls the attention the lower value for Bolivia which is 0.19. This is explained by the lower rate of investment that this country has had in the last years. The rate of investment in Bolivia has been12 percent on average. These values are consistent with other neoclassical general equilibrium models, done for each of the selected countries.[10]

The consumption share γ has been calibrated to match the Global Participation Rate (GPR) for each country.[11] This parameter differs from the value used by Rioja (2001) and Rioja (2003) where he considered a fixed value of 0.35. Here, this parameter has a value between 0.49 and 0.64.

The parameters that correspond to the exogenous shocks A and b have been estimated with the corresponding Ordinary Least Squares (OLS) regressions. Some slope coefficients have been modified based on the regression results, to calibrate the trade balance for each country. In all cases I used quarterly data for the GDP and external debt for each country. The series for external debt correspond to multilateral debt and have been extracted from the Bank of International Settlements. The series have been seasonally smoothed using the X12 method and the slope has been extracted using the Hodrick-Prescott filter.[12]

[10] See Quiroz, Bernasconi, Chumacero and Revoredo (1991) for Bolivia, Kehoe (2003) for Argentina, Bugarin, de Goes Ellery Jr., Silva and Muinhos (2005) for Brazil, Medina and Soto (2005) for Chile, and Hausmann (2001) for Venezuela.

[11] The Global Participation Rate is defined as the ratio between the economic active population and the population in age of work.

[12] The law of movement of bonds has been estimated in logarithms only for Brazil, Bolivia

Finally the value of λ has been computed using the World Bank Data Base of Investment in Infrastructure. This Data Base has yearly data of public and private investment in infrastructure for 9 Latin American countries, including the ones considered here in this study. The investment in infrastructure is divided by sectors, including roads, railways, electricity, gas, water and telecom and the values have been collected from different works done in each country. Nevertheless, the only problem with these data is that it covers the period 1980-1998. I tried to complete the series with more up-to-date values, but I found only isolated values. I have been able to complete the data only until the year 2001, using the paper of Calderón and Servén (2004). So, the National Account ratios that I used correspond to the average for the last ten years (1990-2001). These ratios are shown in table 2.

Table 2: Calibrated Values

		GPR	$\frac{Consumption}{GDP}$	$\frac{Investment}{GDP}$	$\frac{I.inInfrastructure}{GDP}$	$\frac{TradeBalance}{GDP}$
		$\overline{n}$	$\overline{c}/\overline{y}$	$\overline{i}/\overline{y}$	$\overline{I}/\overline{y}$	$\overline{TB}/\overline{y}$
Argentina	Data	0.4592	0.8188	0.1930	0.0046	-0.0164
	Model	0.45911	0.81902	0.19299	0.0046	-0.016608
Bolivia	Data	0.62	0.8574	0.1311	0.0280	-0.0166
	Model	0.62016	0.85727	0.13111	0.0280	-0.016382
Brazil	Data	0.561	0.817	0.1877	0.0114	-0.0162
	Model	0.56039	0.81759	0.18767	0.0114	-0.01666
Chile	Data	0.5383	0.7579	0.1915	0,0157	0,0349
	Model	0.53548	0.75756	0.19153	0.0157	0.035204
Venezuela	Data	0.656	0.666	0.17	0.0013	0.1627
	Model	0.65081	0.66463	0,17002	0.0013	0.16406

Note: GPR=Global Participation Rate

Naturally, $\overline{I}/\overline{y}$ corresponds to the value of λ and it is exactly the same as in the data since it is a value extracted directly from there.[13] The data value of $\overline{n}$, which is the Global Participation Rate, corresponds to 2005 values extracted from the "Compas Laboral", Interamerican Development Bank. In the next section I report the long-run effects of increasing this value.

4 Long-run and Welfare Effects

4.1 Long-run Effects

This section analyses the long-run macroeconomic and welfare effects of increasing public infrastructure investment in each of the five countries. In particular, I analyze the effects on GDP, consumption, private capital investment, trade balance, labor and wages. These effects are also analyzed using time

and Chile, because they report a deficit in trade balance. For Venezuela and Chile we needed negative values, so logarithms cannot be used.

[13] These values are also very similar to the ones used by Calderón and Servén (2004).

series calculated with the second order approximation technique proposed by Schmitt-Grohé and Uribe (2004b), but since the time series calculations showed negligible differences to those of the steady-state values, I will present all of the results using the steady-state values. The fact that the second-order approximation results do not differ from the steady-state results means that volatilities or second order effects do not play an important role in explaining the effects of infrastructure investment.[14]

The following table shows the effects of a 2, 4 and 6 percent increase of public infrastructure investment on the aforementioned macroeconomic variables. These percentage changes are changes of public infrastructure investment as a share of GDP and are within a feasible and observable range.

Table 3: Macroeconomic Effects of Public Infrastructure Investment (percent change)

$\Delta\lambda$	Δy	Δc	Δi	Δtb	$\Delta labor$	$\Delta wage$
Argentina						
2%	5.24	3.06	3.12	0	0.0332	3.09
4%	6.58	2.25	2.30	0	0.0246	2.27
6%	7.06	0.60	0.61	0	0.0066	0.60
Bolivia						
2%	6.63	4.35	4.43	0	0.0308	4.40
4%	10.9	6.22	6.34	0	0.0433	6.29
6%	13.99	6.82	6.95	0	0.0472	6.90
Brazil						
2%	5.91	3.69	3.77	0	0.0326	3.74
4%	8.44	3.97	4.05	0	0.0349	4.02
6%	9.83	3.10	3.16	0	0.0275	3.14
Chile						
2%	6.17	4.20	4.02	0	-0.0833	4.10
4%	9.27	5.05	4.83	0	-0.0993	4.93
6%	11.16	4.59	4.38	0	-0.0906	4.48
Venezuela						
2%	4.70	3.24	2.60	0	-0.2181	2.83
4%	5.48	1.56	1.25	0	-0.1067	1.36
6%	5.75	-0.75	-0.60	0	0.0524	-0.66

First, it can be seen that by increasing public infrastructure investment by 2 percent, the impact on GDP growth is in the range between 4.7 percent and 6.63 percent. Bolivia and Chile, which are the countries with the largest public infrastructure investment shares, are able to reach GDP rates of growth larger than 6 percent. This result contrasts with previous literature, where it is found that the countries with the lowest rates of investment in public infrastructure are the ones that reach larger rates of GDP growth.

[14] The second-order approximation results are available upon request from the author.

In Venezuela, where investment in infrastructure is only 0.13 percent of GDP, 2 and 6 percent increases in public infrastructure investment as a share of GDP can increase GDP by 4.7 percent and up to 5.75 percent. Consider then, the opposite case of Bolivia, which has 2.8 percent of GDP invested in public infrastructure. There, the growth gain of increasing public infrastructure investment by 2 and 6 percent can increase GDP between 6.63 percent and up to almost 14 percent

If we think on this issue as an elasticity, an elasticity of growth with public infrastructure investment, I can affirm that this elasticity is larger than one in all cases and turns out even larger when a country has already an important stock of public capital. So, countries that are not investing too much in public capital will find it difficult to reach higher rates of output growth, since the marginal increases of output growth are inferior.

It is also noticeable in the table that the rate of output growth is always an increasing function of public infrastructure investment (for these rates of growth of public infrastructure investment). But, consumption, private capital investment, labor and wages present rates of growth that increase until some point and then begin to decrease. This issue depends strongly on the initial stock of public capital. For example, all the variables have an increasing rate of growth for Bolivia, but a decreasing rate for Argentina and Venezuela. Furthermore, in the case of Venezuela, when public infrastructure investment is raised by 6 percent, consumption, private investment and wages report a negative rate of change.

This fact means that public investment in infrastructure as a share of GDP (represented by λ) has two effects. Let's call them an income effect and a substitution effect. These effects affect the marginal products of capital and labor, given by $r_t = (1-\lambda)\alpha y_t/k_t$ and $w_t = (1-\lambda)(1-\alpha)y_t/n_t$ respectively.[15] Recall that the new infrastructure is financed by an income tax represented also by λ. So, an increase in λ decreases the wage rate. This is the substitution effect. Notice that this increase in λ cannot affect the net-of-tax rate of return r. This fact implies that, ceteris paribus, inputs need to adjust to keep the marginal product of capital equal to r.

The second effect -income effect- works in opposite direction, as λ increases, the raw stock of public capital G_t increases (see equation 7) and by equation 6 the effective aggregate stock of public infrastructure G_t^* also increases. So the marginal product of labor increases and the wage rate also increases. Of course this income effect tends to increase also the marginal product of capital. Again inputs need to adjust to maintain r fixed. In sum, the substitution effect and income effect offset each other, keeping the net-of-tax marginal product of capital constant at r.

The results shown in table 3 are reinforced by the graphs shown in the appendix, where it becomes clear that after some threshold point the substitution effect dominates the income effect. In the graphs, it can be seen that raising λ has at first a positive effect, which later diminishes and eventually becomes

[15] Rioja (2001) calls this effects the resource cost and the resource benefit.

negative. This inverse U effect is valid for private investment, consumption and wage. Furthermore, the magnitude of change in these three variables is similar.

Notice also that the maximum point of this inverse U is closer to 0 in the horizontal axis for countries with lower infrastructure investment as a share of GDP, as in Argentina and Venezuela. This means that the substitution effect tends to be stronger in countries with lower stocks of public capital. In other words, countries with lower levels of infrastructure investment as a share of GDP are more sensitive to income taxes, used to finance the new public infrastructure.[16]

Table 3 also shows that public investment in infrastructure has no effect on the trade balance and a negligible effect on labor. The latter result is corroborated by the graphs in the appendix, from which it is clearly seen that public infrastructure investment does not affect labor supply. The fact that private investment decreases as public investment increases means that public investment can generate a crowding out effect. Nevertheless this crowding out effect only appears at a certain point and it can be interpreted as a point that restricts public investment. In other words a government that does not want to reduce the rate of growth of private investment as a share of GDP can invest in public infrastructure only until that point.

The results found in this section imply a marked policy implication. A government will be restricted in its public infrastructure investment decisions by the private investment share of GDP. Actually, it is also restricted at the same time by consumption and wages, because these variables also present the U inverse effect. This constraint represents a financing constraint. Countries with lower levels of public infrastructure investment or public capital stock will be constrained by the fact that trying to finance larger levels of public investment will result in a depression of consumption and private capital investment.

4.2 Welfare Effects

The welfare gains associated with an increase in infrastructure investment are computed as in Schmitt-Grohé and Uribe (2004a). I measure welfare as the conditional expectation of lifetime utility as of time zero, that is,

$$welfare = V_0 \equiv E_0 \sum_{t=0}^{\infty} \beta^t u(c_t^j, l_t^j) \tag{12}$$

where c_t^j, l_t^j are the contingent plans for consumption and leisure, respectively.

I compute the welfare cost/gain of an increase in public infrastructure investment relative to the optimized rule as follows: Consider two infrastructure regimes, a reference infrastructure regime denoted by r and an alternative infrastructure regime denoted by a. This alternative regime will be of course, the regime with a higher level of public infrastructure. So, I define two welfare measures associated with both regimes using equation (12), where $j = r, a$.

[16] Notice also that output growth shows this inverse U effect, but for larger and unfeasible rates of change of λ.

Let μ denote the welfare cost/gain of adopting the optimal regime a instead of the reference policy regime r. I measure μ as the fraction of regime r's consumption process that a household would be willing to give up to be as well off under regime r. Formally, μ is implicitly defined by

$$V_0^a \equiv E_0 \sum_{t=0}^{\infty} \beta^t u((1-\mu)c_t^r, l_t^r) \tag{13}$$

For the particular functional form for the period utility function, the welfare cost/gain is computed using the following formula:

$$welfare\ cost = \mu \times 100 = \left\{ 1 - \left[\frac{(1-\sigma)(1-\beta)V_0^a + 1}{(1-\sigma)(1-\beta)V_0^r + 1} \right]^{\frac{1}{\gamma(1-\sigma)}} \right\} \times 100 \tag{14}$$

In table 4, I report the welfare cost/gain for the five economies.[17] The results are very similar to those found in the previous section related to macroeconomic effects. In particular, the welfare gains stream is similar in magnitude and in form to the streams of consumption, private investment and wage, as can be seen clearly in the appendix. This inverse U pattern implies that there is one maximum level of welfare that can be reached with a specific level of public infrastructure investment. The last column of table 4, reports this value for each country.

Table 4: Welfare Effects of Raising Infrastructure Investment

	$\Delta\lambda$	2%	4%	6%	Maximum Level
Argentina	Δw	-3.03	-2.23	-0.59	-3.03 ($\Delta\lambda = 2.46\%$)
Bolivia	Δw	-4.32	-6.17	-6.77	-6.8 ($\Delta\lambda = 9.2\%$)
Brazil	Δw	-3.66	-3.94	-3.08	-4.02 ($\Delta\lambda = 4.44\%$)
Chile	Δw	-4.28	-5.15	-4.68	-5.15 ($\Delta\lambda = 5.67\%$)
Venezuela	Δw	-3.50	-1.69	0.81	-3.70 ($\Delta\lambda = 1.43\%$)

It seems that welfare gains as output gains are also associated with the initial level of public infrastructure investment. Countries with lower stocks of public capital experience lower welfare gains and countries with larger stocks experience larger welfare gains. An exception to this "rule" is Venezuela when it invests 2 percent of GDP in public infrastructure. Although this country has a lower stock of public capital than Argentina, it experiences a welfare gain of 3.5 percent, while Argentina experiences a gain of only 3.03 percent.

The maximum levels of welfare differ for each country. Naturally, Bolivia and Chile are the countries that can reach the highest levels of welfare, although they need larger levels of infrastructure investment as a share of GDP. Argentina and Venezuela can reach a maximum welfare gain of 3 percent and 3.7 percent respectively, and they need to raise their levels of public investment in infrastructure by 2.46 percent and 1.43 percent respectively. These maximum levels also depend on the initial, stock of public capital, except for Venezuela.

[17] The minus sign of all the values represent a negative cost, or in another words a gain.

4.3 Significance of Effectiveness

In general, the results of any General Equilibrium model depend on the parameters used: so, precise and accurate parameter values are needed to give accurate policy implications. The key parameters of the model used in the paper are the effectiveness parameter θ and the public capital share in the production function parameter ϕ. This subsection analyzes the effects of increasing and decreasing the effectiveness of public capital on GDP, when infrastructure investment increases by 1 percent. Rioja (2003) makes a similar exercise, under the rationale that new public investment is more productive the higher the degree of effectiveness in the whole system. I make the same exercise, but assuming that for each value of θ, the associated values of ϕ differ for each country.

Many papers have been written to estimate the share of public infrastructure parameter ϕ, also known as the elasticity of infrastructure (see Zugasti (2001)). Using different econometric techniques, different values have been estimated for this parameter. This many different results do not allow me to be confident about the values used in the parameterizations. It would be better to have country regressions. Nevertheless, the results obtained are in concordance with reality, since they reflect reasonable rates of GDP growth. Consider that in the last years, Latin America's rate of growth has been on average around 4 percent, a rate lower than in Asia (around 7 percent) and even lower than in Africa (around 5 percent).[18]

Table 5 shows the net effects of raising public investment by 1% of GDP (i.e., raising λ by 1 percent) under different degrees of effectiveness. I change the infrastructure effectiveness index θ from 0.2 to 1. Recall that the closer θ is to 1, the more effective the public capital stock and the larger the benefit that firms get. For all the countries considered in the study, it can be seen that as public capital turns out more effective, the growth gains are larger.

Table 5: Long-Run Effects of changing the effectiveness parameter θ

Effect. Index	Argentina	Bolivia	Brazil	Chile	Venezuela
θ	$\%\Delta Y$	$\%\Delta Y$	$\%\Delta Y$	$\%\Delta Y$	$\%\Delta Y$
0.2	0.58	0.80	0.49	0.59	0.84
0.3	1.07	1.34	0.94	1.15	1.38
0.4	1.57	1.95	1.40	1.65	1.92
0.5	2.08	2.53	1.87	2.16	2.20
0.6	2.59	3.19	2.34	2.69	2.75
0.7	3.12	3.83	2.83	3.31	3.30
0.8	3.64	4.55	3.32	3.87	3.86
0.9	4.18	5.24	3.82	4.44	4.42
1	4.73	5.97	4.34	5.03	5.00

Imagine that our five Latin American countries would be able to reach industrial countries in the degree of effectiveness ($\theta = 1$). Bolivia's GDP could increase by 6 percent, Argentina's GDP could increase by 4.73 percent, Chile

[18] See Velasco (2005).

and Venezuela's GDP could increase by 5 percent and finally Brazil's GDP could increase by 4.34 percent. Recall that Brazil is the country with the highest index of effectiveness, while Bolivia is the country with the lowest index. So, I can assert that countries that are not efficient in using their infrastructure could attain higher rates of GDP growth by raising their effectiveness than countries that are already using their infrastructure in a more efficient way.

On average, infrastructure in these five countries is 65 percent effective. By the results on table 3, we can see that on average these countries' GDP would grow 3 percent if public infrastructure investment rises by 1 percent. If effectiveness was lower, say $\theta = 0.3$, increasing investment by 1 percent of GDP would raise GDP by only around 1 percent also.

Not shown in the table are the different values of ϕ associated with the values of θ. These values are country-specific and range from 0 to 0.14. Various authors have estimated the elasticity of infrastructure for a sample of many countries. Among these authors I can mention Barro (1990) who estimated a value of 0.13 for a sample of 118 countries for the period 1960-1985, Easterly and Rebelo (1993) who estimated a value of 0.16 for a sample of developed countries, Nourzad and Vrieze (1995) who estimated a range of values between 0.045 and 0.055 for a sample of OECD countries for the period 1963-1988 and Calderón and Servén (2002) who estimated a value of 0.16 for a large panel data set of 101 industrial and developing countries. In sum, the values used in the parameterizations agree with the values estimated by the empirical literature.

Three conclusions can be extracted from this policy experiments. First, there is a positive relation between efficiency and growth. As countries turn out more efficient (i.e. maintain their roads, provide services with high quality, reduce corruption, etc.) the impact over GDP of a raise in public infrastructure investment is larger. Second, the GDP effect depends on the actual level of effectiveness. The marginal increase in the GDP rate of growth is larger when a country has a lower index of effectiveness. Third, good individual estimates for the parameters θ and ϕ and its correlations are needed. The use of calibrated values for each country gives us some insights, though.

5 Conclusions

This paper presents a general equilibrium model used to quantify the long-run macroeconomic and welfare effects of an increase in public infrastructure investment as a percentage of GDP. The model is dynamic, stochastic, and internally consistent, which means that it has been accurately calibrated for each of the five Latin American countries selected for the study. Jemio (2006) stresses the importance of using general equilibrium models to analyze the impact of infrastructure and this paper contributes to this branch of the literature by presenting a simple model of a small open economy that through a tough methodology answers the question: Which proportion of GDP should a country invest in infrastructure to attain a productive transformation.?

One of the principal findings of this paper is that the magnitude of the effects of raising public infrastructure investment depends strongly on the actual conditions of public infrastructure. Countries that currently have a larger share of GDP's infrastructure investment will experience larger rates of GDP growth as well as welfare gains, by increasing their public investments in infrastructure (as a share of GDP) just by small amounts; such as in Bolivia and Chile where an additional investment of only 2 percent of GDP in infrastructure will result in growth rates of more than 6 percent. The opposite occurs in Argentina and Venezuela where a 6% increase will be required to obtain mostly the same growth rates of 6 and 7% respectively.

By studying the effects of infrastructure policy on consumption, private investment and wages, I found that public infrastructure investment will be restricted by these variables. Infrastructure investment can adversely affect consumption, private investment and wages due to increased taxation necessary to fund it. For instance Venezuela's situation is noteworthy, because it shows that with a 6 percent increase in public infrastructure investment, consumption and private investment decrease by 0.75 percent and 0.6 percent respectively. The latter effect shows that a country's infrastructure policy must consider the crowding-out effects that public investment could have on private investment. This same effect occurs in all countries studied except at much higher infrastructure investment rates.

This paper also contributes to the literature by using country specific values for the effectiveness and public capital share parameters, the two key parameters of this type of models. These calibrated parameters work well with the model and generate reasonable predictions in terms of infrastructure efficiency. For instance, Bolivia, which is the least efficient country, could increase the impact of public infrastructure investment by 2 percentage points on its GDP rate of growth, by attempting to improve its effectiveness index to the levels of the industrialized countries. This means that the infrastructure policy should consider also mechanisms to increase the efficiency of infrastructure attacking corruption, bureaucracy, lack of maintenance of existing infrastructure, etc.

Finally from the point of view of IIRSA Initiative, this paper contributes to it by showing the levels of investment in public infrastructure that each country should reach (as a share of GDP) in order to maximize its rates of growth and welfare. Also, it shows that it is very important that the countries improve their levels of efficiency in order to take more advantage of the increases in public investment.

More research is needed to understand the relation between the infrastructure effectiveness parameter and the share of public capital in the production function. This paper shows that this relation is country-specific and thus should be analyzed in deep, using econometric techniques.

References

Arrow, K. J. and Kurz, M.: 1970, *Public Investment, the Rate of Return and Optimal Fiscal Policy*, Resources for the Future, The Johns Hopkins Press.

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

Aschauer, D. A.: 1989b, Public investment and productivity growth in the group of seven, *Economic Perspectives* (13).

Aschauer, D. A.: 1989c, Does public capital crowd out private capital?, *Journal of Monetary Economics* **24**, 171–188.

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

Bugarin, M. N. S., de Goes Ellery Jr., R., Silva, V. G. and Muinhos, M. K.: 2005, Steady-state analysis of an open economy general equilibrium model for brazil, (92).

Calderón, C. and Servén, L.: 2002, The output cost of latin america's infrastructure gap, (186). Central Bank of Chile Working Paper.

Calderón, C. and Servén, L.: 2004, Trends in infrastructure in latin america, 1980-2001, (269). Central Bank of Chile Working Paper.

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

Fay, M. and Morrison, M.: 2005, Infrastructure in latin america and the caribbean: Recent developments and key challenges, *Technical Report 32640-LCR*, The World Bank. Main Report.

Hausmann, R.: 2001, Venezuela's growth implosion: A neo-classical story?

Hulten, C. R.: 1996, Infrastructure capital and economic growth: How well you use it may be more important than how much you have, (5847). NBER Working Paper.

Jemio, L. C.: 2006, Modelo de evaluación económica de proyectos de inversión en infraestructura, *Technical report*, Corporación Andina de Fomento.

Kehoe, T. J.: 2003, What can we learn from the current crisis in argentina, *Scottish Journal of Political Economy* **50**, 609–633.

Medina, J. P. and Soto, C.: 2005, Model for analysis and simulation (MAS). Central Bank of Chile Working Paper.

Nourzad, F. and Vrieze, M.: 1995, Public capital formation and productivity growth: Some international evidence, *Journal of Productivity Analysis* **6**, 283–295.

Quiroz, J. A., Bernasconi, F. A., Chumacero, R. A. and Revoredo, C. I.: 1991, Modelos y realidad. enseñando macroeconomía en los noventa, *Revista de Análisis Económico* **6**(2).

Rioja, F. K.: 2001, Growth, welfare, and public infrastructure: A general equilibrium analysis of latin american economies, *Journal of Economic Development* **26**(2), 119–130.

Rioja, F. K.: 2003, The penalties of inefficient infrastructure, *Review of Development Economics* **7**(1), 127–137.

Schmitt-Grohé, S. and Uribe, M.: 2004a, Optimal simple and implementable monetary and fiscal rules. Manuscript.

Schmitt-Grohé, S. and Uribe, M.: 2004b, Solving dynamic general equilibrium models using a second-order approximation to the policy function, *Journal of Economic Dynamics and Control* **28**, 755–775.

Velasco, A.: 2005, Why doesn't latin america grow more, and what can we do about it? Working Paper.

Weitzman, M. L.: 1970, Optimal growth with scale economies in the creation of overhead capital, *Review of Economic Studies* pp. 555–570.

Zugasti, A. A.: 2001, *El Impacto de la Infraestructura Pública Sobre la Actividad Privada, Un Análisis Por Regiones Y Ramas de la Actividad En la Economia Espanola*, PhD thesis, Universidad de Málaga.

Appendix

Table A1: Infrastructure Loss Indicators for each Country

Country	Year	Power[a]	Telecom[b]	Paved Roads[c]	Water[d]	Inf. Effec.
Argentina	90/98/02	20	17	41	30	
Weighted		8	1.7	10.25	7.5	72.55%
Bolivia	90	16	46	79	30	
Weighted		6.4	4.6	19.75	7.5	61.75%
Brazil	02	14	3	31	30	
Weighted		5.6	0.3	7.75	7.5	78.85%
Chile	90/02	19	3	58	30	
Weighted		7.6	0.3	14.5	7.5	70.10%
Venezuela	90	18	6	60	30	
Weighted		7.2	0.6	15	7.5	69.70%
Ind. Countries						
Average (1990)		7	13	15	8	
Weighted-Average		3.5	1.17	4.5	0.88	89.95%

a. System losses (% of total output), 1990.

b. Faults (per 100 mainlines per year), 1990 (Bolivia and Venezuela), 2002 (Argentina, Brazil and Chile).

c. Percentage of roads not in good conditions, 1990 (Bolivia, Chile and Venzuela), 2002 (Argentina and Brazil)

d. Losses (% of total water provision) 1990 (average of countries)

Figure A1: Macroeconomic Effects in Argentina

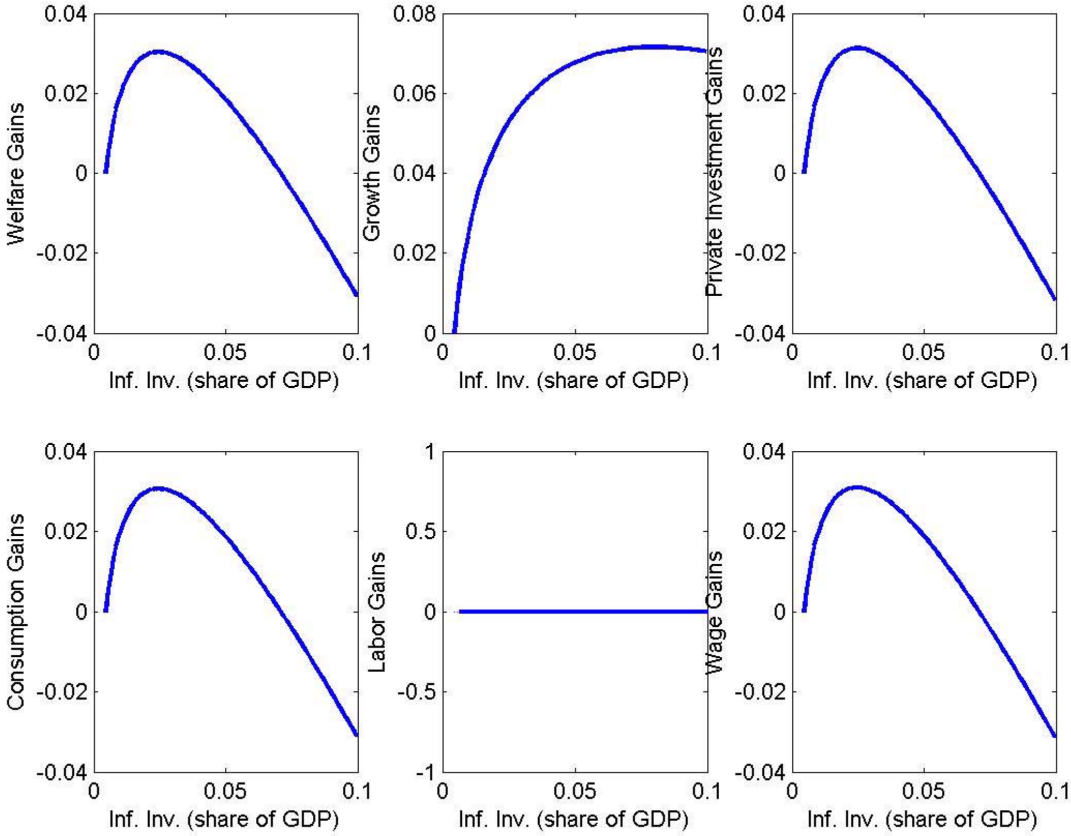

Figure A2: Macroeconomic Effects in Bolivia

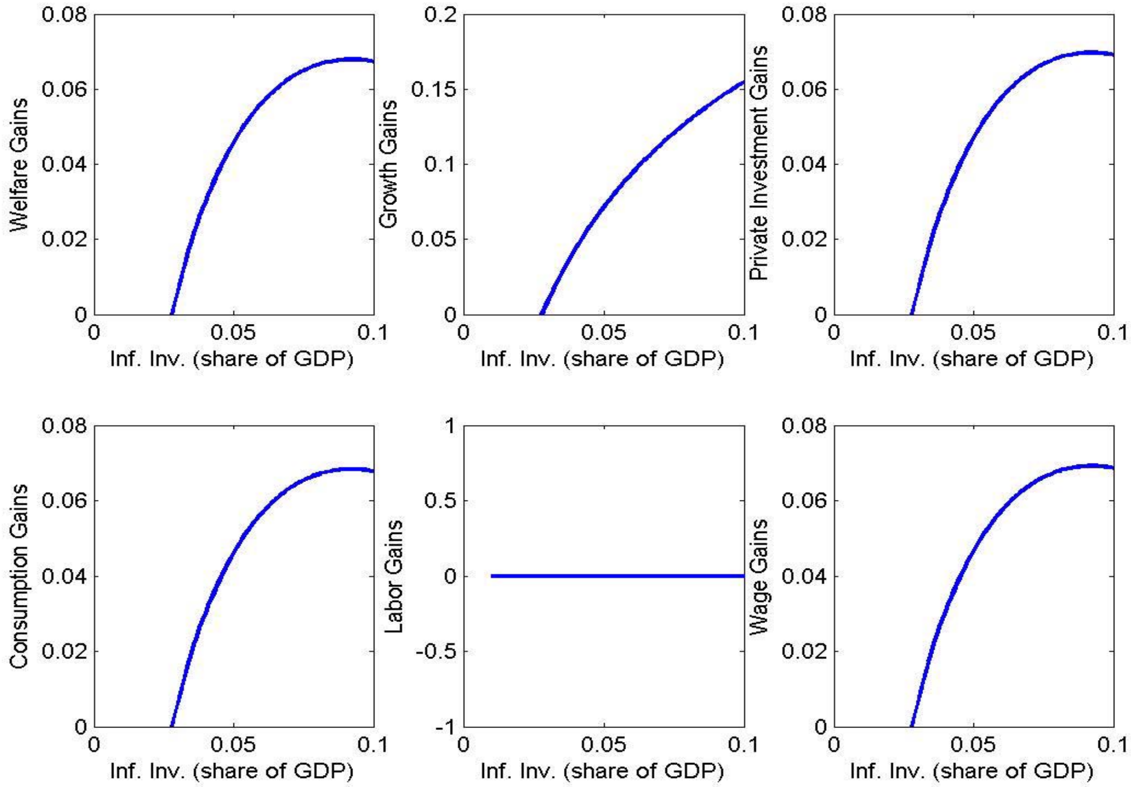

Figure A3: Macroeconomic Effects in Brazil

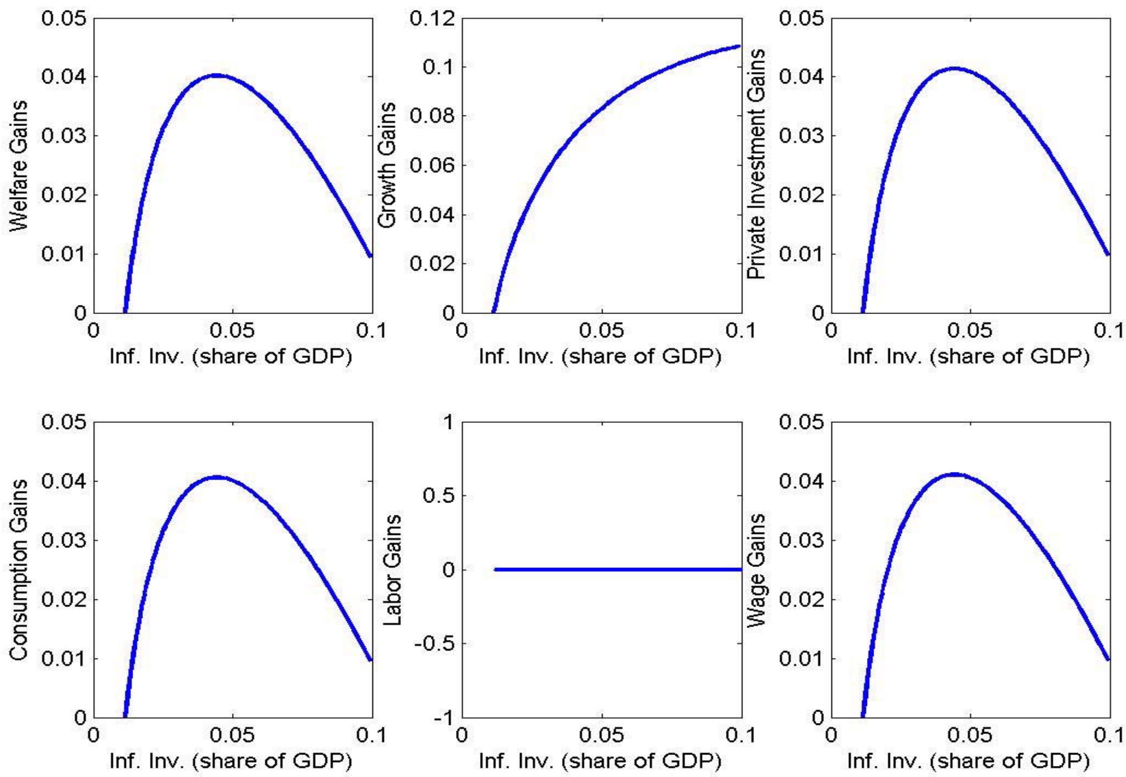

Figure A4: Macroeconomic Effects in Chile

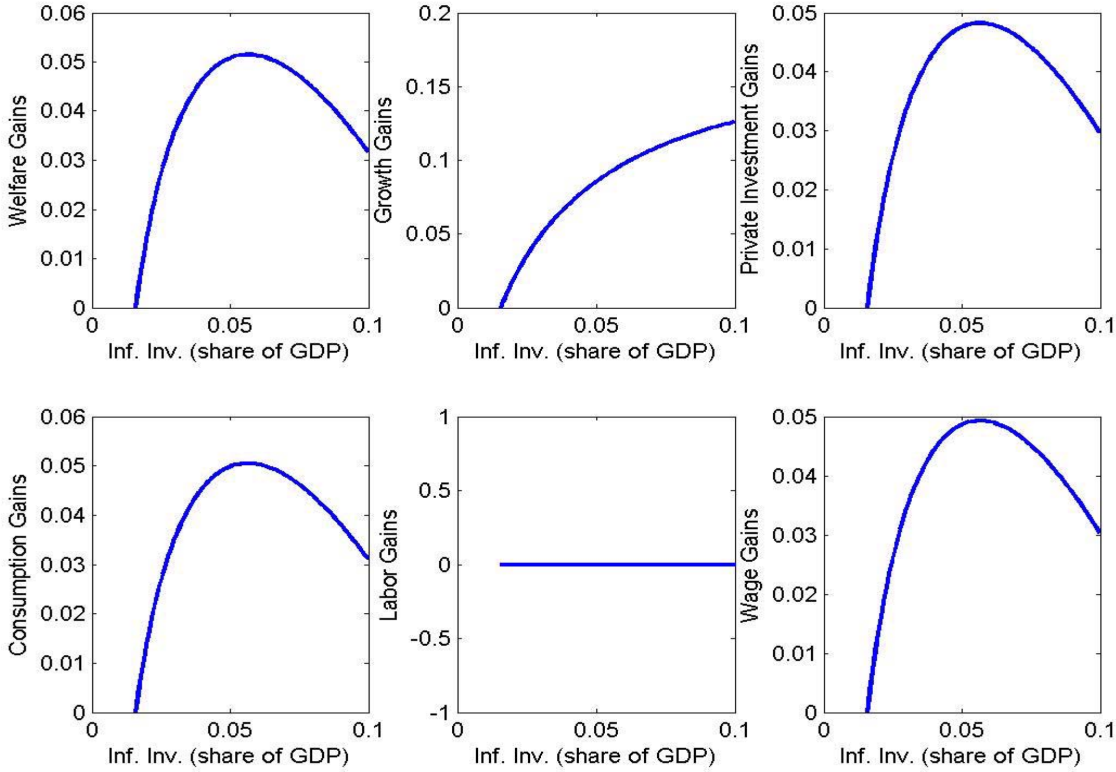

Figure A5: Macroeconomic Effects in Venezuela