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**Public Infrastructure and Economic Growth  
In Mexico**

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## Abstract

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*We develop a model where investment in infrastructure complements private investment. We then provide time series evidence for Mexico on both the impact of public infrastructure on output, and on the optimality with which levels of infrastructure have been set. In particular, we look at the long-run effects of shocks to infrastructure on real output. We compute Long-Run Derivatives for kilowatts of electricity, roads and phone lines, and find that shocks to infrastructure have positive and significant effects on real output for all three measures of infrastructure. For electricity and roads, the effect becomes significant after 7 and 8 years, respectively, whereas for phones, the effect on growth is significant only after 13 years. These effects of infrastructure on output are in agreement with growth models where long-run growth is driven by endogenous factors of production. However, our results indicate that none of these variables seem to be set at growth maximizing levels.*

## Resumen

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*Desarrollamos un modelo donde inversión en infraestructura complementa inversión privada. Proveemos evidencia de series de tiempo para México del impacto de infraestructura pública sobre la producción, y sobre la fijación de los niveles de infraestructura en niveles óptimos. En particular, medimos efectos de largo plazo de shocks en infraestructura sobre el PIB. Calculamos derivadas de largo plazo para kilowatts de electricidad, kilómetros de carreteras y número de líneas telefónicas. Encontramos que shocks a infraestructura tienen efectos positivos y significantes para nuestras tres medidas de infraestructura. Para electricidad y carreteras, encontramos que el efecto se vuelve significativo cuando incluimos 7 y 8 años respectivamente de rezagos en nuestras derivadas de largo plazo. Para teléfonos, el efecto se vuelve significativo para 13 años de rezagos. Estos efectos concuerdan con modelos teóricos de crecimiento donde el crecimiento de largo plazo es generado por factores de producción endógenos.*

# Public Infrastructure and Economic Growth in Mexico

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## Abstract

We develop a model where investment in infrastructure complements private investment. We then provide time series evidence for Mexico on both the impact of public infrastructure on output, and on the optimality with which levels of infrastructure have been set. In particular, we look at the long-run effects of shocks to infrastructure on real output. We compute Long-Run Derivatives for kilowatts of electricity, roads and phone lines, and find that shocks to infrastructure have positive and significant effects on real output for all three measures of infrastructure. For electricity and roads, the effect becomes significant after 7 and 8 years, respectively, whereas for phones, the effect on growth is significant only after 13 years. These effects of infrastructure on output are in agreement with growth models where long-run growth is driven by endogenous factors of production. However, our results indicate that none of these variables seem to be set at growth maximizing levels.

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# 1 Introduction

The role of public infrastructure on output has received wide attention since the contributions of Aschauer (1989), who shows a significant effect on public investment on growth for the United States, and the theoretical model of Barro (1990). These seminal papers induced further research with mixed results<sup>1</sup>. For example, Barro (1991), using a cross section for 98 countries in the period 1960-85, finds no significant effect of public investment on growth rates. Given that there is no clear empirical consensus, it becomes interesting to study the Mexican case.

We develop a theoretical model based on Barro (1990), where investment in infrastructure complements private investment. We then provide time series evidence for Mexico on both the impact of public infrastructure on output, and on the optimality with which levels of infrastructure have been set. In particular, we look at the long-run effects of shocks to infrastructure on real output. Mexico is a particularly interesting case, since it is a country that has implemented severe stabilization and structural adjustment programs as a response to the crises of the eighties and nineties. Aschauer (1998) reports that for some variables, growth rates of public capital became negative for that period.

We use annual data from 1950 to 1994 on real GDP, and public infrastructure variables, as in Canning and Pedroni (1999), comprise kilowatts of electricity, kilometers of roads, and number of telephone lines. Using Fischer and Seater (1993) notion of a long-run derivative over a horizon of twenty years, we find that shocks to infrastructure have positive and significant effects on real output for all three measures of infrastructure. For electricity and roads, the effect becomes significant after 7 and 8 years, respectively, whereas for phones, the effect on growth is significant only after 13 years. Thus, these effects of infrastructure on output are in agreement with growth models where long-run growth is driven by endogenous factors of production. However, our results indicate that none of these variables seem to be set at growth maximizing levels.

The remainder of this paper proceeds as follows: Section 2 presents the theoretical model. Section 3 discusses the data and econometric methodology, while section 4 discusses the empirical results. Section 5 concludes.

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<sup>1</sup>See Gramlich (1994) for a survey of the literature.

## 2 Model

We develop a simple growth model adapted from Barro (1990), where public infrastructure is an input in the production of final output, and is financed by taxes on output. The production function has the Cobb-Douglas form

$$y_t = A_t k_t^\alpha g_t^\beta \quad (1)$$

where  $\alpha + \beta \leq 1$ ,  $y_t$  and  $k_t$  are output and capital per worker, respectively,  $A_t$  is an index of technology, and  $g_t$  is the quantity of infrastructure services provided to each producer. Infrastructure expenditures are financed by an income tax according to

$$g_t = \tau_t y_t \quad (2)$$

where

$$\tau_t = \bar{\tau} + \eta_t \quad (3)$$

and

$$\eta_t = \phi \eta_{t-1} + \varepsilon_t. \quad (4)$$

Combining (3) and (4) we have that

$$\tau_t = \bar{\tau} + \phi^k \eta_{t-k} + \sum_{j=1}^k \phi^{j-1} \varepsilon_{t-(j-1)} \quad (5)$$

Equation (3) models the erratic behavior of Mexico's share of infrastructure to GDP: it fluctuates around a fixed value  $\bar{\tau}$ , the fluctuations being governed by the *AR* process (4). The closer  $\phi$  to 1, the more persistent are shocks to infrastructure. We assume that  $\varepsilon_t$  a zero-mean stationary random variable.

There is an infinite-lived representative household whose utility function is given by

$$\int_0^\infty \frac{c_t^{1-\theta} - 1}{1-\theta} e^{-\rho t} dt, \quad (6)$$

where  $c_t$  is consumption,  $\theta > 0$  is the intertemporal elasticity of substitution between consumption, and  $\rho > 0$  is the constant rate of time preference. When there is no population growth and depreciation is zero, capital evolves according to  $\dot{k}_t = (1 - \tau_t) A_t k_t^\alpha g_t^\beta - c_t$ .

The competitive equilibrium solution when  $\alpha + \beta = 1$  has the growth rate of the economy

$$\gamma_y = \frac{1}{\theta} \left[ (1 - \tau_t) \alpha A_t k_t^{\alpha-1} g_t^\beta - \rho \right]. \quad (7)$$

When  $\tau_t$  is constant, then the economy is on a balanced growth path, and there is endogenous growth driven by constant return to scale in both private capital and infrastructure. However, when  $\alpha + \beta < 1$ , then there are diminishing returns in both inputs, and long-run growth will be driven exogenously by technological progress, captured by  $A_t$ .

From (2) we know that  $\tau_t = g_t/y_t$ , substituting it in (7), and maximizing with respect to  $g_t$  we get

$$\frac{\partial \gamma_{yt}}{\partial g_t} = \frac{1}{\theta} \frac{\alpha}{k_t} \left[ \frac{\beta}{\tau_t} - 1 \right]. \quad (8)$$

This derivative equalized to zero implies that the optimal tax rate for the economy is  $\tau_t^* = \beta$ , Barro's famous result.

Combining (1), (2), (5) and taking derivatives we arrive at the long-run derivative – the effect of an infrastructure disturbance on real output relative to that disturbance's ultimate effect on infrastructure –

$$\frac{\partial y_t / \partial \eta_{t-k}}{\partial g_t / \partial \eta_{t-k}} = \frac{\beta}{\bar{\tau} + \phi^k \eta_{t-k} + \sum_{j=1}^k \phi^{j-1} \varepsilon_{t-(j-1)}} \quad (9)$$

where the denominator is  $\tau_t$ . Given that  $\tau_t^* = \beta$  at its growth maximizing level, then (9) is optimal at one. Further, if we find the long-run derivative (*LRD* from now on) to be different from zero, then shocks to infrastructure are persistent. This thus would provide support for models of endogenous growth.

### 3 Data and Econometric Methodology

The objective in this section is to provide time series evidence for Mexico on both the impact of public infrastructure on income, and on the optimality with which levels of infrastructure have been set, using annual data from 1950 to 1994. We utilize real gross domestic product divided by the labour force, to approximate real income per worker. The public infrastructure variables comprise kilowatts of electricity, kilometers of roads, and number of telephones. The source of the data is Comisión Federal de Electricidad, Secretaría de Comunicaciones y Transportes, and Teléfonos de Mexico. In many cases, data were collected from these federal agencies in quite an artisan way, drawing from different sources of internal statistical reports. The series for real income per worker was constructed using the data set in

Alzati (1997). The sample size is the longest homogeneous data set possible, given the available information.

In particular, we are interested in the long-run effects on real output, of stochastic shocks to the level and trend of infrastructure. Fisher and Seater (1993) develop an econometric methodology to measure the long-run effect of money on output. We adapt their notion of a long-run derivative to measure the ultimate effect of an infrastructure shock on the level of real (per capita) output, relative to the effect of that same shock on the level (or trend) of public provision of infrastructure (per capita), based on a bivariate VAR. If the long-run effect is not significantly different from zero, then public investment in infrastructure is neutral. If the effect departs away from zero significantly, then public infrastructure investment has permanent effects on real output, positive or negative, and is, therefore, non neutral. Finally, if the long-run effect approaches 1, then impacts to infrastructure move the economy towards its growth maximizing level. In terms of our growth model, if  $\frac{\beta}{\tau_t} \rightarrow 1$  in (9), then the derivative in (8) will equal zero.

To fix ideas, consider the following stationary invertible bivariate Vector Autoregression (VAR) in per capita infrastructure provision by the government,  $g_t$ , and real per capita output,  $y_t$ :

$$\begin{aligned} a(L)\Delta^{\langle g \rangle} g_t &= b(L)\Delta^{\langle y \rangle} y_t + \eta_t \\ d(L)\Delta^{\langle y \rangle} y_t &= c(L)\Delta^{\langle g \rangle} g_t + w_t \end{aligned} \quad (10)$$

where  $a(L)$ ,  $b(L)$ ,  $c(L)$  and  $d(L)$  are polynomials in the lag operator  $L$ , with  $a_0 = d_0 = 1$ ,  $\Delta = (1 - L)$ , and the symbol  $\langle x \rangle$  stands for the order of integration of  $x$ ; i.e.  $\langle x \rangle = 1$ , means that  $x$  is integrated of order one ( $I(1)$ ). The errors vector  $(\eta_t, w_t)$  is assumed to be *iid*, zero mean with covariance matrix  $\Sigma$ , with elements  $\sigma_{\eta\eta}$ ,  $\sigma_{\eta w}$ ,  $\sigma_{w\eta}$ ,  $\sigma_{ww}$ . The solution, or impulse-response representation of system (10) is given by:

$$\begin{aligned} g_t &= \Delta^{\langle -g \rangle} [\alpha(L)\eta_t + \beta(L)w_t] \\ y_t &= \Delta^{\langle -y \rangle} [\gamma(L)\eta_t + \delta(L)w_t] \end{aligned}$$

where  $\alpha(L) = d(L)/A$ ,  $\beta(L) = b(L)/A$ ,  $\gamma(L) = c(L)/A$ ,  $\delta(L) = a(L)/A$ , with  $A = a(L)d(L) - c(L)b(L)$ . Then the effect of public infrastructure is measured through the long-run derivative of output with respect to permanent stochastic exogenous changes in public infrastructure:



$$LRD_{y,g} \equiv \lim_{k \rightarrow \infty} \frac{\partial y_{t+k} / \partial \eta_t}{\partial g_{t+k} / \partial \eta_t} \quad (11)$$

The limit of the ratio in (11) measures the ultimate effect of a (stochastic) infrastructure disturbance on real output relative to that disturbance's ultimate effect on the infrastructure variable.  $g$  is said to be neutral (superneutral) when, following a permanent shock to the level (trend) of infrastructure,  $LRD_{y,g}$  is equal to zero ( $LRD_{y,\Delta g}$  is equal to zero). One can show that the computation of the  $LRD$  depends on the order of integration of each variable, according to the formula,

$$LRD_{y,g} = \frac{(1-L)^{\langle g \rangle - \langle y \rangle} \gamma(L) |_{L=1}}{\alpha(1)} \quad (12)$$

from which one can obtain values for the  $LRD$  under different empirically relevant orders of integration of the variables. The  $LRD$  for superneutrality is derived from the same formula by replacing  $g$  with  $\Delta g$ .

First of all, the order of integration of infrastructure should be at least equal to one ( $\langle g \rangle \geq 1$ ), otherwise there are no stochastic permanent changes in infrastructure that can affect real output. When  $\langle g \rangle - \langle y \rangle > 0$  the long-run derivative is zero, providing direct evidence of no long-run effect of infrastructure on output. When  $\langle g \rangle = \langle y \rangle \geq 1$ ,  $LRD_{y,g} = \gamma(1)/\alpha(1) = c(1)/d(1)$ , and the significance of the impact of a permanent change in the level of infrastructure on output is measurable. For testing superneutrality, the relevant long-run derivative is given by  $LRD_{y,\Delta g} = \gamma(1)/\alpha(1) = c(1)/d(1)$ . Superneutrality, however, is not addressable when there are no permanent changes in the growth rate of infrastructure. In other words, superneutrality requires  $\langle g \rangle \geq 2$ . Table 1 summarizes the various possibilities.

Table 1

$LRD_{y,g}$				$LRD_{y,\Delta g}$		
$\langle y \rangle$	$\langle g \rangle = 0$	$\langle g \rangle = 1$	$\langle g \rangle = 2$	$\langle g \rangle = 0$	$\langle g \rangle = 1$	$\langle g \rangle = 2$
0	undefined	$\equiv 0$	$\equiv 0$	undefined	undefined	$\equiv 0$
1	undefined	$c(1)/d(1)$	$\equiv 0$	undefined	undefined	$c(1)/d(1)$

Source: Adapted from Fisher and Seater (1993).

For the cases where  $LRD = \gamma(1)/\alpha(1) = c(1)/d(1)$ , and assuming  $b(1) = \sigma_{uw} = 0$ , an estimate of  $c(1)/d(1)$  is given by  $\lim_{k \rightarrow \infty} b_k$ , where  $b_k$  is the coefficient from the OLS long-horizon regression

$$\left[ \sum_{j=0}^k \Delta^{(y)} y_{t-j} \right] = a_k + b_k \left[ \sum_{j=0}^k \Delta^{(g)} g_{t-j} \right] + \varepsilon_{kt}. \quad (13)$$

In terms of our growth model, the *LRD* can be expressed as:

$$LRD_{y,g} = \lim_{k \rightarrow \infty} \frac{\beta}{\tau_t} \quad (14)$$

where  $\tau_t$  is given by (5). Furthermore, it was found the optimal tax rate for the economy to be  $\tau_t^* = \beta$ . Hence, in a growth maximizing setting, *LRD* should be equal to one. In other words, infrastructure has to be non neutral and  $\frac{\beta}{\tau_t} \rightarrow 1$ , for the economy to approach maximum growth. The significance of the limit of  $\frac{\beta}{\tau_t}$  is measured through a sequence of OLS estimates of  $b_k$  in (13) for  $k = 1, \dots, 20$ , together with 95-percent confidence bands around the parameter estimates, using the Newey-West covariance matrix estimator. The non neutrality of an infrastructure variable implies that growth is endogenous.

## 4 Empirical Results

As noted above, the order of integration of the variables is a crucial first step in calculating the *LRD*. To this end, we apply augmented Dickey-Fuller (ADF) tests for a unit root for each of the four variables. In Dickey and Pantula (1987), it was observed empirically that the probability of rejecting the null hypothesis of one unit root (denoted  $H_1$ ) against the alternative of stationarity ( $H_0$ ) increases with the number of unit roots present. In Pantula (1989), two asymptotically consistent sequential procedures for testing the null hypothesis  $H_r$  against the alternative  $H_{r-1}$  are presented. We assume that it is known a priori that the maximum possible number of unit roots present in the data is  $s = 3$ . Based on Pantula's results, the hypotheses must be tested sequentially in the order  $H_3$ ,  $H_2$  and  $H_1$ . Table 2 summarizes the time series properties of the variables for Mexico.

We perform unit root tests downwards, starting with a test of the null hypothesis  $H_3$ : exactly three unit roots (or a unit root in the second differences of the data). If the null  $H_3$  is rejected, then we test the null  $H_2$ : exactly two unit roots, against the alternative  $H_1$ : one unit root in the autoregressive representation of the series. If both  $H_3$  and  $H_2$  are rejected, we test  $H_1$  against  $H_0$ .

Table 2

Order of Integration of real income and infrastructure variables, Mexico,  
(1950 – 1994)

$$\text{Regression: } \Delta^r X_t = \mu + \beta t + a_r^* \Delta^{r-1} X_{t-1} + \sum_{j=1}^l b_j^* \Delta^r X_{t-j} + \varepsilon_t$$

$r = 1, 2, 3.$

Variable	$H_3(\mu = \beta = 0)$	$H_2(\beta = 0)$	$H_1$
<i>Real GDP</i>	-9.31** (1)	-6.08 <sup>a,**</sup> (0)	-0.69 (0)
<i>Electricity</i>	-6.61** (4)	-5.06** (3)	-3.07 <sup>b</sup> (0)
<i>Roads</i>	-8.54** (0)	-4.49** (0)	-2.02 (1)
<i>Telephones</i>	-7.52** (1)	-3.26* (0)	-3.22 (3)

Notes:

\*, and \*\* stand for significant at the 5%, and 1% level, respectively.

*a*: this regression includes a constant and a linear trend

*b*: for this regression, the fourth lag resulted significant, however neither the constant nor the linear trend are significant. There were no other significant values for  $l$ . We report results for  $l = 0$ , for which both constant and trend are highly significant, and the AIC and the standard error of regression indicate a better fit.

In Table 2, the second column reports augmented Dickey-Fuller (ADF) statistics for testing the null  $H_3$  against the alternative  $H_2$  where no constant nor linear trend are allowed in the auxiliary regression. Columns 3 and 4 have a similar interpretation. The numbers in parenthesis correspond to the order of the autoregressive approximation, following Perron's  $l - \max$  criterion.<sup>2</sup> As can be seen, the ADF tests strongly reject the presence of three and two unit roots for all variables. The last column indicated that it is not possible to reject one unit root in the AR representation for each series, implying that our vector of series is integrated of order one. We also applied four additional test statistics, advocated in Ng and Perron (2001), and obtained the same results.<sup>3</sup>

Once we have established that  $\langle y \rangle = \langle g_i \rangle = 1, i = e, r, p$ , it is now possible to compute the  $LRD_{y, g_i}$  to test whether our infrastructure variables are long-run neutral or not. That is, using the  $LRD$  we investigate the

<sup>2</sup>We start with a maximum value for the autoregressive component,  $l \max$ , of 5, and reduce the length of lag if the  $t$ -statistic on  $\hat{b}^*$  was significant at the 5% level (instead of the 10% level used by Perron). In all cases we check the resulting correlogram to verify there is no remaining autocorrelation in the residuals using the estimated  $\hat{l}$ , reported in the Table.

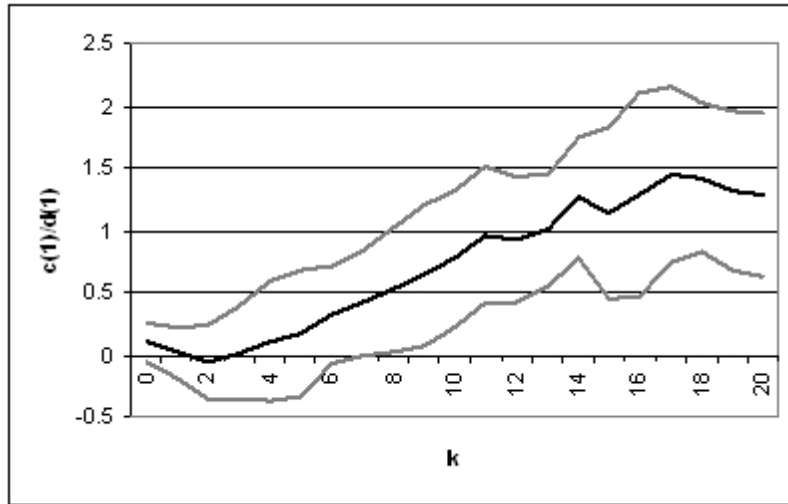
<sup>3</sup>These tests are extensions of the  $M$  tests of Perron and Ng (1996) that use  $GLS$  detrending of the data, together with a modified information criterion for the selection of the truncation lag parameter. These tests are the  $MZ_t^{GLS}$ ,  $ADF_{MAIC}^{GLS}$ ,  $MZ_\alpha^{GLS}$ , and the  $MSB^{GLS}$ . In applying these tests, we also used the procedure of Pantula (1989).

extent to which each infrastructure variable and real income per worker are ultimately changed by an exogenous infrastructure disturbance. If the respective infrastructure variable happens to be non neutral (neutral), then exogenous shocks to this variable should (not) increase per capita income<sup>4</sup>.

Figures 1 to 3 present estimates of the *LRD* for each pair of real output and an infrastructure variable for a horizon of 20 years, with 95% confidence interval bands.

Figure 1 suggests that the effect of investing in electricity for Mexico becomes positive after 2-3 years, significantly different from zero after a period of 7 years, and remains significant for the remainder of the years computed. This suggests that public investment in electricity has a permanent effect on output, supporting the notion of endogenous growth. Further, investment in electricity is close to the optimal effect on output growth for  $10 \leq k \leq 13$ .

Figure 1  
Kilowatts of Electricity



For roads, figure 2 indicates that a permanent shock to infrastructure has positive and significant effect on real output after a period of 8 years, and remains significantly different from zero thereafter. Although the *LRD* becomes significant after 8 years, it does not reach the optimal provision level even after a period of 20 years.

<sup>4</sup>Since the neutrality tests of Fischer and Seater (1993) are based on how *changes* in the infrastructure variable are ultimately related to *changes* in output, cointegration is neither necessary nor sufficient for long-run neutrality.

Figure 2  
Kilometers of Roads

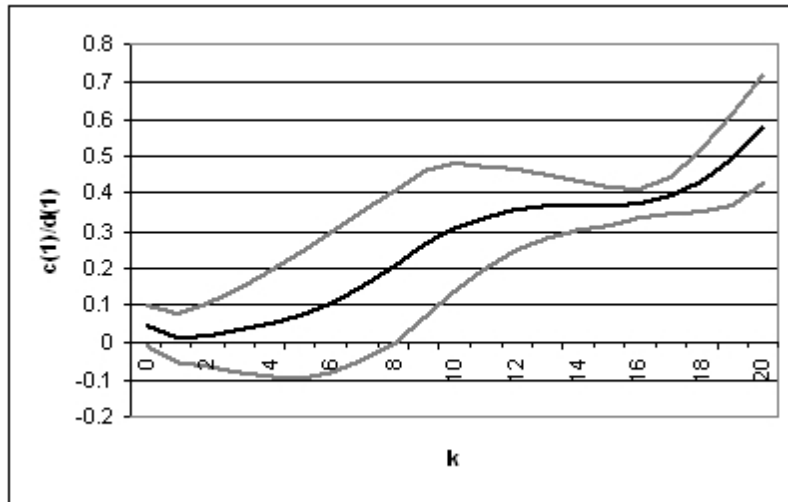
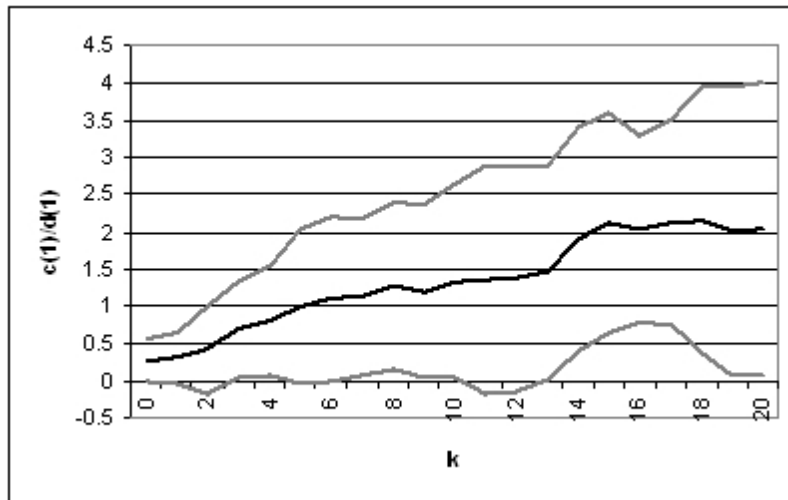


Figure 3 depicts the effect of telephone lines provision on output. The effect is always positive and crosses the optimal level of one around year 5, but continues to increase after that. Finally, it becomes only significantly different from zero after 13 years.

Figure 3  
Telephones



## 5 Conclusion

This paper developed a theoretical model based on Barro (1990), where investment in infrastructure complements private investment. We then provide time series evidence for Mexico on both the impact of public infrastructure on output, and on the optimality with which levels of infrastructure have been set. Using Fischer and Seater (1993) notion of a Long-Run Derivative over a horizon of twenty years, we found that shocks to infrastructure have positive and significant effects on real output for all three measures of infrastructure. For electricity and roads, the effect becomes significant after 7 and 8 years, respectively, whereas for phones, the effect on growth is significant only after 13 years. Thus, these effects of infrastructure on output are in agreement with growth models where long-run growth is driven by endogenous factors of production. However, our results indicate that none of these variables seem to be set at growth maximizing levels.

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