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Infrastructure and Economic Growth

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Infrastructure and Economic Growth

1. Institutions, Infrastructure, and Economic Growth: A Cross Country Analysis.

1.1 Introduction

The relationship between infrastructure capital and economic growth has been controversial. A number of empirical studies have found very high returns to infrastructure investment (Aschauer, 1989; Canning and Fay, 1993). But, the robustness of the results have been questioned in other empirical studies and surveys (Gramlich, 1994; Munnell, 1992).[2] A major problem seems to be that interactions between infrastructure and GDP are mediated in the short run by a host of variables that cannot all be captured in statistical studies, and in the long run causality between infrastructure and GDP cannot be established. While infrastructure may give rise to higher productivity and output, past and future economic growth also tend to raise the demand for infrastructure services and induce increased supply.[3] Moreover, infrastructure inadequacies may not have tangible output consequences in the short or medium run because infrastructure services have substitutes and the assets may be used with different intensities.[4] As a result, the empirical basis of the case for high returns to infrastructure investment has been elusive.

The economic growth literature has avoided the issue by focusing on the reduced form solution for income growth that includes infrastructure only as part of the initial conditions. This

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[2] *World Development Report 1994*, especially Box 1.1, also provides a congenial discussion.

[3] Indeed, some time-series estimates for the US and other countries find that causality tends to go from GDP to infrastructure rather than the other way around. Other studies find a reverse causality as well. See Gramlich (1994), Tatom (1993), and Munnell (1992).

[4] For example, in the case of shortage of electricity generation capacity, generator maintenance may be postponed or users may invest in their own captive generators. In the absence of piped water, households may obtain potable water by purchasing from trucks or, if geography permits, by digging wells or collecting rain water. Also, telephone lines may be shared, roads may be overcrowded and trucks may be overloaded.

is, however, inadequate because to understand the process of growth one needs to go beyond the aggregate and distant relationships and to uncover the mechanisms through which various factors shape aggregate performance. Structural relationships behind aggregate growth are particularly needed when one tries to identify the source of growth and reach policy conclusions. For example, a reduced form regression can show that weak institutions and poor infrastructure at the start of a decade slow down economic growth during the decade (see, e.g., Easterly and Levine, 1997). But, one wonders to what extent exogenous shifts in infrastructure growth can help concurrent economic performance, how much infrastructure responds to aggregate growth, and what factors determine the magnitude of that response. Also, reduced form estimations leave open the possibility that other variables influence growth by working through infrastructure. These questions, of course, apply to other variables that have been substituted out as well. But, infrastructure provides an important example because it entails externalities that signify the role of institutions and other factors that have been found to have substantial impact in reduced form regressions of growth.

Estimating a structural model of interaction between aggregate economic growth and one of its components poses an identification problem. Any factor that affects the component may be affecting the aggregate output through other channels. As a result, identifying the role of the component becomes difficult. This may be an important reason why structural models of growth are rare. However, to ask deeper questions about the growth process, the identification problem has to be solved on theoretical or empirical grounds.

This section is organized as follows. Part 2 develops a structural model that helps discern the mutual effects of infrastructure and the rest of the economy on each other. We show that the model can be specified as a recursive system that solves the identification problem and can be estimated simultaneously. Part 3 specifies the econometric equations that to be estimated. Part 4 presents the results from the cross-country estimates of the model and discusses their policy implications. The results show that the contribution of infrastructure services to GDP is indeed quite substantial and in generally exceeds the cost of provision of those services. The model also allows one to examine the role of various economic and institutional characteristics in helping a country address infrastructure inadequacies and achieve efficient levels of investment. Although lack of detailed data precludes a clear identification of the specific factors that shape a country's response to its infrastructure needs, we show that general capacities to administer and to commit to efficient economic policies play important roles in infrastructure performance. Also, lack of sufficient data restricts the focus of this paper to asset formation in telecommunications and power sectors. These sectors are likely to be representative of the rest of any country's infrastructure and the quantities of their assets tend to be correlated with the quality of service. However, these relations are by no means one-to-one and future studies should expand the exercise to include more infrastructure sectors and develop quality measures for them.

1.2 A Model of Output and Infrastructure Growth

Economic growth is the consequence of accumulation of factors that permit an economy to take advantages of opportunities for increasing its income. To identify the determinants of factor accumulation rate and, therefore, the rate of growth, it is common practice to start by denoting production opportunities of the economy as a function that maps the vector of factors into aggregate output, Y. For the purpose of this paper, let's focus on four types of factors: Labor, L, capital, k, infrastructure, N, and all other exogenous factors that influence factor productivity, Q. Assume that labor and the productivity factor grow exogenously at rates ℓ and q, respectively, while k and N grow endogenously. We let the production function be Cobb-Douglas with constant returns to scale and, without further loss of generality, assume that Q represents labor productivity:[5]

(1.1) $Y = K^{\alpha}N^{\beta}(QL)^{1-\alpha-\beta}$,

[5] The model can be easily extended to cases of increasing or decreasing returns to scale be replacing 1 in the exponent of QL with the returns to scale, σ. This adds a two terms involving L and ℓ multiplied by $\sigma - 1$. We tested the model with those terms and found $\sigma - 1$ to be insignificant. For ease of presentation, here we ignore the possibility that $\sigma \neq 1$. The Cobb-Douglas assumption is because this is the only functional form consistent with a steady-state growth in the presence of technological progress that is not exclusively labor augmenting. For a proof, see Barro and Sala-i-Martin (1995). Eicher and Turnovsky (1997) have further shown that unless the production function is Cobb-Douglas, the existence of a steady state with positive per capita growth in endogenous growth models requires stringent restrictions on the production function. Since there does not seem to be a definite tendency for growth rates to be ever increasing or ever decreasing, it is reasonable to assume that the true production function can be approximated by a Cobb-Douglas one.

where α and β are positive parameters. Factors other than the ones listed above may be involved in production as well. But the model can be kept simple by viewing all those factors as part of those listed.

Infrastructure assets are distinguished from other types of capital because market imperfections make the accumulation and operation of those assets more sensitive to government policy and institutional characteristics of the country. Infrastructure services often entail economies of scale due to network externalities. Also, cost recovery from users tends to be more difficult and inefficient in infrastructure because often the marginal cost is declining, the services are viewed as basic needs (e.g., water), or exclusion of non-paying users is too costly (e.g., urban streets and rural roads). All these elements imply that there is greater potential for regulatory intervention and institutional arrangements play a more important role in the provision of infrastructure services. Furthermore, the parameters α and β may diverge from shares of their corresponding factors in output. This latter effect is important because it suggests that the small expenditure or cost shares of infrastructure in GDP may be a misleading indicator of the contribution of those sectors to the economy. In fact, the entire debate about the role of infrastructure revolves around the claim that β is much larger than the share of infrastructure.[6]

To estimate β, a straightforward procedure may seem to be an estimation of the production function in log-level or, alternatively, in first-difference or growth form:

$$(1.2) \qquad \gamma_y = (1-\alpha-\beta)q + \alpha\gamma_k + \beta\gamma_n \, ,$$

where γ_y, γ_k, and γ_n are the growth rates of the per-capita endogenous variables: $y = Y/L$, $k = K/L$, and $n = N/L$, respectively. This is, indeed, what the initial attempt at measuring the role of infrastructure tried to do. However, this procedure faces two problems. First, the non-infrastructure capital stock is very difficult to measure especially because it should include all types of capital, physical and non-physical. This poses the problem of missing variables that may be correlated with γ_n and may bias its estimated coefficient. Second, infrastructure growth is

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[6] Holtz-Eakin and Schwartz (1995) find β to be about 0.1 for the US states and argue that a 10% increase in infrastructure investment rate would have a trivial impact on productivity growth. However, since the infrastructure investment rate is in the order of 0.02-0.04, their result seems to indicate severe under-investment and high marginal product of capital in infrastructure sectors.

likely to be driven by demand factors that may be motivated by GDP growth. As a result, there is a simultaneity problem and one needs to identify equation (1.2) from the infrastructure demand equation that also relates γ_y and γ_n. Dealing with these two problems has been at the heart of the controversy over the infrastructure-growth relationship. The time-series approach has not adequately dealt with these problems because the lags seem to be long. Simple instrumental variables methods are also problematic because they may not address the identification problem.

Our solution to the problem is a simultaneous equations model based on the dynamics generated by deviations of the economy from the steady state. Letting the units of *K* and *N* be the amount of each that can be formed with one unit of output, capital and infrastructure are accumulated according to:

(1.3) $\gamma_k = s_k y/k - \delta - \ell$ and

(1.4) $\gamma_n = s_n y/n - \delta - \ell$,

where δ is the depreciation rate and s_k and s_n are the shares of output allocated to accumulation of capital and infrastructure, respectively.[7] Households in the economy are interested setting s_k and s_n so as to maximize the long term expected utility of their consumption. However, market imperfections, government policies, and institutional factors may intervene and prevent the households from receiving the exact marginal benefit of their savings. As a result, the rates of accumulation generally depend on institutional and policy factors as well as production opportunities in the economy.

The steady state of this model is a situation where the savings rates as well as the growth rates of *y*, *k*, and *n* are constant. Equations (1.3) and (1.4) then imply that in the steady state k/y and n/y are constant and, thus, all three endogenous per-capita variables grow at the same rate, which according to (1.2) must equal q. Indicating the steady-state values by *, we have:

(1.5) $s_k^* y^*/k^* = s_n^* y^*/n^* = q^* + \ell + \delta$,

(1.6) $k^*/y^* = s_k^*/(q^* + \ell + \delta) \equiv \omega_k$ and $n^*/y^* = s_n^*/(q^* + \ell + \delta) \equiv \omega_n$.

[7] For simplicity, the depreciation rates of both factors are assumed to be the same.

Note that we differentiate between the short- and long-run growth rates of Q and indicate the latter by q^*.

The actual output growth that one observes may differ from its steady state rate because shocks to the economy affect the current output or the steady state one. When k/y or n/y are away from their steady-state levels, γ_k and γ_n will diverge from q^* and create a tendency for those variables to converge to the steady state. In the neighborhood of the steady state, the convergence speed for each of these variables can be calculated based on initial conditions and steady state parameters. We have:[8]

(1.7) $\gamma_k - q^* \approx (q^* + \ell + \delta)\{1+[\log(s_k/s_k^*)]/G_k\}G_k,$

(1.8) $\gamma_n - q^* \approx (q^* + \ell + \delta)\{1+[\log(s_n/s_n^*)]/G_n\}G_n,$

where $G_k \equiv \log[\omega_k/(k/y)]$ is the gap between the initial and the steady state capital-output ratio. $G_n \equiv \log[\omega_n/(n/y)]$ is similarly defined for infrastructure-output ratio. In a model with fixed investment rates, as in the Solow-Swan growth model, the last terms inside the curly brackets on the right-hand sides of (1.7) and (1.8) vanish and the growth rates of both factors can be simply represented by $\gamma_i = q^* + (q^* + \ell + \delta)G_i$, $i = k, n$. However, in the presence of imbalances in capital stocks, one expects investment rates to deviate from their steady state rates. Indeed, in models with a representative utility-maximizing household, the investment ratio terms, $\log(s_i/s_i^*)]/G_i$, $i = k, n$, are positive and depend on the household's rate of time preference and technological parameters. When investment decisions involve institutions, the characteristics of those institutions as well as other economic, social, or political factors may also matter in those terms. We let $\log(s_i/s_i^*)/G_i = g_i(X)$, where $g_i(.)$, $i = k, n$, is a function of a vector of country characteristics, X. Substituting these in (1.7) and (1.8) and from (1.7) into (1.2), we arrive at

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[8] The derivation for (2.7), for example, is as follows:

$$\gamma_i - q^* = s_i y/i - (q^* + \delta + \ell) = (q^* + \delta + \ell)[(s_i y/i)/(s_i^* y^*/i^*) - 1]$$
$$\approx (q^* + \delta + \ell) \log[(s_i y/i)/(s_i^* y^*/i^*)] = (q^* + \delta + \ell)[G_i + \log(s_i/s_i^*)].$$

(1.9) $\gamma_y = (1-\beta)q^* + (1-\alpha-\beta)(q - q^*) + (q + \ell + \delta)[1 + g_k(X)][\alpha\log\omega_k - \alpha\log(k/y)] + \beta\gamma_n$,

(1.10) $\gamma_n = q + (q + \ell + \delta)[1 + g_n(X)][\log\omega_n - \log(n/y)]$.

Equation (1.10) allows one to estimate infrastructure growth rate in a reduced form and to use the predicted values in the output growth regression based on (1.9) to measure β. As in most of the growth literature, we assume that the population growth rate is exogenous and the long-term rate of productivity growth, q, is constant across all countries. The steady-state capital-output ratio, ω_k, and infrastructure-output ratio, ω_n, depend on $q^* + \ell + \delta$ as well as the preferences that shape long-term investment rates. Since there is no comprehensive measure of k, one has to substitute from the production function into equation (1.9) to write $-\alpha\log(k/y)$ in terms of more measurable variables:

(1.11) $-\alpha\log(k/y) = -(1-\alpha)\log y + (1-\alpha-\beta)\log Q + \beta\log n$.

As has been commonly observed in the literature, equations (1.9)-(1.11) imply that given the initial income level, a higher initial productivity factor, Q, should be associated with a higher per capita GDP growth because it implies a lower capital-output ratio and a greater tendency for the capital stock to grow. If we control for infrastructure growth rate, the initial infrastructure level should also have a positive effect on growth for the same reasons. A parametric rise in the initial level of per capita income, on the other hand, should lower economic growth. The effects of initial income and infrastructure, however, tend to diminish once the endogeneity of γ_n is taken into account because a higher infrastructure-income ratio lowers the infrastructure growth rate.

The terms $(q^* + \ell + \delta)[1 + g_i(X)]$, $i = k, n$, are the adjustment rates of k and n toward the steady state allocation. They indicate convergence rates for each sector when income grows on its steady-state path. In other words, the terms show how fast the country responds to capital and infrastructure misallocation. Part of the adjustment, of course, comes from natural population growth, depreciation, or technological change that make income and capital stocks adjust toward the steady state. If we let $g_i(X) = 0$, the implied convergence rate for per capita GDP, defined as $\gamma_y/\log(y^*/y)$, would be $(q^* + \delta + \ell)(1 - \alpha - \beta)$, which is a standard finding. When the savings rate is allowed to vary under the most efficient set of institutions, which is captured by the single representative household model, the speed of convergence is generally faster because the household adjusts its savings rate according to the changes in the marginal product of capital. However, when adjustment requires collective decision-making, this may no longer be the case. In that case, the process of convergence should tend to slow down as the effectiveness of the institutions that guide decision-making declines. Indeed, the empirical growth models that drop the usual assumption of a constant convergence rate by allowing it to depend on the level of education find this variable to speed up adjustment (Barro and Sala-i-Martin, 1995). We specify the adjustment rate terms for capital and infrastructure separately and include additional country characteristics in X.

In the next section, we specify the measures that represent various variables for econometric estimation of the model.

1.3 The Econometric Model and the Data

The above model assumes one infrastructure sector. Extending the model to a case where there are more infrastructure sectors, with each one's stock entering the production function as a separate Cobb-Douglas factor is straight-forward. Using (1.6) and (1.11) and letting t and p respectively denote telephones and power production per capita, the system (1.9)-(1.10) extends to

(1.12) $\gamma_y = \beta_t\gamma_t + \beta_p\gamma_p + (1-\beta_t-\beta_p)q^* + (1-\alpha-\beta_t-\beta_p)(q-q^*) + (q+\ell+\delta)[1+g_k(X)]\alpha G_k,$

with $\alpha G_k = \beta_t \log t + \beta_p \log p - (1-\alpha)\log y + (1-\alpha-\beta_t-\beta_p)\log Q + \alpha\log s_k^* - \alpha\log(q^*+\ell+\delta).$

(1.13) $\gamma_t = q^* + (q^* + \ell + \delta)[1+g_t(X)][-\log(t/y) + \sigma_t \log(s_t^*) - \lambda_t \log(q^*+\ell+\delta)],$

(1.14) $\gamma_p = q^* + (q^* + \ell + \delta)[1+g_p(X)][-\log(p/y) + \sigma_p \log(s_p^*) - \lambda_p \log(q^*+\ell+\delta)].$

For estimation purposes, we replace $1+g_i(X)$ by a linear function of X. The σ and λ parameters in (1.13) and (1.14) are all theoretically equal to one. However, the data for investment in infrastructure are limited and for the aggregate investment, which we use as a proxy, the theoretical constraints may be too stringent. Constraining these parameters affects the coefficient estimates for some of the variables included in the adjustment expressions in (1.13) and (1.14), but has virtually no effect on the measurement of β's, which is the main goal of the exercise. A similar problem exists in the estimation of α in (1.12). In that case, there is an additional problem that as specified in (1.12) the expressions for 1+ $g_k(X)$ and αG_k are each identified only up to a scaling factor. To address these problems, we first we scale 1+ $g_k(X)$ by $1-\alpha$ and αG_k by $1/(1-\alpha)$ and then replace the coefficients where α appears by more general parameters. That is, the last term on the right-hand side of (1.12) will be estimated as

$$(1.15)\quad (q+\ell+\delta)(\theta_0 + \theta X)[\,-\log y + \mu_t\beta_t \log t + \mu_p\beta_p \log p + \varphi Z + \mu_k \log s_k^* + \mu_\ell \log(q^* + \ell + \delta)],$$

where Z is a vector of the determinants of Q and (θ_0, θ) and φ are vectors of parameters. Theoretically, $\mu_t = \mu_p = \frac{1}{1-\alpha}$ and $\mu_k = -\mu_\ell = \frac{\alpha}{1-\alpha}$. But, after estimation we found that not all four coefficients satisfy these constraints. However, as we see below, absence or presence of these constraints has little impact on the estimates of β's, which are the main parameters of interest.

A key issue in completing the specification of the model is which variables should be included in X and what role should they be expected to play in the adjustment rate. For rapid adjustment in response to shocks, a country needs efficient and credible policy-making machinery. To measure credibility, we use the ICRG contract repudiation indicator (CONTR) discussed in section 2. ICRG data set also contains an index of bureaucratic quality, which is closely related to CONTR and does not show any significance when used in conjunction with it. As a proxy for administrative effectiveness, we use the average years of secondary education (EDUC) in the population 25 year and older. As argued above, limited educational attainment indicates the failure of public institutions to help the population obtain a pivotal and valuable factor for improving its standard of living. It also conveys information about the supply of skills and the ease with which the government and the polity communicate. Education may also have other effects on the infrastructure adjustment process. But, on the whole, one expects all these effects to facilitate adjustment (i.e., raise the adjustment rate).

Another aspect of administrative effectiveness is the ease with which the government can make decisions. This aspect depends on the extent of divisions in the polity and the policy-making institutions. To gauging these aspects, we employ the measure of ethnolinguistic heterogeneity (ELH) provided by Easterly and Levine (1997). Based on our earlier discussion of this variable, we expect a higher value of ELH to impede adjustment toward steady-state allocation of resources.

In addition to CONTR, EDUC, and ELH, we include time dummies in X to control for international events and technological shocks that may have affected adjustment. Openness of the economy and infrastructure availability may also affect adjustment, but those variables did not show any significance in the regressions and are not included in the result presented here. For infrastructure sectors, adjustment may depend on their ownership status (public vs. private) as well. Thus, we include a dummy variable (TPRIV) in $1+ g_t(X)$ which indicates whether the telecommunication sector is largely operated by private enterprises or not. A similar measure, PPRIV, is included in $1+ g_p(X)$. The prior expectation is that private operation should speed up adjustment.

As an indicator of steady-state investment rates, we use the total economy-wide investment rate averaged over each decade (INVEST). Since this variable is simultaneously determined with economic growth and we instrument for it by its own lagged value. We also used a number of other country characteristics (including all the variables employed to represent X and Q) that may have an impact on the steady state investment rates. These variables showed no significance in the infrastructure growth equations. In the GDP growth equation, Q is present in the initial capital gap expression and its impact on investment rate, if any, is indistinguishable from that on the initial productivity.

For gauging the initial level of productivity, we follow Barro and Sala-i-Martin (1995) and Easterly and Levine (1997) to replace $(1 - \alpha - \beta_t - \beta_p) \log Q$ with a linear combination of a number of variables that are commonly believed to influence the initial level of productivity. These variables are the contract repudiation index (CONTR), educational attainment (EDUC), ethnolinguistic heterogeneity (ELH), and black market premium on the exchange rate (as a measure of market distorting policies) (BLACK). The first two are expected to raise productivity and the latter two should have negative effects. All these variables, except BLACK, are measured at the start of the period over which growth is observed. BLACK is subject to large movements and using its one-time observation may introduce large measurement error. To avoid this problem, we use the average value of BLACK over the period and instrument for it by its lagged value.

There is a host of other variables that have appeared in the empirical studies of economic growth as determinants of productivity. We experimented with many of those variables in the regressions did not find consistent results. In particular, their statistical significance was lost once we introduced the infrastructure variables. Moreover, their impact on the parameters of interest, β_t and β_p, was negligible. To keep the paper short, we do not report those results here except of life expectancy at birth (LIFE), which we provide as an example.[9] There are also other variables that may affect productivity, such as terms of trade level, but we do not have useful cross-country measures for them.

As pointed out before, the long-term movement of the overall productivity is assumed to be a constant. For the productivity shock term, $q - q^*$, we use the rate of change in the terms of trade over each decade (TOT). The growth rates of CONTR, EDUC, and 1+BLACK are also likely to contain exogenous productivity shock factors, but did not show any significance in our regressions once they were appropriately instrumented.

The data used for the estimation of the model is a panel data set for 125 countries over three decades (1965-75, 1975-85, and 1985-95). The variables used in the regressions and their summary statistics are presented in Table 1.1. There were many missing values for some of the variables. The main source of the data is Barro and Lee (1994), augmented for the 1990-95 period by adding the information from the World Bank's World Development Indicators 1997 (WDI). For infrastructure data, we used the data set collected by the World Bank for World Development Report 1994 as well as WDI. The ethnolinguistic measure, ELH, is obtained from Easterly and Levine (1997). The data for private ownership in infrastructure sectors was constructed by examining information about individual countries. ICRG's contract repudiation data is available only for the post 1982 period. To avoid eliminating all observations from the 1960s and 1970s, we extrapolated these data using similar measures from Business Environmental Risk Intelligence (BERI) data set, which has information about the 1970s, but for fewer countries. We used the extrapolated data for the first half of the 1970s as the value of this variable for the 1965-75 period. For the two other decades, we used variable values for the initial year of the decade. We fixed the depreciation rate at $\delta = 0.04$. The main results are not sensitive to this assumption.

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[9] Other popular variables that we applied and did find support for them after accounting for infrastructure are: openness, government consumption, distance from the Equator, landlocked dummy, shares of primary products in GDP and exports, political instability, and political hazard (Henisz, 1997).

Since measurement errors can generate an inverse relationship between growth rates and initial levels for *y*, *t*, and *p*, the initial levels were instrumented by their lagged values. The lagged values that were used as instrumental variables for observations in each decade refer to the earlier decade, except for the 1965-75 observations that use 1960 or 1960-65 averages as instruments. The three-equation system, (1.12)-(1.14), is estimated by a 2SLS method.

1.4 The Estimation Results

Table 1.2 presents the results of estimation for growth rates of telephones and power production per capita. Columns (2) and (4) show the results of the full model, while columns (1) and (3) assume that adjustment is independent of institutional factors. The estimated coefficients all have the predicted signs and are generally significant. Interestingly, the theoretical constraints on the coefficients in the initial gap expression, $\sigma_t = \lambda_t = 1$ and $\sigma_p = \lambda_p = 1$, cannot be rejected for the full model. The adjustment rate is also positive and significant. It is negatively affected by ethnic divisions, and positively aided by contract enforcement, educational attainment, and private ownership, although the latter two effects are less significant in the case of the power sector.

The estimated contribution of private ownership to adjustment rate is quite substantial. In fact, it raises the average adjustment rate for the telecommunications by 0.02, which is 50 percent of the average adjustment rate in the absence of private ownership! The impact of private ownership in the power sector is of the same order of magnitude, although it is not statistically very significant. This may reflect inaccuracy of estimation. But, it may also indicate that ownership change plays a much smaller role in the power sectors. This point is important because, in fact, most countries find the privatization of telecoms easier and proceed with it earlier. A number of factors seem to contribute to this phenomenon. Technological change has made competitive arrangements in the sector much more feasible and has diminished any positive role that heavy government involvement may have played a few decades ago. Moreover, rapid technological change and demand growth in the sector have made it quite costly for the government to act opportunistically vis-à-vis private investors (Levy and Spiller, 1996). If new investment is withheld, shortages quickly rise and lead to economic problems and political discontent. As a result, investors can be more confident that the government will not take away their quasi-rents. Also, the fact that telecommunications revenues in many developing countries depend highly on international calls gives foreign investors more confidence that they can ensure themselves a minimum of return by controlling revenues generated abroad. In contrast, the power sector entirely depends on domestic revenues and has experienced a slower technological change. In fact, many countries that have privatized their power sector, have found that arranging transmission on a market basis is not an easy task. The power sector continues to require a heavy regulatory role for the government. Interestingly, using the private ownership dummy as a determinant of the steady state investment rate in infrastructure did not generate any significant result. This suggests that private ownership helps infrastructure services reach their steady state positions faster, but does not affect the long-term infrastructure-output ratios

The role of dynamism in the telecommunications sector is also evident in the much smaller impact of government commitment and credibility (contract enforcement) in that sector's adjustment process compared to the power sector or the rest of the economy (shown in Table 1.4 and discussed below). The technological shocks are also reflected in the estimated coefficient for the time dummy for 1985-95, which seems to be positive in the adjustment expression of the telecommunication sector, but negative in that of the power sector.

Columns (1) and (3) of Table 1.2 clearly show that the infrastructure gap by itself plays an important role in driving infrastructure growth. However, columns (2) and (4) make it clear that institutional and organizational factors also play important roles in this "catch-up" effect, as reflected in the significance of their coefficients and the large rise in the R^2 when those variables are included in the model. (The sample size difference across regressions explains approximately half of the rise in R^2, but remainder is still substantial.) To demonstrate the contribution of these factors to infrastructure growth, in Table 1.3 we present the adjustment rates for various regions, estimated based on 2SLS regressions of the unconstrained model for the 1985-95 period. To make the numbers comparable, Table 1.3 assumes that all countries are operating their infrastructure sectors through public enterprises.

The first notable fact about the figures in Table 1.3 is that infrastructure adjustment rates are generally faster than the convergence rates of 2-3% per year estimated for GDP per capita commonly found in the literature (see also the fixed convergence rate in column (1) of Table 1.4). In fact, as the last two columns of Table 1.3 (which are derived from the GDP growth equation) show, other types of capital tend to adjust slower than infrastructure. Controlling for income growth, it takes on average about 13 years for a country to close half of the gap between its current telecommunications stock and the steady state path. For the power sector the average half life of a gap is 18 years and for other forms of capital it is 20 years. The substantially faster adjustment rate in telecoms is likely to be a consequence of the rapid technological changes that have cheapened the service and facilitated network expansion.

A second important observation concerning adjustment rates is that they vary greatly across countries because of institutional differences. For example, while most developed countries (included in the "other" region in Table 1.3) tend to close half of their telephone shortage gap in 11 years, a country with a low of education level, such as Algeria, does the same thing in more than two decades and a country with weak contract enforcement and high ethnic diversity, such as Iran, takes more than three decades. African countries are is worst position in this sense and take more than five decades to cover half of their telecommunications gap. A similar difference between these countries exists in their ability to deal with power shortages, although in that case, contract enforcement and population heterogeneity play a much more important role.

Table 1.4 presents the estimation results for the per-capita GDP growth equation. The first column shows the model with a fixed convergence rate and no infrastructure variables. This is similar to other basic regressions in the literature where infrastructure is treated as part of the overall capital accumulation process. However, unlike other models, we have estimated the convergence rate based on the initial income gap from its steady state path rather than simply as the coefficient of the initial income level. Nevertheless, the results are quite similar with the convergence rate being 2.9% and with the terms of trade, contract enforcement, education, life expectancy, and investment rate raising growth and ethnic divisions and market distortions lowering it.

The second column of Table 1.4 reports the results when institutional influence on convergence is taken into account. The new specification is clearly superior because we obtain a much better fit with the same variables. The second column shows that contract enforcement and education help improve the overall GDP convergence, while the role of heterogeneity is muted. All of these variables, however, lose their significance as determinants of the initial productivity factor. This effect is reinforced once we introduce infrastructure variables, but the performance of the regression vastly improves even after controlling for the sample size. As columns (3) and (4) show, infrastructure supply has significant impact on production. Moreover, the role of ethnic heterogeneity in adjustment of capital stock becomes much clearer. While variables such as life expectancy lose their significance, the coefficients of theoretically relevant variables such as $\log(q^{*} + \ell + \delta)$ gain significance with the right sign and order of magnitude. The role of the 1975-85 dummy is particularly interesting because it captures the adverse productivity shocks to the world economy and the enhanced adjustment process that came about through recycling of petro-dollars. In contrast, adjustment after 1982 may have been slower due to the international debt crisis and the slow down of capital movements.

Testing for the relationship across variable coefficients in the capital gap expression rejects the theoretical constraints. As columns (3) and (4) indicate, this is largely due to the weakness in the coefficient of the initial power supply variable. For the telephones per capita, the estimated coefficient implies an α of approximately 0.47, which is not too far from the 0.32 implied by the coefficient of log of investment-GDP ratio and 0.55 implied by the coefficient of $\log(q^{*} + \ell + \delta)$. Whatever the reason for this outcome, the impact on the estimated elasticities of output with respect to telecommunications and power production seems to be negligible. In column (5), we show the consequence of imposing the constraint and adjusting the variables included in each expression. In all our regressions, the coefficients of infrastructure growth variables maintained their level and statistical significance quite remarkably as long as we estimate the GDP and infrastructure growth equations together. Interestingly, OLS regressions of equation (4.1) yield insignificant coefficients for the telecommunications growth variable.

The adjustment rates for non-infrastructure capital can be calculated by dividing the adjustment rate expression estimate in Table 1.4 by $1-\alpha$. The last two columns of Table 1.3 show the results assuming that $\alpha = 0.4$. These rates rise with the assumed α. However, as long as the output elasticity of capital is less than 0.47, which seems a relatively high figure, the capital adjustment rates would remain generally lower than infrastructure ones and their weighted average would be below 4.4% per year. This finding is somewhat surprising because non-infrastructure sectors tend to be more market-based, which is expected to facilitate adjustment. Evidently, other factors slow down adjustment in those sectors as well.

The estimated coefficients indicate that if the growth rate of telephones per capita parametrically rises from about 5% per year as in Africa to about 10% per year as in East Asia, the annual growth rate of GDP per capita may rise by about 0.7 percentage points.[10] In the power sector, an increase of per-capita production growth rate from 2% as in Africa to 6% as in East Asia can raise annual GDP growth rate by another 0.6 percentage points. Although these estimates are not as large as those found in some other studies, they are by no means trivial. In particular, they indicate that the elasticity of output with respect to infrastructure sectors is substantially larger than the share of those sectors in GDP, which means that the marginal products of infrastructure services are much higher than their cost of provision. The presence of such inefficiencies is attributable to market failures in infrastructure sectors and underlines the importance of institutional arrangements that can address those failures and raise service levels.

Our econometric results suggest that the main impact of institutional capabilities on economic growth is through their contribution to the adjustment rates. As we show in Table 1.5, the infrastructure and capital gaps implied by our estimates are typically quite large. As a result, even small increases in adjustment rate can raise GDP growth by large amounts. To see this point, consider the impact of an increase in Tunisia's educational attainment at the secondary level from 0.73 years (in 1985) to 2.83 (that of Korea in the same year). This will raise Tunisia's adjustment rates in telecoms, power, and other capital forms by 2.7, 1, and 2.4 percentage points, respectively. Given the estimated gaps for these three sectors, this raises the growth rates in those sectors by 2.0, 1.2, and 1.9 percentage points, respectively. Considering the estimated output elasticities, these effects raise the GDP growth rate by 0.3, 0.2, and 0.8 percentage points, for a total of 1.3 percent, which is quite considerable. Similarly, an increase in Tunisia's contract enforcement rating from 4 to 7 (prevailing in Korea in 1985) will contribute another 0.7 percentage points to the aggregate growth (0.1, 0.2, and 0.4 percentage points through the three sectors, respectively). These growth rates, of course, decline as assets accumulate and the gaps diminish, but relatively high growth rates can be sustained for at least a couple of decades.

The estimated gaps reported in Table 1.5 display an interesting pattern. As the logic of our model suggests, the gaps are larger in the faster growing economies that are either experiencing a positive shock to their steady-state income path (e.g., East Asia during 1965-95) or

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[10] Note this will have a compounding effect in future years as the level of telephones rises and stimulates investment in non-infrastructure sectors. But, for an average case, that effect would only add up to an extra 0.04% of GDP growth and would be partially offset by the induced slowdown in telecommunications investment as the gap in that sector declines.

recovering from a temporary adverse shock (e.g., Turkey after 1980). Furthermore, there is a positive correlation among the gaps across sectors, which shows the importance of the aggregate shocks to productivity and steady-state income path. Middle East North Africa (MENA) countries, however, display a somewhat different pattern. Their infrastructure gaps are generally large, while the capital gap of many of them is small. This reflects the fact that the large natural resource rents in the earlier decades have helped build the capital stock and raise income levels in the region, but low adjustment rates in infrastructure have prevented those sectors from fully catching up. Since the mid-1980s, as the rents have declined, the investment rates and incomes have fallen. This has driven up the capital- and infrastructure-output ratios and has reduced investment in infrastructure, even though imbalances linger on in those sectors and under more effective institutional circumstances could have helped maintain a faster pace of growth.

Finally, it is interesting to note that an exogenous 10% rise in GDP, say through an improvement in the terms of trade, on average raises the telecoms growth rate by 0.68% and the power sector growth rate by 0.44%. These, in turn will stimulate further investment in the rest of the economy and, on average, add about 0.16% to the GDP growth rate. Although this effect may seem trivial for a one time increase in GDP, in a rapidly growing economy, it can quickly compound over the years and become a tangible contribution to production.

1.5 Summary of Results

The model of economic growth and infrastructure investment estimated in this paper offers quite striking results. Once one accounts for the simultaneity between infrastructure and GDP growth rates, the impact of infrastructure on GDP growth turns out to be substantial. Countries can gain a great deal by improving investment and performance in infrastructure sectors. But this takes institutional and organizational reforms that are more fundamental than simply designing infrastructure projects and spending money on them.

A very useful feature of the model is that it allows one to estimate the gaps between the current and the steady state asset-output ratios as well as the speed of adjustment in assets in response to those gaps. Using this methodology, we identify a number of key variables that influence the gaps and the adjustment rates. The estimation results suggest that institutional capabilities that lend credibility and effectiveness to government policy play a particularly important role in the adjustment process.

The research reported in this paper is not free from shortcomings. First, the issue of infrastructure quality has not been addressed in the model analyzed and estimated here. Also, other infrastructure sectors (transportation, water, irrigation, etc.) need to be analyzed. Second, the existing data lack information on institutional details that can shed more direct light on the sources of institutional capability and the ways it can be built. Third, there is a need to obtain data on a variety of organizational arrangements that exist in infrastructure sectors and can have important roles in the performance of those sectors. This study only distinguishes between private and public ownership, while participation of private sector can have different degrees and public corporations are themselves differentiated according to the extent of their autonomy and objectives. Lack of measures for many relevant institutional and organizational variables partly explains why, despite its reasonable success, the model estimated here leaves the bulk of variation in infrastructure growth unexplained. Finally, the present model does not endogenize the organizational choice between private and public ownership.

Table 1.1: Summary Statistics of Variables Included in Estimation

Variable	Mean	Standard Deviation	Minimum	Maximum
Growth rate of GDP per capita	0.0155	0.0284	–0.0745	0.1112
Log of initial GDP per capita	7.7010	1.0305	5.6700	10.1830
Population Growth Rate	0.0207	0.0117	–0.0070	0.0786
Log of life expectancy at birth	4.0448	0.2134	3.4904	4.3490
Average years of secondary education	0.8724	0.8541	0.0100	4.8300
Log investment as percentage of GDP	–2.0614	0.7875	–4.5914	–0.9058
Log(1+exch. Rate black market premium)	0.1820	0.2710	0.0000	1.8595
Terms of trade change	0.0067	0.0687	–0.1305	0.5169
Ethnolinguistic heterogeneity	0.3684	0.3073	0.0000	1.0000
Contract Enforcement	5.8867	2.0170	1.0000	10.0000
Initial power production per capita	–1.1130	2.0961	–8.2215	3.2137
Growth rate of per-capita power production	0.0461	0.0864	–0.2598	1.1535
Initial telephones per capita	3.0261	2.006	–1.3222	6.8964
Growth rate of per-capita telephones	0.0585	0.0496	–0.1242	0.2781
Private ownership in telecoms sector	0.0751	0.2639	0.0000	1.0000
Private ownership in power sector	0.0631	0.2434	0.0000	1.0000

Sources: See text.

Table 1.2: Infrastructure Growth Equations

Estimation Method	2SLS		2SLS	
Dependent Variable: Growth Rate of	**Telephones per Capita**		**Power Production per Capita**	
Column	(1)	(2)	(3)	(4)
Number of observations	247	247	238	238
R^2	0.1551	0.2980	0.2391	0.3427
Variables	**Coefficient/(t–statistic)**			
Constant (q^*)	0.0404 (3.084)	0.0299 (3.052)	0.0497 (6.521)	–0.0094 (–0.894)
Adjustment Rate Expression				
Constant	0.1565 (2.763)	0.1178 (1.177)	0.2063 (2.248)	0.5562 (2.275)
Contract Enforcement		0.0351 (2.476)		0.0841 (2.263)
Ave. Years of secondary education		0.1417 (2.276)		0.0915 (0.820)
Ethnolinguistic heterogeneity		–0.3182 (–3.895)		–0.4796 (–2.235)
Private ownership		0.2262 (2.135)		0.2282 (0.999)
Dummy for 1975-85	–0.0558 (–1.254)	–0.0523 (–1.189)	–0.1103 (–0.939)	–0.1424 (–1.560)
Dummy for 1985-95	0.0921 (1.497)	0.0737 (1.054)	0.4027 (3.433)	–0.3009 (–2.355)
Initial Infrastructure Gap Expression				
Constant	–6.5953 (–1.956)	–3.5942 (–1.906)	–6.2908 (–2.248)	–8.0723 (–4.005)
Investment rate	1.2081 (5.265)	0.6653 (3.066)	1.1318 (6.230)	0.8878 (3.793)
$\text{Log}(q^* + \ell + \delta)$	–2.3746 (–1.698)	–0.6516 (–0.928)	0.0962 (0.084)	–0.8864 (–1.513)

Table 1.3: Annual Adjustment Rates in Telecommunications, Power Production, and Other Capital, 1985-95

Region	Telecommunications		Power Production		Other Capital[c]	
	Adjustment rate (%)	Half life of a gap[b]	Adjustment rate (%)	Half life of a gap[b]	Adjustment rate (%)	Half life of a gap[b]
Averages weighted by:	*GDP*	*GDP*	*GDP*	*GDP*	*GDP*	*GDP*
Africa	2.08	40.0	2.27	34.1	1.33	52.0
South Asia and China	3.29	22.0	2.76	25.4	2.05	33.9
MENA	3.55	21.5	3.10	25.6	2.12	32.7
Latin America	5.63	12.8	3.71	19.5	2.35	29.5
East Asia	5.42	14.2	3.48	25.1	2.39	29.0
Others	8.22	9.4	5.12	14.4	4.87	14.2
World	6.76	12.9	4.41	17.9	3.89	17.8

[a] Education data are missing for Morocco, Oman, and Saudi Arabia. The average of secondary education for Middle East North Africa (MENA) countries was used instead.

[b]Years taken to close 1/2 of the gap assuming steady-state income path.

[c] Assuming $\alpha = 0.4$.

Source: Computed based on columns (2) and (4), Table 1.2, and column (4), Table 1.4.

Table 1.4: Per Capita Growth Equation

Model	(1)	(2)	(3)	(4)	(5)
Description	Fixed aggregate adjustment rate	Institutional influence on aggregate adjustment	Infrastructure differentiated from other capital	Infrastructure differentiated, less significant variables dropped	Constrained parameters, less significant variables dropped
Estimation Method	IV	IV	2SLS	2SLS	2SLS
Number of observations	217	217	204	204	204
$\mathbf{R^2}$	0.4127	0.5081	0.6595	0.6584	0.5935
Adjusted $\mathbf{R^2}$	0.3836	0.4656	0.6202	0.6252	0.5725
Variables	**Coefficient/(t-statistic)**				
Constant	–0.0267 (–0.398)	0.0074 (2.616)	–0.0165 (–2.193)	–0.0177 (–2.785)	0.0238 (0.911)
Terms of trade change	0.1164 (4.818)	0.1237 (4.957)	0.1025 (4.839)	0.1019 (4.848)	0.1040 (4.896)
Output elasticity with respect to					
Telephones			0.1379 (4.112)	0.1382 (4.254)	0.1519 (4.118)
Power production			0.1428 (4.248)	0.1453 (4.340)	0.1410 (4.002)
Adjustment rate expression					
Constant	0.0293 (7.946)	–0.1189 (–0.878)	0.1111 (0.717)	0.0828 (0.560)	0.1156 (2.022)
Contract Enforcement		0.0633 (2.720)	0.0489 (1.777)	0.0576 (2.277)	0.0289 (1.445)
Ave. Years of secondary Education		0.2688 (4.042)	0.1436 (1.672)	0.1766 (2.372)	
Ethnolinguistic Heterogeneity		–0.0349 (–0.360)	–0.3054 (–2.385)	–0.2628 (–2.177)	
Dummy 1975		0.0454 (0.582)	0.3064 (2.510)	0.2780 (2.221)	
Dummy 1985		–0.2519 (–3.164)	–0.0789 (–0.742)	–0.1283 (–1.204)	

Table 1.4: Per Capita Growth Equation (continued)

Model	(1)	(2)	(3)	(4)	(5)
Description	Fixed aggregate adjustment rate	Institutional influence on aggregate adjustment	Infrastructure differentiated from other capital	Infrastructure differentiated, less significant variables dropped	Constrained parameters, less significant variables dropped
Initial Capital Gap Expression					
Constant		–2.1049 (–0.759)	0.3904 (0.104)	1.1507 (0.350)	5.7377 (5.724)
$\beta_t \log t$ (μ_t)			2.1024 (2.545)	2.2060 (2.841)	1.2829 (11.31)
$\beta_p \log p$ (μ_p)			–0.8303 (–0.913)	–0.5441 (–0.697)	1.2829 (11.31)
Contract enforcement	0.1399 (3.916)	0.0553 (1.304)	0.0279 (0.541)		0.1797 (2.653)
Ave. Years of secondary Education	0.1920 (2.466)	0.0650 (1.157)	0.0422 (0.392)		
Ethnolinguistic Heterogeneity	–0.8283 (–3.415)	–0.3772 (–1.454)	0.0643 (0.209)		–0.6443 (–2.632)
Log(1+black market Foreign exch. Premium)	–0.3748 (–0.794)	–1.5263 (–3.229)	–0.9234 (–2.829)	–0.9650 (–3.034)	–0.8923 (–3.383)
Log of life expectancy at birth	2.3109 (3.558)	2.5117 (3.788)	1.0089 (1.145)	0.8879 (1.137)	
Log of investment-GDP Ratio	0.4155 (2.452)	0.5687 (3.292)	0.4728 (2.390)	0.4479 (2.488)	0.2829 (2.494)
$\text{Log}(q^* + \delta + \ell)$	0.0680 (0.265)	–0.3880 (–1.140)	–1.2840 (–3.283)	–1.2242 (–3.488)	–0.2829 (–2.494)
Dummy 1975	–0.3025 (–2.339)	–0.1458 (–1.312)	–0.5580 (–2.267)	–0.4879 (–2.403)	
Dummy 1985	–0.3178 (–2.094)	0.0090 (0.063)	–0.0983 (–0.399)	–0.0487 (–0.235)	

Source: Computed.

Table 1.5: Estimated Gaps in Telecommunications, Power, and Other Capital, 1985

Region	Telecommunications	Power Production	Other Capital[a]
Averages weighted by:	*GDP*	*GDP*	*GDP*
Africa	1.36	0.90	1.25
South Asia and China	3.38	1.62	1.94
MENA	1.33	1.25	0.06
Latin America	0.80	1.26	0.98
East Asia	2.94	2.36	2.02
Others	0.11	1.34	1.46
World	0.89	1.44	1.51

[a] Assuming $\alpha = 0.4$.

Source: Computed based on columns (2) and (4), Table 1.2, and column (4), Table 1.4.

2. Infrastructure and Economic Growth in Colombia

2.1 Introduction

The relationship between infrastructure and economic growth has been studied in large extend for the United States and for others developed countries.[11] In general, these studies find that the contribution of infrastructure to GDP growth is substantial. Nonetheless, this relationship has not been studied extensively for Colombia. Only recently few studies have attempted to measure the contribution of infrastructure on the Colombian economy growth.[12] However, these studies ignore the long run causality between these two variables by focusing on the reduced form for economic growth that includes infrastructure as only one additional determinant.[13]

In this section, we estimate the structural model developed in section one using data from the Colombian departments. The results from the cross-departmental estimates are in the same line than those found in the cross-country estimates from section one. That is, the results suggest that infrastructure contributes considerably to GDP growth and the estimated adjustment rates and estimated gaps values from the Colombian data are of similar magnitude than those estimated for the panel of countries. Unfortunately, the lack of detailed data precludes a deeply analysis of the role of the institutional characteristics in the evolution of infrastructure and economic growth.

2.2 Data

Empirical studies on economic growth based on cross section estimations using data from the Colombian departments are scarce, mainly because of the lack of detailed regional data. One exception are the studies of Cardenas et al. (1993, 1995a, 1995b, 1997), which constituted our main source of information for this section.

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[11] For instance, see D. Aschauer (1989a, 1989b), A. Munnell (1990), Eberts (1990), Holtz-Eakin (1994) , Berndt and Hansson (1991), among others.

[12] See Cardenas M., and A. Escobar (1995), Cardenas M, Escobar A, and C. Gutierrez (1995), Roa N., Stevenson C. and F. Sanchez (1995), and Sanchez F. Rodriquez J. I. and J. Nuñez (1996).

[13] Sanchez F. Rodriquez J. I. and J. Nuñez (1996) use as dependent variable the total, industrial and agricultural productivity.

The data used for the estimation of the model are panel data set for twenty four departments[14] over three decades (1960-1970, 1970-1980, and 1980-1990). As we will see below, the lack of complete information of some variables, in particular GDP and human capital, limits the analysis to the second half of the century. Since there were some missing values for some of the variables, we ended up with about 57 observations. Table 2.1 summarizes the statistics of the variables included in the estimations. For infrastructure data we assembled departmental information for telephone lines for the period 1930-1990 from the *Anuario General de Estadistica de Colombia*. For power we used the data set for the years 1938, 1951, 1964, 1973, 1985 and 1992 from Cardenas et al. (1995a). The sources of roads and railroads for the period 1930-1990 are in M.T. Ramírez (1999). For human capital we used the primary and secondary net enrollment rates from Cardenas et al. (1997) for the years 1950, 1960, 1970, 1980, 1985, 1990. We took the data for population for the period 1912 to 1990 from the *Anuario General de Estadistica de Colombia*. The data for real GDP per capita are from Cardenas et al. (1993) and Cardenas et al. (1997) for the years 1950, 1960, 1970, 1980, 1989 and 1992. We also included variables that have appeared in empirical studies of economic growth such as infant mortality and crime rates. These variables are also taken from Cardenas et al. (1997). However, these variables were not significant in the estimations.

Data for investment share in GDP are not available at regional level. Therefore, we use as a proxy the national investment rate averaged over each decade. This choice has the problem that assumes that the national level of the series is the same for all the departments. We also include other national values as proxies for the departmental value such as the rate of change in terms of trade averaged over each decade. However, this variable was not significant in the estimations.

In addition to the above variables we include regional[15] and decade dummies to control for regional differences and shocks that may affect the adjustment rate. Table 6 summarizes the

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[14] The departments included are Antioquia, Atlantico, Boliva, Boyaca, Caldas, Caqueta, Cauca, Cesar, Choco, Cordoba, Cundinamarca, Guajira, Huila, Magdalena, Meta, Nariño, Norte de Santander, Quindio, Risaralda, Santander, Sucre, Tolima and Valle del Cauca. We also include the national capital, Santafe de Bogota.

[15] We construct four regional dummies as follows. The dummy for the Atlantic region includes the departments of Atlantico, Bolivar, Cesar, Cordoba, Guajira, and Magdalena. The dummy for the Central region includes the departments of Antioquia, Caldas, Cundinamarca, Quindio, Risaralda, Santander, Tolima and the national capital, Santafe de Bogota. The dummy for the Pacific region includes de

average value of some variables by region. The main evidence extracted from the table is the significant difference in the economic conditions across regions. For instance, the central region has the larger GDP per-capita and the larger infrastructure and education indicators while the Atlantic departments have the lower indicators.

Finally, the lagged values that were used as instrumental variables in each decade refer to the earlier decade. For instance, for the decade 1960-1970 we used as instrumental variables the values from the decade 1950-1960. As we did in section one we also fixed the depreciation rate at δ=0.04.

2.3 Estimations Results

We use the estimating equations from the model developed in section one.

(2.1) $\gamma_y = \beta_t\gamma_t + \beta_p\gamma_p + (1-\beta_t-\beta_p)q^* + (1-\alpha-\beta_t-\beta_p)(q-q^*) + (q+\ell+\delta)[1+g_k(X)]\alpha G_k$,

with $\alpha G_k = \beta_t \log t + \beta_p \log p - (1-\alpha)\log y + (1-\alpha-\beta_t-\beta_p)\log Q + \alpha \log s_k^* - \alpha\log(q^*+\ell+\delta)$.

(2.2) $\gamma_t = q^* + (q^* + \ell + \delta)[1+g_t(X)][-\log(t/y) + \sigma_t \log(s_t^*) - \lambda_t \log(q^*+\ell+\delta)]$,

(2.3) $\gamma_p = q^* + (q^* + \ell + \delta)[1+g_p(X)][-\log(p/y) + \sigma_p \log(s_p^*) - \lambda_p \log(q^*+\ell+\delta)]$.

The three-equation system is estimated by a two stage least squares method. Table 2.2 reports the results from the estimations of growth rates of power and telephones per capita. In the power growth equation the coefficients have the predicted signs and almost all are significant. In particular, the adjustment rate is affected positively by education, and negatively affected by the dummy for the decade of the eighties. This can be explained by the fact that the major power expansions were made in earlier decades.[16] On the other hand, the initial gap plays a significant

departments of Cauca, Choco, Huila, Nariño, and Valle del Cauca, and the dummy for Others departments includes the departments of Boyaca, Meta and Norte de Santander.

[16] However, we run some regressions including a dummy for the decade of the seventies and it appears with a positive sign but is not statistically significant.

role in infrastructure growth. However, the theoretical constraints on the coefficients in the initial gap expression, $\sigma_p=\lambda_p=1$, is rejected. This result can be explained by the fact that the theoretical constraint may be too restrictive to the choice of the aggregate investment rates as a proxy of the departmental investment values. In particular, it is important to mention that the coefficient of $\log(q^{*}+ \ell + \delta)$ is significant with the right sign, although its order of magnitude is higher than the theoretical one. Conversely, the coefficient of the investment share appears not significant.

Regarding the telephone per capita growth equation, the decade dummy for the eighties and the dummy for the Atlantic region[17] affects positively the adjustment rate while education does not have any effect. As in the power sector the theoretical constraint on the coefficients in the initial gap expression, $\sigma_t=\lambda_t=1$ is rejected. The share of investment, as expected, is significant with the right sign. But, the coefficient of $\log(q^{*}+ \ell + \delta)$ appears not significant in the estimations.

Table 2.3 presents the adjustment rates calculated for four different regions of the country for the 1980-1990 period. As in section one, the adjustment rates for telephones and other types of capital are faster than the convergence rates of 2.89% per year estimated for the GDP per capita presented in column (1) of table 2.4.[18] The adjustment rate of the power sector is of the same order of magnitude (2.83%) as the convergence rate for GDP. Contrasting with table 3 of section one, we observe that in general the adjustment rates for telecommunications in Colombia (7.10%) are higher than those found by the average of Latin America countries (5.63%), but it is almost of the same order of magnitude as the adjustment rate for the total number of countries (6.76%). The case is similar for other types of capital. However, the adjustment rates for the power sector in Colombia are lower than for the Latin America standard, except for the case of the departments in the central region.[19] To close half of the gap between telephone stock and the steady state path, in Colombia, it takes on average 9.8 years, for the power sector it takes 28.1 years, and for other types of capital it takes 17.3 years.

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[17] Dummies for other regions appear not significant in the regression, then we excluded them.

[18] The value of the convergence rate, 2.89% per year, estimated for the departmental GDP per capita in this section, is very close to that found in the literature. In fact, this rate is almost the same as the value estimated in section one for the panel of countries.

[19] See Table 6 for a summary of average values of some variables across regions.

Among regions, the magnitude of the adjustment rates differs, especially for the power sector. For instance, in the central region the adjustment rates for the three sectors are higher than the rates for the other regions. This result can reflect the institutional and economic differences that exist across regions. In fact, the central region includes the more developed departments[20] in the country. This outcome is consistent with the international evidence found in section one, in which the developed countries (see table 1.3, section one) have faster adjustment rates for all sector than the less developed countries.

Table 2.4 presents the results for the GDP per capita growth equation. As we mention above, the estimated convergence rate is 2.89% (see column one). The magnitude of this coefficient lies in the range of values reported in the literature (see section one). In Column (2) we introduce the infrastructure variables. The estimations show that the infrastructure sectors play an important role in the growth of GDP. Output elasticity with respect to telephones, 0.12, is very close to the value found in section one. However, the output elasticity with respect to power, 0.35, is considerably higher in the estimation for Colombia than in the cross-country estimations.[21] Similarly, in the gap expression the initial value of telephones per capita appears significant and with the right sign and order of magnitude as the expected one while the initial value of the power sector appears to be not significant. In the adjustment expression, education has a positive and significant effect as observed in the cross-country exercise. Besides the infrastructure variables, the initial gap expression is affected positively by education (at 10% of significance). Surprising, infant mortality and the investment share do not appear significant in the growth equation. The coefficient of $\log(q^{*} + \ell + \delta)$ is significant with the right sign but its magnitude is lower than the predicted by the theory. The regional dummy for the Atlantic region is negative reflecting the low

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[20] It is important to note that the central region includes also the national capital, Bogota whose economic and social indicators are in general higher than in the rest of the country.

[21] The magnitude of the elasticities lies in the range of those found in the literature. J.A. Ocampo (1996) summarize the empirical evidence between infrastructure stock and economic development in Colombia. He pointed out that Sanchez (1993) found a elasticity of 0.32 between infrastructure and total factor productivity and 0.68 between core infrastructure and industrial productivity for the period 1960-1992. Similarly, the DNP (1995) found an elasticity of 0.34 between core infrastructure and industrial factor productivity, and an elasticity of 0.17 between core infrastructure and total factor productivity for the period 1960-1994. On the other hand, Cardenas et al. (1995) found a elasticity of 0.18 between core infrastructure and total factor productivity, 0.07 between telephone lines and fsctor productivity, and 0.40 between public capital and regional total factor productivity during the period 1950-1994.

economic growth of this region. For completeness in the last column of the table we include roads in the growth equation. Roads do not appear significant in the adjustment expression or in the initial gap expression.

In general, as in section one, the theoretical constraint over the coefficients is rejected. One reason could be, as in the infrastructure growth equation, the choice of the aggregate investment share value as a proxy for the departmental value. On the other hand, the calculated value of α is lower than the calculated value from the cross-country estimations (see section one). In fact, the estimated coefficient for telephones implies α equal to 0.28, and the estimated coefficient for $\log(q^{*} + \ell + \delta)$ implies α equal to 0.24. Therefore, the implied values for α from those coefficients are very similar. But they are lower than those assumed in section one. For comparison purposes we assumed a α=0.4 in the calculation of the gaps in table 2.5.

Table 2.5 presents the estimated gaps. In general, the estimated gaps in telecommunications and other type of capital for Colombia are very similar to the average of Latin America countries (section one). However, the estimated gap in power is considerable lower (0.2) than that estimated for Latin America (1.26). Among regions, the telecommunication gap is larger for the Atlantic region, which is the region with the lowest number of telephones per capita but with the highest rate of growth in this sector. The estimated gaps for the power sector do not differ much across regions. Finally, the capital gap is larger in the Central region, which is the region with the highest GDP per capita.

2.4 Conclusion

The data for the Colombian departments appear to fit well the model developed in section one. In fact, the values of the coefficients for the infrastructure variables as well as the adjustment rates and gap expressions are of similar magnitude as those estimated for the panel of countries. The impact of infrastructure on GDP growth for the Colombian departments is considerable as section one predicts.

We found the magnitude of the estimated gaps and rates of adjustment varies across regions. Differences in the economic and social indicators as well as in the institutions capabilities of the region can explain the behavior of those values. Unfortunately, the lack of detailed data on institutional variables precludes a deeper analysis of the role of the institutional characteristics in the evolution of the infrastructure provision and economic growth.

Table 2.1: Summary Statistics of Variables Included in Estimation

Variable	Mean	Standard Deviation	Minimum	Maximum
Growth rate of GDP per capita	0.0216	0.0221	–0.0107	0.1148
Log of initial GDP per capita	9.5033	0.3413	8.8311	10.3402
Population Growth Rate	0.0207	0.0137	0.0020	0.0606
Log of infant mortality	2.8254	0.8049	0.5452	4.1745
Secondary education	25.0271	17.4075	2.5684	90.5718
Log secondary education	2.9498	0.7905	0.9433	4.5061
Primary education	67.8620	16.2458	31.7284	101.345
Log primary education	4.1868	0.2562	3.4572	4.6185
Log total investment as percentage of GDP	–1.5433	0.0376	–1.5829	–1.4937
Log public investment as percentage of	–2.8552	0.3174	–3.2468	–2.4765
Initial log power	3.8351	0.5410	2.6714	4.5889
Growth rate of power production	0.0383	0.0310	–0.0024	0.1385
Initial log telephones per-capita	2.7830	1.3540	0.3796	6.4656
Growth rate of per-capita telephones	0.0765	0.0561	–0.0180	0.2626
Initial log total roads per-capita	0.8526	0.6766	–0.9315	2.1149
Growth rate of per-capita total roads	0.0063	0.0397	–0.0793	0.1221

Sources: See text.

Table 2.2: Infrastructure Growth Equations

Estimation Method	2SLS		2SLS	
Dependent Variable: Growth Rate of	**Telephones**		**Power**	
Column	(1)	(2)	(3)	(4)
Number of observations	57	57	57	57
R^2	0.3586	0.5107	0.7309	0.7405
Adjusted R^2	0.2574	0.4182	0.6861	0.6885
Variables	**Coefficient/(t–statistic)**			
Constant (q^*)	0.0848	0.0813	0.0258	0.0328
	(6.909)	(7.071)	(2.455)	(2.839)
Adjustment Rate Expression				
Constant	–0.1176	0.3570	–0.2517	–0.3804
	(–0.785)	(1.672)	(–0.819)	(–1.286)
Education	0.0716	0.1349	0.3660	0.3957
	(1.517)	(1.500)	(3.653)	(4.289)
Dummy for Atlantic region	0.3515	0.3281		–0.1022
	(2.307)	(2.626)		(–1.112)
Dummy for 1980-90		0.3955	–0.9284	–0.7814
		(2.575)	(–3.828)	(–3.227)
Initial Infrastructure Gap Expression				
Constant	3.7787	3.0608	–9.9813	–10.080
	(0.600)	(0.419)	(–5.908)	(–5.893)
Log of investment-GDP Ratio	1.4440	2.0358	–0.3808	–0.3963
	(1.978)	(2.465)	(–1.105)	(–1.145)
$\text{Log}(q^* + \ell + \delta)$	3.3689	2.0659	–1.4419	–1.4708
	(1.253)	(0.675)	(–3.550)	(–3.417)

Source: Computed.

Table 2.3: Annual Adjustment Rates in Telecommunications, Power, and Other Capital, 1980-90

Region[a]	Telecommunications		Power		Other Capital[c]	
	Adjustment rate (%)	Half life of a gap[b]	Adjustment rate (%)	Half life of a gap[b]	Adjustment rate (%)	Half life of a gap[b]
Central	7.30	9.65	3.63	21.60	4.58	19.32
Atlantic	7.11	9.75	2.36	32.03	4.03	19.12
Pacific	6.74	10.30	2.24	34.47	3.02	23.87
Others	7.01	9.91	2.46	30.85	4.08	20.75
Total Departments	7.10	9.76	2.83	28.14	4.05	20.19

[a]The Central region includes the departments of Antioquia, Caldas, Cundinamarca, Quindio, Risaralda, Santander, Tolima and Santa Fe de Bogota.

The Atlantic region includes the departments of Atlantico, Bolivar, Cesar, Cordoba, Guajira, and Magdalena.

The Pacific region includes the departments of Cauca, Huila, Nariño, and Valle del Cauca.

Others include the departments of Boyaca, Meta and Norte de Santander.

[b]Years taken to close 1/2 of the gap assuming steady-state income path.

[c]Assuming α=0.3

Source: Computed based on Table 2.2, and Table 2.4.

Table 2.4: Per Capita Growth Equation

Model	(1)	(2)	(3)
	Fixed	Infrastructure excluding	Infrastructure including roads
Estimation Method	IV	2SLS	2SLS
Number of observations	57	57	57
R^2	0.2345	0.6099	0.6729
Adjusted R^2	0.1427	0.4463	0.4911
Variables	**Coefficients/(t-statistic)**		
Constant	0.2364 (1.257)	–0.0374 (–4.817)	–0.0361 (–3.886)
Terms of trade change	0.1151 (1.446)		
Output elasticity with respect to			
Telephones		0.1153 (1.722)	0.0997 (1.673)
Power		0.3555 (3.101)	0.3487 (3.213)
Roads			0.1218 (1.382)
Adjustment rate expression			
Constant	0.0289 (2.504)	–2.0469 (–1.122)	–1.5125 (–0.949)
Education		0.0539 (1.695)	0.0387 (1.355)
Dummy Atlantic region		3.5742 (1.433)	3.1581 (1.352)

Initial Capital Gap Expression			
Constant		5.4760	8.2527
		(2.376)	(2.801)
$\beta_t \log t$ (μ_t)		1.3809	2.5315
		(2.002)	(1.704)
$\beta_p \log p$ (μ_p)		0.8025	1.0087
		(1.358)	(0.930)
$\beta_r$og r (μ_r)			0.4241
			(0.423)

Table 2.4: Per Capita Growth Equation (continued)

Education	0.0310	0.0152	0.0091
	(2.240)	(1.561)	(0.561)
Log of infant mortality	0.0081	–0.2132	–0.3656
	(0.045)	(–1.191)	(–1.267)
Log of investment-GDP Ratio	–0.2675	–1.0581	–0.9238
	(–0.347)	(–1.394)	(–1.052)
$\text{Log}(q^* + \delta + \ell)$	0.6898	–0.3117	–0.0671
	(0.239)	(–1.641)	(–0.227)
Dummy Atlantic region	–0.0643	–0.5248	–0.7659
	(–0.165)	(–1.942)	(–1.613)

Source: Computed.

Table 2.5: Estimated Gaps in Telecommunications, Power, and Other Capital, 1980-1990

Region[a]	Telecommunications	Power Production	Other Capital[b]
Central	–0.29	0.14	1.72
Atlantic	1.53	0.17	0.61
Pacific	0.50	0.10	0.96
Others	0.94	0.40	0.77
Total Departments	0.62	0.19	1.07

[a]The Central region includes the departments of Antioquia, Caldas, Cundinamarca, Quindio, Risaralda, Santander, Tolima and Santa Fe de Bogota.

The Atlantic region includes the departments of Atlantico, Bolivar, Cesar, Cordoba, Guajira, and Magdalena.

The Pacific region includes the departments of Cauca, Huila, Nariño, and Valle del Cauca.

Others include the departments of Boyaca, Meta and Norte de Santander.

[b]Assuming α=0.3

Source: Computed based on Table 2.2 and Table 4.4.

Table 2.6: Average value of some variables by region, 1980

Variable	Central	Atlantica	**Pacifica**	**Others**
Growth rate of GDP per capita	0.0217	0.0271	0.0168	0.0067
Log of initial GDP per capita	9.9763	9.5619	9.5872	9.7264
Population Growth Rate	0.0164	0.0203	0.0128	0.0164
Secondary education	52.5891	37.1965	36.6346	38.9932
Primary education	91.6332	75.6516	77.1423	82.5562
Initial log power	4.4130	4.2433	4.2205	4.1772
Initial log telephones per-capita	4.4523	2.7589	3.1882	3.1947

Sources: See text.

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