ELSEVIER

Journal of Development Economics 70 (2003) 443–477

JOURNAL OF Development ECONOMICS

www.elsevier.com/locate/econbase

Institutions, infrastructure, and economic growth

Hadi Salehi Esfahani[a,*], María Teresa Ramírez[b]

[a] *Department of Economics, University of Illinois at Urbana-Champaign, 210 DKH 1407 W. Gregory Drive, Urbana, IL 61801, USA*

[b] *Central Bank of Colombia, Bogota, Colombia*

Received 1 May 2000; accepted 1 February 2002

Abstract

This paper develops a structural model of infrastructure and output growth that takes account of institutional and economic factors that mediate in the infrastructure–GDP interactions. Cross-country estimates of the model indicate that the contribution of infrastructure services to GDP is substantial and, in general, exceeds the cost of provision of those services. The results also shed light on the factors that shape a country's response to its infrastructure needs and offer policy implications for facilitating the removal of infrastructure inadequacies.

JEL classification: O4; O57; H54; L33; L9

Keywords: Economic growth; Convergence; Infrastructure; Institutions

1. Introduction

The relationship between infrastructure capital and economic growth has been controversial. A number of empirical studies have found high returns to infrastructure investment (Aschauer, 1989a,b; Easterly and Rebelo, 1993; Canning et al., 1994; Sanchez-Robles, 1998). But, the robustness of the results has been questioned in other empirical studies and surveys (Munnell, 1992; Tatom, 1993; Gramlich, 1994).[1] An important concern has been endogeneity and the direction of causality between infrastructure and aggregate output: While infrastructure may affect productivity and output, economic growth can also shape the demand and supply of infrastructure services, which is likely to cause an upward bias in the estimated returns to infrastructure if endogeneity is not addressed. Some of the studies that have examined this bias do not find it to be large (e.g.,

* Corresponding author. Tel.: +1-217-333-2681; fax: +1-217-333-1398.

E-mail address: Esfahani@uiuc.edu (H.S. Esfahani).

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

doi:10.1016/S0304-3878(02)00105-0

Flores de Frutos and Pereira, 1993; Fernald, 1999). However, a number of papers based on state-level panel data for the United States have shown that introducing long-run fixed effects may wipe out the positive effect of infrastructure on output growth (Holtz-Eakin, 1994; Holtz-Eakin and Schwartz, 1995; Garcia-Mila et al., 1996). On the other hand, using a cross-country panel data, Canning and Pedroni (1999) find that allowing for heterogeneity in the short-run infrastructure–GDP interactions yields two-way causality in most countries. These results suggest that taking account of both endogeneity and heterogeneity in the steady-state as well as the short-run relationships between infrastructure and output may be important for gaining better insights into the returns to infrastructure investment.

Most studies of economic growth consider the role of infrastructure and find positive effects by including infrastructure indicators on the right-hand side of reduced-form models (Barro and Sala-i-Martin. 1995). However, this is 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 sources 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 contribute to concurrent economic performance. Also, it is important to know how much other variables that seem to influence growth work through infrastructure. More generally, the question is how infrastructure development comes about and what feedback effects are generated by output growth, especially if one is in search of policy solutions to growth challenges. These issues, of course, apply to other variables that have been substituted out in reduced form growth models as well. But, infrastructure provides an important example because it is typically subject to extensive government controls, the efficacy of which depends on many of the country characteristics that are found consequential in reduced-form growth regressions.

The potential contribution of a structural growth model to the research on the determinant of infrastructure development is significant in its own right. That literature has examined infrastructure investment from different perspectives, ranging from public finance concerns (Randolph et al., 1996) to institutional considerations (Levy and Spiller, 1996; Bergara et al., 1998) and combinations of the two (Poterba, 1995). These studies identify a host of variables that may affect infrastructure capital formation, but take economic growth essentially as given. This may seem a pragmatic simplification, but it is problematic because of the simultaneity between GDP and infrastructure. Instrumenting for GDP can of course solve the problem, but it is not an easy solution. One often needs a more complete structural model to estimate the two-way relationship between GDP and infrastructure simultaneously or, at least, to identify appropriate instruments.

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 in theoretical and empirical terms.

In this paper, we develop a structural growth model that helps discern the mutual effects of infrastructure and the rest of the economy on each other. The model specifies the ways in which country characteristics and policies enter the infrastructure–GDP interactions and lead to heterogeneity of outcomes across situations. We distinguish heterogeneity in both steady-states and in the rate of convergence toward a steady state. We derive the infrastructure–output interactions as a recursive system that can be estimated simultaneously while solving the identification problem. Also, the relationships between infrastructure and income are formulated as error-correction processes to account for both simultaneous effect of infrastructure innovations and responses to deviations from the steady state. This formulation resolves the apparent inconsistency in earlier models where non-stationary initial levels of income and infrastructure are specified as determinants of stationary growth rates. Here, the levels only enter stationary expressions that measure the gap between the initial conditions and the steady state.

While the importance of country heterogeneity in growth dynamics has been well recognized in the literature, the short time span of country panel data does not allow accurate estimation of convergence rates and other short-run dynamic parameters by means of panel regression techniques (Lee et al., 1997, 1998; Canning and Pedroni, 1999). For this reason, panel data regressions that assume dynamic heterogeneity essentially produce information about the distributions of the short-run parameters and help deal with the biases that may arise if heterogeneity is ignored. That framework does not allow one to identify the factors that cause variation in the parameters. Moreover, the framework requires one to assume that the short run dynamic parameters are constant within a country, even though there are changes in country conditions over time. Our approach specifies the convergence rates and steady-state conditions of various assets as functions of country characteristics and estimates them as such, taking only the parameters of such functions as constant. This allows for more accurate estimation of convergence rates and steady-state conditions, without ruling out their variability across countries or over time.

Cross-country estimates of the model indicate that the contribution of infrastructure services to GDP is indeed substantial and in general exceeds the cost of provision of those services. In addition, we find that the steady-state elasticity of infrastructure with respect to total investment is greater than one, which means that the countries that manage to invest more do so particularly in infrastructure sectors. In other words, factors that prevent countries from investing at high rates tend to particularly hinder investment in infrastructure.

By examining the variables that account for heterogeneity across countries and over time, we draw attention to the more specific mechanisms through which various factors influence growth. These findings also shed light on the factors that shape a country's response to its infrastructure needs and offer policy implications for facilitating the removal of infrastructure inadequacies. One interesting result in this respect is that private ownership of infrastructure assets and government credibility (low risk of contract repudiation) matter for infrastructure growth, but mainly in speeding up the rate of adjustment rather than the steady-state asset–income ratios. It seems that in the long run, governments can manage to invest in infrastructure by themselves, but they have a much harder time dealing with infrastructure imbalances in the short and medium runs. Interestingly, the ability to coordinate policies within a country (as measured by the degree of centralization) seems to ease adjustment. Credibility also plays a similar role in the adjustment process of non-infrastructure capital. Moreover, in line with the findings in other empirical studies of growth, credibility tends to raise the level of productivity and the steady-state per capita income. Other institutional characteristics such as democracy and ethnic and income diversity mostly matter for the steady state asset–income ratios. Both forms of diversity have negative effects on the steady state asset ratios and on per capita income, though such effects tend to diminish in the presence of greater democracy, as Collier (1998) has observed.

Besides institutional factors, we examine the role of many economic and policy characteristics in shaping the steady state and the adjustment rates. In particular, we find that human capital and market distortions have insignificant roles in infrastructure growth, though they do matter for other forms of capital that drive aggregate growth. Another notable result is that population density and urbanization tend to lower the steady-state ratios of infrastructure assets to GDP and speed up their adjustment to imbalances. This seems to reflect the network properties of infrastructure assets that increase the returns to investment as population density rises. This view is further supported by the contrasting finding that population density reduces the speed of adjustment for non-infrastructure capital.

Because our model provides estimates of both the steady-state level of income per capita and its transitory behavior, our results are related to research on growth as well as the literature on the geographic and social determinants of income levels (which concerns long run outcomes). Among the latter group, Hall and Jones (1997, 1999) and Acemoglu et al. (in press) show that per capita income is closely related to the quality of existing institutions. McArthur and Sachs (2000) further argue that geography also matters in the long run. While not all their variables show significance in our regressions, our results generally support their conclusions. In particular, we find that institutions that improve contract enforcement help raise the level of per capita income, while being landlocked and having a heterogeneous population have the opposite effect. However, the structural model that we estimate helps shed light on how and where in the economy such variables may play a role.

Lack of sufficient data restricts the focus of this paper to infrastructure asset formation in power and telecom sectors. These sectors are likely to be representative of the rest. Indeed, the correlation coefficient between per capita phone mainlines and per capita electricity generation capacity in our sample is 0.94. The quantities of infrastructure assets also tend to be correlated with the quality of service. For example, based on a cross-section of 40 countries for which data is available in *World Development Report 1994* for 1990, the correlation coefficient between phone mainlines per capita and the line fault rates per year is -0.38. For the same sample, the correlation between electricity generation capacity per capita and the transmission and distribution losses as percent of total power production is -0.64. These correlations are indicative, but they are of course by no means one-to-one, hence the need for including more infrastructure sectors and developing quality measures for them remains.

The rest of this paper is organized as follows. Section 2 develops the model. Section 3 specifies the econometric equations to be estimated. Section 4 presents the results and discusses their policy implications. Section 5 concludes.

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 income growth rate, 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, infrastructure assets, N, non-infrastructure capital, K, and all other factors that influence productivity, Q. To keep the model simple, we interpret these labels broadly so that any factor that may be involved in production can be treated as part of one of these categories. We let the production function to be Cobb–Douglas with constant returns to scale and, without further loss of generality, assume that Q represents labor productivity:[2]

$$Y = K^{\alpha} N^{\beta} (QL)^{1-\alpha-\beta}, \tag{2.1}$$

where α and β are positive parameters.

The model can be easily extended to cases of increasing or decreasing returns to scale by replacing 1 in the exponent of QL with a parameter, σ, representing the returns to scale. This introduces a "non-scale" endogenous growth process into the model, which adds a term, $(\sigma-1)\log(L)$, to the log of income in the steady state and another term, $(\sigma-1)\ell$, where ℓ is the growth rate of L, to the steady-state income growth. Testing the model with these terms showed that $\sigma-1$ is insignificant. Therefore, for ease of presentation, we ignore the possibility that $\sigma \neq 1$ and let the sources of steady-state growth to work through the productivity factor, Q. These sources can be modeled as endogenous processes. However, such processes generally boil down to two possible terms in the long run growth equation: One, called the *scale* effect, is directly related to L and the other, a *non-scale* source of growth, is proportional to ℓ (see, among others, Segerstrom, 1998; Young, 1998; Jones, 1999; Eicher and Turnovsky, 1999a,b, 2000). We included such terms in our empirical estimations, but as in the case of $\sigma-1$, we found them to be insignificant. Other studies have also arrived at similar results (Jones, 1995). For these reasons, in this paper, we treat Q as exogenous. We also take labor supply, L, to be exogenous.

Infrastructure assets are distinguished from other types of capital because a number of market imperfections make the accumulation and operation of those assets prone to extensive government interventions and give rise to a special role for institutional characteristics. A widely recognized imperfection in infrastructure services is economies of scale due to network externalities (World Bank, 1994). Another factor is the broad consumption of infrastructure services that makes them politically more sensitive and

[2] 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 (1999a) further show 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. 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.

encourages the government to use regulations and controls not only to address externalities, but also to redistribute income (Noll, 1989).[3] This problem is particularly important for infrastructure sectors because production in those sectors is highly capital intensive and potential investors are naturally concerned about the possibility of ex post expropriation of their quasi-rents through nationalization or regulatory mechanisms (Levy and Spiller, 1996). Mitigating this problem requires either effective commitment and administrative capabilities or sufficient public resources for government investment. Besides intensifying government intervention, these elements imply that the share of infrastructure assets in output may diverge from the parameter α, as would be the case if those assets received their marginal productivity. This effect is important because it suggests that the small expenditure or cost shares of infrastructure sectors in GDP may be misleading indicators 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 cost share of infrastructure.

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

$$\gamma_y = (1 - \alpha - \beta)q + \alpha\gamma_k + \beta\gamma_n, \tag{2.2}$$

where q is the growth rate of Q and 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 attempts at measuring the role of infrastructure did. 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 physical and non-physical capital. This poses the problem of missing variables that may be correlated with γ_n and may bias its estimated coefficient. Second, infrastructure growth is likely to be driven by demand factors that depend on GDP growth. As a result, there is a simultaneity problem and one needs to identify Eq. (2.2) 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 and panel data approaches try to deal with these problems, but heterogeneity of dynamic interactions make the measurement of β difficult (Canning and Pedroni, 1999). 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:

$$\gamma_k = s_k y/k - \delta - \ell \tag{2.3}$$

and

$$\gamma_n = s_n y/n - \delta - \ell, \tag{2.4}$$

[3] Some infrastructure services are further plagued by the problem that cost recovery tends to be difficult and inefficient because the services are often viewed as "basic needs" (e.g., water sold to low income households) or exclusion of non-paying users is economically too costly (e.g., urban streets and rural roads).

where δ is the depreciation rate and s_k and s_n are the shares of output allocated to the accumulation of capital and infrastructure, respectively.[4] 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 preferences and production opportunities in the economy.

The steady state of this model is a situation where the savings rates, s_k and s_n, as well as the growth rates of y, k, and n are constant. Eqs. (2.3) and (2.4) 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 Eq. (2.2) must equal q. Indicating the steady-state values by *, we have:

$$s_k^* y^*/k^* = s_n^* y^*/n^* = q^* + \ell + \delta, \tag{2.5}$$

Note that we differentiate between the short- and long-run growth rates of Q and indicate the latter by q^*. As in most of the growth literature, we assume that the long-term rate of productivity growth, q^*, is constant across all countries. Then, the steady-state non-infrastructure capital–output ratio, k^*/y^*, and infrastructure–output ratio, n^*/y^*, are determined by $q^* + \ell + \delta$ as well as the preferences and the economic and technological factors that shape long-term investment rates for the two types of assets.

The actual output growth that one observes in an economy at a given time may differ from the steady state rate because shocks to the economy affect the current output or its steady state path. 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. For asset i, $i = k$, n, using Eqs. (2.3) and (2.5), we have:

$$\begin{aligned}\gamma_i - q^* &= s_i y/i - (q^* + \delta + \ell) = (q^* + \delta + \ell)\left[\frac{s_i y/i}{s_i^* y^*/i^*} - 1\right] \\ &= (q^* + \delta + \ell)\left(\frac{s_i}{s_i^*}\right)\left[G_i + \frac{s_i - s_i^*}{s_i}\right],\end{aligned} \tag{2.6}$$

where $G_i \equiv \frac{i^*/y^*}{i/y} - 1$ is the *gap* between the initial and the steady state asset–output ratio.[5]

In a model with fixed investment rates, as in the Solow–Swan growth model, we have $s_i = s_i^*$, which means that the growth rate of factor i can be simply represented by $\gamma_i = q^* + (q^* + \ell + \delta)G_i$, $i = k$, n. In this case, the term $(q^* + \ell + \delta)$ is the convergence rate of k and n toward the steady state allocations because it represents the percentage by which asset i adjusts in each period for each percentage deviation of i/y from its steady state. In the more general case when s_i may deviate from s_i^* in the short run, $(s_i - s_i^*)/s_i$ is likely to rise and fall with G_i and the speed of adjustment may be different. This is in fact the outcome of models with a representative utility-maximizing household. In most applica-

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

[5] An important advantage of this specification is that it conditions asset growth rates on asset–output ratios, which are ergodic and vary around situation-specific means (Blinder and Pesaran, 1999). This is in contrast to many other models that condition growth, which is a stationary variable, on per capita output, which is not a stationary.

tions of the neoclassical growth model this effect is assumed away as a second-order effect in the neighborhood of the steady state where s_i can be approximately set equal to s_i*. But, the investment rate response to asset imbalances can be large, especially at the sectoral level. For example, when power shortages arise, governments tend to pay more attention to that sector and make an attempt to channel more public or private resources toward investment in electricity. When there is excess capacity, on the other hand, the investment rate often declines. As a result, even if s_i/s_i^* in parentheses on the right-hand side of Eq. (2.6) can be approximates as one, $(s_i - s_i^*)/s_i$ may be large relative to G_i and should not be eliminated. Indeed, as a first-order approximation, $(s_i - s_i^*)/s_i$ can be written as

$$(s_i - s_i^*)/s_i = g_i(X)G_i, \qquad i = k, n. \tag{2.7}$$

where $g_i(.)$, $i = k$, n, is a function of a vector of other variables, X, that affect the responsiveness of investment to asset imbalances.

In the representative household model, X consists of preference and technology variables. However, when adjustment requires interaction among different decision-makers, additional variables that reflect the effectiveness of institutions in guiding the process also matter. Indeed, some empirical growth models that allow variables such as educational attainment of the population influence the convergence rate do find significant results (Barro and Sala-i-Martin, 1995). In this paper, we consider a variety of potential variables and specify the adjustment rate terms for capital and infrastructure separately. The details are discussed in Section 3.

Substituting from Eq. (2.7) into Eq. (2.6), in the neighborhood of the steady state we have

$$\gamma_i = q^* + (q^* + \ell + \delta)[1 + g_i(X)]G_i, \qquad i = k, n. \tag{2.8}$$

Eq. (2.8) indicates that when the investment rate responds to asset excesses or shortages relative to the steady state allocations, the adjustment rate for asset i is $(q^* + \ell + \delta)[1 + g_i(X)]$, which varies with country conditions. In the neighborhood of the steady state, we also can write

$$G_i = \log(i^*/y^*) - \log(i/y) = \log(s_i^*) - \log(q^* + \ell + \delta) - \log(i/y), \quad i = k, n. \tag{2.9}$$

which shows that the gap for asset i can be expressed in terms of the initial asset–output ratio and the determinants of long-term investment rate in the asset. We use these approximations to linearize the main expressions of the model and make the model's estimation more manageable.

Non-infrastructure capital included in our model is an aggregate measure of a variety of productive assets that can be accumulated. Some authors identify it with non-infrastructure physical capital, but empirical studies have consistently suggested that it should be more broadly defined (Mankiw et al.,1992). Since there is no comprehensive measure of such a variable, one can substitute γ_k as determined by Eq. (2.8) into Eq. (2.2) to obtain a growth equation for the aggregate output per capita:

$$\gamma_y = (1 - \beta)q^* + (1 - \alpha - \beta)(q - q^*) + \beta\gamma_n + (q^* + \ell + \delta)[1 + g_k(X)]\alpha G_k, \tag{2.10}$$

G_k can also be expressed in terms of variables other than k by substituting from the production function:

$$\alpha G_k = \alpha \log(s_k^*) - \alpha \log(q^* + \ell + \delta) - (1-\alpha)\log y + (1-\alpha-\beta)\log Q + \beta \log n. \tag{2.11}$$

This equation still include two variables, Q and s_i^*, that cannot be directly measured. However, for empirical implementation, they can be replaced by a series of variables that act as their determinants (more on this in the next section). As has been commonly observed in the literature, Eq. (2.10) implies 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 reason. A parametric rise in the initial level of per capita income, on the other hand, should lower economic growth. The effects of the initial income and infrastructure levels, 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, as can be seen in Eq. (2.8).

The model that we estimate is based on Eqs. (2.10) and (2.8) with $i = n$. The latter allows us to estimate infrastructure growth rate in a reduced form. We use the predicted values of infrastructure growth from this equation in the output growth equation, Eq. (2.10), to measure β and other parameters. The next section specifies the econometric model in detail.

3. The econometric model and the data

We estimate the above model for average infrastructure and per capita GDP growth rates of 75 countries for which we have complete data over any of the three decades, 1965–1975, 1975–1985, and 1985–1995.[6] Altogether we have 195 complete observations. Except when noted, all the right-hand side variables are measured at the start of the period (or the vicinity of that time when dictated by data availability). For some variables included on the right-hand side, there are potential endogeneity or measurement error problems, which may bias the coefficient estimates. Our general approach for addressing these problems is to use the lagged values of such variables as instruments, except for cases where we explicitly specify alternative instruments. The lagged values employed for each decade refer to the earlier decade, except for the 1965–1975 period, where we use the 1960 values or the 1960–1965 averages as instruments. The use of lagged values applies particularly to the initial levels of income and infrastructure assets, which are subject to measurement errors that induce automatic inverse relationships between those variables and their growth rates. The sources data and the detailed definitions of variables are given in Appendix A.

[6] Although annual data on infrastructure assets and output are available, many of the variables included in our model are not observed annually and necessitate longer-term durations for each observation.

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 straightforward. Letting 't' and 'p' subscripts denote telephones and power generation capacity per capita, respectively, the system (Eqs. (2.8)–(2.11)) extends to

$$\gamma_y = \beta_{\rm t}\gamma_{\rm t} + \beta_{\rm p}\gamma_{\rm p} + (1-\beta_{\rm t}-\beta_{\rm p})q^* + (1-\alpha-\beta_{\rm t}-\beta_{\rm p})(q-q^*) + (q^*+\ell+\delta)[1+g_k(X_k)]\alpha G_k, \text{ with } \alpha G_k = \beta_{\rm t}\log t + \beta_{\rm p}\log p - (1-\alpha)\log y + (1-\alpha-\beta_{\rm t}-\beta_{\rm p})\log Q + \alpha\log s_k^* - \alpha\log(q^*+\ell+\delta). \quad (3.1)$$

$$\gamma_{\rm p} = q^* + (q^*+\ell+\delta)[1+g_{\rm p}(X_{\rm p})][-\log(p/y)+\log(s_{\rm p}^*)-\log(q^*+\ell+\delta)]. \quad (3.2)$$

$$\gamma_{\rm t} = q^* + (q^*+\ell+\delta)[1+g_{\rm t}(X_{\rm t})][-\log(t/y)+\log(s_{\rm t}^*)-\log(q^*+\ell+\delta)], \quad (3.3)$$

If data on Q and s_i^*, $i=k, p, t$, were available, we could proceed with the estimation of Eqs. (3.1)–(3.3) after appropriate specification of $g_i(X_i)$. However, these variables are not directly observable and one has to replace them with suitable proxies. We represent $\log(s_i^*)$ by a linear combination of the log of the actual economy-wide *investment–GDP ratio*, log s_a, and a set of country characteristics that are likely to shape the steady-state share of investment in asset of type i, $i=p, t, k$. Since log s_a is simultaneously determined with γ_y, we instrument it with its lagged value. For $1+g_i(X_i)$, we use a linear function of the X_i variables. Note that in Eq. (3.1) the expressions for $1+g_k(X_k)$ and αG_k are each identified only up to a scaling factor. To address this problem, we scale $1+g_k(X_k)$ by $1-\alpha$ and αG_k by $1/(1-\alpha)$. After replacing $[1+g_k(X_k)]/(1-\alpha)$ by a linear function, $\theta_0+\theta X_k$, the last term on the right-hand side of Eq. (3.1) becomes

$$(q^*+\ell+\delta)(\theta_0+\theta X_k)[-\log y + \mu_n(\beta_{\rm t}\log t + \beta_{\rm p}\log p) + \varphi Z_k + \mu_k\log s_a + \mu_q\log(q^*+\ell+\delta)], \quad (3.4)$$

where Z_k is the vector of variables for the representation of $\log(s_k^*)$ as well as the determinants of log Q, (θ_0, θ) and φ are vectors of parameters, and μ's are scalar parameters. The model suggests that $\mu_n=1/(1-\alpha)$. One may also be tempted to assume $\mu_k=-\mu_q=\alpha/(1-\alpha)$, but these constraints may not hold because s_a is only one the indicators of s_k^* and, in addition, $\log(q^*+\ell+\delta)$ may be related to the determinants of initial productivity and investment composition. For similar reasons, in our estimations we let $\log(q^*+\ell+\delta)$ in Eqs. (3.2) and (3.3) to have a general coefficient, which may differ from -1.

A key issue in completing the specification of the model is which variables should be included in X_i and Z_i, $i=p, t, k$, where Z_p and Z_t are, respectively, the vectors of the determinants of $\log(s_p^*)$ and $\log(s_t^*)$ other than log s_a. The variables that are used for these purposes in the empirical growth literature are almost always treated as the determinants of the steady state capital and output. In the following, we review those variables along with some others and examine their potential roles in the steady state asset–output ratios as well as in the adjustment rates. In most cases, it is not clear a priori which effect exists or happens to be dominant. Empirically, we include all these variables in both expressions in the three equations of the model and let the data determine where each variable plays a role. The rest of this section is devoted to the discussion of the relevant variables.

To begin with, the steady state investment rates and the responsiveness to imbalances are likely to be lower when the country lacks effective and credible policy-making machinery. To measure credibility, we use the "contract repudiation" indicator available from the International Country Risk Guide (ICRG) dataset. We refer to this variable as *contract enforcement* because it rises when the chance of repudiation declines. This index, which was popularized in the growth literature by Knack and Keefer (1995), is a survey-based ranking that reflects the country's institutional characteristics that motivate policy-makers to honor the government's promises to investors and contractors. In other words, it is an indicator of government credibility and commitment and, thus, should be associated with higher steady state investment rate and faster convergence.[7] The same data set also contains indices of *bureaucratic quality* and *lack of corruption* that reflect other aspects of governance and are expected to help raise the steady-state income and speed up adjustment to imbalances.

Easterly and Levine (1997) have suggested ethnolinguistic heterogeneity (ELH) as another important variable that affects policymaking in a country. Ethnic diversity has a number of potentially detrimental effects. It may lower the level of trust among interest groups and politicians, raise the threat of violence, delay decision-making, and increase patronage. However, as Collier (1998) points out, such adverse effects may be mitigated by other institutional arrangements, especially democratic rule. As he succinctly puts it,

> Cooperation might be sufficiently easy in homogenous societies that it does not depend upon democratic institutions, whereas in diverse societies these institutions make the difference between zero sum and cooperative solutions. An ethnically diverse society might thus gain more from democracy than a homogenous society because the latter has less need of dispute resolution.

Collier recognizes that democracy may provide a more fertile ground for identity politics, which can exacerbate the role of ethnic divisions. But, his empirical finding supports the dominance of the mitigating effect. Similar arguments may apply to other institutional factors that shape decision-making; in particular, the degree of centralization. While centralization is costly because it limits decision-making and response to local conditions, it helps coordination in policymaking, which can be particularly helpful in sectors with network externalities. This latter effect is likely to play a positive role in the adjustment

[7] Henisz (1997) has also developed an interesting measure of government commitment based on the probability of policy change given the structure of politics and institutions in each country. That measure is correlated with the ICRG's contract enforcement index and carries the same signs in our regressions, but it is statistically less significant. For this reason, we use ICRG's index, although we consider the similarity of results with those obtained with Henisz's more objective measure an important assurance about the relevance of commitment capability for achieving growth.

process of infrastructure sectors, although not necessarily in their steady state investment rates. In the rest of the economy, where network externalities are far less prominent and coordination can be achieved through markets, centralization is likely to have a more ambiguous effect. We test the empirical relevance of these effects by including indices for ELH, *democracy*, and *centralization* as direct as well as interactive terms in both asset-gap and adjustment expressions. To measure *democracy* and *centralization*, we use rankings provided by the Polity III data set (see Appendix A).

Heterogeneity in the form income disparities can be another source of conflict and potential political instability that discourage investment, though opposite effects may also be present and complicate the relationship (Figini, 1998; Forbes, 2000; Banerjee and Duflo, 2000). The potential positive effects may arise from the interactions of inequality with imperfections in the markets for capital, education, or technology, which are crucial for growth (Saint-Paul and Verdier, 1993; Benabou, 1996; Galor and Tsiddon, 1997a,b). In the context of infrastructure growth, income distribution is likely to have added negative effects because the capital intensive nature of the sector and the heavy involvement of the government make investment in the sector more sensitive to potential political problems (Levy and Spiller, 1996). In addition, income distribution is likely to have important effects on the demand for infrastructure. In particular, controlling for average income and other factors, the demand for electricity is likely to be lower when income is more concentrated and the households in the lower income brackets have difficulty affording the service. This effect is likely to be weaker in the case of telephones because in most developing countries, telephone services have been more of a luxury than electricity.

As in the case of ELH, the level of democracy may matter in mitigating or exacerbating the effects of income heterogeneity. Democracy can play a positive role by allowing political demands be better expressed and by helping conflicts be resolved more systematically and credibly. But, as Persson and Tabellini (1994) have argued, it is also possible that the suppression of redistributive demands under dictatorships may make inequality less relevant for growth, while in the presence of democracy inequality may manifest negative growth effects. A similar ambiguity exists concerning the interaction inequality with centralization. Centralization can help facilitate redistribution in response to regional disparities, but it also tends reduce the responsiveness of policymakers to local concerns, which has opposite consequences. Thus, the direction of the net effects in these cases is an empirical matter, which we examine by including an index of income concentration (the *Gini* coefficient measured at the start of each decade) and its interactions with *democracy* and *centralization* indicators in the X_i and Z_i vectors.

In addition to institutions at the macro level, the organization of production in the infrastructure activities may also affect their adjustment and investment rates. For capturing this effect, we create *private ownership* dummies for the telecommunications and power generation that equal 1 when the majority of assets are under private control by the first half of the observation decade and 0 otherwise. Since private enterprises are likely to be more responsive to demand and supply factors, we expect these dummies to have positive coefficients in the adjustment expressions. The impact on the steady state investment rates is not clear because under public ownership, the government may create excess capacity to compensate for operational inefficiencies. We let the private ownership dummies remain equal 0 in a few cases where privatization occurred in the second half of the decade. This prevents the dummies from capturing the effects of private ownership in a few years at the end of the decade in these cases, but helps avoid simultaneity problems, in case slow infrastructure growth causes privatization.

Besides institutional features that shape the policymaking process, most empirical growth models include measures of policy outcomes that indicate the character of policies being adopted. The most common measure of this kind is the *black market premium* on the foreign exchange rate, which is taken to be an indicator of the extent of market-distorting policies.[8] Such policies are typically assumed to lower the steady state aggregate investment, but the impact on individual sectors may be more conflicting because distortion may create incentives for excessive investment in some sectors. Distortions may also slow down the adjustment process. We examine these effects by including the average *black market premium* among the determinants of steady state growth and convergence rates. Our *black market premium* measure is the average for the decade and, to avoid simultaneity problems, is instrumented by its own lagged value.

The vectors X_i and Z_i include technological and economic factors as well. In particular, educational attainment of the population has been found to raise the labor productivity factor (Barro and Sala-i-Martin, 1995). This means that an indicator of *education*—for which we use the average years of secondary education in the population of age 25 years and older—should be included in Z_k.[9] We include education in X_i and other Z_i vectors as well because higher levels of education may facilitate adjustment and raise the steady state investment rates by facilitating investment or creating demand for infrastructure.

A number of other important economic and technological factors, especially concerning the infrastructure sectors, are captured by the sectoral structure of production, the degree of urbanization, and population density. Industrialization (measured by *industry share* in GDP) is likely to be associated with faster the adjustment processes because it entails diversity of activities and skills that should make the economy more capable of asset formation. The relationship of *industry share* with the steady state capital formation rates, however, is less clear because a higher share of industry may be associated with a higher demand or a lower investment cost in some sectors, but not in others. For the power sector, one expects the steady state investment rate to rise with the size of industry, but this may not be the case for telecoms investment rate because other sectors, especially services, may have a stronger demand for telecoms.

Urbanization (share of population in urban areas) and *population density* (population per square kilometer) are important variables for infrastructure sectors because they enhance the economies of scale effects of networks. The high cost of expanding telephone and power networks to rural and sparsely populated areas has always been a major issue in the political economy of infrastructure services. Having a more urban and concentrated population is likely to make network adjustment easier. However, this may not raise the

[8] Some studies, such as Sachs and Warner (1995), take the black market premium as an indicator of anti-trade policies. But, as Rodriguez and Rodrik (1999) argue, this variable is likely to indicate the adverseness of the policy environment in general rather than just trade policy distortions. This is also the interpretation of many other studies such as Barro and Sala-i-Martin's (1995).

[9] In selecting the indicator for education, we follow Barro and Sala-i-Martin's (1995) who find secondary education to be more significant than primary and higher education. Using total years of education does not change the results much, though it shows slightly less statistical significance than the secondary education years.

steady state investment rates because these factors may reduce the demand for infrastructure per dollar of output. For other sectors of the economy where the economies of scale effect is not relevant, urbanization and higher population density may cause congestion and, thus, slow down the rate of adjustment to asset imbalances.

Openness of an economy is another variable included in the growth regressions, with presumed positive effects. Rodriguez and Rodrik (1999) have challenged those results, arguing that there is little evidence to that effect. Measures of openness except for the *black market premium* (to the extent that it can be considered as such) show little systematic significance in our regressions. However, a dummy for *landlocked* countries, which may be viewed as the difficulty of access to international markets (Sachs and Warner, 1995), does carry a significant negative coefficient as a determinant of state-steady investment and productivity in non-infrastructure sectors.

There is a host of other variables that have appeared in the empirical studies as determinants of growth and productivity. Prominent examples of such variables are: political instability, government consumption, life expectancy at birth, distance from the equator, shares of primary products in GDP and exports, inflation, and financial depth. These variables generally lost their statistical significance once we introduced the infrastructure indicators and allowed for variation in convergence rates. To keep the paper short, we do not report those results here except for life expectancy, which we provide as an example. Anyway, the impact of inclusion and exclusion of these variables on the parameters of interest, especially β_t and β_p, is negligible. We include period dummies in X_i and Z_i vectors to control for international events and technological shocks that affect all countries. We also examine the role of regional dummies.

We assume that the long-term growth rate of the overall productivity, q^*, is constant across countries and decades. For the productivity shock term, $q - q^*$, we use the rate of change in the terms of trade over each decade.[10] The growth rates of other factors determining the productivity level, Q, should also be included in the expression for $q - q^*$, but our experiments with variables such as education did not generate any tangible results once such variables were appropriately instrumented. For the depreciation rate, in principle it is possible to come up with an estimate as part of the regression. However, the presence of two additive parameters, q^* and δ, as the arguments of a log function in the asset gap expressions makes the solution algorithm relatively unstable and hampers its convergence. For this reason, we fixed the value at 0.04, which was typical of what we found whenever we could reach convergence while estimating it. Experiments with different values of δ showed that the results are not sensitive to this assumption.

We estimate the three-equation system, Eqs. (3.1)–(3.3), by IV/2SLS methods, assuming that each has its i.i.d. error term.[11] The large set of variables that we consider for inclusion in X and Z vectors may include irrelevant ones in each vector, which tends to

[10] This implies that the terms of trade level are among the determinants of Q and should, therefore, be included in the Z_k vector. However, we do not have any useful cross-country measure of terms of trade level to perform this task.

[11] Using the seemingly unrelated equations method is certainly preferable. However, the nonlinear nature of the equations causes difficulties for the convergence of the solution algorithm that prevented us from applying that method.

reduce the precision of estimates. To deal with the problem, after inclusion of all variables, we eliminated the ones that showed least significance one by one to end up with regressions in which all variables were reasonably significant. At later stages of this process, we tried back the eliminated variables individually and included them in the regressions again when they proved significant. We did this to ensure that the process is not path dependent. In a few cases we faced the problem that two variables were relatively insignificant when they were included individually but not when they entered together. In such cases, we selected variables for inclusion based on their *t*-statistics. We report part of this process below to show what it does. In all but two cases, the significance of the coefficient of one of the variables was marginal and choice was easy. Both exceptions to this pattern concerned the inclusion of the same variable, *Gini*, in the gap and convergence expressions for telephone and GDP growth equations. In the power generation capacity equation, *Gini* was only significant in the gap expression. Also, the interactive term of *Gini* with *democracy* was significant in the gap expression for all three equations. When we jointly included *Gini* and *Gini* × *democracy* in the convergence expressions and eliminated them both from the gap expressions, they proved insignificant. This observation and a comparison with the power generation capacity equation suggested that it was reasonable to assume that the combination of *Gini* and *Gini* × *democracy* must be together and in the gap expressions. In any event, this choice had little effect on the estimates of

Table 1
Summary statistics of variables included in estimation

Variable	Mean	Standard deviation	Minimum	Maximum
Growth rate of GDP per capita	0.0168	0.0242	− 0.0427	0.0819
Log of initial GDP per capita	7.8595	0.9787	5.7004	9.7153
Population growth rate	0.0201	0.0110	− 0.0070	0.0477
Log of initial telephones per capita	3.4116	1.8346	− 0.6049	6.8521
Growth rate of per-capita telephones	0.0551	0.0355	− 0.0032	0.1638
Private ownership in telecoms sector	0.1128	0.3172	0.0000	1.0000
Log initial power production per capita	− 1.9558	1.7019	− 6.2599	1.7219
Growth rate of per-capita power production	0.0401	0.0386	− 0.0377	0.1874
Private ownership in power sector	0.0974	0.2973	0.0000	1.0000
Average years of secondary education	0.9262	0.8989	0.0100	4.8300
Log of investment as percentage of GDP	− 1.9187	0.6596	− 4.4132	− 0.9826
Terms of trade change	0.0060	0.0576	− 0.0832	0.3115
Democracy score	4.6103	4.3520	0.0000	10.0000
Ethnolinguistic heterogeneity	0.3302	0.3081	0.0000	0.8902
Democracy × Ethnolinguistic heterogeneity	0.9886	1.5945	0.0000	6.8536
Centralization	1.3897	0.7474	1.0000	3.0000
Contract enforcement	6.0986	1.9594	1.0000	10.0000
Log(1 + exchange rate black market premium)	0.1868	0.2958	0.0000	1.8595
Gini coefficient	42.3080	9.3407	23.3000	68.2600
Log of population density	3.6442	1.3424	0.3930	8.2953
Urbanization	47.2462	24.5602	4.8000	100.0000
Share of industry in GDP	30.0538	9.7437	3.8755	56.5721
Log of Life Expectancy at Birth	4.0842	0.1861	3.6082	4.3477
Landlocked	0.1282	0.3352	0.0000	1.0000

other coefficients of the model. The variables used in the reported regressions and their summary statistics are presented in Table 1.

4. The estimation results

Table 2 presents the results of estimation for growth rates of telephones and power production per capita. Columns (1) and (5) show the results of regressions with fixed adjustment rates comparable to those estimated in the literature on infrastructure growth (e.g., Bergara et al., 1998). These regressions can be represented by an equation of the following form:

$$\gamma_i = \rho_i[-\log(i/y) + \varphi_i Z_i], \qquad i = t, p, \tag{4.1}$$

where ρ_i is the adjustment rate and the $\varphi_i Z_i$ expression represents the steady state asset–GDP ratio of infrastructure service i. The estimates of the parameter ρ_i for the two sectors are shown as the constant adjustment rates in columns (1) and (5) of Table 2. The estimated adjustment rates for both telephones and power generation capacity are statistically significant and remarkably similar to the 2–3% rates often found in the cross-section GDP growth regressions (Barro and Sala-i-Martin, 1995). (See also the fixed convergence rate for the GDP growth equation in column (1) of Table 4.)

The variables included in vector Z_i for estimating Eq. (4.1) are those that show significance at least in some regressions (see the lower parts of columns (1) and (5) in Table 2). A number of these variables—namely, *democracy*, *urbanization*, and *industry share*—are the same as those employed by Bergara et al. (1998). Those authors also include measures of GDP per capita, policy commitment, and the share of hydroelectric power in electricity production in their model of level of power generation capacity. However, these variables do not show any significance in our estimations of the growth form model, Eq. (4.1), when we take account of simultaneity biases. The estimated coefficient of *investment–GDP ratio* is greater than 1 and highly significant, which indicates a rising steady state share for infrastructure as aggregate investment rises.

Among other variables that show significance in the benchmark regressions of columns (1) and (5), ELH turns out to have a negative effect on the steady state infrastructure–GDP ratios, though it becomes weaker as the extent of *democracy* increases. Based on Wald tests of the linear expression that multiplies ELH, this overall negative effect in the case of telephones is statistically different from zero at least at the 5% level for about 60% of the sample with low democracy scores. The corresponding percent for the power sector is 45. Later, we will see that under a more complete specification of the model, the statistically significant effects of ELH on the steady-state infrastructure availability is less negative, but it is still relevant for countries with democracy scores below 6 for telephones and below 5 for power. This supports Collier's (1998) point about the mitigating role of democracy in ethnically fragmented countries.

The overall impact of *Gini* on the steady-state telephone-GDP ratio that emerges from the estimates of Eq. (4.1) shown in columns (1) and (5) of Table 2 is generally positive, but in the more complete version of the model that we examine below it becomes more negative, though insignificant except at very low levels of democracy. For power generation

Table 2
Infrastructure growth equations

Dependent variable	Growth rate of telephones per capita				Growth rate of power generation capacity per capita			
Estimation method	IV				IV			
Column	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Number of observations	195	195	195	195	195	195	195	195
R^2	0.353	0.509	0.506	0.533	0.471	0.623	0.619	0.626
Adjusted R^2	0.307	0.446	0.446	0.467	0.433	0.574	0.580	0.581
Variables	Coefficient/*t*-statistics (in italics)							
Constant (q^*)		– 0.0059	– 0.0097	– 0.0010		0.0081	0.0131	0.0126
		– 0.495	*– 0.934*	*– 0.080*		*1.271*	*2.689*	*2.216*
Adjustment rate expression								
Constant	0.0251	– 0.1411	– 0.1391	– 0.1546	0.0201	– 0.1612	– 0.1702	– 0.1486
	5.430	*– 1.121*	*– 1.129*	*– 1.199*	3.815	*– 1.238*	*– 1.390*	*– 1.305*
Centralization		0.0523	0.0509	0.0419		0.0435	0.0465	0.0384
		1.981	*1.872*	*1.636*		*1.412*	*1.608*	*1.420*
Contract enforcement		0.0292	0.0274	0.0253		0.0267	0.0334	0.0316
		1.975	*1.841*	*1.779*		*1.722*	*2.088*	*2.077*
Private ownership		0.2879	0.3290	0.1602		0.3179	0.2571	0.2035
		1.920	*1.994*	*0.913*		*2.037*	*1.953*	*1.671*
Log of population density		0.0198	0.0309	0.0366		0.0729	0.0676	0.0593
		1.248	*2.385*	*2.366*		*3.361*	*3.494*	*3.128*
Urbanization		0.0078	0.0077	0.0056		0.0011		
		3.754	*3.641*	*3.326*		*0.883*		
Dummy for 1975–1985		– 0.0683	– 0.0783	– 0.0373		0.1210	0.1272	0.1347
		– 1.291	*– 1.396*	*– 0.669*		*1.918*	*2.074*	*2.271*
Dummy for 1985–1995		0.1266	0.1256	0.2897		– 0.2438	– 0.2076	– 0.1532
		1.617	*1.498*	*2.412*		*– 2.956*	*– 2.609*	*– 2.040*
Initial infrastructure gap expression								
Constant	2.4423	– 1.6338	– 1.8294	– 4.018	– 0.0150	– 3.0637	– 3.1496	– 5.071
	1.165	*– 0.909*	*– 1.023*	*– 2.380*	– 0.004	*– 1.157*	*– 1.207*	*– 1.817*
Log of investment rate	1.5466	1.0796	1.1375	1.0023	1.6652	1.4814	1.4068	1.4538
	5.095	*5.754*	*5.834*	*5.778*	3.793	*5.602*	*7.733*	*6.572*
Democracy	– 0.4899	– 0.1965	– 0.2222	– 0.1014	– 0.6005	– 0.3115	– 0.3054	– 0.2617
	– 1.945	*– 2.091*	*– 2.283*	*– 1.063*	– 1.737	*– 2.890*	*– 2.999*	*– 2.156*
Democracy × Ethnolinguistic heterogeneity	0.0275	0.1785	0.1665	0.1318	0.0906	0.1356	0.1391	0.0762
	0.347	*2.818*	*2.589*	*2.178*	*0.920*	*2.003*	*2.142*	*0.978*
Ethnolinguistic heterogeneity	– 1.3308	– 1.5460	– 1.5249	– 1.2044	– 1.0608	– 0.9156	– 1.0497	– 0.830
	– 2.795	*– 4.064*	*– 3.951*	*– 3.541*	*– 1.850*	*– 2.425*	*– 3.184*	*– 2.264*
Democracy × Gini coefficient	0.0114	0.0042	0.0046	0.0025	0.0124	0.0053	0.0052	0.0046
	1.935	*2.022*	*2.184*	*1.283*	*1.577*	*2.313*	*2.367*	*1.776*
Gini coefficient	– 0.0342	– 0.0235	– 0.0248	– 0.0000	– 0.0778	– 0.0525	– 0.0492	– 0.0368
	– 1.292	*– 1.837*	*– 1.896*	*– 0.004*	*– 1.923*	*– 3.405*	*– 3.440*	*– 2.325*
Private ownership	– 0.4243	– 0.3859	– 0.5134	– 0.2367	0.5027	– 0.4318		
	– 1.252	*– 1.360*	*– 1.671*	*– 0.877*	*0.996*	*– 1.100*		

(continued on next page)

Table 2 (*continued*)

Dependent variable	Growth rate of telephones per capita				Growth rate of power generation capacity per capita			
Estimation method	IV				IV			
Column	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Initial infrastructure gap expression								
Log of population density	0.1805	0.0563			0.0817	−0.2252	−0.2027	−0.2409
	2.092	*1.052*			*0.799*	*−3.076*	*−2.981*	*−2.789*
Urbanization	0.0085	−0.0192	−0.0193	−0.0115	−0.0033	−0.0020		
	1.286	*−2.512*	*−2.501*	*−1.840*	*−0.397*	*−0.338*		
Share of industry in GDP	−0.0236	−0.0312	−0.0321	−0.0298	0.0026	−0.0030		
	−1.707	*−3.157*	*−3.117*	*−3.090*	*0.155*	*−0.284*		
$\text{Log}(q^* + \ell + \delta)$		−1.5312	−1.7656	−1.8432		−0.6189	−0.3922	−1.023
		−2.366	*−2.902*	*−3.004*		*−0.721*	*−0.455*	*−1.059*
Dummy for 1975–1985	−0.6058	0.1712	0.2073	−0.0266	−0.3055	−0.7479	−0.7103	−0.908
	−1.151	*0.605*	*0.663*	*0.077*	*−0.442*	*−1.951*	*−2.097*	*−2.206*
Dummy for 1985–1995	0.7357	0.1838	0.1901	−0.277	−1.9098	−0.4287	−0.7704	−0.996
	1.996	*0.624*	*0.591*	*−0.633*	*−2.049*	*−1.001*	−1.995	−2.177
Dummy for East Asia				0.3321				0.3516
				1.135				*1.087*
Dummy for South Asia				−0.4891				0.6399
				−1.244				*1.463*
Dummy for MENA				0.6924				0.4579
				2.756				*1.500*

capacity, however, the overall impact of *Gini* is mostly negative, especially under the more complete specifications where it is significantly negative for well over half of observations, where democracy score is less than 6. The difference between the two sectors is interesting because it supports the above conjecture that inequality should matter more for electricity than for telephones, which is more of a luxury service than former.

The expressions that form the coefficients of *democracy* in steady-state infrastructure expressions are linear functions of *Gini* and ELH. The coefficient estimates show that these expressions rise with both variables. Based on the estimates of Eq. (4.1) in columns (1) and (5) of Table 2, the expression in the telephone equation is negative for 50% of the sample and the one in the power equation for 60% of the sample. These expressions reach statistical significance with a negative sign for countries with a combination of high income and ethnic homogeneity. They are positive and significant for countries with relatively high degrees of heterogeneity in both income and ethnicity. Under the more complete specification of the model, the results are similar, but the expression is less frequently negative in the telephones equation (about 40% of the sample) and more frequently negative in the power equation (almost 70% of the sample).

A number of variables included in the estimates of Eq. (4.1) do not show significance, though they proved consequential under the more complete specification of the model. In particular, as we see below, *urbanization*, *private ownership*, and *centralization* are among such variables.

Making the adjustment rates dependent on institutional and economic variables changes the picture in many respects. As columns (2) and (6) of Table 2 show, quite a few variables prove significant in the adjustment expressions. The adjusted R^2 of the regression also rises sharply. Dropping the less significant variables in the regressions—as done in columns (3) and (7) of Table 2—further raises the precision of the estimates and improves the adjusted R^2s. *Centralization*, *contract enforcement*, *private ownership*, *population density*, and *urbanization* all prove important in speeding up the response to infrastructure gaps. As argued above, the latter two variables reduce the cost of network expansion and the first three increase the responsiveness of policymakers, producers, and investors to imbalances. Other variables proved irrelevant in the adjustment rate expressions of infrastructure sectors. *Urbanization* (in the case of telecoms) and *private ownership* are particularly effective in speeding up convergence: Privatization and one standard deviation increase in urbanization both reduce the half life of a gap in infrastructure assets by about 25%, on average. One standard deviation increase in the other variables reduces the half life by about 5–10%.

After allowing for variability in the adjustment rate, most coefficient estimates of the initial gap expressions maintain their signs and rise in significance (Table 2). In the telephone growth equation, *population density* loses its significance and *urbanization* gains a negative and significant coefficient. In the case of power growth equation, it is *population density* that gains a negative and significant coefficient, while *urbanization* remains insignificant. These outcomes suggest that lower costs of network adjustment in densely populated and urban areas have a positive effect mainly in the adjustment process. In the steady state, *urbanization* leads to more output being produced per telephone and high *population density* makes it possible to maintain lower power generation capacity per dollar of output. *Industry share* has negative effects on steady state infrastructure–output ratios, although it is insignificant in the case of power sector. It seems that relative to other sectors, industry generates more output per telephone line in the long run. The service sector, in particular, may be requiring more telephones per dollar of output. However, our experiments with the share of services in GDP did not produce significant results.

Although the *private ownership* dummies play important roles in adjustment rates, they remain relatively insignificant as determinants of the steady state investment rate in infrastructure. The negative signs of these dummies in the asset gap expressions, especially in the case of telephones, suggest that when the government owns infrastructure, it may over-invest in the long run. Whether this is a compensation for ineffective maintenance and lower quality of public enterprise services is an interesting hypothesis to test, but goes beyond the scope of this paper. Our current results essentially imply that private ownership helps infrastructure services reach their steady state positions faster, but has little effect on the long-term asset–output ratios.

The 1975–1985 and 1985–1995 decade dummies are relatively insignificant for telephones, but they prove important in both adjustment and gap expressions of the power sector. The marginally significant and positive coefficient of the 1985–1995 dummy in the telephone adjustment rate may be reflecting the recent technological improvements that have reduced the cost of telecommunications equipment. In the power sector, the adjustment rate had increased in the 1975–1985 decade and dropped afterwards far below the rate in the 1965–1975 decade. This seems to be due to the massive recycling of petrodollars in the second half of the 1970s that facilitated investment in power generation capacity in many developing countries; a process that was sharply reversed in the 1980s following the international debt crises. The negative signs of the decade dummies in the gap expression are likely to represent increased efficiency of energy use following the oil price shocks of the 1970s.

Our experiments with regional dummies showed that they are not very significant in the infrastructure growth equations. But, three of them—namely, the dummies for East Asia, South Asia, and the Middle East and North Africa (MENA)—display significance in the aggregate growth equation, when they are included in the expression for the steady-state ratio of non-infrastructure capital to GDP. In columns (4) and (8) of Table 2, we show the results of the inclusion of these dummies in the infrastructure growth equations, Eqs. (3.2) and (3.3). According to these estimates, only the MENA dummy in the telephone growth equation has a significant coefficient. The main consequence of introducing these regional dummies is that the terms involving *private ownership* and *Gini* lose their significance. This is largely due to multicollinearity caused by the similarity of privatization trends and income distribution within each region. The coefficient estimates for other variables remain by and large unchanged.

The estimations of the model with variable convergence rates show that institutional and economic conditions play important roles in closing infrastructure gaps. To make the results more tangible, in Table 3 we present the average adjustment rates for various regions of the world, estimated based on columns (3) and (7) of Table 2. The first notable fact about the figures in Table 3 is that infrastructure adjustment rates are generally faster than the 2–3% per year convergence rates found when they are assumed to be fixed. Indeed, the results become more similar to the rates found in panel data estimations that allow for heterogeneity among countries (Islam, 1995). However, our specification of the model helps identify the sources of heterogeneity and shows that variability is not only across countries, but also across sectors and over time (see also the last two columns of Table 3 that are derived from the GDP growth equation). For example, as the numbers in Table 3 indicate, adjustment in generation capacity per dollar of output has been slower than in other types of capital, particularly after the mid-1980s when the sovereign debt problem became a major barrier to capital movements to most developing countries. The telecommunications sector fared better because of its rapid technological change and privatization in some Latin American and OECD countries.

Another interesting observation in Table 3 is that the connection between the speed of convergence and the level of development is rather weak. (Note that the regional country groups in Table 3 are listed in the order of increasing average per capita income in the past two decades.) While stronger institutions and privatization raise the responsiveness of more developed countries of Latin America, East Asia, and OECD to infrastructure imbalances, greater centralization and density of population speed up the closing of gaps in many poorer countries. Higher population growth rate also contributes to the adjustment rates in the latter group of countries, though it also lowers the steady-state income per capita. It is notable that the role of stronger institutions and privatization became more prominent in the power sector adjustment rate during 1985–1995 (see Table 3), when a common shock reduced the average convergence rate and the variations in country characteristics came to play a bigger role in the outcome. In that situation, while East Asian countries could close half of the gap in their power generation capacity in less than three decades, it would take Middle Eastern countries almost a century to do the same.

Table 3
Annual adjustment rates in telecommunications, power production, and other capital

Region	Telecommunications		Power production		Other capital[a]	
	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
Period: 1965–1975						
Sub-Saharan Africa	2.23	31.15	2.48	27.91	3.91	17.73
South Asia	1.66	41.77	2.67	25.92	1.56	44.43
Mid-East and N. Africa	2.77	25.05	2.56	27.13	4.79	14.48
Latin America	3.08	22.53	2.13	32.56	6.30	11.00
East Asia	2.98	23.30	2.36	29.31	5.83	11.89
OECD and Others	4.18	16.59	3.67	18.86	7.62	9.10
World	3.74	18.53	3.35	20.71	6.78	10.22
Period: 1975–1985						
Sub-Saharan Africa	2.26	30.66	4.00	17.33	5.13	13.51
South Asia and China	1.52	45.72	4.09	16.95	2.95	23.48
Mid-East and N. Africa	2.76	25.07	3.83	18.09	6.40	10.83
Latin America	2.90	23.90	3.01	23.03	7.56	9.17
East Asia	2.22	31.18	4.37	15.85	4.89	14.18
OECD and Others	3.37	20.57	4.03	17.21	7.05	9.84
World	3.10	22.39	3.92	17.69	6.68	10.38
Period: 1985–1995						
Sub-Saharan Africa	3.46	20.04	0.88	78.73	4.89	14.19
South Asia and China	2.58	26.92	1.38	50.21	4.03	17.19
Mid-East and N. Africa	3.94	17.59	0.75	92.30	4.15	16.70
Latin America	5.17	13.40	0.77	90.38	5.77	12.02
East Asia	4.71	14.72	2.60	26.62	4.07	17.02
OECD and Others	4.58	15.15	2.34	29.56	7.16	9.68
World	4.29	16.15	1.98	34.94	6.27	11.06

Source: computed based on columns (3) and (7) of Table 2 and column (4) of Table 4.
[a] Assuming $\alpha = 0.4$.
[b] Years taken to close 1/2 of the gap assuming steady-state income path.

Table 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—a formulation akin to that of Eq. (4.1). Nevertheless, the results are quite similar in the two cases: The estimated convergence rate is about 2% and the per capita GDP growth rate rises with the terms of trade, contract enforcement, education, life expectancy, and investment rate, while declining with ethnic divisions, unequal income distribution, and market distortions. Our model also includes the interactive terms between democracy and ethnic and income disparities, with estimated coefficients being significant and positive, as in the case of infrastructure growth equations. There are a few other variables that display significance when included in this model, but

Table 4
Per capita GDP growth equation

Model	(1)	(2)	(3)	(4)	(5)
Description	Fixed aggregate adjustment rate	Institutional influence on aggregate adjustment	Infrastructure differentiated from other capital	Same as (3), less significant variables dropped	Same as (4) with regional dummies
Estimation method	IV	IV	2SLS	2SLS	2SLS
Number of observations	195	195	195	195	195
R^2	0.5542	0.6451	0.7069	0.7057	0.7436
Adjusted R^2	0.5141	0.5950	0.6595	0.6622	0.7004
Variables	Coefficient/*t*-statistics (in italics)				
Constant (q^*)		0.0282	0.0159	0.0231	0.0147
		2.569	*1.561*	*2.034*	*2.063*
Terms of trade change	0.0873	0.1008	0.0982	0.0950	0.0822
	3.633	*4.397*	*4.603*	*4.536*	*4.083*
Output elasticity with respect to					
Telephones			0.0911	0.0949	0.0779
			2.218	*2.348*	*2.084*
Power generation capacity			0.1561	0.1545	0.1277
			3.809	*3.772*	*3.462*
Adjustment rate expression					
Constant	0.0205	0.0506	0.0373	0.0625	0.0289
	5.662	*0.805*	*0.432*	*0.885*	*0.365*
Contract enforcement		0.0363	0.0490	0.0395	0.0366
		2.380	*2.394*	*2.383*	*2.564*
Ethnolinguistic heterogeneity		– 0.1280	– 0.1786	– 0.1546	– 0.1942
		– 2.303	*– 2.367*	*– 2.345*	*– 2.929*
Log of population density		– 0.0227	– 0.0348	– 0.0292	– 0.0261
		– 1.522	*– 1.699*	*– 1.675*	*– 1.818*
Share of industry in GDP		0.0021	0.0029	0.0025	0.0044
		1.863	*1.826*	*1.936*	*2.427*

Dummy 1975		0.0469	0.0604	0.0440	0.0652
		1.295	*1.317*	*1.220*	*1.744*
Dummy 1985		0.0474	0.0743	0.0556	0.0817
		1.244	*1.428*	*1.342*	*1.944*
Initial capital gap expression					
Constant	2.6896	7.1363	7.0333	6.4940	4.1391
	0.618	*1.460*	*1.446*	*3.858*	*2.316*
$\beta_t \log t + \beta_p \log p$ (μ_n)			0.4975	0.4895	1.1914
			1.025	*1.051*	*2.340*
Log of investment–GDP ratio	0.5454	1.2111	0.8630	0.8742	0.7346
	2.617	*4.586*	*3.493*	*3.660*	*3.496*
Democracy score	− 0.2419	− 0.2967	− 0.1828	− 0.1978	0.0036
	− 2.368	*− 2.939*	*− 2.096*	*− 2.220*	*0.0446*
Democracy × Ethnolinguistic heterogeneity	0.1637	0.2342	0.2086	0.2152	0.1339
	2.585	*3.154*	*2.610*	*2.661*	*1.837*
Ethnolinguistic heterogeneity	− 1.4144	− 2.3460	− 2.0057	− 2.1848	− 1.7339
	− 3.373	*− 3.538*	*− 3.126*	*− 3.362*	*− 3.142*
Democracy × Gini coefficient	0.0043	0.0051	0.0029	0.0032	− 0.0005
	1.990	*2.504*	*1.655*	*1.766*	*− 0.279*
Gini coefficient	− 0.0285	− 0.0313	− 0.0184	− 0.0191	0.0128
	− 2.240	*− 2.722*	*− 1.792*	*− 1.851*	*1.134*
Contract enforcement	0.1722	0.2436	0.2033	0.2410	0.1409
	3.134	*2.499*	*2.384*	*2.784*	*2.093*
Log(1 + Black Market Foreign Exchange Premium)	− 0.7196	− 0.6575	− 0.6404	− 0.6252	− 0.5775
	− 1.360	*− 2.073*	*− 2.116*	*− 2.142*	*− 2.248*
Ave. years of secondary education	0.3365	0.2012	0.1728	0.1541	0.1295
	2.882	*2.271*	*2.049*	*1.895*	*1.665*
Log of life expectancy at birth	1.8462	0.2309	− 0.0865		
	1.842	*0.207*	*− 0.077*		

(continued on next page)

Table 4 (*continued*)

Model	(1)	(2)	(3)	(4)	(5)
Description	Fixed aggregate adjustment rate	Institutional influence on aggregate adjustment	Infrastructure differentiated from other capital	Same as (3), less significant variables dropped	Same as (4) with regional dummies
Estimation method	IV	IV	2SLS	2SLS	2SLS
Log of population density	0.1546	0.0566	0.0416		
	2.340	*1.082*	*0.896*		
Landlocked	− 0.2089	− 0.5284	− 0.4369	− 0.4256	− 0.3231
	− 1.000	*− 2.422*	*− 2.226*	*− 2.320*	*− 1.869*
Log($q^* + \delta + \ell$)		− 0.8909	− 1.0138	− 0.9987	− 1.4746
		− 1.180	*− 1.447*	*− 1.452*	*− 2.304*
Dummy 1975	− 0.6211	− 0.2716	− 0.1766	− 0.1496	− 0.3932
	− 2.885	*− 1.477*	*− 1.117*	*− 0.933*	*− 2.316*
Dummy 1985	− 0.6495	− 0.1667	0.0339	0.0783	− 0.2372
	− 2.577	*− 0.736*	*0.166*	*0.410*	*− 1.209*
Dummy for East Asia					1.1371
					3.188
Dummy for South Asia					1.3315
					2.631
Dummy for MENA					0.7643
					3.066

Dependent variable: average growth rate of GDP per capita.

quickly become irrelevant when we allow for variability in the adjustment rate and distinguish infrastructure assets from the rest.

Column (2) of Table 4 reports the results when institutional influence on convergence is taken into account, but infrastructure capital is not differentiated from the rest. The variables included in the adjustment rate expression are the ones that ultimately prove significant when we differentiate between infrastructure and other capital. Despite its limitations, the new specification is clearly superior because we obtain a much better fit with the same variables. The regression results show that *contract enforcement* and *industry share* help improve the overall GDP convergence, while ELH and *population density* have the opposite effect. The case of *population density* is particularly interesting because in the linear regression it seems to have a positive effect on growth, but once it enters the adjustment rate expression, its role in the asset gap expression becomes insignificant and its effect on transition proves negative. While population density seems to strongly help adjust rates in infrastructure sectors, its congestion effects seem to dominate in most other sectors. In the gap expression, *life expectancy* also loses significance, but the institutional variables remain relevant and the *black market premium* and *landlocked* indicators gain more significance.

Introducing separate infrastructure variables and simultaneous estimation improve the fit of the regression considerably—see columns (3) and (4) of Table 4. The coefficient of the initial infrastructure expression, μ_n, does not show much significance. This is not due to the constraint placed on the coefficients of the infrastructure levels, because removing the constraint still yields relatively insignificant coefficients for the expression. But the coefficients of the infrastructure growth terms prove highly significant and of considerable magnitude. All other variables that were significant in column (2) remain so, suggesting that the aggregate equation mainly captures their impact on the non-infrastructure sectors. Interestingly, while contract enforcement seems to play very similar roles in the adjustment rates of all sectors, the impacts of *urbanization* and *industry share* are more sector specific and the *population density* has opposite effects on adjustment in infrastructure and non-infrastructure sectors.

The estimated expressions for asset gaps in infrastructure and non-infrastructure sectors indicate that there is a similarity in the way institutional factors affect steady-state investment rates. As in the case of infrastructure assets, ELH has a generally negative impact on the steady-state ratio of non-infrastructure capital to GDP, which is significant for about 50% of the sample with low democracy scores (again based on Wald tests of the expression that multiplies ELH). The overall impact of *Gini* on non-infrastructure asset–GDP ratio is negative at democracy scores below average. It becomes significant at the 5% level at very low democracy scores (0 and 1). The overall impact of democracy on non-infrastructure assets is within the range of its effects on telephones and power. It is negative for about half of the observations with relatively homogenous societies and is positive for the rest, reaching significant at the upper and lower thirds of the sample. The negative effect of democracy may reflect the increased coordination problems that it introduces into the policymaking process. This effect is overshadowed in more heterogeneous societies by the positive role of democracy in overcoming the disadvantages of ethnolinguistic diversity. The results also highlight the complexity of the relationships between economic outcomes and the indicators of democracy, inequality, and ethnic heterogeneity. They suggest reasons why earlier studies have not found stable relationships between the latter variables and economic growth.

The role of *contract enforcement* proves somewhat different between infrastructure and non-infrastructure sectors: It seems to be relevant for the non-infrastructure gap, while it was not for infrastructure gaps. This is likely to be the case because the substitution for k in the non-infrastructure gap expression results in a term with the log of the initial productivity factor, log Q, which must be positively related to the government's commitment capability. The same applies to the *black market premium* and *education* variables. Among other variables, only the *landlocked* dummy showed significance with a negative effect on non-infrastructure asset gap.

Adding regional dummies to the GDP growth regression affects few term—see column (5) of Table 4. As in the case of infrastructure growth regressions, the terms involving *Gini* become insignificant. The decade dummies, on the other hand, gain more significance and indicate that the speed of adjustment has increased after 1975, while the steady-state per capita capital stock may have declined. Also, the coefficient of $\log(q^* + \ell + \delta)$ gains significance. This coefficient has the correct (negative) sign in all equations and display statistical significance in the telephone growth equation as well (see Table 2). The estimated coefficients of the regional dummies themselves indicate that East and South Asia as well as the MENA region have had higher steady-state incomes than the levels captured by the variables included in the model.

The estimated value of q^* based on the GDP growth equation is around 0.02 and is generally significant. The magnitude seems reasonable in light of the historical long-term growth data from the United States and other developed countries. The estimate based on the power generation capacity equation, 0.013, is also within a reasonable range. The telephone equation, however, produces a negative estimate, although it is not significant. Constraining q^* to be the same across the three equations proved unwieldy for the solution algorithm of the estimation process because of the non-linear nature of the equations system. However, fixing q^* at the same number across equations in a relatively wide range around 0.01–0.025 did not change the results in any substantial way. Since two of the equations that generate significant estimates of q^* suggest that the magnitude should be in that range, it seems that our results are unlikely to be affected much by the lack of cross equation constraint on q^*.

For our purposes, an important characteristic of the regressions with different specifications and values of q^* is that the estimated elasticities of output with respect to telecommunications and power generation capacity, β_t and β_p, are remarkably robust in terms of magnitude and significance. Moreover, these elasticities turn out to be rather large. Even the lower estimates from the regressions with regional dummies—0.08 for telephones and 0.13 for power generation capacity—indicate that if the growth rate of telephones per capita rises parametrically 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 would rise by about 0.4 percentage points.[12] In the power sector, an increase of per-capita production growth rate from 2% as in

[12] 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.

Africa to 6% as in East Asia can raise annual GDP growth rate by another 0.5 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 (typically about 0.01–0.02), which means that the marginal products of infrastructure services are much higher than the cost of providing them.

The large productivities of infrastructure services relative to their output shares suggest that there must be strong incentives within the economy to increase the supply of such services much faster than other assets. Indeed, in most countries the growth rates of infrastructure services have been much higher than the GDP growth rate. However, as we saw earlier, the convergence rates in infrastructure are much lower than in other sectors. As a result, relatively large gaps have persisted in infrastructure, while in other sectors the asset–GDP ratios during the past three decades have been mostly above their steady-state levels (see Table 5). Of course, as the logic of our model suggests, the gaps are originally generated by output shocks in the past or by technological and institutional changes that affect the steady-state asset–GDP ratios. In this respect, it is interesting to note that because of improvements in their steady-state conditions, more dynamic countries of East Asia have had much larger gaps than the institutionally weaker countries of Africa and the Middle East (Table 5). In the Middle East, the relatively low gaps may also be attributable to the fact that large natural resource rents in the earlier decades have helped those countries build their capital stocks, while the more recent shocks have lowered their steady state asset–GDP ratios.

The calculation of adjustment rates and gaps for non-infrastructure capital in Tables 3 and 5 require some explanation. These calculations use an estimate of α because, as the discussion leading to Eq. (3.4) indicates, the adjustment rate expression in Table 4 gives that rate multiplied by $1-\alpha$ and the gap expression yields the gap times $(1-\alpha)/\alpha$. The coefficient of infrastructure levels term in the output growth equation should, in principle, generate an estimate of α, but unfortunately that coefficient is not estimated with any accuracy to be useful for this purpose. To the extent that the coefficient of $\log(s_a)$ represents $\alpha/(1-\alpha)$, it can be inferred from the estimates in the last three columns of Table 4 that α is about 0.42–0.46. This range is higher than the coefficient of capital commonly observed in the case of the US economy and it may be an overestimate because the greater-than-one elasticity of infrastructure with respect to total investment observed in Table 2 suggests that the non-infrastructure investment must be less elastic and, thus, the coefficient of *investment–GDP ratio* in Eq. (3.4) must be less than $\alpha/(1-\alpha)$. For this reason, we use a benchmark value of $\alpha=0.4$ to assess the adjustment rate and gap size for non-infrastructure capital in Tables 3 and 5. Our observations about gaps remain valid regardless of this assumption and the results concerning adjustment rates across sectors hold for all values of α greater than 0.3, which is a plausible range.

Finally, it is interesting to note that given the convergence rates of 0.043 and 0.020 for telephones and power under the conditions of 1985–1995, an exogenous 10% rise in GDP, say through an improvement in the terms of trade, could on average raise the telecoms growth rate by 0.43% and the power sector growth rate by 0.20%. These, in turn will stimulate further investment in the rest of the economy and, on average, add about 0.07%

Table 5
Estimated gaps in telecommunications, power production, and other capital, 1985

Region	Telecommunications	Power production	Other capital[a]
Averages weighted by:	GDP	GDP	GDP
Period: 1965–1975			
Africa	3.08	1.74	−0.71
South Asia	4.37	1.79	−0.60
MENA	2.86	2.20	−1.66
Latin America	2.65	2.19	−0.89
East Asia	2.93	2.34	−0.69
OECD and Others	1.23	1.44	0.20
World	1.78	1.62	−0.04
Period: 1975–1985			
Africa	2.56	0.82	−2.11
South Asia and China	4.19	0.81	−0.59
MENA	2.78	1.69	−2.31
Latin America	2.42	1.30	−1.15
East Asia	3.79	2.00	−0.04
OECD and Others	1.39	0.36	−0.47
World	1.88	0.63	−0.66
Period: 1985–1995			
Africa	1.08	−0.70	−1.88
South Asia and China	4.13	1.29	0.37
MENA	1.85	0.57	−2.71
Latin America	1.23	0.52	−1.59
East Asia	2.83	1.66	−0.10
OECD and Others	1.06	0.30	−0.11
World	1.66	0.53	−0.29

Source: computed based on columns (3) and (7) of Table 2 and column (4) of Table 4.
[a] Assuming $\alpha = 0.4$.

to the GDP growth rate. Although this feedback effect may seem trivial for a one-time increase in GDP, in a rapidly growing economy, it can compound over the years and become a tangible contribution to production.

5. Conclusion

The model of economic growth and infrastructure investment estimated in this paper offers quite striking results. After accounting for the simultaneity between infrastructure and GDP, the impact of infrastructure on GDP growth turns out to be substantial. However, realizing the potential of this effect for economic growth depends on institutional and economic characteristics that affect steady state asset–GDP ratios as well as the adjustment rates when asset–GDP ratios diverge from their steady state values. The model and the empirical exercise based on it allow us to identify a number of key variables that influence the gaps and adjustment rates. The results suggest that institutional capabilities that lend credibility and effectiveness to government policy play particularly important roles in the development process through infrastructure growth. The effects indicate that countries can gain a great deal by improving investment and performance in infrastructure sectors. But, the exercise also implies that achieving better outcomes requires institutional and organizational reforms that are more fundamental than simply designing infrastructure projects and spending money on them.

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 a large part of variation in infrastructure growth unexplained. Finally, the present model does not endogenize the organizational choice between private and public ownership. Making progress in all these directions is the plan for future research.

Acknowledgements

We are indebted to Lee Alston, Werner Baer, Ron Johnson, Larry Neal, and an anonymous referee for helpful comments on earlier drafts of this paper. Hadi Salehi Esfahani acknowledges a generous grant from IBM that has facilitated the implementation of this project. María Teresa Ramírez would like to thank the Central Bank of Colombia for financial assistance.

Appendix A. Data sources and definitions

The source of data for GDP, investment, population, black market premium on foreign exchange, terms of trade, and openness is Barro and Lee (1994). We used the Penn World Tables 5.6 dataset (Heston and Summers, 1995), the World Bank's World Development Indicators (WDI) CD-ROM, and World Currency Year Book, 1996 (published by Currency Data and Intelligence, Brooklyn, NY) to update the data and extended them for the 1985–1995 period. WDI was also the source of data for urbanization, industry share in GDP, and population density. The infrastructure data is from Canning (1998), with the telephone availability part of that data slightly extended by information collected from International Telecommunication Union publications. The indicator of landlocked countries was created by looking at a detailed map of the world. Educational attainment data is based on Barro and Lee (1996). Income distribution data comes from Deininger and Squire (1996), with the observation closest to the start of each period adopted as the initial level. The measure of ethnolinguistic heterogeneity is the average index calculated by Easterly and Levine (1997) and reflects the probability that two randomly selected individuals in the population speak different first languages. Easterly and Levine (1997) is also the source of a number of other variables such as financial depth, with which we experimented.

The institutional variables that we used in the model came from two sources. The data for democracy and centralization ranking are from Jaggers and Gurr's (1996) Polity III dataset. The degree of centralization refers to the geographic devolution of decision-making authority of the state, with values of 1 and 3 assigned to federal and unitary systems, respectively, and value of 2 given to intermediate categories.[13] The democracy score is the average of eight indicators ranking the process of selection of policymakers and the constraints on them. For *contract repudiation*, *bureaucratic quality* and *corruption*, the indicators were obtained from Political Risk Services (1995), International Country Risk Guide (ICRG) data file. These are subjective measures based on survey information. *Contract repudiation* indicates the risk of a modification in a contract taking the form of repudiation, postponement, or scaling down due to budget cutbacks, indigenization pressure, a change in government, or a change in government economic and social policies. Higher scores indicate lower risks. *Bureaucratic Quality* indicates autonomy from political pressure and strength and expertise to govern without drastic changes in policy or interruption in government services as well as the existence of an established mechanism for recruiting and training. Higher scores indicate higher quality. *Corruption* is an indicator of the degree of "improper practices" in the government. The higher the indicator, the lower the degree of corruption. The ICRG data starts in 1982 and we used its 1985 observation for the 1985–1995 decade. To generate more observations, we extrapolated ICRG data backward to 1972 by means of another data set from Business Environmental Risk Intelligence (BERI), which has similar measures for a smaller number of countries. We used the 1975 observation of the extrapolated variables as the initial condition indicators for the 1975–1985 decade and the earliest observations available for the 1965–1975 decade. For more information on ICRG and BERI datasets, see Knack and Keefer (1995).

For indicators of private ownership in infrastructure, we examined various sources. In particular, we used country literature, the *Country Profiles* of the Economist Intelligence Unit, Sader (1995), and the World Bank's Privatization Transactions in Developing Countries 1988–1994, to identify the countries that have had private ownership or have privatized their main power and telecoms companies in recent decades. An infrastructure service was labeled as privately owned in a given decade if the majority of supply came from companies that had been private or were privatized in the first half of the decade.

[13] This is the reverse of ranking given in the original data set, which represents the degree of decentralization.

Appendix B. Data availability

Country	1965–1975	1975–1985	1985–1995
Algeria	Complete data	Complete data	Black market premium not available
Argentina	Complete data	Complete data	Complete data
Australia	Complete data	Complete data	Complete data
Austria	Complete data	Complete data	Complete data
Bangladesh	Data mostly not available	Lagged infrastructure data not available	Complete data
Belgium	Complete data	Complete data	Complete data
Bolivia	Complete data	Complete data	Complete data
Brazil	Complete data	Complete data	Complete data
Cameroon	Gini not available	Complete data	Complete data
Canada	Complete data	Complete data	Complete data
Chile	Complete data	Complete data	Complete data
Colombia	Complete data	Complete data	Complete data
Costa Rica	Complete data	Complete data	Complete data
Cote d'Ivoire	Complete data	Complete data	Complete data
Denmark	Complete data	Complete data	Complete data
Dominican Rep.	Complete data	Complete data	Complete data
Ecuador	Complete data	Complete data	Complete data
Egypt	Complete data	Complete data	Complete data
El Salvador	Complete data	Complete data	Complete data
Ethiopia	Share of industry in GDP not available	Share of industry in GDP not available	Complete data
Finland	Complete data	Complete data	Complete data
France	Share of industry in GDP not available	Complete data	Complete data
Germany	Complete data	Complete data	Growth rate of power production not available
Ghana	Complete data	Black market premium not available	Lag of black market premium not available
Greece	Complete data	Complete data	Complete data
Guatemala	Complete data	Complete data	Complete data
Honduras	Complete data	Complete data	Complete data
Hungary	Lag of initial GDP, share of industry, black market premium, lag of investment rate not available	Share of industry and lag of black market premium in GDP not available	Complete data
India	Complete data	Complete data	Complete data
Indonesia	Complete data	Complete data	Complete data
Iran, I.R. of	Complete data	Complete data	Complete data
Ireland	Share of industry in GDP not available	Share of industry in GDP not available	Complete data
Italy	Complete data	Complete data	Complete data
Jamaica	Complete data	Complete data	Complete data
Japan	Complete data	Complete data	Complete data
Jordan	Complete data	Complete data	Complete data
Kenya	Complete data	Complete data	Complete data

(continued on next page)

Appendix B (*continued*)

Country	1965–1975	1975–1985	1985–1995
Korea	Complete data	Complete data	Complete data
Liberia	Complete data	Complete data	GDP Growth, black market premium not available
Madagascar	Complete data	Complete data	Complete data
Malawi	Complete data	Complete data	Complete data
Malaysia	Complete data	Complete data	Complete data
Mexico	Complete data	Complete data	Complete data
Morocco	Complete data	Complete data	Complete data
Netherlands	Share of industry in GDP not available	Complete data	Complete data
New Zealand	Complete data	Complete data	Complete data
Nicaragua	Complete data	Complete data	Complete data
Niger	Complete data	Complete data	Complete data
Nigeria	Complete data	Complete data	Black market premium not available
Norway	Complete data	Complete data	Complete data
Pakistan	Lag of initial power production not available	Complete data	Complete data
Panama	Complete data	Complete data	Black market premium not available
Peru	Complete data	Complete data	Black market premium not available
Philippines	Complete data	Complete data	Complete data
Portugal	Share of industry in GDP not available	Share of Industry in GDP not available	Complete data
Senegal	Complete data	Complete data	Complete data
Sierra Leone	Lag of initial GDP and black market premium not available	Lag of black market premium not available	Complete data
Singapore	Terms of trade change not available	Complete data	Complete data
South Africa	Complete data	Complete data	Complete data
Spain	Share of industry in GDP not available	Share of industry in GDP not available	Complete data
Sri Lanka	Complete data	Complete data	Complete data
Sweden	Share of industry in GDP not available	Share of industry in GDP not available	Complete data
Tanzania	Complete data	Complete data	Complete data
Thailand	Complete data	Complete data	Complete data
Togo	Complete data	Complete data	Complete data
Trinidad and Tobago	Black market premium and its lag not available	Lag of black market premium not available	Complete data
Tunisia	Complete data	Complete data	Complete data
Turkey	Complete data	Complete data	Complete data
Uganda	Complete data	Complete data	Complete data
United Kingdom	Complete data	Complete data	Complete data
United States	Complete data	Complete data	Complete data
Uruguay	Complete data	Complete data	Complete data
Venezuela	Complete data	Complete data	Complete data
Zambia	Complete data	Complete data	Complete data
Zimbabwe	Complete data	Complete data	Complete data

References

Acemoglu, D., Johnson, S., Robinson, J.A., in press. The colonial origins of comparative development: an empirical investigation. American Economic Review.

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

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

Banerjee, A., Duflo, E., 2000. Inequality and Growth: What Can the Data Say? Massachusetts Institute of Technology, manuscript.

Barro, R., Lee, J.-W., 1994. Data set for a panel of 138 countries, manuscript.

Barro, R., Lee, J.-W., 1996. International measures of schooling years and schooling quality. American Economic Review, Papers and Proceedings 86 (2), 218–223.

Barro, R.J., Sala-i-Martin, X., 1995. Economic Growth. McGraw-Hill, New York.

Benabou, R., 1996. Heterogeneity, stratification, and growth: macroeconomic implications of community structure and school finance. American Economic Review 86 (3), 584–609.

Bergara, M., Henisz, W.J., Spiller, P.T., 1998. Political institutions and electric utility investment. California Management Review 40 (2).

Blinder, M., Pesaran, M.H., 1999. Stochastic growth models and their econometric implications. Journal of Economic Growth 4, 139–183.

Canning, D., 1998. A database of world infrastructure stocks, 1950–1995. World Bank Economic Review 12, 529–547.

Canning, D., Pedroni, P., 1999. Infrastructure and long run economic growth. Paper presented at the 1999 Econometric Society Summer Meeting, Madison, Wisconsin.

Canning, D., Fay, M., Perotti, R., 1994. Infrastructure and growth. In: Bsaldassarri, M., Paganetto, M., Phelps, E.S. (Eds.), International Differences in Growth Rates. St. Martins Press, New York, pp. 285–310.

Collier, P., 1998. The political economy of ethnicity. Paper presented at the Annual World Bank Conference on Development Economics, Washington, D.C., April 20–21, 1998.

Currency Data and Intelligence, 1996. World Currency Year Book. Brooklyn, NY.

Deininger, K., Squire, L., 1996. A new data set measuring income inequality. World Bank Economic Review 10 (3), 565–591.

Easterly, W., Levine, R., 1997. Africa's growth tragedy: policies and ethnic divisions. Quarterly Journal of Economics 112 (4), 1203–1250.

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

Eicher, T.S., Turnovsky, S., 1999a. Non-scale models of economic growth. The Economic Journal 109, 394–415.

Eicher, T.S., Turnovsky, S., 1999b. Convergence in a two sector non scale growth model. Journal of Economic Growth 4, 413–426.

Eicher, T.S., Turnovsky, S., 2000. Scale, congestion and growth. Economica 67, 325–346.

Fernald, J.G., 1999. Roads to prosperity? Assessing the link between public capital and productivity. American Economic Review 89 (3), 619–638.

Figini, P., 1998. Inequality and Growth Revisited. Trinity College, Mimeo.

Flores de Frutos, R., Pereira, A., 1993. Public Capital and Aggregate Growth in the United States: Is Public Capital Productive. University of California at San Diego, Discussion Paper.

Forbes, K.J., 2000. Reassessment of the relationship between inequality and growth. American Economic Review 90 (4), 869–887.

Galor, O., Tsiddon, D., 1997a. The distribution of human capital and economic growth. Journal of Economic Growth 2 (1), 93–124.

Galor, O., Tsiddon, D., 1997b. Technological progress, mobility, and economic growth. American Economic Review 87 (3), 363–382.

Garcia-Mila, T., McGuire, T.J., Porter, R.H., 1996. The effect of public capital in state level production functions reconsidered. Review of Economics and Statistics 78, 177–180.

Gramlich, E.M., 1994. Infrastructure investment: a review essay. Journal of Economic Literature 32 (3), 1176–1196.

Hall, R.E., Jones, C.I., 1997. What have we learned from recent empirical growth research? Levels of economic activity across countries. American Economic Review, Papers and Proceedings 87 (2), 173–177.

Hall, R.E., Jones, C.I., 1999. Why do some countries produce so much more output per worker than others? Quarterly Journal of Economics 114 (1), 83–116.

Henisz, W.J., 1997. Judging the Impact of Political Constraints on Economic Growth. University of California, Berkeley, mimeo.

Heston, A., Summers, R., 1995. Penn World Tables Mark 5.6 Dataset. University of Pennsylvania.

Holtz-Eakin, D., 1994. Public sector capital and the productivity puzzle. Review of Economics and Statistics 76, 12–21.

Holtz-Eakin, D., Schwartz, A.E., 1995. Infrastructure in a structural model of economic growth. Regional Science and Urban Economics 25, 131–151.

Islam, N., 1995. Growth empirics: a panel data approach. Quarterly Journal of Economics 110 (4), 1127–1170.

Jaggers, K., Gurr, T.R., 1996. Polity III: Regime Type and Political Authority, 1800–1994, Computer file. Boulder, CO: Keith Jaggers/College Park, MD: Ted Robert Gurr, producers. Ann Arbor, MI: Inter-university Consortium for Political and Social Research, distributor.

Jones, C.I., 1995. Time series tests of endogenous growth models. Quarterly Journal of Economics 110 (2), 495–525.

Jones, C.I., 1999. Growth: with or without scale effects? American Economic Review, Papers and Proceedings 89 (2), 139–144.

Knack, S., Keefer, P., 1995. Institutions and economic performance: cross-country tests using alternative institutional measures. Economics and Politics 7 (3), 207–227.

Lee, K., Pesaran, M.H., Smith, R., 1997. Growth and convergence in a multicountry empirical stochastic solow model. Journal of Applied Econometrics 12, 357–392.

Lee, K., Pesaran, M.H., Smith, R., 1998. Growth empirics: a panel data approach—a comment. Quarterly Journal of Economics 113, 319–323.

Levy, B., Spiller, P. (Eds.), 1996. Regulations, Institutions and Commitment: The Case of Telecommunications. Cambridge Univ. Press, Cambridge.

Mankiw, G.N., Romer, D., Weil, D.N., 1992. A contribution to the empirics of economic growth. Quarterly Journal of Economics 107 (2), 407–437.

McArthur, J.W., Sachs, J.D., 2000. Institutions and Geography: Comment on Acemoglu, Johnson and Robinson. NBER, Working Paper No. W8114.

Munnell, A.H., 1992. Infrastructure investment and economic growth. Journal of Economic Perspectives 6 (4), 189–198.

Noll, R., 1989. The politics of regulation. In: Schmalansee, R., Willig, R. (Eds.), Handbook of Industrial Organization, vol. 2. North-Holland, Amsterdam, pp. 1251–1287.

Persson, T., Tabellini, G., 1994. Inequality harmful for growth. American Economic Review 84 (3), 600–621.

Political Risk Services, 1995. International Country Risk Guide Data, 1982–95, Computer file, Syracuse, NY: Compiled by IRIS Center. University of Maryland, College Park, MD.

Poterba, J.M., 1995. Capital budgets, borrowing rules, and state capital spending. Journal of Public Economics 56, 165–187.

Randolph, S., Bogetic, Z., Heffley, D., 1996. Determinants of Public Expenditure on Infrastructure: Transportation and Communication. Policy Research Working Paper No. 1661, the Word Bank.

Rodriguez, F., Rodrik, D., 1999. Trade Policy and Economic Growth: A Skeptic's Guide to the Cross-National Evidence. National Bureau of Economic Research, Working Paper 7081.

Sachs, J.D., Warner, A.M., 1995. Economic reform and the process of global integration. Brookings Papers on Economic Activity 1995 (1), 1–118.

Sader, F., 1995. Privatizing Public Enterprises and Foreign Investment in Developing Countries, 1988–93 FIAS Occasional Paper 5. Washington, DC: International Finance.

Saint-Paul, G., Verdier, T., 1993. Education, democracy, and growth. Journal of Development Economics 42 (2), 399–407.

Sanchez-Robles, B., 1998. Infrastructure investment and growth: some empirical evidence. Contemporary Economic Policy 16, 98–108.

Segerstrom, P., 1998. Endogenous growth without scale effects. American Economic Review 88 (5), 1290–1310.

Tatom, J.A., 1993. The spurious effect of public capital formation on private sector productivity. Policy Studies Journal 21, 391–395.
World Bank, 1994. World Development Report 1994. Washington, DC.
World Bank Privatization Transactions in Developing Countries 1988–1994. Washington, DC.
World Bank World Development Indicator (WDI), CD-ROM.
Young, A., 1998. Growth without scale effects. Journal of Political Economy 106 (1), 41–63.