Infrastructure Effectiveness as a Determinant of Economic Growth: How Well You Use it May Be More Important than How Much You Have

Charles R. Hulten
University of Maryland
and NBER

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I. Introduction

Most contemporary explanations of economic growth assign a prominent role to capital formation. This includes the huge literate of the sources of economic growth in the tradition of Solow (1957) and Jorgenson and Griliches (1967), but it also includes the smaller literature on social overhead capital and public infrastructure.[1] However, this literature has focused primarily on investment in new capital goods, and comparatively little attention has been given to the effective use of capital stocks once they are in place. This is a potentially important omission, since it is the flow of services from the stock, not the stock itself, that influences output. If this flow is diminished by the inefficient operation of the stock, or by its poor condition, additional capital formation may be of little help in stimulating economic growth.

The relative neglect of the effectiveness dimension of infrastructure capital is due largely to the scarcity of appropriate data. Fortunately, there is one major exception to this problem: the 1994 issue of the World Bank's World Development Report (WDR) is devoted to role played by infrastructure investment in the process of economic development and contains estimates of the effectiveness of various infrastructure systems in a broad cross-section of developing counties for a single year. This study revealss a significant problem with the reliability and condition of the systems studied. One finding suggests that $12 billion in timely road maintenance in Africa over the preceding decade would have avoided the need for $45 billion in reconstruction and rehabilitation. Moreover, "inadequate maintenance means that power systems in developing countries have only 60 percent of their

[1] Development economists have long recognized that social overhead capital is a necessary input in the structure of production (e.g., Hirschman (1958)). Infrastructure was incorporated into formal growth theory by Arrow and Kurz (1970) and Weitzman (1970). Empirical studies of the importance of infrastructure as a source of growth gained prominence with the papers of Aschauer (1989a,1989b), which were followed by a large body of econometric research. The more general capital formation sources-of-growth literatures are surveyed in Hulten (1990, 2001).

generating capacity available at a given time, whereas best practice would achieve levels of 80 percent ... [and] water supply systems deliver an average of 70 percent of their output to users, compared with best-practice delivery rates of 85 percent (page 4)." The WDR goes on to note that these deficiencies often arise from inadequate management of the existing infrastructure assets, as distinct from inadequate levels of new construction. This is seconded by the remark by Easterly and Levine (1996) that, while Chad may have 15,000 telephones, 91 percent of all telephone calls are unsuccessful.

The existence of an infrastructure effectiveness problem is therefore a well-documented phenomenon, and the corresponding penalty that it imposes on output was investigated by Lee and Anas (1992), who found that an unreliable electrical supply limited the use of certain types of machinery, putting companies at a competitive cost disadvantage. However, the overall penalty on macroeconomic economic growth arising from was not estimated in the WDR (or elsewhere), so it is hard to say just how quantitatively important the infrastructure effectiveness problem as a barrier to economic development.

Assessing the magnitude of this growth penalty at the macroeconomic level of growth is the main goal this paper. A summary effectiveness indicator is derived from the separate WDR indexes and the result is then embedded in a model of economic growth in order to assess the importance of the factor as a co-determinant of long-run output per capita. The model developed by Mankiw, Romer, and Weil (1992) (hereafter “MRW”) is used for this purpose. The resulting estimates for a sample of 46 low and middle income countries, covering the period 1970 and 1990, suggest that infrastructure effectiveness is an important factor in explaining differences in rates of real GDP growth during this period, even after controlling for various dimensions of political instability. This kind of control is needed in order to allow for possibility that the infrastructure effectiveness index is acting as a surrogate for a more general productive inefficiency that extends beyond infrastructure. With these controls, the estimate of the direct infrastructure penalty implies that a one-percent decrease in the infrastructure effectiveness index reduces the *output* by 0.51 percent. When the dynamic effects of this penalty are taken into account, the *long-run* penalty is estimated to be even larger, 0.79 percent. Cross-national differences in growth are also large: the 13 countries with the least efficient infrastructure have an average effectiveness index of 37 (out of 100) and an average annual growth rate of -0.70%; the 14 above average countries have an index value of 78 and an average annual growth rate of 2.68%. Viewed yet another way, the absolute level of productive efficiency is 30 percent lower at each point in time (relative to what might have been achieved) because infrastructure is used ineffectively. That is, the average country in the sample could increase output by 30 percent by using its existing capital and labor resources more effectively.

II. A Model of Infrastructure Effectiveness and Economic Growth

1. Economic efficiency is, at one level, a matter of the technology and organization of production, but at deeper level, it is a reflection of underlying societal institutions and culture. It is not easy to bring the two together in an analysis of growth. The literature on the estimation of production functions, as well as the literature on the measurement of total factor productivity, simply treats economy efficiency as a technical parameter to be estimated, usually as a residual, with no attempt to get at its deeper determinants. Observed changes in productive efficiency over time are interpreted as 'technical change' in the productivity literature (cite Hulten (2001)). When the focus is on cross-country comparisons of economic growth, as in this paper, the usual approach is to treat measured differences in factor efficiency as an indicator of the gap between the best practice technology and the actual level of technology in each country (cite Young, TFP catch up). In this context, measuring the contribution of infrastructure inefficiency to this gap is one way to get at the size of the associated growth penalty.

The literature of growth and development, on the other hand, does introduce institutional and cultural variables into the analysis, but typically without a specific link to the structure of production. The issue of infrastructure effectiveness lies somewhere between these two literatures. From the standpoint of production theory, all inputs to production are subject to variations in the efficiency with which they are used to production output. In the model of factor-augmenting technical change, each input is multiplied by a scalar index that represents the efficiency with which the input is used. Infrastructure inefficiency has a natural interpretation in this model as the factor-augmentation parameter associated with the stock of infrastructure capital. The resulting production function in this case is

$$Y_{i,t} = F[\phi_{i,t}L_{i,t}, \psi_{i,t}K_{i,t}, \omega_{i,t}G_{i,t}] \quad . \tag{1}$$

$Y_{i,t}$ denotes real output in country i in year t, $L_{i,t}$ is labor input, and $K_{i,t}$ and $G_{i,t}$ are the stocks of private and public capital, respectively. The corresponding factor-augmentation indexes are $[\phi_{i,t},\psi_{i,t},\omega_{i,t}]$, with $\omega_{i,t}$ representing infrastructure efficiency index.

Technical change over time occurs, in this specification, when the indexes increase over time because of improvements in the organization of production and because technological improvements allow the inputs to be used more efficiently. Cross-sectional differences in the indexes at any point in time are interpreted as the penalty gap between potential and actual productive efficiency in country i.[2]

The factor-augmentation index, $\omega_{i,t}$, can be given additional structure by making it an explicit function of the index of infrastructure effectiveness, $\theta_{i,t}$. We will assume, for simplicity, that the function has the constant elasticity form

[2] In the special case in which all factor input are equally influenced by technical change, the production function has the well-known Hicks'-neutral form $Y_{i,t} = A_{i,t}\ F(L_{i,t},K_{i,t},G_{i,t})$. The model developed below makes use of this specification in combination with a separate factor-augmentation parameter for infrastructure.

(2) $$\omega_{i,t} = \theta^{\rho}_{i,t} \ .$$

This formulation links the effectiveness of a country's infrastructure directly to its real GDP, by inserting (2) into the production function (1) and observing that the elasticity of output with respect to the measured index $\theta_{i,t}$ is simply the parameter ρ times the GDP share of infrastructure (or $\rho\gamma$, where the share is denoted by γ). This implies that each one-percent decline in infrastructure efficiency reduces real GDP by $\rho\gamma$ percent. This is the direct penalty that the inefficient use of infrastructure exacts on economic growth.[3]

2. The factor-augmentation parameters are usually taken as determined outside the estimation model. Even the step taken in the formulation of (2) is somewhat unusual, though it does have some precedent (e.g., in the literature on the contribution of R&D to economic growth). However, the efficiency with which infrastructure and other inputs are used may itself be a reflection of deeper causal factors, like bureaucratic red tape, over-regulation of firms, inflexible labor markets, corruption, weak enforcement of property rights, and civil unrest. If these latent "X" factors change only gradually over time, they can safely be treated as exogenous parameters in the in the production function, to be measured but not explained. In cross-sectional studies, however, it is precisely these factors that may contribute the most to national differences in economic growth. In terms of the factor-augmentation model, the index $\theta_{i,t}$ might itself depend on a set of these "X" factors. In

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[3] In this formulation, the infrastructure effectiveness index, $\theta_{i,t}$, is treated as a scalar index that applies to the stock of infrastructure as a whole. In reality, infrastructure facilities tend to be congestible public goods that are organized into capital-intensive *networks* (e.g., roads and bridges, railroads, air and water transport, water and sewer systems, electricity generation and distribution networks, telecommunications facilities). Each segment of the network could plausibly be regarded as a separate investment, with it's own efficiency index. The index $\theta_{i,t}$ used in this paper is an aggregate indicator of the system as a whole, a sort of weighted average across the entire system. By implication, some parts of network which may actually work efficiently, with the further implication that the same value of $\theta_{i,t}$ in two countries may imply have different policy implications.

this case, the index has the form $\theta(X_{i,t})$, thus making $\omega_{i,t}$ a function of these factors as well. Moreover, the latent "X" characteristics so might also influence the augmentation parameters for labor and private capital, $\phi_{i,t}$ and $\psi_{i,t}$. In this situation, the elasticity of output with respect to an index of the X-efficiency variables might be considerably larger than $\rho\gamma$, and any attempt to force the whole effect onto the infrastructure variable might over-state the role of infrastructure effectiveness.

3. The primary goal of this paper is to isolate and estimate the infrastructure inefficiency penalty, $\rho\gamma$, and its variants and correlates. The straightforward way to proceed, in view of (1) and (2), is to specify a specific functional form for the production function and to estimate the magnitudes ρ and γ. However, there are two problems with the direct estimation of the production function. First, there is the practical issue that estimates of the stocks of public and private capital are of problematic reliability for some developing countries, and they may not exist at all for some countries. But, second, even if when reliable data data are available, direct estimation the production function is subject to the problem that the stocks of capital are jointly determined with output. More capital leads to more output, and more output leads to more investment and thus more capital, creating the potential for the simultaneous-equations bias that has plagued many econometric studies of infrastructure's affect on output (e.g., Aschauer (1989a,1989b))

Both of these problems care ameliorated in the approach developed in Mankiw, Romer, and Weil (1992). This model is based on the Solow (1956) model of economic growth, in which the rate of saving and not the stock of capital is the explanatory variable.[4] The capital stocks entering the production

[4] In the simplest version of the Solow growth model, output per worker converges to a steady-state growth path along with the growth rates of output and capital equal the growth rate of the labor force. Convergence occurs according to the following mechanism. A constant fraction of the output, s, is set aside in each year for investment, which increases the stock of capital. If the increase in capital is greater than the growth in the labor force, capital per worker expands, increase output per worker in the next year. The fraction s of this

function are endogenously determined by accumulation equations for each type of capital, and by an investment equation in which investment is a constant fraction of output. This fraction, the rate of investment in each type of capital is assumed to be exogenously determined (s_k,s_h,s_g), as are the growth rates of labor, n, labor-augmenting technical change (the rate of change of $\phi_{i,t}$ above), λ, and to depreciation rate of capital, δ. The Solow growth model is thus a system of equations in which the production function is but one element. MRW solve this system of equations for its reduced form, expressing the growth rates of output and capital in terms of the exogenous rates of investment, depreciation, technical change, and labor growth. Since the flow on investment, and thus the investment rate, is more readily measured than the corresponding stock of capital, this reduced-form approach is more easily implemented than direct estimation of the parameters of the production function. Moreover, because it is more plausible to assume that the rate of investment is independent of the level of output than to believe that the stocks are exogenously determined, the problem of simultaneous equations bias is addressed.

MRW proceed by assuming that the production function has the Cobb-Douglas form, with constant returns to scale. In this paper, we expand the MRW specification to includes infrastructure capital and effectiveness (although MRW actually use a combined concept of physical capital, G+K, in their study), as well as the X-efficiency variables, and retain the MRW human capital variable, $H_{i,t}$. We will also work with a special case of the general factor-augmentation model (1), in which the latent X-efficiency variables are embodied in a general Hicksian efficiency term that shifted the production function as per footnote X, and in which the infrastructure-efficiency variable augments the public infrastructure variable as in equation (2).

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larger output is set aside for capital formation, and if the increase in capital is again greater than the growth in the labor force, capital per worker expands, increasing output per worker, and so one. Because of diminishing marginal return to capital, each successive increase in output per worker is smaller, and the process come to an end when the increase in capital just equals the growth in the labor force. At this point, the steady-sate balanced growth path is attained.

Expressed in an "intensive" format, in which the endogenous variables are divided by labor input, the resulting production function has the form

$$y_{i,t} = A(X_{i,t})\, k^{\alpha}_{i,t} h^{\beta}_{i,t} (\theta^{\rho} g_{i,t})^{\gamma}\,, \tag{3}$$

where (k,h,g) are the <u>per worker</u> magnitudes of private fixed capital, human capital, and public capital respectively.[5] The parameter (α,β,γ) are the output elasticities with respect to the capital stocks, (k,h,g). Operating through the shift term $A(X_{i,t})$, the latent X-efficiency variables augment each input equally, implying that "bad" institutions shift a country's aggregate production function downward relative to the maximal "best-practice" frontier. The infrastructure efficiency index also shifts the production function (3) downward when infrastructure is used inefficiently, but since it is "attached" to the infrastructure stock variable, the elasticity of output with respect $\theta_{i,t}$ is the constant $\rho\gamma$.

The Cobb-Douglas production function is solved with the accumulation equations for each type of capital, and the corresponding investment equations. A steady state growth path (y^*,k^*,h^*,g^*) is shown by MRW to be a function of the constant investment rates (s_k,s_h,s_g), and the rate at which the effective work force expands, $n+\lambda$, plus the constant replacement rate of capital, δ. The sum $n+\lambda+\delta$ is rate at which capital stocks must grow in order to keep the capital-labor ratio constant. MRW show that the multiplicative form of the Cobb-Douglas production function carries over to the reduced form equations, as do the Cobb-Douglas parameters. The reduced form equations for steady output per worker, and for each of the types of capital per worker, is given by:

[5] Labor is expressed here in efficiency units, $e^{\lambda t}L_{i,t}$, where λ is the rate of labor-augmenting technical change. Output per unit of (efficient) labor is then $y_{i,t} = Y_{i,t}/e^{\lambda t}L_{i,t}$, etc.

(4) $$y^* = \left\{\frac{A(X)\ s_k^{\alpha} s_h^{\beta} (\theta^{\rho} s_g)^{\gamma}}{(n + \lambda + \delta)^{\alpha+\beta+\gamma}}\right\}^{\frac{1}{1-\alpha-\beta-\gamma}}$$

$$k^* = \left\{\frac{A(X)\ s_k^{1-\beta-\gamma} s_h^{\beta} (\theta^{\rho} s_g)^{\gamma}}{n + \lambda + \delta}\right\}^{\frac{1}{1-\alpha-\beta-\gamma}}$$

$$h^* = \left\{\frac{A(X)\ s_k^{\alpha} s_h^{1-\alpha-\gamma} (\theta^{\rho} s_g)^{\gamma}}{n + \lambda + \delta}\right\}^{\frac{1}{1-\alpha-\beta-\gamma}}$$

$$g^* = \left\{\frac{A(X)\ s_k^{\alpha} s_h^{\beta} (\theta^{\rho} s_g)^{1-\alpha-\beta}}{n + \lambda + \delta}\right\}^{\frac{1}{1-\alpha-\beta-\gamma}}$$

Because this system characterizes the steady-state growth path, time subscripts are omitted. The country "i" subscripts are also suppressed for expositional clarity. These equations indicate the long-run effect of changing the various rates of investment, and demonstrate the endogeneity of the corresponding capital stocks.

In this formulation each percentage decline in effectiveness lowers steady-state output per worker by $\rho\gamma/(1-\alpha-\beta-\gamma)$ percent. This is larger than the direct penalty, $\rho\gamma$, obtained by differentiating the Cobb-Douglas production function. The difference lies in the multiplier effect that an exogenous variable has on steady-state output per worker. A one percent decline in θ lowers output directly by $\rho\gamma$, and the lower output then supports less capital formation via the investment equations, thereby lowering steady-state output further until the total reduction is $\rho\gamma/(1-\alpha-\beta-\gamma$ (all else equal). This is *long-run penalty* exacted by inefficiency.

4. The reduced form equations (4) characterize the steady-state solution toward which the economy is converging, not the actual path followed by the economy. The economy of any country i actually moves along a transitional

path from the initial level of output per worker to the steady state path, which, following MRW, can be defined by the following expression:

$$\text{(5)} \qquad \ln(y_{i,t}/y_{i,0}) = (1-e^{-\mu t})\ln(y_i^*) + e^{-\mu t}\ln(y_{i,0})$$

where $y_{i,0}$ is the level of output per worker in the initial year, y_i^* the steady state value toward which the economy is moving, and μ the parameter determining the rate of convergence. This is a partial adjustment model with an endogenous "target," y_i^*, and a rate of adjustment determined by the parameters equal of the Solow model, $\mu = (n+\lambda+\delta)(1-\alpha-\beta-\gamma)$.

The transitional dynamics implied by (5) can be operationalized by combining this expression with the natural logarithm of first equation of (4). The resulting equation does not involve the unobserved steady-state, y_i^*, but is instead a relation between observable variables that can, in principle, be estimated. Letting $y_{i,70}$ denote real GDP per unit of labor in country $\underline{i}$ in 1970, and $y_{i,90}$ the 1990 value of this variable, the left-hand side of equation (5) becomes

$$\text{(6)} \quad \ln[y_{i,90}/y_{i,70}] = b_0 + \textstyle\sum_i b_i X_i + b_k \ln[s^k_i(n_i+\lambda+\delta)] + b_h \ln(s^h_i/(n_i+\lambda+\delta)] + b_g \ln[s^g_i/(n_i+\lambda+\delta)] + b_\theta \ln(\quad) + b_c \ln(y_{i,70})) + \epsilon_i \,.$$

This is the basic regression equation of this paper. Because the regressions are applied to a cross-section of countries, the time subscripts are largely absent, but the countries subscripts are included.

The regression parameters (b_k,b_h,b_g) can be interpreted as the elasticities of growth with respect to the investments rates (s^k_i,s^h_i,s^g_i), b_θ as the growth elasticity of infrastructure effectiveness, and b_c as the elasticity of "catch-up." These growth rate elasticities are not the same as the output elasticities, (α,β,γ), because of the steady-steady multiplier effect described above for the infrastructure-effectiveness penalty. They are, however, related by the formulae: $\alpha = b_k/(b_k+b_h+b_g-b_c)$, $\beta = b_h/(b_k+b_h+b_g-b_c)$, and $\gamma = b_g/(b_k+b_h+b_g-b_c)$. The level of Hicksian efficiency, A_i, is derived from the constant term and the effects of the latent institutional variables, by taking the exponent of $b_0 + \sum_i b_i X_i$, evaluated at the means of the "X" variables. The rate of convergence, μ, is derived from b_c. Estimation of the parameters (b_k, b_h, b_g, b_c) thus gives estimates of the output elasticities, (α, β, γ), the level of productive efficiency, and the rate of convergence.

III. <u>Data</u>

1. The data used in this study are derived from four main sources: the Easterly-Rebelo (1993) data base, the World Bank's World Development Indicators, and the 1994 World Development Report, the Summers and Heston (1991) Penn World Tables. The analysis is restricted to low and middle income countries, and spans the years 1970 to 1990. A summary list of the variables is shown in Table 1, along with the data sorted by income-growth rate terciles. A list of countries in the sample is given in Appendix Table A.

The main income concept used in this paper is based on Summers-Heston real GDP per capita adjusted for purchasing-power parity, although unadjusted World Bank estimates of real GDP per capita were also used as a robustness check. These data are summarized in the top panel of Table 1. The dependent variable in all regressions is the growth rate of real GDP per capita between 1970 and 1990. The basic right-hand side variables of the regression equation (6) are the investment rates of public capital/infrastructure, private capital, and human capital. Various alternatives are used for the public capital/infrastructure variable, but only one private investment rate is used. Since no purchasing-power parity adjustment for public or private capital flows is available in the data bases, all investment rates are expressed as a fraction of unadjusted GDP, averaged over the period 1970 to 1990. Human capital was proxied by primary and secondary education enrollment rates, but expenditures on health and education as a fraction of GDP we also used in some varaints of the analysis. The investment rates are deflated by the average rate of population growth between 1970 and 1990, to which is added .05 (following MRW) to allow for the average rate of capital depreciation and labor-augmenting technical change.

The Easterly and Rebelo investment rates are shown in the second panel of Table 1. The measure of gross public investment is broadly encompassing, and includes investment by public firms that are similar in function to those in the private sector. It should be noted that the rate of public investment differs greatly from the rate of <u>infrastructure</u> investment, which is only 3.0 percent in the 24 countries for which this variable is available. Easterly and Rebelo indicate that their estimate of infrastructure investment may be biased downward because it excludes the infrastructure investments of publicly-owned and private firms.

Another variant of the analysis examined infrastructure stocks rather than flows. The 1994 World Development Report presents information on the stock per capita of paved roads, telephone mainlines, electricity generation capacity, irrigation, and railroads. These data are largely physical indicators of the total stock, not perpetual inventory estimates. They are shown in the third panel of Table 1, expressed in 1980 dollars. There is apparently little difference among the three groups in the total amount of infrastructure capital, though the composition does change across groups. The most rapidly growing countries placed more emphasis on road transport than on rail, and had a larger stock of irrigation capital.

2. Measures of the effectiveness of the various infrastructure systems are shown in the bottom panel of Table 1. One indicator was selected for each of the four main systems. These measures are taken as being representative of the efficiency of the various systems. The construction of an aggregate effectiveness index is further complicated by the fact that each of the individual indicators is measured in its own units -- e.g., mainline faults per 100 telephone calls, electricity generation losses as a percent of total system output, the percentage of paved roads in good condition, diesel locomotive availability as percent of the total -- and there is no natural way of adding up the indicators in this form to arrive at a total. The 1994 WDR did not offer an aggregate measure of performance.

Given these difficulties, a simple two-stage procedure is used to aggregate the individual performance indicators. First, each indicator was sorted into quartiles, and the top quartile assigned a value of 1.00, the second, 0.75, the next 0.50, and the bottom assigned a value of 0.25. This produced a quartile ranking for each of the four systems for each country in the sample, θ_{ij}. An aggregate indicator for each country, θ_i, was computed by simple averaging of the θ_{ij}. For some countries, the θ_{ij} quartile values were available for all four systems, but for many countries, the average is taken over only two or three indicators (countries with only one value were dropped from the analysis). This averaging procedure retains as many countries as possible in the sample while making use of data for the different infrastructure systems. The resulting aggregate index provides a country ranking according to qualitative performance in those infrastructure functions for which data are available.

3. The institutional variables used to control for latent sources of economic inefficiency are derived from two sources. Easterly and Rebelo provide three such variables in the larger data set used in this paper. They include, for each country: assassinations per million, 1970-85; revolutions and coups, 1970-85; and, war casualties per capita, 1970-88. These are the “X” variables used in the estimation of the regression model (6). They are background variables that can be expected to affect the ability of an economy to function efficiently. Political instability may affect the production of output in many ways, including the effectiveness with which infrastructure is used.

The broad effects on output growth are examined in the following section, while Table 2 explores the infrastructure dimension. The first column of this table reports the parameter estimates from the regression of the log of the infrastructure efficiency index, θ_i, on the levels of the three political stability variables. All the slope coefficients all have the expected negative sign, although only war casualties per capita is statistically significant. The R-squared is 0.277, showing the these variables have some explanatory power, but also that there is a great deal of independent variation in the index θ_i. The exponent of the constant term is an estimate of θ_i, when the “X” variables are at the optimal level of zero, but the resulting value of 0.56 is well below the maximal value of 1.0 (again suggesting that the institutional variables fall short of explaining the index θ_i). Indeed, the fitted “X” terms, $\sum_i b_i X_i$, evaluated at the sample means imply a penalty of only eight percent relative to the maximal value of the constant term. It is worth noting that the institutional variables are positively (and significantly) related to the rates of investment in public and private capital, though the relation is not strong. However, this is no relation between the institutional variables and the rates of investment in human capital.

The importance of political instability as a background variable suggests that is might be useful to extend the analysis to include variables reflecting economic-cultural institutions as well. The paper by Mauro (1995) on corruption and growth develops another set of indicators that yield insights into other dimensions of this penalty: corruption, red tape, and an efficiency of the judiciary. These are drawn from the measures produced by Business International. Mauro also develops an index of political instability from the BI measures and develops a separate index of ethnolinguistic fractionaliztion. He finds that these variable have a significant effect on the growth rate of per capita GDP growth in the sample of countries and time period studied. They can also be incorporated into the model developed in this paper, but only for a reduced set of 26 countries.

The second column of Table 2 shows the link between the original three Easterly-Rebelo institutional variables and the index of infrastructure effectiveness for the 26 country sample. The R-squared is higher than with the 46 country sample, and now both assassinations and war casualties have significant coefficients although revolutions has a positive sign. The next column shows the effect on the effectiveness variable of the core Mauro variables. The R-squared for this regression is similar to the fit in column (2). However, only the political stability variable is statistically significant at conventional levels. The last column of the table combines both sets of variables and achieves an R-squared of 0.613. Unfortunately, the economic-cultural variables are not statistically significant, again, and the estimated coefficients of red tape and efficient judiciary both have positive signs. Although the degrees of freedom are small, the contribution of these variables is nevertheless disappointing.

IV. Basic Regresson Results

1. A simple plot the growth tare of GDP per capita against the infrastructure effectiveness variable is shown in Figure 1. This diagram visually indicates a strong link between the two variables absent any other factors. The implied OLS regression is $\ln[y_{i,90}/y_{i,70}] = 0.868 + 1.036 \ln(\phi_i)$, with an R-squared of 0.504 and a standard error on the infrastructure elasticity of 0.155. This establishes infrastructure effectiveness as an important correlate of economic growth. The size of the elasticity, 1.036, also implies a very large (one-to-one) penalty to the poor use of infrastructure stock, other things equal.

Table 3 presents the results of implementing the full model of equation (6), based on the 46 country sample. The regressions include the Easterly-Rebelo institutional variables, but the estimates for these variables are omitted from the tables to save space and because impact is minimal (their effects are included estimates of the other variables). The top panel of Table 3 reports the ordinary least squares estimates of the parameters of the regression equation (6), along with the associated t-statistics. The implied elasticities (α,β,γ) are computed from these estimates, and are shown in the lower panel.

The first column shows the parameter estimates and implied elasticities without the effectiveness variable, θ. The estimates of the output elasticities of capital are statistically significant, and their combined value is similar to the MRW estimate of 0.44 for the combined capital coefficient (MRW Table VI, 75 country sample). The R-squared statistic is 0.56, slightly greater that the one obtained from the regression of the income per capita variable on θ. The estimated coefficient of the initial (1970) GDP per capita is statistically significant, implying a rate of convergence of 0.024, which is close to the theoretical value $(n+\lambda+\delta)(1-\alpha-\beta-\gamma) = 0.020$. It is also close to the MRW estimate of 0.0186.

The second column of Table 3 adds θ to the list of Solow-MRW variables, and is a full implementation of the regression equation (6). The infrastructure effectiveness variable enters in strongly significant way, with a long-run elasticity of 0.794, and the R-squared increases to 0.71. This result implies a very large long-run penalty: a ten percent reduction in the efficiency with which infrastructure is used reduces the log-change in income per capita by 7.94 percent, when the feedback effects of reduced capital formation are counted. When they are not, the penalty in 0.51. This is the equivalent to a downward shift in the production function (3) by this factor for each level of income per capita.

The addition of θ also reduces the public capital variable to statistical insignificance, and lowers the significance of private capital and primary education, while promoting that of secondary education. This reflects, in part, the correlation between the independent variables $(s_k, s_{h1}, s_{h2}, s_g)$: the corresponding partial correlation between these variables and θ are 0.42, 0.24, 0.22, and 0.32, respectively. The partial correlation between s_g and θ may reflect, in part, a virtuous growth environment in which the decision to invest in public capital and the efficient operation of that capital are part of the same phenomenon, this could also extend to investment in private capital and education. Finally, the rate of convergence is, again, reasonably close to the theoretical value (0.029).

The reduction in the importance of the public capital stock, s_g, is particular notable in light on debate over the role of public investment as a stimulus to economic growth and development. It suggests that how infrastructure is used is at least as important as how much there is. It is worth noting again, in this regard, that public infrastructure systems are typically networks of individual investments. Adding links to a system that is not efficiently used may not have much effect on output if the links are themself not efficiently placed (e.g., to relieve congestion), or may not have much effect at all if the condition or operation of the system as a whole is poor. Conversely, improvements in system efficiency may have a large effect of output even if there is little or no new investment in capacity.

The output elasticity of Θ is, in principle, equal to $\rho\gamma$. The estimated output elasticity of the public capital coefficient, γ, is 0.069, implying a value for ρ equal to 7.78. This seems too large for an exponential term (recall equation (2)), an it may reflect that the infrastructure variable acts, in part, as a proxy for the overall degree of economic efficiency of the economic system, despite having controls for the Easterly-Rebelo institutional variables. In fact, the Easterly-Rebelo variables do not contribute much to the explanation of economic growth. None of the variables are statistically significant and, as column (3) of the table indicates, the effects of omitting these variables from the analysis are minimal.

The regressions of Table 3 were redone with the Mauro institutional variables for the 26 countries for which they overlapped with the larger sample, with the hope that a richer set of institutional variables would serve as a better control for the assessing the effect of the infrastructure index. The results were disappointing, in that lagged income per capita was the only variable that was statistically significant in any of the regression involving institutional variables. When the regression corresponding to the last column of Table 3 was performed, that is, without any institutional variables, the estimated direct effectiveness elasticity, $\rho\gamma$, was found to be 0.331 (compared to 0.496 in Table 3), and the infrastructure stock parameter, γ, was 0.158 (compared to 0.046 in Table 3). The fit was also better, with an R-squared of 0.767 versus 0.692 in the larger sample. Thus, the countries in the smaller Mauro sample were characterized by a stronger infrastructure stock effect and somewhat weaker efficiency effect.

As with Table 3, adding the Easterly-Rebelo institutional variables had a minimal effect in the smaller sample. The estimated direct effectiveness elasticity, $\rho\gamma$, fell from 0.331 to 0.286 and the infrastructure stock parameter, γ, rose from 0.158 to 0.160. Neither variables were statistically significant. When the Mauro institutional variables were added, the estimated direct effectiveness elasticity fell again, this time from 0.286 to 0.266 and the infrastructure stock parameter from 0.160 to 0.197. Given the large standard errors on these estimates, the addition of the two sets of institutional variables did not produce estimates that were statistically significant from the case in which there was no control for these variables. This may reflect the rather low degree of freedom available given the smallness of the sample and the large number of explanatory variables.

2. A number of alternative definitions of the key variables were explored in order to check the robustness of the estimates in Table 3, and several deserve special mention. First, estimates were obtained using the World Bank unadjusted income concept in place of the Summers-Heston PPP-adjusted estimates. Second, the use of primary and secondary enrollments as proxies for the rate of investment in human capital was tested by using expenditures on health and education as a fraction of GDP to estimate the human capital elasticities. Neither alternative yields results that are significantly at odds with those of Table 3.

Third, the use of ordinary least squares with a lagged endogenous variable (ln y(70)) may introduce a bias into the estimates. To control for this problem, instrumental variables were used to obtain a fitted value for ln(y(70)); these variables included the infant mortality rate in 1970, the primary enrollment rate in 1960, and energy consumption per capita in 1970. The results indicate that the instrumental variables had a negligible effect on the parameters of interest. Other sets of instruments produced a similar result.

Fourth, Easterly-Rebelo estimates of investment in infrastructure, as opposed to investment in public capital, are available for a small number of countries. The latter averages approximately nine percent of GDP, while the rate of public <u>infrastructure</u> investment averages only about 3.0 percent. A shift from a broad to a narrow definition of infrastructure alters the results considerably, with a large decline in the elasticity of ln s_g.

Finally, the scatter of points in Figure 1 suggests that the link between the output growth and infrastructure effectiveness is robust to adding or deleting countries from sample (a known problem with this type of model). However, this was checked by subtracting Zambia from the sample. This increased the estimated public capital coefficient and reduced the infrastructure effectiveness estimate by a noticeable amount, but not by enough to alter the conclusions based on the main results. The procedure adopted in this paper is to present estimates for the maximum number of countries for which data are available, since there are no *a priori* reason to exclude any observation from the sample, but sample composition effects are potentially important and the results should be interpreted with this in mind.

V. Results II: Stock Measures of Infrastructure

The preceding analysis is based on the assumption that it is the rate of investment that is exogenously determined, not the capital stock. However, if the stock of infrastructure capital is the policy variable that the government seeks to control, the reduced form system (4) has a different form. The Solow model can be solved with the infrastructure stock as an exogenous variable instead of the investment rate, in which case the first equation of the reduced form can be expressed in terms of the stock of infrastructure, g, rather than the investment rate s_g:

$$y^* = \left\{\frac{\theta s_k^{\alpha} s_h^{\beta} (\theta g)^{\gamma}}{(n + \lambda + \delta)^{\alpha+\beta}}\right\}^{\frac{1}{1-\alpha-\beta}} \quad (7)$$

The rest of the steady-state model (4) is modified accordingly. This modification yields a variant of the basic estimating equation (6) in which the infrastructure stock replaces the investment rate.

This model was applied to the 1980 values of five types of infrastructure stock: telephone systems (proxied by telephone mainlines per capita), road networks (measured as kilometers of paved roads per capita), electric power systems (proxied by electric generating capacity per capita), railroads (kilometers per capita), and irrigated land area (thousands of hectares). These stock measure are essentially indicators of physical capacity, unadjusted for quality or effectiveness difference. The expectation is thus that the addition of an effectiveness indicator to the analysis will have a larger impact than in Table 3.

The resulting estimates are shown in Table 4, which is similar to Table 3, except that the aggregate infrastructure stock replaces public investment as the measure of ln s_g. To bridge the gap between the two measures, Column (1) presents estimates based on the Table 3 measure of public investment and is comparable to column (1) of that table, except that the analysis is now limited to the 42 countries for which complete infrastructure stock data is available (rather than 46). Nevertheless, the omission of four countries in passing from one to the next has only a small effect on the estimated parameter elasticities (another robustness check). However, with Table 3, a large effect is recorded in jumping from the public investment variable of Column (1) to the aggregate infrastructure stock of column (2). The estimate of b_g falls by a factor of ten, and the t-statistic falls from 2.706 to 0.254. The importance of effectiveness-adjusted infrastructure as an explanator of cross-national growth thus disappears.

Some of the explanatory power is restored in column (3) with the addition of the effectiveness indicator. As in Table 3, the efficiency effect is many times larger than the direct public capital effect. Indeed, a comparison of the estimated elasticities in the lower panels of the two tables reveals a high degree of similarity. Two differences should, however, be noted. As might be expected, given that the infrastructure stocks are physical indicators unadjusted for efficiency, the statistical significance of the effectiveness indicator increases relative to Table 3. Second, the possibility raised by Table 2 that the omission of the efficiency variable from the analysis imparts an upward bias to the estimate of the infrastructure elasticity is not evident with the physical stocks (perhaps because they are not adjusted for efficiency differentials).

VI. Conclusion

The results of this paper strongly suggest that those countries that fail to use their infrastructure effectively pay a penalty in the form of lower growth rates. Moreover, this effect is found to be at least as strong as investment in new public capital, suggesting that some of the policy attention focused on the latter might better be directed to the former. International aid programs aimed only at new infrastructure construction may have a limited impact on economic growth with a corresponding effort at supporting the maintenance and operation of new and existing infrastructure stocks. Indeed, investment in new infrastructure capacity may actually have a perverse effect if they divert scarce domestic resources away from operational efforts.

However, a great many qualifications must be placed on any conclusions and policy recommendations emerging from this paper. First, the infrastructure-effectiveness index developed above is, at best, a rudimentary representation of the underlying efficiency with which countries operate their infrastructure capital. Moreover, the results of the preceding section are perhaps too strong to be attributed to the effective use of public capital alone, and it is possible that the effectiveness index is a proxy variable for overall total factor productivity. If this is the correct interpretation, it has an interesting implication for the debate of the relative importance of total factor productivity as a source of economic growth. Young (1995) has argued that TFP <u>growth</u> played a much smaller role in the development of East Asia than is commonly supposed. If the results of this paper are given a TFP interpretation, they imply that the <u>relative level</u> of total factor productivity is an important correlate of growth in a broad range of low and middle income countries.

The robustness of the analysis to changes in sample composition is another source of concern. However, the conclusion about the importance of the effectiveness variable tends to hold up across different samples. And, confidence in this conclusion is greatly enhanced by the wealth of institutional analysis provided in the 1994 WDR. The WDR documents the importance of the infrastructure effectiveness variables and the results of this paper can be regarded as a macroeconomic gloss for the micro analysis of the WDR. The implication for future research is clear: just as early studies of the sources of international growth inappropriately ignored infrastructure capital, it is not appropriate to ignore the efficiency with which this capital is used.

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TABLE 1
Mean and Distribution of Key Variables

Rank	Summers-Heston GDP Growth Rate 1970-90	Summers-Heston GDP Level 1970	Summers-Heston GDP Level 1990	Assassin-ations (scaled) 1970-85	War Casual. (scaled) 1970-88	Revolutions & Coups (scaled) 1970-85
Top Third	0.044	$1651	$3145	21	86	86
Mid Third	0.015	$1961	$2413	48	73	73
Last Third	-0.014	$1958	$1674	218	232	136
Average	0.198	$1857	$2393	100	100	100

	Public Inv Rate 1970-90	Private Inv Rate 1970-90	Populn Gr. Rate 1970-90	Primary Educ Rate	Secondary Educ Rate
Top Third	0.124	0.100	0.023	0.807	25.1
Mid Third	0.083	0.121	0.028	84.1	20.6
Last Third	0.086	0.087	0.026	67.7	17.8
Average	0.097	0.102	0.025	77.1	21.1

	Railroads* 1980	Paved* Roads 1980	Elect* Gener 1980	Telephone* Mainlines 1980	Irrigat.* 1980	Total* Infra. 1980
Top Third	36	81	82	10	68	278
Mid Third	42	57	112	12	54	277
Last Third	87	47	80	8	48	270
Average	56	62	90	10	57	275

	Electricity System Loss Index	Road Condition Index	Telephone Fault Index	Locomot. Avail. Index	Average Efficiency Index
Top Third	0.519	0.568	0.722	0.818	0.647
Mid Third	0.481	0.500	0.679	0.500	0.530
Last Third	0.423	0.467	0.469	0.417	0.446
Average	0.474	0.506	0.625	0.602	0.539

* Variable in per capita units

Table 2

Regression of Infrastructure Effectiveness Index on Institutional and Latent Variables

	Institutional and Latent Variables:			
	Easterly and Rebelo		Mauro	Combined
	Large Sample	Small Sample	Small Sample	Small Sample
ASSP	-337.21 (-0.87)	-4062.2 (-2.75)		-4239.8 (-2.45)
CS	-17.63 (-2.43)	-155.8 (-2.02)		-156.6 (-2.11)
REVOL	-0.191 (-1.44)	0.159 (0.806)		-0.449 (-2.00)
CORR			-0.245 (-1.15)	-0.221 (-1.19)
EF			0.005 (0.02)	0.127 (0.54)
RT			-0.076 (-0.36)	0.053 (0.28)
PS			0.731 (1.90)	1.033 (-2.81)
ETH			-0.053 (-1.18)	-0.047 (-1.24)
Constant	-0.590	-0.532	-1.375	-2.426
R-Squared	0.277	0.358	0.330	0.613
# Obs.	46	26	26	26

Institutional and Latent Variables: From Easterly and Rebelo: assassinations per million (ASSP), revolutions and coups (REVOL), war casualties per capita (CS). From Mauro: corruption (CORR), red tape (rt), efficiency of the judiciary (EF), and ethnolinguistic fractionaliztion (ETH), political instability (PS). Dependent Variable: Infrastructure Effectiveness Index, θ_i. T-statistics are in parentheses.

Table 3

OLS Estimates of Model Parameters
(46 Country Sample)

	(1) Without Effectiveness Index	(2) With Effectiveness Index	(3) With Eff. Index but Without Institut. Vbls.
Public Capital, b_g	0.355 (2.811)	0.107 (0.892)	0.068 (0.607)
Effectiveness, b_θ		0.794 (4.238)	0.747 (4.267)
Private Capital, b_k	0.344 (3.603)	0.180 (2.052)	0.162 (1.951)
Primary Enrollment, b_{h1}	0.180 (1.185)	0.082 (0.638)	0.062 (0.503)
Secondary Enrollment, b_{h2}	0.167 (1.848)	0.185 (2.473)	0.184 (2.567)
1970 GDP per capita, b_c	-0.386 (-3.566)	-0.350 (-3.884)	-0.324 (-3.902)
Constant	0.768	1.656	1.623
<u>Implied Output Elasticities</u>			
ϕ_i		0.513	0.496
γ	0.174	0.069	0.046
α	0.168	0.116	0.110
β_1	0.089	0.053	0.042
β_2	0.081	0.119	0.124
Converge. Rate	0.024	0.021	0.020
R Squared	0.558	0.705	0.692
# Observations	46	46	46

Dependent Variable: log difference in GDP per capita, 1970-90. T-statistics are in parentheses.

Table 4
OLS Estimates of Using Total Infrastructure Stock
Instead of the Gross Public Investment Rate

	(1) Gross Public Investment w/o Eff Param	(2) Infrastructure Stock w/o Eff Param	(3) Infra Stock Intercept Eff. Param	(4) Infra Stock Both Eff Parameters
Public Capital	0.371	0.030	0.092	-0.043
	(2.706)	(0.254)	(1.074)	(-0.181)
Effectiveness			0.998	0.198
			(5.611)	(0.149)
Interactive Eff.				0.244
				(0.606)
Private Capital	0.287	0.161	0.106	0.106
	(2.491)	(1.388)	(1.251)	(1.246)
Pri. Enrol	0.219	0.184	0.067	0.090
	(1.331)	(0.972)	(0.490)	(0.623)
Sec. Enrol	0.184	0.204	0.210	0.200
	(1.812)	(1.519)	(2.173)	(2.013)
1970 GDP PC	-0.413	-0.418	-0.434	-0.441
	(-3.614)	(-2.840)	(-4.090)	(-4.092)
Constant	0.611	0.750	1.899	1.367
<u>Implied Output Elasticities</u>				
θ			1.097	1.006
γ	0.252	0.030	0.101	0.094
α	0.195	0.162	0.116	0.115
β_1	0.148	0.184	0.074	0.097
β_2	0.125	0.205	0.231	0.216
Conv. Rate	0.027	0.027	0.028	0.029
R-Squared	0.489	0.377	0.686	0.690
# Obs.	42	42	42	42

Dependent Variable: log difference in GDP per capita, 1970-90. T-statistics are in parentheses.

APPENDIX TABLE A

Countries and Selected Data

	SH GDP PC 1990 (y90)	GDP PC AAGR 1970-90 $\Delta y/y$	Public Inv Rate 1970-90 s_g	Private Inv Rate 1970-90 s_k	Populn AAGR 1970-90 η	Primary Educ Rate h_1	Sec Educ Rate h_2
Algeria	2660	0.020	0.31	0.04	0.030	76	11
Argentina	3513	-0.011	0.07	0.11	0.015	105	44
Bolivia	1594	0.001	0.08	0.06	0.026	76	24
Burkina Faso *	533	0.015	0.12	0.19	0.024	13	1
Burundi	522	0.017	0.10	0.01	0.023	30	2
Cameroon	1235	0.009	0.13	0.08	0.029	89	7
Central Afr. Rep.*	554	-0.021	0.10	0.03	0.025	64	4
Chile	3992	0.001	0.07	0.08	0.016	107	39
Colombia	3186	0.014	0.06	0.10	0.021	108	25
Costa Rica	3618	0.009	0.07	0.15	0.028	110	28
Cote d'Ivoire	1179	-0.010	0.11	0.09	0.040	58	9
Dominican Rep.	2030	0.011	0.06	0.15	0.024	100	21
Ecuador	2793	0.021	0.08	0.12	0.028	97	22
Egypt, Arab	1838	0.042	0.18	0.06	0.023	72	35
Gabon *	3919	0.019	0.13	0.18	0.041	85	8
Guatemala	2077	0.001	0.04	0.12	0.028	57	8
Honduras	1298	0.007	0.07	0.13	0.034	87	14
India	1068	0.024	0.09	0.10	0.022	73	26
Indonesia	1942	0.044	0.09	0.12	0.021	80	16
Kenya	912	0.011	0.09	0.12	0.036	58	9
Malaysia	4904	0.035	0.11	0.15	0.025	87	34
Mali	522	0.011	0.08	0.11	0.023	22	5
Mauritania	810	-0.019	0.20	0.11	0.024	14	2
Mauritius	5655	0.049	0.08	0.16	0.013	94	30
Mexico	5379	0.014	0.08	0.13	0.025	104	22
Morocco	2021	0.018	0.11	0.10	0.025	52	13
Mozambique *	736	-0.046	0.15	0.01	0.026	47	5
Nigeria	775	-0.023	0.09	0.05	0.030	37	4
Pakistan	1360	0.008	0.09	0.07	0.031	40	13
Panama	3032	0.008	0.10	0.14	0.023	99	38
Peru	2041	-0.018	0.05	0.14	0.025	107	31
Philippines	1751	0.008	0.05	0.16	0.025	108	46
Portugal	6525	0.040	0.11	0.10	0.004	98	57
Rwanda	658	0.004	0.06	0.10	0.032	68	2
Senegal	1080	-0.005	0.05	0.10	0.029	41	10
Sierra Leone	835	-0.024	0.05	0.06	0.022	34	8
Sudan	960	-0.004	0.05	0.08	0.029	38	7
Syrian Arab	3993	0.025	0.14	0.05	0.034	78	38
Thailand	3532	0.043	0.07	0.16	0.023	83	17
Togo	624	-0.004	0.13	0.11	0.030	71	7
Tunisia	2860	0.024	0.15	0.12	0.023	100	23
Turkey	3711	0.024	0.11	0.10	0.023	110	27
Uruguay	4278	-0.003	0.04	0.08	0.005	112	59
Venezuela	5754	0.008	0.11	0.14	0.030	94	33
Zambia	701	-0.031	0.19	0.03	0.031	90	13
Zimbabwe	1287	0.012	0.08	0.10	0.031	74	7

* Not in the 46 country sample.

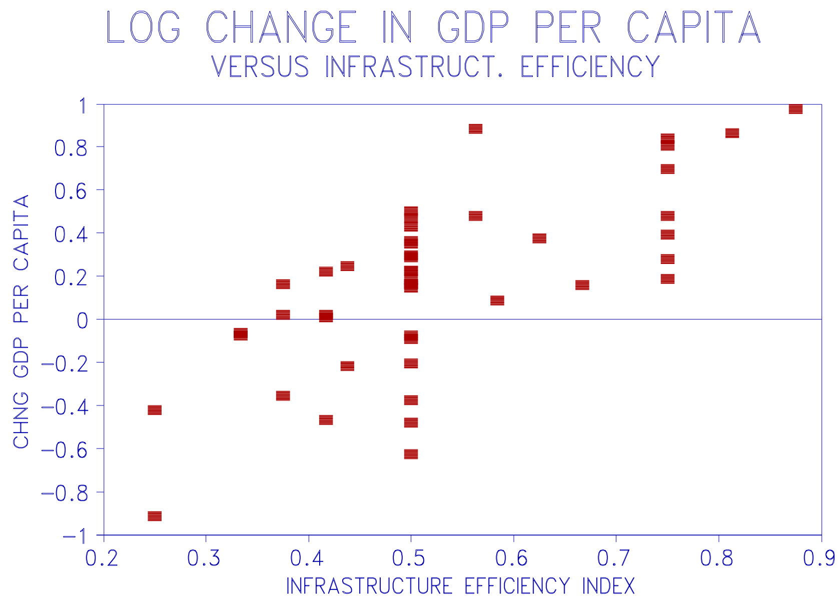
LOG CHANGE IN GDP PER CAPITA
VERSUS INFRASTRUCT. EFFICIENCY
CHNG GDP PER CAPITA
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
INFRASTRUCTURE EFFICIENCY INDEX

FIGURE 1