The Social Rate of Return

on Infrastructure Investments

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This paper has been produced as part of a World Bank research project “Infrastructure and Growth: A Multicountry Panel Study” (RPO 680-89), sponsored by the Public Economics Division of the Development Research Group and by the Transport, Water, and Urban Development Department.

Abstract

We estimate social rates of return to electricity generating capacity and paved roads by looking at their effect on aggregate output and comparing this to their costs of construction. Our results are driven by our finding that both types of infrastructure are highly complementary with physical and human capital, but have rapidly diminishing returns if increased in isolation. This produces an optimal mix of capital inputs and makes it very easy for a country to have too much, or too little, infrastructure.

For policy purposes, we compare the rate of return to investing in infrastructure with our estimated rate of return to capital as a whole. The strong complementarity we find between physical and human capital, and lower prices of investment goods in developed countries, means that we calculate that rich countries have rates of return to capital just as high as those in the poorest countries, though the highest rates of return to capital are found in the class of middle income (per capita) countries.

We find that the rates of return to both electricity generating capacity and paved roads are on a par with, or lower than, that on other forms of capital in most countries. However, in a limited number of countries we find evidence of very acute shortages of electricity generating capacity and paved roads, and large excess returns to infrastructure investment. For electricity generating capacity these excess return countries tend to be low income countries; for paved roads they are all middle income countries. These excess returns are evidence of sub-optimal investment, that, in the case of paved roads, appear to follow from a period of sustained economic growth during which road building stocks has lagged behind investments in other types of capital. This effect is accentuated by the low costs of road construction we find in middle income countries relative to poorer and richer countries.

Keywords: Aggregate production function, productivity, transport networks, electricity.

1. Introduction

The construction of infrastructure has traditionally had a large public sector component. For some kinds of infrastructure, the argument for public provision is that they represent non-rival public goods, as is the case of rural roads, or a natural monopoly, as is the case of electricity distribution systems and land-line telephone networks. Public sector provision, often in the absence of market pricing mechanisms, has led to projects being evaluated by the methods of cost benefit analysis, as is the practice of the World Bank in its infrastructure projects. The average economic rate of return for World Bank projects evaluated over the period 1983-1992 was 11 percent for electricity projects, and 29 percent for road building(Wold Bank, 1994). Rates of that order might be described as adequate, but not exceptional. Where they prevail there is an argument for infrastructure provision, but no indication of a serious shortage of the infrastructure.

There are, however, a number of well-known problems with rates of return based on cost benefit analysis. Actual practice of such studies often departs far from the theoretically correct methodology (Little and Mirrlees (1990)). Even if done correctly, however, microeconomic cost benefit analysis is likely to miss important benefits of infrastructure if those occur in the form of externalities. Transportation infrastructure may have a profound impact on the extent of the market and the ability of producers to exploit economies of scale and specialization. Widening the market then brings benefits in terms of increased competition and contestability in markets. Transportation infrastructure also allows greater dissemination of knowledge and technology. Models incorporating these ideas are now common in the "new economic geography," and there is increasing empirical evidence for these effects, see, for example, Krugman (1991, 1996), Borland and Yang (1992), Krugman and Venables (1995), Kelly (1997), Porter (1998), Gallup, Sachs and Mellinger (1999), Limao and Venables (1999).

Other infrastructure, such as electricity generating capacity, should be important in the type of "big push" models of economic development as proposed by Murphy Shleifer and Vishny (1989). If the takeoff in developing countries relies on a co-ordinated bout of investment, the public provision of risky, large scale, infrastructure projects may provide a trigger for private sector investment and escape from a poverty trap.

These arguments point to very large potential benefits of infrastructure which nevertheless elude identification and measurement by conventional cost-benefit analysis. Unless measured in a convincing way, however, we do not know whether the size of these effects provides a case for expanding infrastructure beyond current levels, or even perhaps for adopting a policy of infrastructure-led development. This remains true even under the current trend of providing infrastructure though the private sector, or at least to have some form of pricing mechanism. While public or private pricing schemes can recover at least in part, the costs of a project, prices can only capture private benefits. If infrastructure has large positive externalities, even under private provision we may wish to have a policy of subsidies to ensure provision on an adequate scale.

Our approach to finding the benefits of infrastructure is to estimate an aggregate production function for a panel of countries over the last 40 years, including as explanatory variables physical capital and human capital as well as our infrastructure variables, paved roads and electricity generating capacity. We can then calculate the marginal product of infrastructure as its contribution to aggregate output. While this approach misses any benefits to infrastructure that do not appear in Gross Domestic Product (for example, time savings that lead to increased leisure) it should allow us to see if infrastructure has large output effects.

Using aggregate production functions to estimate the contribution of infrastructure has become quite common (for example, Andrews and Swanson (1995), Boarnet (1997), Carlino and Voith (1992), DeFrutos, GarciaDiez and PerezAmaral (1998), GarciaMila, McGuire and Porter (1996),or Pinnoi (1994)). The main problem with estimating these function is reverse causality. An increase in income leads to increased demand for infrastructure, and so a positive correlation between infrastructure stocks and output levels may be simply due to increased demand, and may not reflect any supply side productivity effect. To overcome this problem, we use the techniques developed in Canning (1999) based on a panel data, cointegration, analysis, as outlined in 2.1 below. One appealing feature of our approach is that the estimates we get for the productivity of human and physical capital are close to those found in microeconomic studies of their private rates of return. This suggests that the procedure does indeed remove the bias introduced by reverse causality which we suspect to be just as great for investment in physical and human capital as for infrastructure.

A major difference between the results in this paper and those in Canning (1999) is that here we base our approach not on a Cobb-Douglas production function but on a trans-log specification. The Cobb-Douglas production function imposes a declining marginal product of each type of capital as the capital-labor ratio rises. This virtually imposes a finding of a high rate of return to all capital goods in lower-income countries and a low rate of return in high-income countries, which is greatly at odds with observed private rates of return on physical and human capital and the pattern of capital flows between countries (Lucas (1990)). The trans-log specification, on the other hand, allows for flexibility in the pattern of rates of return across countries.

A further major reason for adopting this specification is to allow us to examine the pattern of complementarity and substitutability between inputs into the production function. We find that each type of infrastructure, on its own, has rapidly diminishing returns, which implies little support for a policy of purely infrastructure led growth. However, infrastructure is found to be strongly complementary with both physical and human capital, giving it an important role in a process of balanced growth and the possibility of acute infrastructure shortages if investment in other types of capital takes off but infrastructure investment lags behind. We explain these relationships in sections 2.2 and 2.3 below. Together with the cost of infrastructure (section 3 below) these productivity relationships enter into the determination of the social rates of return to infrastructure (section 4 below).

For many countries, across the whole range of income levels, we estimate rates of return to infrastructure that are in line with, or actually lower than, those found for physical capital as a whole. Given the extra costs caused by the distortions involved in raising taxes to fund public infrastructure projects, this gives little support for a general policy of increasing infrastructure stocks.

However, the rate of return to infrastructure is found to be highest in countries with infrastructure shortages, that is low levels of infrastructure relative to their levels of human and physical capital, and countries that have low costs of infrastructure construction. Among a subset of middle income countries[1], we find evidence of an acute shortages of paved roads, coupled with very low costs of road building. This generates exceptionally high estimated rates of return to paved road building in these countries. We find similar evidence of high rates of return to electricity generating capacity, but this time mainly in a subset of lower and lower-middle income countries.

It should be emphasized that for all higher income countries, and for the vast majority of lower and middle income countries, we find that the estimated rates of return to infrastructure are in line with, or below, those for capital as a whole. High rates of return to infrastructure are the exception rather than the rule, making the case for large scale investment in infrastructure depend on an analysis of a country's characteristics rather than a blanket prescription or sector-specific rules or schemas.

2. The Effect of Infrastructure on Aggregate Output

2.1 Theory

We begin by examining the contribution of infrastructure to aggregate production. The approach used is to argue that there is a common world-wide production function given by

$$y_{it} = a_i + b_t + f(k_{it}, h_{it}, x_{it}) + e_{it} \qquad (1)$$

where y is log output per worker, a is a country specific level of total factor productivity, and b is a time dummy capturing world-wide changes in total factor productivity while k, h

[1] Our country groups are based on World Bank definitions measured in US Dollar Purchasing Power Parity terms; Low Incomes (43 of 123 countries) have an upper limit of (1985) $ 1,690 p.c.; Lower Middle Income (40 countries) range from $1,890 to $4,735 p.c.; Upper Middle Income (16 countries, from Venezuela to Romania), from $4,904 to $6,764 p.c., and 24 High Income countries (from Saudi Arabia to Switzerland), from $6,765 to $17,000 p.c.

and x represent the log of per worker inputs of physical capital, human capital, and infrastructure capital respectively. The term e represents a random error.

By defining everything in per worker terms we rule out economies of scale at the aggregate level that may in fact be important for measuring the effect of infrastructure (Morrison and Schwartz (1994)). For simplicity, we include infrastructure as a normal factor of production, ignoring the possible effects of infrastructure on the long growth rate of technology and total factor productivity that are examined in Duggal, Saltzman and Klein (1999). We also assume random errors in output around our production function, rather than allow for a stochastic frontier approach as used by Mullen, Williams and Moonmaw (1996). The motivation for our straightforward approach to the production function is that it allows us to use techniques that control for reverse causality. Since it is reverse causality that is the major issue for the credibility of aggregate production functions, this seems worthwhile, even if it is at the cost of using a simple functional form.

We allow the production function, f, to take two different forms. Our first approach is to assume that the underlying production function is Cobb-Douglas, so that, in logs, we have

$$f(k_{it}, h_{it}, x_{it}) = a k_{it} + b h_{it} + g x_{it} . \qquad (2)$$

A second approach is to assume a more complex functional form given by

$$f(k_{it}, h_{it}, x_{it}) = a_1 k_{it} + b_1 h + g_1 x_{it} + a_2 k_{it}^2 + b_2 h_{it}^2 + g_2 x_{it}^2 + y_{kh} k_{it} h_{it} + y_{kx} k_{it} x_{it} + y_{hx} h_{it} x_{it} . \qquad (3)$$

This variant of the trans-log production function allows for different degrees of substitutability and complementarity between the different types of capital. However, by using capital per worker variables we again impose constant returns to scale and are ruling out the interaction effects between each type of capital and labor that would appear in a standard trans-log specification. The larger the number of variables to be estimated, the lower will be the precision of our estimates, so that (3) represents a trade-off between a more general model and the parsimonious specification that one would like to have for estimation purposes.

A major problem in estimating the production function as set out above is the potential for reverse causation. If capital investments depend on income (for example, through a savings function s_i) we can write

$$\Delta K_{it} = s_i(Y_{it}) - dK_{it} \tag{4}$$

where K is the capital stock, Y is the total GDP, and d is the depreciation rate. This gives the steady state relationship

$$K_{it} = \frac{s_i(Y_{it})}{d}. \tag{5}$$

This implies a feedback from income to the capital stock, making it difficult to identify the results of regressions such as (2) or (3) as a production function relationship. There is also obvious potential for a feedback from income to a demand for infrastructure. If we follow a country through time, output will grow as capital accumulation proceeds, but capital accumulation will follow income, making it very difficult to establish the causal links in each direction. The positive feedback from higher income to greater capital accumulation in infrastructure might lead us to expect an over- estimation of the coefficients in a production function regression.

While this problem of reverse causality usually precludes simple direct estimation of the production function, there are circumstances under which we can estimate a relationship such as (1) using simple methods. As shown in Canning (1999), each of the series that appear in (1) are non-stationary. We can, therefore, think of (1) as a long run cointegrating relationship. Note however, that in each country, (5) may also be a cointegrating relationship, holding even when we divide though by the number of workers.

It follows that when we estimate the “production function” as a cointegrating relationship we will in practice estimate a mixture of a production function and an investment relationship.[2]

However, in panel data the problem disappears, provided the long run relationship (1) is homogeneous across countries while the investment relationship (5) differs across countries. In a panel we can pool data across countries, and while (1) remains a cointegrating relationship, when we pool the data and estimate a homogeneous form of equation (5),

$$K_{it} = \frac{s(Y_{it})}{d} + u_{it} \tag{6}$$

we find that the error term, due to actual investment behavior in each county being different from the world average relationship, is given by

$$u_{it} = \frac{s_i(Y_{it}) - s(Y_{it})}{d}. \tag{7}$$

It follows that the error term in each country is non-stationary, and eventually becomes very large, because the error produced by using a pooled relationship, rather than the true country specific relationship, depends on the income level, which is non-stationary. Even if we have a long run relationship between income and investment for each country, pooling the data across countries allows us to identify the long run production function relationship. This argument, of course, depends on the assumption that our model (1) is correct and holds across countries. It also depends on the relationship between income and investment being heterogeneous across countries but, as Chari, Kehoe and McGratten (1996) point out, differences in the security of property rights and tax policies are likely to produce very different investment rates even for countries at the same level of income.

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[2] Even if we adopt Johansen’s (1991) technique, which allows the estimation of multiple cointegrating vectors, the results depend on an arbitrary normalization and provide a basis for the subspace spanned by the cointegrating vectors rather than the structural relationships themselves.

If we accept this argument, we can estimate equation (1) consistently by ordinary least squares (OLS). However, OLS has poor small sample properties in this framework and its reported t-values are not appropriate, even asymptotically. Banerjee (1999) and Phillips and Moon (1999) each give an overview of recent techniques for estimating long run relationships using panel data that overcome these problems. In this paper we follow Kao and Chiang (1999) who argue that a dynamic OLS estimator that includes leads and lags of the first differences of the explanatory variables, has good small sample properties and gives a method (based on the long run variance co-variance matrix of the innovations and residuals) of estimating consistent t statistics.

The method used by Kao and Chiang (1999) is appropriate when we estimate a Cobb-Douglas production function relationship, as in equation (2), since all the variables appear to be I(1)[3], and we postulate that the production function is a cointegrating relationship[4]. However, estimation of the more complex production function (3) is somewhat more problematic. The difficulty is that if capital stock and infrastructure variables are I(1), the higher order squared and cross product terms cannot be I(1). However, Chang, Park and Phillips (1999) show that estimating non-linear functions of I(1) variables does not affect the consistency properties of the standard OLS estimator, though it does affect the speed of convergence of the estimates[5]. In addition, while we report adjusted t-statistics in the same way as for the linear case, it is not clear than these are asymptotically consistent for the non-linear case. Therefore, while we have a

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[3] I(1) means integrated of order one; that is non-stationary, but stationary when first differenced. The tests for non-stationarity are reported in Canning (1999). Here we use paved roads rather than paved roads plus railway lines but this change makes little difference to the time series properties of the series.

[4] When estimating a single time series relationship with non-stationary variables it is important to test for cointegration because the time trends in non-stationary variables can lead to a “spurious” regression suggesting a close relationship, when in fact none exists. However, Phillips and Moon (1999) point out that this does not occur in panel data, and we can safely estimate long run relationships relationships by OLS, even without cointegration.

[5] The speed of convergence of a parameter estimate to the true parameter value depends on the range of variation of the explanatory variable, relative to the variance of the error term. Non-stationary variables tend to have much greater variance than stationary variables, giving much faster convergence of parameter estimates in cointegrating relationships than in standard regressions (so called “super-consistency”). Our higher power terms exhibit even an greater range of values than I(1) variables, indicating that their parameter estimates will converge to the true value even more quickly.

consistent estimate of the parameters of equation (3), and regard these as our "best estimates" of the long run relationship between inputs and aggregate output, we do not carry out hypothesis testing of the significance of the estimates.

2.2 Cobb-Douglas Production Function Estimates

Data for output per worker and capital stock per worker are from the Penn World Tables 5.6 (see Summers and Heston, 1991). For output per worker we use purchasing power parity GDP per worker (chain index). Our physical capital measure is constructed using a perpetual inventory method; assuming a capital-output ratio of three in the base year (usually 1950) we update each year's capital stock by adding investment (from Penn World Tables 5.6) and subtracting 7% depreciation from the previous year's capital stock. Since our estimation only starts in 1960 this gives a reasonable period of time for our capital stock estimates to lose their dependence on the arbitrary initial condition. The results of this procedure for producing capital stock estimates are remarkably robust to variations in the initial choice of capital-output ratio and the depreciation rate. Human capital per worker is measured by the average years of schooling of the workforce, from Barro and Lee (1993).

The two infrastructure stock variables used are kilowatts of electricity generating capacity and the length of paved roads, (including urban paved roads), both taken from the processed data in Canning (1998). These physical measures do not reflect quality differences in infrastructure across countries and over time. These differences may occur at the time of construction; roads differ enormously in terms of their capacity (number and width of lanes) and durability. Electricity generating capacity comes in many forms (e.g. oil fired, coal fired, nuclear, hydroelectric) with different construction costs and running costs. In addition, the effectiveness of infrastructure may depend crucially on its quality, both initially and in terms of maintenance (see Hulten (1997)). In particular, there is evidence of wide variation in the quality of roads in different countries due to different climatic conditions, as well as different levels of maintenance and repair. The lack of comprehensive quality data means we use our simple quantity measures in our estimation;

however, it is worth noting that the fixed effect specification we use to capture cross country differences in total factor productivity tends to net out any cross-country infrastructure quality differences that are constant over time.

In table 1 we report the results of our estimates using the Cobb-Douglas production function. All regressions in this paper include country specific intercepts and world-wide year dummies (which are not reported). The regressions also include the value, current, as well as one lead and one lag, of the growth rate of each capital input per worker (the first differences of the capital stock variables). The short-term effects of these growth rates are estimated separately for each country, to allow for country specific business cycle multiplier/accelerator effects. Estimating the short -run coefficients separately for each country uses up a large number of degrees of freedom, but may improve the small sample properties of the estimators considerably.

The first column reports results for a standard Cobb-Douglas production function specification including only capital per worker and human capital per worker. Both coefficients are statistically significant; they can be interpreted as the elasticity of output with respect to each input. The coefficients found are consistent with what emerged from the calibration of a Cobb-Douglas model using microeconomic studies on private rates of return to physical and human capital (Klenow and Rodriguez-Clare (1997)). We take that as indicating that any externalities to physical and human capital are small on average. On the other hand, our results contrast with the finding in some macroeconomic studies of much higher elasticities, particularly for human capital (e.g. Mankiw , Romer and Weil (1992)). However, these earlier studies may be contaminated by a feedback from income to savings (or savings rates) which biases their estimates upwards; the similarity between our macroeconomic estimates and those based on micro-evidence on private returns suggests that our econometric methods have overcome the feedback problem.

When we add electricity generating capacity (column 2 of table 1)we find a significant, positive, coefficient. Since electricity generating capacity is already included in total capital, we have a double counting problem in interpreting regression 2: an increase in electricity generating capacity will have two effects, increasing the capital stock as well as the stock of generating capacity. The coefficient on log electricity generating capacity can be thought of as the effect of increasing generating capacity while holding capital stock constant; that is, it is the effect of diverting resources from other types of capital to investment in generating capacity. As shown in Canning (1999), a positive coefficient implies a gain in output from shifting resources to generating capacity, provided that the reallocation is carried out at world average prices. In general, therefore, a positive coefficient on generating capacity implies a higher rate of return to generating capacity than that for other types of physical capital, though this may not hold in countries where the cost of generating capacity is relatively high compared with that of other types of capital.

We find a similar result for paved roads, (column 3 of table 1), suggesting that paved roads have, in general, higher rates of return than other types of capital. These positive results retain their statistical significance when we add both types of infrastructure together (column 4 of table 1).

The result that paved roads and electricity generating capacity have higher returns than found for capital in general is at odds with the results reported in Canning (1999), where no evidence of significant excess returns was found. One difference between the two studies is that here we use paved roads instead of transport routes (which include railway line length). In addition, we drop Singapore and Hong Kong from the roads sample. These city states have very high incomes, despite having very low road lengths, and including them in the data set tends to produce a much lower estimate for the effects of roads, since they suggest that roads are not required to generate a high income level. We remove them from our estimation when we include paved roads as an explanatory variable on the grounds that as city states their unusual geography, in particular their high population densities, make them unrepresentative of the development process.

However, the main difference between the two studies is that in this paper, when estimating the effect of paved roads and electricity generating capacity on output, we do not include telephones as an extra explanatory variable. The difficulty with including telephones in the regressions is that it has a very large estimated coefficient, and tends to swamp the effect of the other variables. The large coefficient would still not justify exclusion if it were a true reflection of the productivity of telephones, but the estimated productivity effects are implausibly large (giving rates of return of over 10,000% per year) and may well reflect the fact that the number of telephones is to a greater extent more demand determined than the other types of infrastructure we are considering.[6] To avoid this difficulty we exclude telephones from our inputs in this study.

We could use the result in table 1 to compute the marginal product, and rate of return, to infrastructure. However, the Cobb-Douglas production function imposes the assumption of a constant elasticity of output with respect to each type of input and ignores the possibility that the elasticity may vary across countries. In table 2 we report the result of splitting the sample into two equal sub-samples, based on each country's income per worker in 1975.[7] We find that the coefficients on the infrastructure terms in poorer countries are very small, and statistically insignificant, but that they remain large, and significant, in richer countries. This implies that infrastructure in the poorer countries appears to have the same effectiveness in raising output as other types of physical capital, while having a greater effectiveness than other types of capital in richer countries.

2.3 Trans-Log Production Function Estimates

We can investigate the production function relationship in greater detail by adopting the more complex trans-log style of production function set out in equation (3). The results of these trans-log regressions are shown in table 3. In the first column we report results for capital and human capital on their own. In column 2 we add electricity generating capacity while in column 3 we add paved roads. In all three regressions we add

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[6] Formally, the problem may be that the feedback from income level to the number of telephones is fairly homogeneous across countries, so that this is what our estimation procedure picks up, while the institutional structures of roads building and installing electricity generating capacity are more varied across countries, and so do not bias our results.

[7] Splitting the sample on the basis of income tends to bias the results slightly because of the correlation between sample selection and the disturbance terms. However, table 2 is intended for illustration purposes only and is not used in calculating rates of return.

short run adjustment terms including current, lagged, and a lead of each capital stocks growth rate, again estimated separately for each country.[8]

In the trans-log specification the important points are the size and sign of the higher power terms. In our base specification (column 1), the squared term in capital is positive. The elasticity of output with respect to capital is, therefore, rising, giving capital a greater effectiveness in countries that already have a great deal of it. On the other hand, the squared term for human capital is negative, implying rapidly diminishing returns to investment in human capital. The interaction effect between human capital and physical capital in column 1 is positive, suggesting that the two are complements, which is consistent with the complementarity between capital and skilled labor found by Berndt and Christensen (1974).

In column 2 of table 3 we add electricity generating capacity, EGC, to the specification. The squared term in EGC is negative, indicating rapidly diminishing returns to investment in electricity taken in isolation. However, the interactive terms between electricity and physical capital, and electricity and human capital, are both positive. This implies that electricity generating capacity is complementary to physical and human capital, with its effectiveness increasing in their presence. Since we measure the various capital stocks each per worker, the effectiveness of EGC is found to be rising with capital deepening.

We find the same pattern for paved roads, with the squared term in roads being negative, but both interaction terms, between roads and the other forms of capital, being positive. These results, for both kinds of infrastructure, indicate that infrastructure investments are not sufficient by themselves to induce large changes in output. However, infrastructure can be a productive investment in economies with high levels of physical

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[8] As noted above, it is unclear we should put much weight on the estimated t statistics in table 3 because of the non-linearities in the specification. In addition, it should be noted that the large increase in the R squared between table 1 and table 3 is an artifact of the fact that in table 3 we include in the R squared the explanatory power of the country specific fixed effects and the worldwide time trend, while in tables 1 and 2 these effects are removed from the data before estimation.

and human capital, and infrastructure itself, in turn, raises the productivity of investment in those other types of capital.

A clearer picture emerges from calculating the elasticity of output with respect to each capital input. Since the elasticities vary with the amount of each input, we begin by doing this for three fictitious countries, one with median inputs of physical capital, and human capital and infrastructure per worker, one with each input at the lower quartile and one with each input at the upper quartile. The results, using input measures taken in 1985, are reported in table 4. Notice that, in general, the actual country with median amount of physical capital in that year will not be the one with median levels of human capital or infrastructure. The table therefore does not represent elasticities in actual countries but in the hypothetical ones that we construct to represent an average, a moderately poor, and a moderately rich country.

For physical capital we find a consistent pattern of rising elasticities. Based on the results in column 1 of table 3, we find that the elasticity of output with respect to capital would be 0.5 for a country at the first quartile in terms of its input levels of human and physical capital, rising to 0.65 in a country that was at the third quartile. On the other hand, the elasticity of output with respect to human capital is fairly steady as we change input levels. Turning to the regressions that include our infrastructure variables we find that the elasticity of output with respect to infrastructure seems to be higher in middle income countries, that have input levels per capita around the world median, than in countries with higher or lower input levels. This reflects the fact that infrastructure in middle income countries benefits from the presence of complementary inputs in the form of physical and human capital, but is not yet extensive enough to have entered the phase of rapidly diminishing returns (reflected in the negative coefficients on infrastructure squared in table 3).

In figures 1 through 4 we plot the elasticities of output with respect to each input, estimated using each country's actual input mix in 1985, and plot the result against its income per capita (at purchasing power parity, from the Penn World tables) in that year. Figures 1 and 2 are based on regression 1 in table 3. Figure 1, for the elasticity of output with respect to physical capital, tells the same story as table 4, with poorer countries having low elasticities while richer countries (with higher levels of input per worker) have high elasticities. For education, shown in figure 2, there is some evidence of a U shaped relationship with elasticities higher in poorer and richer countries and lower in middle income countries. However, the non-linearity in the relationship is not statistically significant.

Adding together the elasticities of output with respect to these two types of capital produces a figure that rises with income, and is close to 0.9 in the most developed countries. This implies that while we have diminishing returns to capital as a whole over the entire income range, these diminishing return may occur very slowly in developed countries. If this is so, then the developed world may have self sustaining "endogenous growth" while developing countries live in a neoclassical paradigm.

Figures 3 and 4 (based on regressions 2 and 3 of table 3 respectively) plot the estimated elasticity of output with respect to our two kinds of infrastructure, in each country against that country's income per capita in 1985. In both cases we see an inverted U shape, with elasticities being higher in middle income countries and somewhat lower in the poor and rich extremes of the income distribution. It is notable that in figures 3 and 4 we find a relatively large number of countries that have negative elasticities of output with respect to paved roads or electricity generating capacity. This does not imply that adding to the stock of these types of infrastructure reduces output; as before, the elasticities refer to the effect of adding to the stock of infrastructure while holding total capital constant. That is, we have the effect of diverting spending away from other physical capital and into the relevant infrastructure; the negative coefficient therefore means that infrastructure spending is less productive than spending on other types of capital (at world prices).

This heterogeneity in the response of output to increases in infrastructure, holding the total capital stock constant, agrees with the results found in Canning and Pedroni (1999) who use a different technique to estimate the sign of this elasticity on a country by country basis. It is notable that in both figures 3 and 4 the heterogeneity of the estimated elasticities is higher for the lower income countries than for the higher income countries. Variations in the elasticity are caused by differences in the relative proportions of physical capital, human capital and infrastructure capital across countries, so that the greater heterogeneity implies that the mix of capital varies more among the less developed countries. We see this as a characteristic of countries in the process of development, that they are in general further from the optimal mix of capital than the richer countries (or just the mix characteristic of developed countries), though the way in which the mix varies differs between countries.

The production function estimates allow us to calculate the impact of infrastructure investment on output, and indeed also the marginal product of infrastructure. To calculate rates of return, however, we need data on construction costs.

3. The Cost of Infrastructure

3.1 Measuring the Cost of Infrastructure

Cost data on infrastructure investment are relatively scarce. Our two main sources are electricity generating capacity costs from the World Bank study by Moore and Smith (1990) and the cost of constructing transportation routes from the United Nations International Comparison Project (ICP). In addition we compared the cost of constructing transport routes from the ICP with data from World Bank projects.

There are several difficulties involved in measuring the cost of constructing infrastructure to go along side our physical measures of infrastructure stocks. One fundamental problem with comparing data across countries is differences in the type and quality of the infrastructure being built. For electricity generating capacity the figures give averages over many different types of capacity that may reflect different combinations of capital and running costs.

In theory, the ICP data for the cost of construction of transport routes are for a common basket of goods and so should adjust for quality differences. However in practice the adjustment may not be complete. Our World Bank project data are superior in that they measure road building costs (rather than transport routes in general) but they are not adjusted for road quality. For these projects we count kilometers of road, not lane kilometers, nor can we distinguish between roads according to the strength of the surface or the width of the lane. A kilometer added in a high-middle-income country is likely to be of higher quality than a kilometer in a low-income country, which may introduce a systematic bias into the data. In addition, the coverage of the ICP data set is much broader than that from World Bank projects and in what follows we rely exclusively on the ICP data though it is worth noting that the ICP and World Bank data, when we have data on both, are in broad agreement.

There is the additional problem for paved roads that our cost figures refer exclusively to construction, without any allowance for the cost of the land. Land costs are one reason why Hong Kong and Singapore are such outliers in terms of their road stocks: not only is the productivity of transport systems likely to be different in such a densely populated environment, but these city states also have notoriously high land costs.

As with cost benefit analysis, the cost of infrastructure construction we use should be the real resource cost. However, our data are actual costs, including any price distortions caused by the tax system or import controls. If we were to take the view that most of the cross country differences in infrastructure projects are due to such distortions, it would be appropriate to take a common world cost for each type of infrastructure as its real resource cost. On that view, the elasticity results in table 4, and in figures 1 to 4, would indicate whether there is an excess return to paved roads over and above that found for other forms of capital. However, while this type of assumption may be appropriate for internationally traded goods, infrastructure projects often involve large scale labor inputs in the country concerned. This makes the real resource cost depend on the productivity of labor in other employment, which can vary dramatically across countries. In what follows we use the actual costs as indicative of the real resource cost.

A problem specific to our data on the cost of electricity generating capacity is that these are measured in US Dollars while our marginal productivities are measured in constant international (ICP)dollars. The value of the international dollar is normalized so that the GDP of the United States is the same in either unit. However, in other countries the two are not equivalent. In poorer countries, where prices (measured at the nominal exchange rate) tend to be lower than in the U.S., the real purchasing power of a U.S. dollar, and so the real resource costs of spending on infrastructure, is high. Before carrying out our rate of return calculations we therefore convert our costs from U.S. Dollars to international dollars by dividing through by the country's 1985 price level (its purchasing power parity exchange rate divided by its nominal exchange rate) taken from Summers and Heston (1991).

3.2 Exploring the Data

Table 5 reports our data on costs by country. We take 1985 as base year for comparisons because this gives us a fairly wide range of data in nearby years that can be deflated to 1985 values. Column (1) of table 5 gives data on the cost of construction of transport routes from the 1985 International Comparison Project. These price indices represent the nominal price of a basket of transport routes deflated by the country's purchasing power parity price level. The indices have been converted in a dollar cost per kilometer of paved road by taking a figure of $627,580 for the U.S.A.. While transport routes are a more general category of infrastructure than paved roads, roads make up a large component of transport routes and these figures do reflect the price of a common basket of routes which tends to lessen the problem of measuring costs for different infrastructure qualities. For a small number of countries we also have data on the cost of road construction from World Bank projects. These data are roughly in line with those from the International Comparison Project but more vulnerable to differences in road quality between countries.

Summers and Heston (1991) show that there is a tendency for capital goods to be relatively more expensive in developing countries than developed countries. When we plot the data on the cost of transport routes in figure 5 we see some evidence of a U- shaped relationship, with costs being high in the poorer developing and in the developed countries, but substantially lower in middle income countries. Regressing log cost on log income per capita and the square of log income per capita gives the result

$$\text{Log Cost per km} = \underset{(4.66)}{25.9} \; - \underset{(2.59)}{3.517} \log y \; + \underset{(2.76)}{0.226} (\log y)^2 \qquad (8)$$

N= 53, R^2 = 0.26

This gives a minimum cost at an annual income level of around $2,300 (in 1985 International Dollars) per capita, which lies in the bottom half of the income range spanned by the 40 countries classified as lower-middle income in 1985 by the World Bank. The World Bank data on costs of paved road construction give a similar picture of U shaped costs. In our calculations of rates of return we use the larger data set based on the cost data we have calibrated from the ICP costs of route construction.

One reason for this U shaped cost structure would be that middle income countries have lower labor costs than developed countries, but also more of the skills and industry required to produce construction materials and equipment than the majority of the low-income countries. Where road construction and paving depend on importing equipment and even raw materials, costs in the poorer countries can rise to levels found in industrialized countries.

Our cost data for electricity generating capacity come from Moore and Smith (1990). Cost, in US dollars, per kilowatt of electricity generating capacity and the corresponding extension of transmission and distribution, in 1989 is shown in column (2) of table 5. The figures are deflated to 1985 values using the GDP deflator and then converted to International Dollars, using the country's purchasing power parity price level, before being employed in our rate of return calculations. These figures are reported in column (3) of table 5.

Looking at the costs in US Dollars, there is clearly an outlier: Senegal has construction costs in excess of US$13,000 per kilowatt, which is substantially higher than for any other country. In fact, the next two most expensive countries, also in Africa, are Niger and Mozambique, with costs that are about half those found in Senegal. However, when we look at the costs in international dollars we find high real costs of generating capacity in many developing countries due to their low price levels relative to their exchange rate. The relative consistency of prices at nominal exchange rates suggests that developing countries are not, in general, able to exploit their low wage costs to achieve low costs of installing electricity generating capacity.

Once again there is evidence that the cost of installing electricity generating capacity falls with the level of income. A regression of log cost per kilowatt of capacity on log income per capita (both in international dollars) gives the result

$$\text{Log Cost per kW.} = \underset{(16.4)}{11.18} - \underset{(3.58)}{0.287} \log y \tag{9}$$

N=63 R^2 =0.061

t statistics in parenthesis

For both electricity generating capacity and paved roads the difference in construction costs between the cheapest and most expensive countries is a factor of almost 10, while cost differences on the order of a factor of 3 are not unusual. Cost differentials are therefore likely to play an important role in determining rates of return to infrastructure investment.

4. The Rate of Return to Infrastructure

4.1 Rate of Return estimates and Infrastructure Policy

The rationale for our approach is that there may be externalities to infrastructure projects that are not caught in micro-economic cost benefit studies. The inclusion of these externalities potentially allows us to capture the total social rate of return to infrastructure. There are, however, a number of caveats that must be borne in mind when looking at our results.

Firstly, our approach is to look at the impact of infrastructure on aggregate output as measured by GDP. This measure of aggregate output has the potential to capture some of the externalities that microeconomic cost-benefit analysis may miss, it yet has conceptual drawbacks of its own. For example, cost-benefit analysis can estimate the travel time saved by a road project and calculate the value of this time. An analysis using aggregate output will only pick up the time saved if it is devoted to productive uses, time saved that is spent in leisure activities will not be accounted for. In addition, as Haughwout (1998) points out, an analysis which relies on aggregate output may neglect relative price effects of infrastructure construction that can have a significant welfare impact.

A second problem is that our estimate of the effect of infrastructure on output is its long run steady state effect. In calculating rates of return we assume that this long-run effect occurs immediately, and lasts for ever, and we depreciate infrastructure stocks at 7 percent a year to allow for the cost of maintaining the infrastructure in the long run. This creates a difficulty because, when calculating rates of return, the discounting of future flows means that returns in the early years tend to dominate the calculations. It follows that, if it takes several years for infrastructure to reach its full potential, we may be overestimating its rate of return. However, a similar consideration applies to our estimates of the rate of return to private capital, so that when we compare infrastructure rates of return to those found on general capital, we might expect both to be overestimated in similar proportions. While both are probably overestimates, the problem may be worse for infrastructure where there is considerable evidence that construction may sometimes lead demand for infrastructure services, either due to its "lumpy" nature, or to over-optimistic demand projections (World Bank (1994)).

Our macroeconomic estimates of the rate of return to infrastructure also ignore any "crowding in" effects that it may have on other types of capital. While an increase in infrastructure raises the return to other forms of capital, and can lead to an increase in investment, with consequent effects on output and economic growth, these induced changes in investment may have only a very small impact on welfare. As Baldwin (1992) points out, if the marginal product of capital is close to the rate of discount, the marginal benefit and marginal cost of extra investment are roughly the same, implying little or no gain in welfare from the extra investment.[9]

[9] This is simply an application of the envelope theorem.

However, there are two cases in which this negative result does not hold. If, instead of a small increase in infrastructure, we are analyzing a large change, then marginal analysis is no longer appropriate, since the new infrastructure may raise the marginal product of capital substantially above the discount rate. Alternatively, if we have reason to believe that the marginal product of capital already exceeds the discount rate, owing, for example, to a tax wedge, induced increases in investment can have large welfare effects. In our calculation we ignore any “crowding in” effect, implicitly assuming that we are analyzing relatively small infrastructure projects and that the existing allocation of resources to other forms of capital is reasonably efficient (though we do in fact present evidence that in some countries the rate of return to capital is considerably in excess of any reasonable discount rate).

There are also several caveats about the use of our rate of return estimates for policy purposes. First of all, for evidence of externalities to infrastructure to emerge, we have to subtract from our figures the private returns to infrastructure projects. Only if all the returns to infrastructure captured in cost benefit analysis are private benefits (and none externalities)would we arrive at a measure of externalities by subtracting those benefits that are measured in aggregate GDP (private benefits not measured in GDP should be added to aggregate productivity estimates to find social rates of return).

However, it is not clear that we ought to focus on externalities: when the government is the main supplier of infrastructure there is no presumption that it will be setting infrastructure at the optimal level in terms of private benefits. There may be capital misallocation in infrastructure even without externalities. Instead, we shall focus on the rate of return to infrastructure relative to that on other forms of capital. Where this ratio exceeds one, there is a case for arguing that there should be a reallocation of resources to infrastructure.

Note that this is somewhat different from the normal cost-benefit approach which looks at the rate of return to a project in relation to a threshold level that is set by the cost of funds. We find that, in many countries, the rate of return to capital as a whole appears to be considerably higher than the commonly used threshold levels (or test discount rates). In this case there is an argument for encouraging investment in general, and in particular, for removing any distortions that are keeping investment rates low. However, if the rate of return to infrastructure, while high, is lower than that for other capital, the optimal policy is to encourage investment in capital other than infrastructure. Infrastructure investment in those circumstances is very much a second best policy, and would depend on an argument that investments in other types of capital are not feasible for some reason.

4.2 Calculating Rates of Return

In order to estimate the marginal product of infrastructure we must take account of the fact that it appears twice in our production function, once on its own in the form of X, but also as a part of aggregate capital, K. Let Z be non-infrastructure capital, then we can write

$$K_{it} = \frac{Z_{it} p_z + X_{it} p_x}{p_k}. \qquad (10)$$

The aggregate capital stock is the value of total capital (we sum the volume of each type of capital times its price) divided by the price of capital. To construct these volume measures we use world prices of investment goods; all prices are expressed relative to output, which is taken to be the numeraire. For simplicity, we use the approximation $p_z = p_k$, taking the price of non-infrastructure capital as equal to the price of capital as a whole. Given that infrastructure capital is a relatively small component of the total capital stock (certainly less than 20% of the total in each case), this approximation seems reasonable.

Using equation (3) it is easy to derive the country and time specific elasticities

$$e_k = a_1 + 2a_2 k_{it} + y_{kh} h_{it} + y_{kx} x_{it} \qquad (11)$$

$$e_x = g_1 + 2g_2 k_{it} + y_{kx} k_{it} + y_{hx} h_{it}. \qquad (12)$$

The elasticity of output with respect to infrastructure that we estimate is actually the elasticity found when increasing infrastructure but holding aggregate capital (including infrastructure) constant. It can therefore be interpreted as the result of diverting a unit of physical capital from other purposes to infrastructure. From these elasticities, and the definition (10), we can calculate the marginal products of a unit of physical and infrastructure capital - MPK and MPX respectively - as

$$MPK_{it} = e_k \frac{Y_{it}}{K_{it}}, \quad MPX_{it} = MPK_{it} \frac{p_x}{p_k} + e_x \frac{Y_{it}}{X_{it}}. \tag{13}$$

Note that the marginal product of infrastructure consists of two terms, the first representing the effect of infrastructure on aggregate capital and a second, representing the distinctive infrastructure effect.

These equations for marginal productivity highlight an important feature of using aggregate data. To find the marginal product per dollar spent on an input, the estimated elasticity must be multiplied by the ratio of output to the stock of the relevant capital, each measured in dollar terms. For capital as a whole this ratio is quite small (typically less than one third) but for sub-categories of capital this ratio may be large. Multiplying the estimated elasticities by a large number also multiplies up any errors in estimation.

It follows that this method is unlikely to be good for determining the marginal product of small components of the capital stock. Paved roads and electricity generating capacity, valued at replacement cost, each make up around 20% of the capital stock on average, implying that they should have observable effects on aggregate output. Not so, however, telephone main lines which make up less than 2 percent of the capital stock by value. For reasons stated in 2.2 above, we omitted telephone main lines from our analysis. A further reason for that decision is their low share in the total capital stock. We would, therefore, expect to see them have only a small effect on aggregate output . And to find their marginal product, we would have to multiply a badly estimated elasticity by a huge number (the ratio of output to the value of the telephone stock) .

The marginal products measure the output effect of an extra unit of capital. In the case of infrastructure this is the marginal product of an extra kilowatt of electricity generating capacity or an extra kilometer of paved road. To find the rates of return, we need the information on the cost of a unit of capital, its marginal product, and its rate of depreciation. We take the price of investment goods from the Penn World Tables (Mark

6.5) as the price of capital goods and measure both marginal products and costs in a common unit, 1985 international dollars.

Formally, we can find the rates of return to infrastructure type x in country i, given by r_{ix}, by solving for the internal rate of return in the formula

$$\sum_{t=1}^{\infty} \frac{MPX_{it} - dp_{ix,t}}{(1+r_{ix})^t} = p_{ix,0} . \qquad (14)$$

The left hand side of this equation is the discounted flow of benefits from a unit of infrastructure, minus depreciation (or maintenance costs) which occur at a rate d per unit of infrastructure per year. The right hand side represents the cost of the unit of infrastructure. Assuming that the marginal product of infrastructure, and the price at which depreciation is replaced (or maintenance costs), $p_{ix,t}$ are constant over time, and taking a depreciation rate of 7 percent per annum[10], equation (14) simplifies to

$$r_{ix} = \frac{MPX_i}{p_{ix}} - 0.07 . \qquad (15)$$

An equivalent simple formula holds for the rate of return to capital as a whole.

In the following two sections we use these equations to estimate the rate of return to electricity generating capacity and paved roads. It is, nevertheless, worth noting that if the relative price of capital and infrastructure are the same in every country, equation (15) simplifies to

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[10]The simple path of initial expenditure, followed by positive returns to the project, ensures the existence of a unique internal rate of return for the project. The result is exactly the same if, instead of replacing depreciation as it occurs, we assume that we let the capital stock decay to zero over time with proportional reductions in the benefits of the project.

$$r_{ix} = r_{ik} + e_x \frac{Y_{it}}{p_x X_{it}}. \qquad (16)$$

In this case the infrastructure has an excess return over and above that found for capital in general if and only if it has a positive elasticity as given by equation (12). As pointed out by Prittchett (1996), however, and as is also evident in our data, the relative prices vary enormously across countries. We should therefore use equation (15) based on our two stage procedure of estimating the marginal product of a physical unit of infrastructure and then relating this to its price. We could still use equation (16) and figures 3 and 4 to indicate the pattern of the sign of excess social returns to infrastructure, so long as we were to believe that our cost data reflect rents and distortions while the real resource costs of infrastructure relative to other forms of capital are roughly constant across the world. However, it what follows we shall concentrate on the rates of return using actual cost data for the construction of infrastructure. Estimates based on this approach are reported in tables 6 and 7. All data refer to 1985.

4.3 Estimates of the Rate of Return to Electricity Generating Capacity

Table 6 reports the estimated rate of return to electricity generating capacity, physical capital in general, and the ratio between the two rates of return in all countries for which we have the necessary data. The elasticity estimates that underlie these calculations -- that is the elasticities of both electricity generating capacity and capital in general -- come from regression (2) in table 3. There are a wide range of rate of return estimates, from well in excess of 100% a year (in 1985, for Bangladesh, Kenya, Bolivia and China,) to quite low figures (Brazil and Zimbabwe,) and even a negative rate of return for Mozambique. Note that a small negative rate of return does not imply that infrastructure does not benefit output, only that its benefits do not cover the costs of depreciation or maintenance.

One might simply use these rates of return to indicate whether or not investment in electricity generating capacity was a good use of funds. However, the real issue being the allocation of investment between projects, it is more relevant to compare the estimated rate of return to electricity generating capacity with that of physical capital in general. The rate of return to capital (again based on regression (2) of table 3) is reported in column (2) of table 6 while column (3) gives the ratio of the rate of return on electricity generating capacity to the rate of return on capital in general. This ratio takes on a wide range of values. In figure 7 we plot the estimated ratio of rates of return against log income (in purchasing power parity terms) per capita in 1985. There is a clear downward trend in the relationship; the poorer countries, on average, have much higher rates of return for electricity generating capacity than for other capital, while the middle income countries show rates of return to electricity generating capacity that are roughly the same as for capital in general. Unfortunately, our cost data are all for developing countries so that we cannot see how the relationships changes as one moves to high-income levels .

Just as the average rate of return is higher in the poorer countries than in middle income countries, the variation in the rate of return to electricity generating capacity as seen in figure 7 is also greater in the poorer countries. High rates of return in the poorer countries are based on low stocks of electricity generating capacity relative to the stocks of complementary inputs, that is, physical and human capital. A line is drawn across figure 7 at a ratio of one; at this point the returns to infrastructure are equal to those on capital in general. As we can see, it appears to be quite possible for a developing country to have a excessive investment in electricity generating capacity, relative to its stocks of other physical capital and of human capital, driving its rate of return down below that on other forms of capital.

On average, therefore, we find a tendency for returns to electricity generating capacity in the poorer developing countries to exceed the returns to other forms of capital. The *heterogeneity* of the rates of return in the poorer countries suggests independently that these countries tend to be further from an optimal mix of investment than middle, or higher, income countries, perhaps reflecting greater market failure, possibly externalities, or state failure, and thus prime issues for country analysis.

4.4 Estimates of the Rate of Return to Paved Roads

Our cost data for paved roads cover a wider incomes span of countries, especially high-income countries, than those for electricity generating capacity. The first column of table 7 reports the rates of return to paved roads, based on regression 3 of table 3. For some developing countries (in 1985, notably South Korea, Colombia, Bolivia and the Philippines) we find exceptionally high rates of return to paved roads. In some others, (such as Tunisia and Botswana, again in 1985), rates of return are low. Low rates of return are also found in most developed countries, with negative returns being present in Austria and Australia.

Rates of return to capital (this time based on the productivity effects from the same regression 3 of table 3) are reported in column 2 of table 7. These estimated rates of return show much less variation than those for paved roads, partly, no doubt, because of the much larger value of the total capital stock which makes for greater accuracy in the macroeconomic estimates of the marginal product .

In figure 7 we plot the estimated ratio of the rate of return to paved roads to that found on capital in general in each country, against the country's log income per capita. The first point to note is that in most countries, notably in all the developed and high-income countries, but also in the poorer developing countries, the ratio is less than one. In these countries the rate of return to paved roads is lower than that on capital in general . However, in a group of middle income countries the ratio exceeds one by a long way. These countries get the benefit of a high marginal product of roads coupled with a low cost of road building. However, even among middle income countries the rates of return to roads are sometimes lower than the rates of return to capital as a whole.

Once again we find a great deal of heterogeneity across countries in rates of return to paved roads relative to other forms of capital, and once again the heterogeneity is greatest among the low-to upper- middle income countries. However, if we are looking for high rates of return to investment in paved roads, it is in that very class of middle-income countries that we have to look.

4.5 The Rate of Return to Capital

The rate of return to capital as a whole has been used extensively in the last two sections as a benchmark by which to judge the attractiveness of infrastructure investment. We now take the rate of return to capital on its own, basing our estimates on regression 1 (with physical and human capital as the only independent variables) in table 3. Plotting this in fig.9 against log income per capita for a cross section of countries in 1985 we obtain , a graph with an inverted U shape. The highest rate of return is found in middle income countries; and the maximum on the curve corresponds to an income per capita of $3,600 (international dollars) which is in the top half of the 1985 lower-middle income class. This result contrasts starkly with the very steeply downward sloping graph for the rate of return to capital that we obtain from a Cobb-Douglas specification.

The relationship we find is consistent with the observation that actual private returns to capital are quite low in the poorer developing countries and that capital does not flow from the rich to the poor (see Lucas (1990)) but rather to middle-income countries. In developed countries, diminishing returns to capital set in quite slowly because they can keep their marginal productivity of capital up by having large amounts of human capital. We nevertheless find some evidence that returns to capital are higher in middle income developing than in the developed (industrialized) countries, a finding that makes the very high relative returns to paved roads even more interesting.

5. Conclusion

The use of an aggregate production function allows us to calculate rates of return to infrastructure that should capture any externalities that escape microeconomic cost-benefit studies. The model could be improved upon, in particular by estimating a more general production function, including, for example, the effects of industrial structure and geography on the productivity of infrastructure.

Though our results depend on a number of simplifying assumptions, they appear plausible. They suggest that as a rule, infrastructure shortages, signaled by high social rates of return to electricity generating capacity or paved roads, relative to other capital, are symptomatic of limited groups of countries identified by the income per capita class that they belong to, essentially the lower-middle and upper-middle income classes of developing countries. To the extent that such high rates of return are not detected by a microeconomic cost-benefit analysis, they point to macroeconomic externalities associated with infrastructure.

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Table 1. The Cobb Douglas Production Function with Infrastructure

Dependent Variable: Log GDP per Worker 1960-1990

Total Factor Productivity	*Year Dummies, Fixed Effects*	*Year Dummies, Fixed Effects*	*Year Dummies, Fixed Effects*	*Year Dummies, Fixed Effects*
Short Run Dynamics	2 lags, 1 lead	2 lags, 1 lead	2 lags, 1 lead	2 lags, 1 lead
Log Capital per Worker	0.455 (14.7)	0.404 (14.6)	0.417 (11.7)	0.392 (11.9)
Log Human Capital per Worker	0.125 (3.73)	0.051 (1.43)	0.079 (1.77)	0.059 (1.54)
Log Electricity Generating Capacity per Worker		0.085 (5.83)		0.057 (3.13)
Log Paved Roads per Worker			0.083 (4.06)	0.048 (2.30)
R squared adjusted	0.729	0.678	0.716	0.685
Countries	97	90	67	62
Observations	2674	2473	1671	1534
Average T	28	27	25	25

t ratios in parentheses are calculated based on the long run auto-covariance matrix and are asymptotically N(0,1).

Table 2. The Cobb Douglas Production Function with Infrastructure In Low Income and High Income Countries

Dependent Variable: Log GDP per Worker 1960-1990

	Full Sample	*Low Income Countries*	*High Income Countries*
Total Factor Productivity	Year Dummies, Fixed Effects	Year Dummies, Fixed Effects	Year Dummies, Fixed Effects
Short Run Dynamics	2 lags, 1 lead	2 lags, 1 lead	2 lags, 1 lead
Log Capital per Worker	0.392 (11.9)	0.371 (8.58)	0.365 (6.41)
Log Human Capital per Worker	0.059 (1.54)	0.035 (0.64)	0.112 (1.57)
Log Electricity Generating Capacity per Worker	0.057 (3.13)	0.012 (0.50)	0.117 (3.73)
Log Paved Roads per Worker	0.048 (2.30)	0.003 (0.12)	0.134 (4.05)
R squared adjusted	0.685	0.582	0.478
Countries	62	31	31
Observations	1534	781	753
Average T	25	25	24

t ratios in parentheses are calculated based on the long run auto-covariance matrix and are asymptotically N(0,1).

Sample split on the basis of income per capita in 1975

Table 3. The Translog Production Function with Infrastructure

Dependent Variable: Output per Worker

Regression	*(1)*	*(2)*	*(3)*
Log Input(per worker)			
Capital	0.072	-0.038	0.017
	(0.70)	(0.20)	(0.10)
Human Capital	-0.151	0.992	0.569
	(1.39)	(6.31)	(3.27)
Electricity		-0.869	
		(7.47)	
Paved Roads			-0.398
			(2.98)
Capital Squared	0.026	0.034	0.027
	(3.57)	(3.50)	(2.75)
Human Capital Squared	-0.064	-0.114	-0.062
	(5.78)	(5.76)	(2.92)
Electricity Squared		-0.061	
		(10.9)	
Paved Roads Squared			-0.054
			(6.36)
Capital*Human Capital	0.049	-0.049	-0.039
	(3.81)	(3.13)	(1.89)
Capital*Electricity		0.069	
		(6.07)	
Capital*Paved Roads			0.044
			(2.87)
Human Capital*Electricity		0.152	
		(9.31)	
Human Capital*Paved Roads			0.101
			(6.12)
R squared adjusted	0.993	0.995	0.996
N	2674	2473	1671
Countries	97	90	67
Number of Short Run Parameters	582	810	603

Table 4. Elasticity of Output

Regression No.	*Elasticity of Output with Respect to*	*Inputs Per Worker in 1985*		
		Lower Quartile	*Median*	*Upper Quartile*
(1)	capital	0.50	0.59	0.65
	human capital	0.09	0.11	0.11
(2)	capital	0.35	0.52	0.65
	human capital	0.08	0.08	0.13
	electricity	0.06	0.09	0.07
(3)	capital	0.43	0.52	0.61
	human capital	0.14	0.09	0.14
	paved roads	0.05	0.09	0.04

Table 5. Unit Costs of Construction

Infrastructure units *Year*	*Paved Roads, International $ per kilometer* *1985*	*Electricity US $ per kilowatt* *1989*	*Electricity International $ per kilowatt* *1985*
Algeria		2347	2193
Angola		3400	3257
Argentina	80223	1902	2780
Australia	869154		
Austria	506012		
Bangladesh		2815	17833
Belgium	402887		
Bolivia	180458	1740	3177
Botswana	256089		
Brazil	639203	2655	5447
Cameroon	278808		
Canada	500760		
Central Afr.R.		7786	15407
Chile	143840	1924	4126
China		1502	4695
Colombia	169987	2564	5401
Congo		2429	4934
Costa Rica	131966	2301	4143
Cyprus		2655	3982
Denmark	400378		
Dominican Rep.	253455	1914	4850
Ecuador	366371	2439	4581
Egypt		1590	3498
El Salvador	540362	3971	7127
Ethiopia	712160	2689	6128
Fiji		2923	4924
Finland	477889		
France	386139		
Gambia		1769	3929
Germany, West	443177		
Ghana		2460	3274
Guatemala	631965	4719	6785
Honduras	771088	2144	3006
Hong Kong	305218		
Hungary	159311	3439	7878
India	143306	2061	6504
Indonesia	200008	1829	4736
Ireland	399348		
Israel	337680		
Italy	296089		
Ivory Coast	288277	1680	3048
Jamaica		2023	4196
Japan	339714		

Table 5. (continued)

Infrastructure units *Year*	*Paved Roads* *International $ per kilometer* *1985*	*Electricity* *US $ per kilowatt* *1989*	*Electricity* *International $ per kilowatt* *1985*
Jordan		1797	2846
Kenya	285128	1717	3779
Korea, Rep.	92072	2990	4651
Lesotho		2918	14928
Liberia	426839		
Luxembourg	402887		
Madagascar	176712	4882	11174
Malawi	282163	1990	5499
Malaysia		1746	3057
Mali		1957	6145
Mexico		1949	3729
Morocco	270454	2145	6040
Mozambique		6250	15957
Myanmar		2719	7646
Nepal		4346	22989
Netherlands	529989		
New Zealand	456604		
Nicaragua		3229	5280
Niger		7000	14977
Nigeria		2793	2560
Norway	438496		
Pakistan	434650	1390	4550
Panama	187551	3417	4423
Papua N.Guinea		1925	3737
Peru		3393	8273
Philippines	111343	2043	4708
Poland		1851	3404
Portugal	236770	2330	4858
Senegal	306742	13600	32856
Sierra Leone		3038	6304
Somalia		3268	5413
Spain	236990		
Sri Lanka	65277	4451	19930
Sudan		2422	5293
Sweden	522244		
Syria		1539	3458
Tanzania	221723		
Thailand		2034	5823
Tunisia	313404	1189	2415
Turkey	228506	1849	4555
U.K.	777133		
U.S.A.	627580		

Table 5. (continued)

Infrastructure units	*Paved Roads International $ per kilometer*	*Electricity US $ per kilowatt*	*Electricity International $ per kilowatt*
Year	*1985*	*1989*	*1985*
Uruguay	95440	1778	3776
Yugoslavia		1702	3591
Zambia	144577		
Zimbabwe	277287	1927	3660

Table 6. Rates of Return to Electricity Generating Capacity and Capital

	Rate of Return to EGC	*Rate of Return to Capital*	*ROR EGC/ ROR K*
Algeria	0.63	0.15	4.20
Argentina	0.46	0.29	1.59
Bangladesh	0.61	0.80	0.77
Bolivia	0.92	0.19	4.74
Brazil	0.10	0.58	0.16
Central Afr.R.	0.40	0.12	3.25
Chile	0.41	0.73	0.56
China	0.54	0.41	1.31
Colombia	0.28	0.55	0.50
Congo	1.14	0.25	4.58
Costa Rica	0.25	0.36	0.69
Cyprus	0.36	0.31	1.19
Dominican Rep.	0.25	0.61	0.42
Ecuador	0.45	0.50	0.91
Egypt	0.45	0.50	0.90
El Salvador	0.17	0.42	0.40
Fiji	0.32	0.30	1.06
Gambia	1.05	0.23	4.49
Ghana	0.25	0.18	1.37
Guatemala	0.18	0.34	0.52
Honduras	0.95	0.27	3.56
India	0.24	0.53	0.44
Indonesia	1.06	0.62	1.70
Jamaica	0.11	0.20	0.54
Jordan	0.40	0.42	0.96
Kenya	1.25	0.19	6.63
Korea, Rep.	0.31	0.45	0.68
Malawi	0.54	0.18	3.00
Malaysia	0.77	0.44	1.76
Mali	0.51	0.24	2.16
Mexico	0.51	0.52	0.98
Mozambique	-0.07	0.17	-0.42
Myanmar	0.34	0.33	1.03
Nepal	0.40	0.56	0.72
Nicaragua	0.20	0.30	0.67
Niger	0.12	0.13	0.92
Pakistan	0.18	0.95	0.19
Panama	0.21	0.38	0.55
Papua N.Guinea	0.06	0.24	0.26
Peru	0.21	0.40	0.51
Philippines	0.44	0.35	1.25
Portugal	0.07	0.46	0.14

Senegal	0.06	0.24	0.27
Sri Lanka	0.27	0.86	0.31
Syria	0.35	0.80	0.44
Thailand	0.42	0.61	0.69
Tunisia	0.40	0.37	1.07
Turkey	0.32	0.72	0.45
Uganda	0.80	0.02	46.26
Uruguay	0.30	0.51	0.59
Yugoslavia	0.24	0.34	0.72
Zimbabwe	0.05	0.38	0.14

Table 7. Rates of Return to Paved Roads

	Rate of Return to Paved Roads	*Rate of Return to Capital*	*ROR Paved Roads/ ROR Capital*
Argentina	3.85	0.29	13.33
Australia	-0.01	0.30	-0.02
Austria	0.00	0.29	-0.02
Belgium	0.06	0.40	0.14
Bolivia	7.96	0.21	37.09
Botswana	0.20	0.58	0.34
Brazil	0.61	0.57	1.07
Cameroon	1.88	0.35	5.31
Chile	5.24	0.73	7.15
Colombia	9.47	0.54	17.53
Costa Rica	1.96	0.37	5.24
Denmark	0.12	0.30	0.40
Ecuador	1.97	0.51	3.85
El Salvador	1.11	0.47	2.38
Finland	0.15	0.22	0.68
Germany, West	0.16	0.29	0.55
Guatemala	0.76	0.38	2.01
Honduras	0.39	0.34	1.15
India	0.74	0.78	0.96
Indonesia	2.03	0.83	2.45
Ireland	0.06	0.36	0.15
Italy	0.26	0.34	0.76
Japan	0.62	0.20	3.05
Kenya	0.53	0.35	1.51
Korea, Rep.	15.76	0.43	36.95
Liberia	1.04	0.15	6.82
Malawi	0.60	0.40	1.50
Netherlands	0.15	0.32	0.46
New Zealand	0.08	0.36	0.23
Norway	0.02	0.21	0.08
Pakistan	0.52	1.17	0.45
Panama	2.18	0.38	5.76
Philippines	7.19	0.40	17.99
Senegal	0.48	0.45	1.07
Sweden	0.06	0.29	0.21
Tunisia	0.16	0.43	0.36
Turkey	1.58	0.78	2.03
U.K.	0.13	0.39	0.32
U.S.A.	0.07	0.29	0.26
Zambia	0.65	0.24	2.69
Zimbabwe	0.15	0.45	0.33

Figure 1
Elasticity of Output with Respect to Capital

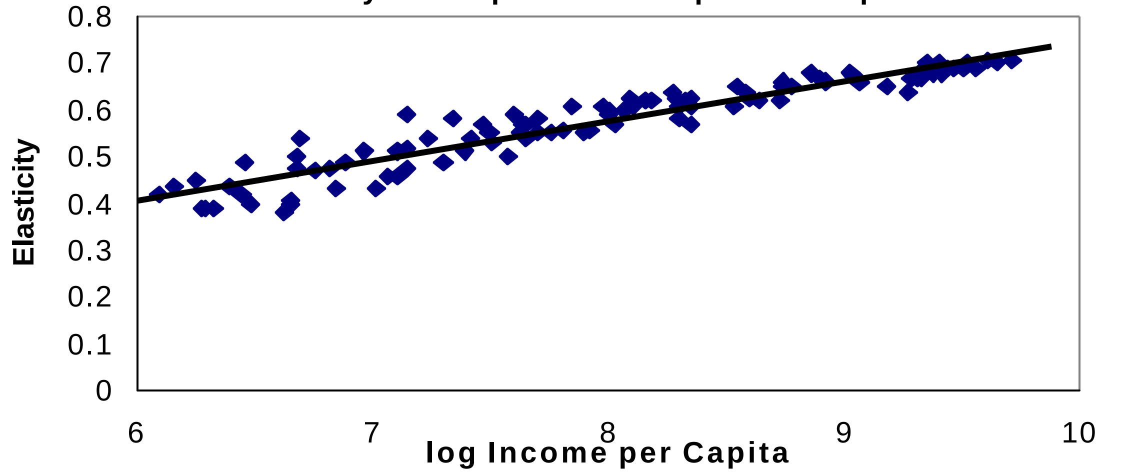
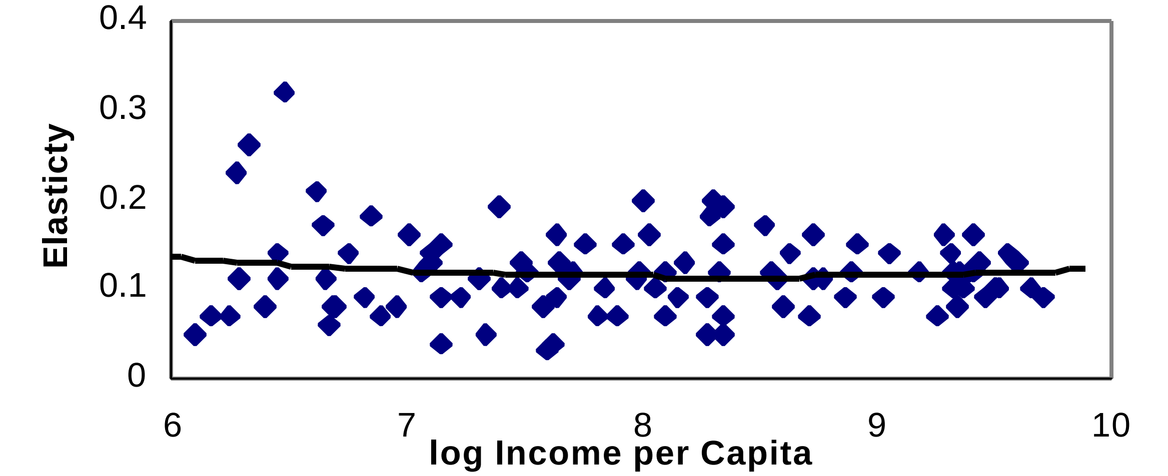


Figure 2
Elasticity of Output with Respect to Education



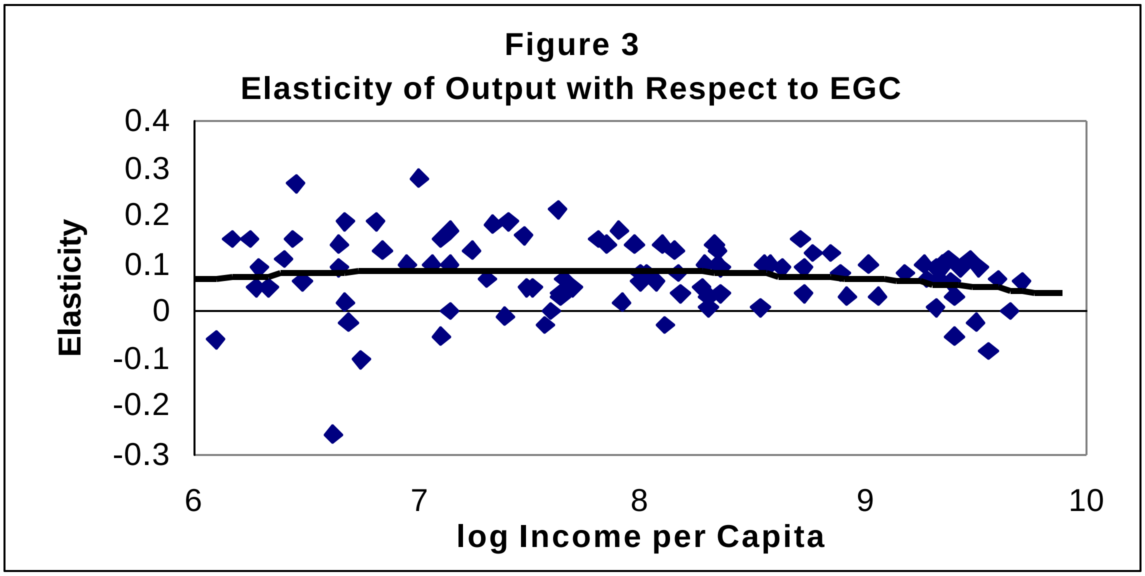


Figure 3
Elasticity of Output with Respect to EGC
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
Elasticity
6
7
8
9
10
log Income per Capita

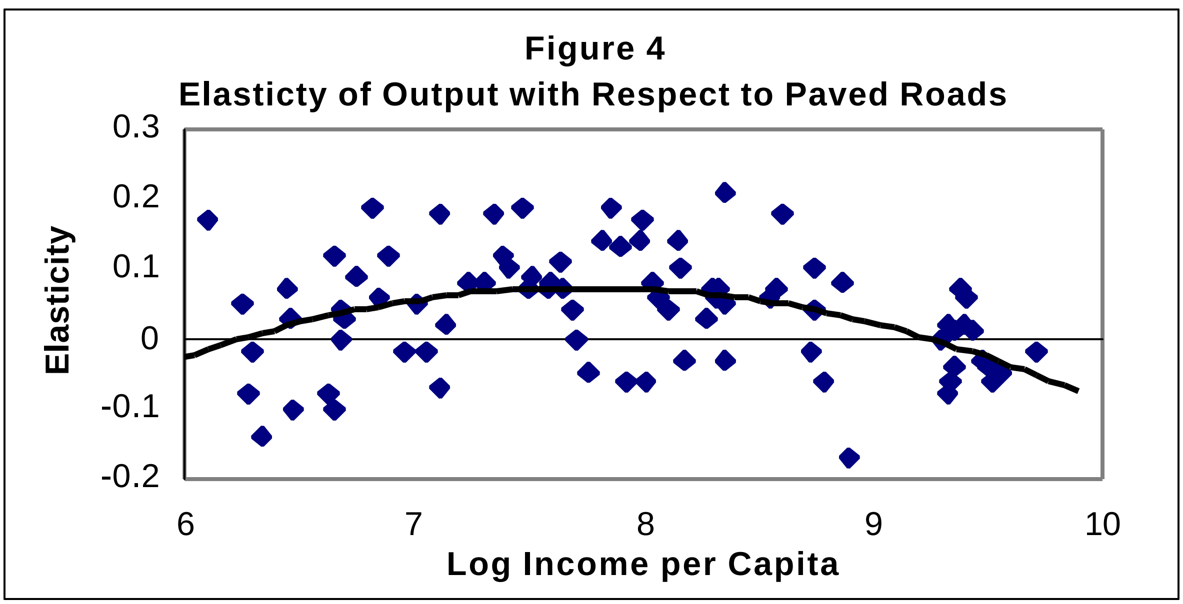


Figure 4
Elasticty of Output with Respect to Paved Roads
0.3
0.2
0.1
0
-0.1
-0.2
Elasticity
6
7
8
9
10
Log Income per Capita

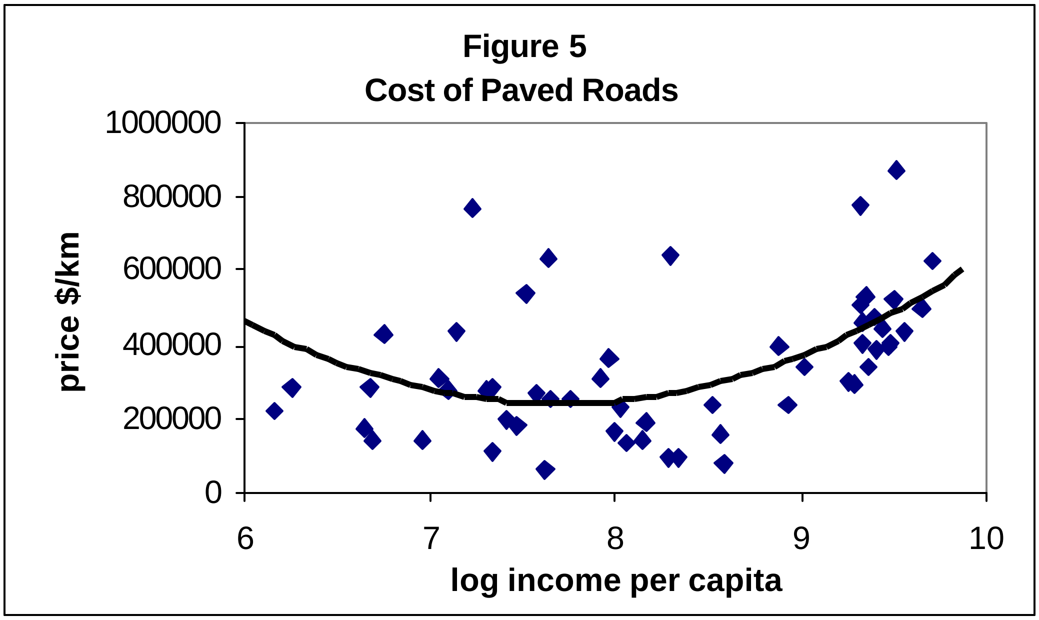


Figure 5
Cost of Paved Roads
price $/km
1000000
800000
600000
400000
200000
0
6
7
8
9
10
log income per capita

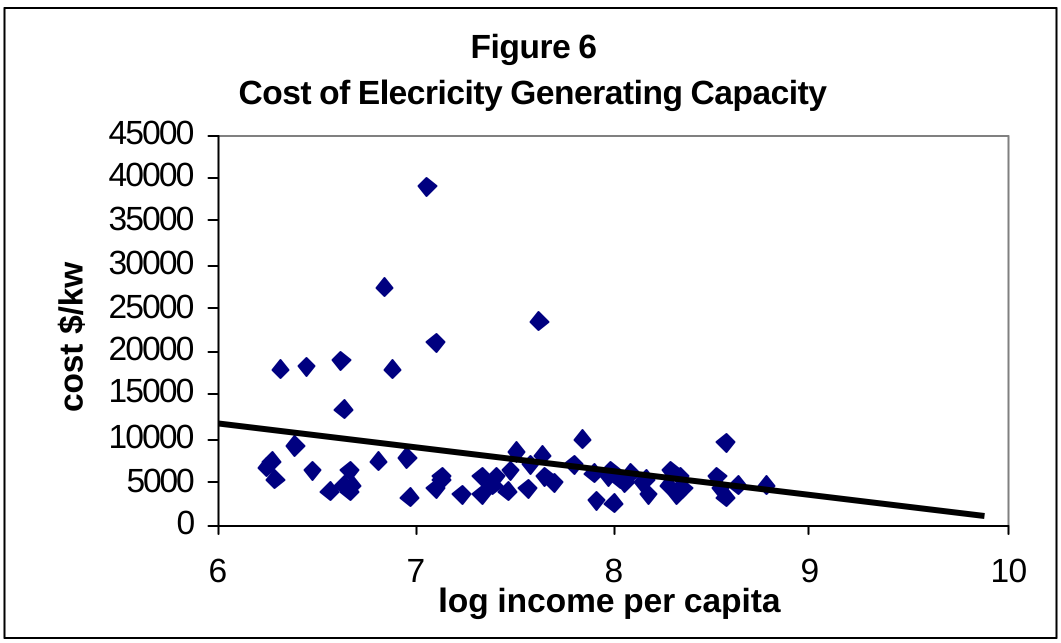


Figure 6
Cost of Elecricity Generating Capacity
cost $/kw
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
6
7
8
9
10
log income per capita

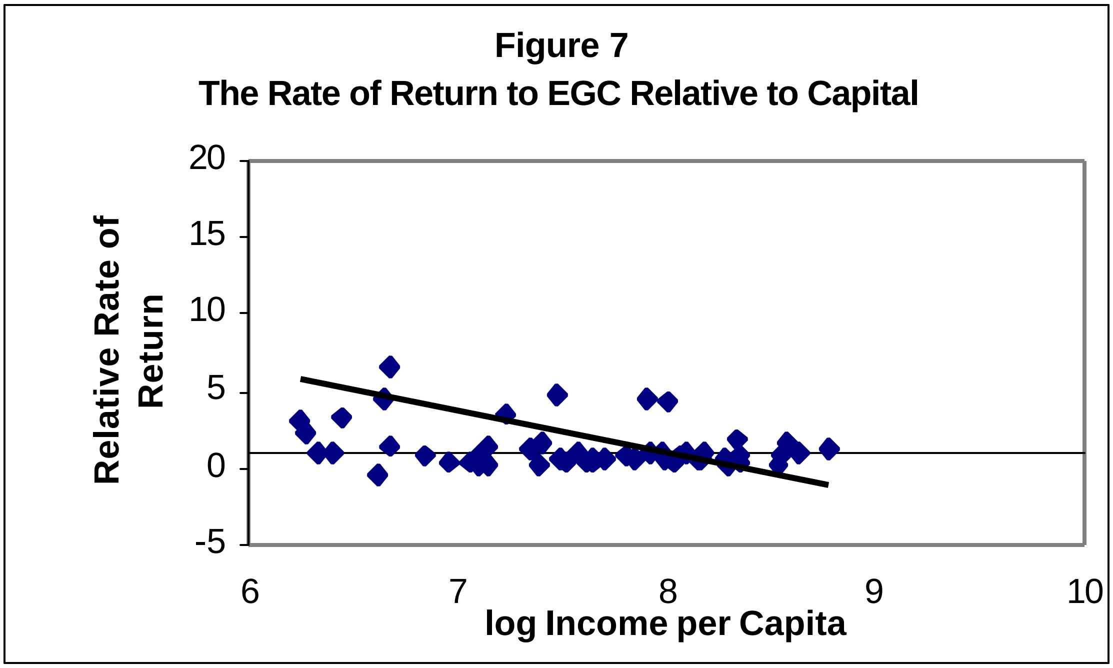


Figure 7
The Rate of Return to EGC Relative to Capital
Relative Rate of Return
20
15
10
5
0
-5
6
7
8
9
10
log Income per Capita

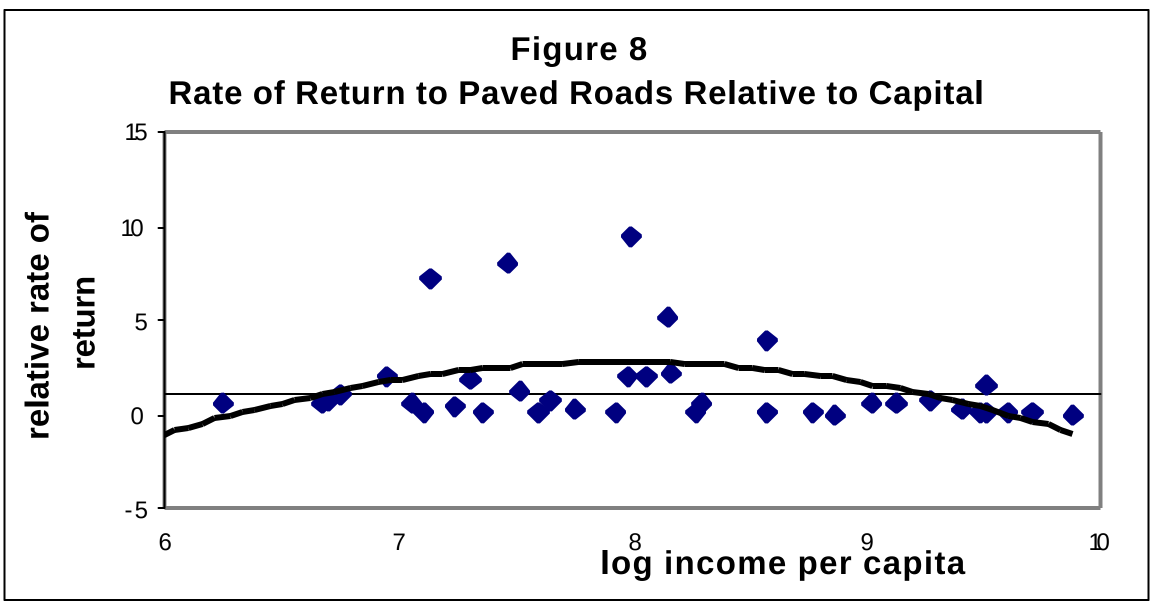


Figure 8
Rate of Return to Paved Roads Relative to Capital
relative rate of return
15
10
5
0
-5
6
7
8
9
10
log income per capita

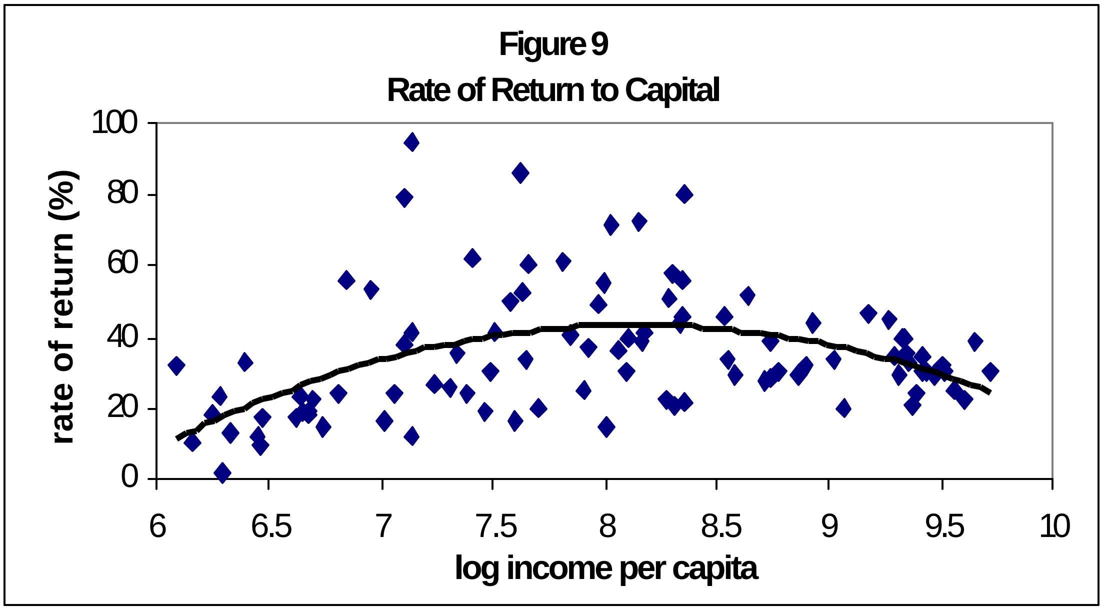


Figure 9
Rate of Return to Capital
rate of return (%)
100
80
60
40
20
0
6
6.5
7
7.5
8
8.5
9
9.5
10
log income per capita