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ABSTRACT

The impact of public infrastructure on output or productivity is a subject of continuing debate. At one extreme are studies that suggest that there are high rates of return to infrastructure investment and those that suggest that the impact is essentially zero or negative. In this paper, we argue that it is inconceivable that efficient investments in large stocks of public capital would provide no output/productivity benefits beyond the direct provision of amenities, especially for developing countries like those in Sub-Saharan Africa where public infrastructure stocks are almost certainly below optimal levels. Using firm level data and key physical public infrastructure assets in Uganda, we empirically test the hypothesis that the impact of infrastructure development on output/productivity is more significant in an economy where there are bottlenecks caused by an underdeveloped infrastructure.

To take into account the serious deficiencies in models used in previous studies, we extend the basic production function approach and apply different formulations and functional specifications. Our approach is comprehensive as individual measures and a composite index are used in the analysis. Final conclusions are based on the results from the model with the preferred functional form, which is decided on the basis of statistical performance and consistency with theory. The findings from our chosen model (translog production function) are that the estimated elasticity between public infrastructure and private sector production is positive, big in magnitude, and significantly different from zero (at 1% level). We also find complementarity between public infrastructure and private capital and substitutability between public infrastructure and private labour employment. The results provide rationale for increased efficient public infrastructure investments in Uganda.

Key words: Public infrastructure, Direct and Indirect effects, Complementarity, Substitutability, Private sector output/productivity

CONTENT

1 INTRODUCTION

The literature has produced a lot of estimates regarding the impact of public infrastructure on output/productivity in developed countries, especially the United States of America and various western European countries. The main motivation for most of the work stemmed from the neglect and slow growth of the stock of public infrastructure that had been observed across these countries and the hypothesis that it was a major factor in explaining the general productivity slowdown, (See for example Aschauer, 1989a). However, the results of these studies have not been without any controversy. At one extreme are studies that suggest that there are high rates of return to infrastructure investment, e.g. Aschauer (1989a), Munnell (1990), Rovolis (2002) and Albala-Bertrand and Mamatzakis (2004) and those that suggest that the impact is essentially zero or negative, e.g. Holtz-Eakin (1994) and Björkroth and Kjellman (2000).[1] The argument of the latter studies is that large, positive effects found in some studies appear to be the artefact of an inappropriately restrictive econometric framework. However the latter studies have also been criticised for applying difference methods which destroy any long-term relationship in the data, leaving only short term impact to be captured in the model (Hsiao 1986; Munnel 1992), yet there are often long lags between infrastructure investment and productivity growth. This could partly explain the zero or negative impact found by many of these studies. Zhang and Fan (2001)'s study points to the importance of first testing for causality in the data to check for length of lagged relationships and the existence of reverse causality, before specifying a final model and the estimating procedure.

Little attention (in terms of empirical work) has been given to the impact public capital could have on output/productivity growth and hence the growth process in developing countries, especially those in Sub-Saharan Africa, Uganda inclusive, yet poor inadequate public infrastructure is always highlighted as one of the main factors curtailing growth in these countries (Grier 2002; World Bank 1994).[2]

In this paper, we argue that it is inconceivable that investments in large stocks of public capital would provide no output/productivity benefits beyond the direct provision of amenities, especially for developing countries like those in Sub-Saharan

[1] Björkroth and Kjellman (2000), however find some evidence of causation running from public capital to private sector output and argue that if correctly targeted, public capital investment could affect private sector performance.

[2] This could be explained by lack of country level data on public infrastructure stocks, especially for African countries.

Africa. High rates of return to infrastructure may depend on a country's particular characteristics, e.g. having much less initial infrastructure stocks. Therefore making a blanket generalisation would be a misrepresentation of the possible impact, since the marginal product of additional infrastructure may be much larger in countries with less than the optimal level of infrastructure stocks. It is also necessary to identify those types of public infrastructure that provide productive spillovers, and those sectors for which the effects are the largest.[3] This maybe particularly important for developing countries given the importance development theories and indeed growth theories attach to the impact of infrastructure on the growth process and "economic take off", Rosenstein-Rodan (1943, 1984), Nurkse (1953), Hirschman (1958), Barro and Sala-i-Martin (1992,1995), Van der Ploeg (1994) and Murphy, Shleifer and Vishny (1989).

In Sub-Saharan Africa public infrastructure investments have in many cases, been victims of fiscal contraction policies promoted by the Bretton Woods institutions and adopted by many developing countries especially in the 1980s.[4] This could partly explain the relatively low infrastructure stocks in some of these countries, e.g. Uganda.[5]

The main motivation and contribution of this work include: (i) we contribute to the literature vis-à-vis estimates of the return of infrastructure investment for developing countries, especially for Sub-Saharan African countries. These countries have not been focused on thus far. The study provides some new evidence on the association between public infrastructure and output/productivity (ii) we assess the efficacy of the arguments of endogenous growth theory models, which imply a big impact on output/productivity growth given their arguments that infrastructure has both level and growth rate effects. This study contends that if this were to be the case then public infrastructure investments can play an important role vis-à-vis "economic take-off" of developing economies. This is what is stipulated by the "big push" models of economic development proposed by Murphy, Shleifer and Vishny (1989),

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[3] Many studies lump together all types public capital, which may partly explain why estimates employing aggregate public capital are insignificant.

[4] Although it was never the intention of the IMF/World Bank programmes to curtail expenditure on public infrastructure, expenditure cuts were more easily done on public investment expenditures than on current expenditures due to political considerations. See Oxley and Martin (1991) and De Haan, Sturm and Sikken (1996), who noted similar behaviour in some OECD countries in the 1970s and 1980s.

[5] Other factors like political instabilities are also partly to problem.

who argue that economic take off in developing countries may depend on co-ordinated investment with the provision of risky, large scale, public infrastructure projects providing a trigger for private sector investment and escape from a poverty trap (see also, Bennathan and Canning 2000).

(iii) Our third contribution is that, unlike the majority of studies, we use physical measures of public infrastructure in our analysis. Most studies use physical capital variables measured in monetary terms, i.e. adding up past investment using the Perpetual Inventory Method (PIM) of estimation. This method has a number of disadvantages especially in the context of developing countries like Uganda. First, all expenditures designated as investment expenditure may not result into increases in the public infrastructure capital stock due to corruption and inefficiency, etc. That is the level of expenditures may not be reflected in the actual infrastructure investments that are made resulting in the overvaluation of public infrastructure capital stock series that are constructed (Pritchett, 1996: Sanchez-Robles, 1998). Secondly there aren't accurate estimates of the service life and depreciation of public infrastructure stocks; hence assumptions about these variables in the Perpetual Inventory technique may not be accurate enough. In the alternative approach that we apply, we took inventory of the quantity and where possible, quality of public infrastructure stocks or their proxies by measuring available physical stocks at district level. One disadvantage of this approach is that it is very difficult and expensive to measure/have physical measures of public infrastructure stocks over time.[6] This partly explains the reason why this study is essentially cross-sectional.

(iv) Our study also differs from many other studies, in that it focuses on firm level effects as opposed to other research, which focus on estimating the effect of public infrastructure using aggregate production functions at regional or national level. Its advantage is that it enables a more direct linkage between physical infrastructure and those that use it. It also enables a more meaningful interpretation of the interaction between public infrastructure and other productive factors as well as the derivation of output and scale elasticities with respect to public infrastructure.

(v) The fifth contribution lies in our assessment of the implications of our findings for fiscal policies of aid recipient countries like Uganda in the enhancement

[6] In any case, public infrastructure stocks have hardly been increased in Uganda overtime, making a time series analysis implausible (see Table 1.1).

and sustenance of economic growth. For this reason, the major effort is to confront theory with data with a strong emphasis on purpose for economic policy.

The predictions of endogenous growth models would justify expansion of infrastructure stocks beyond current levels or even adopting an investment-led growth strategy financed by donor-aid with infrastructure investments taking a leading role. If donor aid were to be used to finance these investments, then the extra costs normally associated with this kind of strategy, i.e. the distortions involved in raising taxes to fund the investments would be avoided.[7] But even when infrastructure investments are provided by the private sector, the implied large positive externalities may justify a policy of subsidies to ensure provision on an adequate scale. These kind of subsidies maybe more important in promoting and sustaining growth in the long run than investment incentives given to firms. It is therefore not only important to examine the relationship between infrastructure and output/productivity growth and to investigate whether public infrastructure complements private capital but also to establish the degree (magnitude) of impact.

Many earlier studies that have attempted to estimate the magnitudes of impact have been criticised for model misspecifications, endogeneity bias, and unchecked restrictions on the coefficients to satisfy constant returns to scale. These studies have used different approaches particularly, the production function approach, profit or cost function approach, cross country approach, structural model approach and Vector Autoregressions.

There are advantages to either approach. Given that our study is at the firm level, we apply the production function approach because it is more straightforward and does not require vast amounts of data as compared to the (cost function) approach. This is particularly appealing when research is on developing countries whose data is in many cases difficult to gather. The cost function approach which is preferred by some researchers requires a lot more detailed data and does not help resolve problems concerning non-stationarity of the time series and the issue of causality (Sturm et al., 1998).

We minimize the problems associated with the production function approach as follows:

[7] However aid financing could have some negative effects on the macroeconomy, depending on the monetary and fiscal policies adopted. It would therefore be important to assess the implications.

(1) Problems related to the time series properties of the data, i.e. in cases where the time series are both non-stationary and not cointegrated when the production function is estimated in levels; the estimates have to be done in first differences. However the estimates then become difficult to interpret, as they no longer take economically meaningful values. This makes it doubtful whether we are estimating a long-run production function. Also, using first differences implicitly assumes that a change in the capital stock affects the level of production in the same year (Sturm et al. 1998). Available data permits us to limit ourselves to a single period cross section study, making these problems less of a concern for our analysis.

(2) Most studies use the Cobb-Douglas production function, which is a restrictive functional form. We circumvent this limitation by checking the data vis-à-vis the constant returns to scale assumption, and in addition apply an alternative more complex but flexible translog production function specification. The translog production function also allows us to assess substitutability and complementarity between different production inputs including public infrastructure capital**.**

(3) We use standard techniques to check and control for unobserved, firm and regional specific characteristics that maybe captured by our public infrastructure parameter.

(4) The more serious problem is one of endogeneity, a common criticism of production function estimates. Theoretically, reverse causation can be present between public infrastructure capital and output/productivity growth. This is the reason why it is argued that the positive coefficient for public capital in many earlier studies may reflect the impact of output/productivity growth on infrastructure capital rather than the reverse. While there are ways to minimize this limitation, for example use of instrumental variables, identifying the direction of causality, use of the GMM dynamic panel data approach[8] or estimating simultaneous equation models, we suggest that endogeneity may not need to be a problem in this study because:

(a) little if any additions have been made to infrastructure stocks in Uganda for a long time and most certainly not prior to our period of study. Questions on community-level infrastructure access between 1992 and 1999/2000 asked retrospectively in the

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[8] See Arellano and Bover, 1995; and Blundell and Bond, 1998. However, the GMM dynamic panel data approach is not without criticism. For example, the Arellano-Bover (1995) approach assumes "weak" exogeneity instead of "strong"exogeneity in the link between variables, which for practical purposes remain somewhat unclear. Also, the method is seen as a black box that yields dubious small sample properties in Monte Carlo experiments by some critics (Hsiao et al., 2001).

1999/2000 household survey revealed relatively little change over time (See table 1.1 below and Deininger and Okidi, 2003).[9] This forecloses the possibility of any feedback effect of firm output/value added growth on public infrastructure investment.

Table 1.1
Selected measures of infrastructure provision: Uganda and Low, Middle and High-income countries

Year	UGANDA 1980	1992/93	1999/2000	Low income countries 2000	Middle income countries 2000	High income countries 2000
Paved roads (km/1000 person)	0.31	0.14	0.13	1.06	1.1	10.54
Paved roads in km/Sq.Km (000s)	19.6	12.3	14.2			
Telephone Mainlines (per 1000 persons)	1.4	2	3	28	127	584
Electricty generating capacity (kilowatts per capita)	0.013	0.009	0.008	116	406	2,031
Percentage of households with access to electricity		7	7			
Mean district level distance to nearest Public Telephone (kms) - district		30.06	30.27			

Sources: Own computations based on data from:
World Bank 1994, 2001, World Bank World Development indicators, 2003
Fay and Yepes 2003 and Uganda National Household surveys, 1992/93 and 1999/2000
UBOS, Statistical Abstract, 2003

(b) Another perception, which also has some credence especially in the case of developing countries, is that, in part at least, infrastructure is exogenously determined. "It is externally set by decision makers, and used by them as a normative planning measure in order to influence economic activity. In this case, policy makers may initiate infrastructure investment in a region that does not demonstrate any demand", (Bar-El 2001, pg 195) or low growth areas are prioritised in infrastructure policies. In the case of Uganda, one may even argue that because of low levels of coverage, political pressures rather than economic ones could be more important (Deininger and Okidi, 2003).[10] In this case our infrastructure coefficient could actually be biased downwards.

The empirical work is based on cross sectional firm level data, quality measures of public infrastructure and physical infrastructure stocks and proxies

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[9] Table 1.1 also compares Uganda's stocks with the average in Low, middle and high income countries. Uganda's stocks are very low even by the levels of low income countries.

[10] See also Calderón and Chong (2004); Rogoff, (1990); and Dixit and Londregan, 1996 vis-à-vis the theory of political business cycles and geographic distribution of expenditures on infrastructure. Expenditures are directed to areas which the incumbent regards as critical for re-election.

(different types of roads, electricity and telephones) collected from Uganda. We link firm level data on output/value added and private inputs, etc to key physical public infrastructure assets in Uganda on the basis of firm location.[11] To avoid high multicollinearity due to high correlations between the different infrastructure variables, we apply the Principal Components Analysis (PCA) method to get a composite index and use the "Centering" method to deal with collinearity in polynomial or product terms vis-à-vis the translog production function specification. Our estimations therefore include individual measures of public infrastructure as well as the composite public infrastructure index making our approach comprehensive as both individual measures and a composite index are used in the analysis.

The paper proceeds as follows: In the next section, a brief review of the underlying theory linking public infrastructure and firm output/productivity is made, section 2.1, introduces the econometric models linking private firm production and public infrastructure capital. In section 2.2, the estimation strategy and testing procedures are discussed, while section 2.3 presents regression model estimations, empirical analysis and results. Conclusions and policy issues are discussed in section 2.4, while the limitations of the study are highlighted in section 2.5.

2.0 Underlying Theory of the Link Between Public Infrastructure and Firm Output/Productivity

Most theoretical work is based on Arrow and Kurz (1970) where it is assumed that public infrastructure is productive and therefore it should be included in the production function as an additional input factor. Unlike the macro (national) level studies e.g. that of Aschauer (1989a), we examine a more direct linkage between physical infrastructure and firm output/productivity, hence we focus on public infrastructure as an input into the firm's production process. Public infrastructure can enhance firm's opportunities for profit through two possible ways, that is, by increasing productivity and by reducing factor costs. There are at least three mechanisms through which these occur;

(i) as an un-priced input to production, e.g. roads

(ii) as a reduction in the price paid by firms for services provided by public infrastructure investment.

[11] One limitation of our approach is that we do not take into account networks effects of infrastructure. This means that the magnitude of our estimations maybe biased downwards.

(iii) as a complement to private inputs leading to reductions in the user cost of private inputs (Bartik, 1991).

This raises the question of whether public infrastructure enters into the production process as a factor augmenting input or as an unpaid input. Meade's (1952) classification of external economies helps in explaining the mechanisms.

As an unpaid factor, the public input is not provided through a market process. It is not paid for on a per-unit basis and therefore does not have a market-determined price. However, it has private-good characteristics because of the possibility of congestion, e.g. free access to roads. From the firm's perspective, the level of public input is fixed, unless it is continually underutilized, (Eberts, 1990).

Since the unpaid-factor type of public input has many private input characteristics, it is entered into the production process in the same way as private inputs. In this case, the public input does not augment the productivity of private inputs but contributes independently to the firm's output (ibid). Hence the direct effect on output/productivity.

As a factor augmenting input, an increase in the level of public inputs results in increased output for all firms through neutral increases in the efficiency with which the private inputs are used. Meade (1952) refers to these types of inputs as "the creation of atmosphere". These include for example, free information and government supported research. Hence, it is hypothesized to influence multifactor productivity and constitutes the indirect effect.

The relationship among public inputs, private inputs and output as described above then introduces the notion of economies of scale. The relationship can then be summarized in a production function with an added variable, A, to reflect the state of technology.[12]

From a dual cost approach perspective, making the assumption of cost minimization behaviour of firms implies that firms choose their bundle of input quantities so as to minimize the total costs, given the state/level of technology and a given level of output. That is, dual to the production function, there exists a cost function relating the minimum possible total cost of producing a given level of output to the prices of the inputs, the level of output, and the state of technology. Here focus

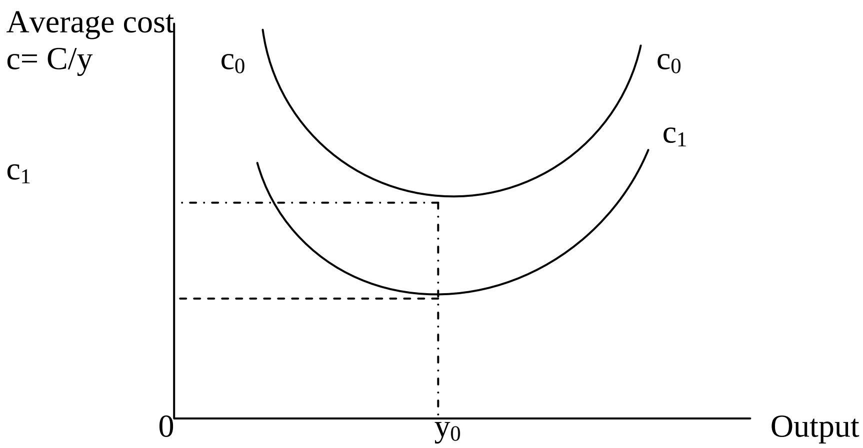
[12] See Barro and Sala-i-Martin (1995), for a similar analogy at macro level vis-à-vis the relationship between public infrastructure and per capita growth.

is on the relationships among private inputs and output and that the state/level of technology is unchanged.

However one can consider increases in public infrastructure as improvements in the level of technology i.e. increases in A. The question then is how does this affect production and costs? As argued by Barro and Sala-i-Martin, (1995) and Berndt (1991), one can think of such improvements as outward shifts in the production function (or production possibility frontier), since given the same combination of private inputs, the maximum possible output increases with improvements in the level of technology. The implication of this is that total and average costs of production decline with improvements in the level of technology.

That is the average cost curve shifts downwards with increases in A (see figure 2.1), that is, a downward shift in curve $c_0 - c_0$ to $c_1 - c_1$.[13, 14]

Figure 2.1



2.1 Econometric Model Linking Private Firm Production and Public Infrastructure Capital

The econometric model linking private firm production and public infrastructure capital is based on the economic theory of production which states that the inputs a firm uses can be related to output (Y) via a production function (F). The applied model reflects a formulation in which the technical relationship is about applying

[13] It is worthy-noting that changes in returns to scale correspond with movements along the average cost curves, whereas changes in the level of technology induce shifts in these curves.
[14] In terms of calculus, one can write the cost minimization problem facing the firm as a constrained optimization problem as is done in studies that apply the cost function approach.

alternative combinations of all conceivable inputs of factors of production to attain maximum output.

On the basis of our discussion in section 2.0, our empirical investigation treats public infrastructure capital, first as a third input which enters the production function directly and second, as a factor that influences multifactor productivity through its positive impact on the productivity of private capital and labour.

Hence we have a three-factor production function for firm output (or value added) in our basic model equation (1) below.[15]

$$\mathrm{Y}_i = A(G_i)\ f(L_i\ \mathrm{K}_i\ G_i\ ) \qquad (1)$$

In most studies in the literature, a generalized Cobb-Douglas form of technology which yields a more specific relationship between inputs and outputs as in equation 2 is assumed.

$$\mathrm{Y}_i = \mathrm{A}f\,(L_i^{\alpha}\mathrm{K}_i^{\beta}G_i^{\gamma}e^{\mu_i}) \qquad (2)$$

Where Y_i = the value of firm i’s output or value added, A is an efficiency parameter (which can be regarded as an indicator of the level of technology), L_i *and* K_i are measures of the firm’s labour and private capital inputs respectively, and G_i represents the stock of public infrastructure capital. μ_i is a normally and independently distributed random disturbance term, while the exponents (α, β *and* γ) are the elasticities of output with respect to each input.

After taking logarithms, equation (2) produces a linear function that can be estimated (see equation 6 below). Taking into account our cross section study, the stochastic disturbance term, μ_i accounts for variations in the technical or productive capabilities of the i th firm.[16]

However, apart from many other limitations (as will be discussed later), a major drawback of this approach is that a Cobb Douglas function estimated in log

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[15] The value of output minus the value of all intermediate inputs, representing therefore the contribution of , and payments to, primary factors of production.

[16] The stochastic disturbance term is additive on the assumption that it is multiplicative in the original formulation of equation (1). Bodkin and Klein (1967) suggest that there is little difference between multiplicative and additive stochastic disturbance terms of the resulting estimated parameters, their standard errors, and so on, so the using of a multiplicative stochastic disturbance term in the original formulation can be justified on the basis of this as well as the resultant computational convenience.

levels, does not allow for the explicit measurement of the direct and indirect impacts of public infrastructure capital. For this reason, we explore alternative functional specifications.

2.2 Data, Estimation Strategy and Testing Procedures

2.2.1 Data

Our data come from different sources and is comprised of both primary and secondary data. The unit of analysis is the firm, which is linked to district level data on infrastructure stocks. The major sources of data are (i) the Uganda Business Inquiry (UBI), 2000 which is a Census of Business Establishments and covers both formal and informal enterprises from various sectors. Although the survey covered both formal and informal enterprises, the data set used in our analysis comprised of only the formal enterprises. Informal sector enterprises did not provide information on fixed assets and/or details on expenditure, which we required for our analysis. We therefore used 962 firms, but including micro, small, medium and large enterprises. Each firm is identified by a unique identification code in combination with a district code and four digit ISIC code. The firms are found in 25 out of the 56 districts in existence and from all four regions of the country. This is a wide geographical coverage given the concentration of firms is in 7 districts found in the central, west and eastern regions of the country. These 7 districts of Kampala and Mukono in the central region, Jinja-Iganga, Mbale-Tororo in the eastern region, and Mbarara in the western region contribute more than 70 percent of manufacturing output, (UBOS, 2004).

For public infrastructure data, our analysis uses both primary and secondary data comprising of different infrastructure stocks at district level. Some of the variables were obtained by aggregation from the Uganda National Household and Community Survey of 1999/00 conducted by the Uganda Bureau of Statistics, and from various agencies including, the Ministry of Works, Housing and Communications and District Local Governments and Municipalities. Other data, e.g. length of different types of roads were obtained by measurement of road distances from topographical and administrative maps as at the year 1996. Attention was restricted to three key "infrastructure stocks" in Uganda, i.e. electricity, telephones and roads of different types. These were ranked as some of the most binding constraints to investment in firm managers' perception surveys (Reinikka and Svensson, 1999).

Roads

Two types of roads were considered by district. Kilometres of paved roads per square kilometre per district and kilometres of all weather (murram) roads per square kilometre per district. They were all adjusted for quality.

Telephone

We use the mean distance to the nearest public telephone per district as a proxy for the stock of telephone infrastructure per district. The distance to the nearest public telephone from the centre of the village or community was retrieved from a community survey, which was part of the 1999/2000 Uganda National Household Survey. We use the average for the district in our analysis. Since each community in the survey has a particular sample multiplier, we use the multiplier as a weight for data aggregation.

Electricity

Similarly, we use the proportion of households with electricity per district as a proxy for stock of electricity infrastructure per district. The data on the number of households with electricity per district was retrieved from the 1999/2000 Uganda National Household Survey. Since each household in the survey has a particular sample multiplier, we use the multiplier as a weight for data aggregation.

2.2.2 Estimation Strategy

We will explore alternative production function specifications but start the research with the introduction of the stock of public infrastructure in the Cobb-Douglas production function.[17] Our econometric estimations apply both the Cobb Douglas and Translog production function specifications. Theoretically, the translog production function would be preferred because of its flexibility and because it allows us to analyse both the direct and indirect effects given the quadratic and interaction terms.

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[17] As noted earlier, the Cobb-Douglas function formulation does not disentangle the direct and indirect effects of public infrastructure capital.

We however test for the appropriateness of either functional specification and the selection of the appropriate form (preferred functional form) is made on the basis of statistical performance and consistency with theory.

The production functions in their basic form can be estimated as[18]:

(a) The Cobb-Douglas (CD) model with several inputs:

$$\ln\left(firm\ value\ added_i\right) = a_0 + \sum_{i=1}^{k} b_i \ln X_i \tag{3}$$

(b) The Cobb-Douglas (CD) model with constant returns to scale:

$$\ln\left(firm\ value\ added_i\right) = a_0 + \sum_{i=1}^{k} b_i \ln X_i , where \sum_{i=1}^{k} b_i = 1 \tag{4}$$

(c). The Translog Model:
Generally for k inputs, the translog function is

$$\ln\left(firm\ value\ added_i\right) = a_0 + \sum_{i=1}^{k} b_i \ln X_i + \sum_{i=1}^{k}\sum_{j=1}^{k} c_{i,j} \ln X_i \ln X_j \tag{5}$$

Where X_i is the ith input and $c_{ij} = c_{ji}$.

The inputs (X_i) as represented in the above equations refer to the firm inputs as described earlier. That is, L_i *and* K_i representing the firm's labour and private capital inputs respectively, and G_i representing the stock of public infrastructure. In the translog model (equation 5), the term $\ln X_i \ln X_j$ represents the product/interaction between two factor inputs or variables.

More specifically, L_i is the number of people employed by the firm, K_i is the firm's total fixed assets while G_i is the stock of public infrastructure relevant at the firm level. Because of the different types of public infrastructure in this study, that is, roads, telephones and electricity, G_i represents the various types of public infrastructure stocks in the district in which the firm is located.

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[18] A number of extensions to these are discussed later.

2.2.2.1 Elaboration of the different forms of the Cobb-Douglas production functions with infrastructure capital

In econometrically estimating the Cobb Douglas production function, we represent the technological relationship between output (value added) and factor inputs. In theory, the inputs should be measured in terms of services of the input per unit of time but such data are generally not available. Here, we measure them as the amount of the input utilized or available in the production process.

The labour input is typically measured as labour hours employed per year, in this study it is measured as the number of employees. Capital input is typically measured by the net capital stock (net of depreciation) as is done in this study. Other inputs could be included in the production function. As discussed earlier we include physical public infrastructure as a separate input.

As regards the capital input, we need to take into account the extent of its utilisation. That is, there is need to deal with the problem of capacity utilisation. However, data on capacity utilization are difficult to obtain. Hence we follow the approach of Solow (1957), in which we assume that the percentage of capital utilized was the same as the percentage of labour utilized and thus reduce the total capital available by the (labour) unemployment rate.

Since the Cobb-Douglas is linear in the logarithms of variables, equation (2) above can be rewritten in log-linear form as;

$$\ln \mathrm{Y} = \lambda + \alpha \ln L + \beta \ln \mathrm{K} + \gamma \ln G + \mu \qquad (\lambda = \ln \mathrm{A}) \qquad (6)$$

The classical approach to estimating the Cobb-Douglas production function is to assume perfect competition and profit maximization so that the necessary (first order) conditions for a maximum are met. These conditions state that the marginal product of each input must equal its real wage, namely the wage (input price) divided by the price of output. It is on the basis of this that the Cobb Douglas production function is normally assumed “a priori” to exhibit constant returns to scale (see Intriligator et al, 1996). Hence the estimated production function equation is in intensive form relating output per worker to the capital-labour ratio, public infrastructure per worker and other explanatory variables. Following the formulation of Aschauer (1989a), many studies tried to estimate the impact of public infrastructure on private sector output/productivity with the “a priori” assumption of constant returns. We differ by testing the validity of this assumption with our data. Therefore, we consider three other formulations;

In our second formulation, the function F (.) in equation (2) may exhibit constant returns to scale in all three inputs, which would imply decreasing returns to scale over private inputs (i.e. $\alpha+\beta+\gamma$ = 1, and $\alpha+\beta<1$ respectively) so that equation 6 would be reformulated to equation 8 as derived below;

$$\ln \mathrm{Y} = \lambda + (1-\beta-\gamma)\ln L + \beta \ln \mathrm{K} + \gamma \ln G \tag{7}$$

$$\ln\left(\frac{Y}{L}\right) = \lambda + \beta \ln\left(\frac{\mathrm{K}}{L}\right) + \gamma \ln\left(\frac{G}{L}\right) + \mu \tag{8}$$

If the assumption of constant returns to scale is valid then equation (8) can be estimated, a formulation used by Aschauer (1989a).[19]

In the third possible formulation, the function F (.) may exhibit constant returns to scale over private inputs or, in other words, increasing returns to scale in all three inputs, (i.e. $\alpha+\beta=1$ and $\alpha+\beta+\gamma>1$ respectively) so that equation 6 would alternatively be reformulated to equation 10 derived below;

$$\ln \mathrm{Y} = \lambda + (1-\beta)\ln L + \beta \ln \mathrm{K} + \gamma \ln G \tag{9}$$

$$\ln\left(\frac{Y}{L}\right) = \lambda + \beta \ln\left(\frac{\mathrm{K}}{L}\right) + \gamma \ln G + \mu \tag{10}$$

In our fourth formulation, no ‘a priori’ restrictions regarding returns to scale are assumed. Equation 8 is reformulated to equation 11 below.

$$\ln\left(\frac{Y}{L}\right) = \lambda + \beta \ln\left(\frac{\mathrm{K}}{L}\right) + \gamma \ln\left(\frac{G}{L}\right) + (\alpha+\beta+\gamma-1)\ln L + \mu \tag{11}$$

If the parameter “$(\alpha+\beta+\gamma-1)$” is significantly different from zero, then the null hypothesis of constant returns to scale is rejected. Alternatively if the assumption of constant returns to scale holds $(i.e.\ \alpha+\beta+\gamma=1)$, then equation (11) reduces to equation (8).

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[19] Aschauer (1989a) included a trend variable and a capacity utilization rate to control for the influence of the business cycle since he was using time series data.

We therefore have four different formulations for estimating the parameters of our Cobb Douglas production function and they involve alternative assumptions and econometric problems. The first (equation 6), estimates the production function itself in log-linear form and requires no returns to scale assumptions, but typically leads to econometric problems of endogeneity, multicollinearity, and heteroskedasticity.

The second formulation is that of estimating the intensive production function in log-linear form (equation 8). Although this method reduces the problems of multicollinearity and heteroskedasticity, it does require the assumption of constant returns to scale and hence cannot be used to test for increasing or decreasing returns. It also has the possibility of the problem of endogeneity. [20]

The third formulation (equation 10) also reduces the problems of multicollinearity and heteroskedasticity, but it does require the assumption of constant returns to scale over private inputs. It also has the possible problem of endogeneity.

Our fourth formulation (equation 11), also reduces the problems of multicollinearity and heteroskedasticity, and does not require the "a priori" assumption of constant returns to scale. However it retains the problem of endogeneity.

None of these formulations dominates the others; each is appropriate in particular situations, depending upon what can be assumed and what is to be investigated.

We use the less restrictive equation 11 as our basic model for estimation and make extensions to this basic model (see below).

Despite our dealing with some of the criticisms of earlier studies in our Cobb-Douglas formulations, the approach still has the limitation of restricting the elasticity of input substitution to equal one and does not allow an explicit analysis of the possibilities of interaction among factor inputs. That is, it does not allow us to disentangle the direct and indirect impacts of public infrastructure capital. To overcome these limitations, our second approach is based on a translog production function which is elaborated on in the next section.

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[20] Intriligator et al., (1996: 136-139; 289), shows that the use of ratios helps reduce these problems particularly heteroscedasticity.

2.2.2.2 *Elaboration of the Translog production function with infrastructure capital*

Our second approach is based on the production function formulation of Christensen, Jorgenson and Lau (1971; 1973). It is a more general functional form and it helps minimize any biases that might result from using the more restrictive Cobb-Douglas specification. It also has the advantage of allowing for the testing of interactions among factor inputs, derivation of output and scale elasticities with respect to public infrastructure capital, allows for a variable elasticity of substitution and is easily estimatable. In addition, it can be considered a sufficiently close approximation to whatever the underlying productive process is since it can be regarded as a second order Taylor approximation to any production function (Thomas, 1993).[21]

In its formulation, the logarithm of output/value added is approximated by a quadratic in the logarithms of the inputs. The basic translog function for the three inputs in this analysis can therefore be written as:

$$\ln \mathrm{Y} = \lambda + \alpha \ln L + \beta \ln \mathrm{K} + \gamma \ln G + \delta \ln L \ln \mathrm{K} + \varepsilon \ln L \ln G + \phi \ln \mathrm{K} \ln G + \vartheta (\ln L)^2$$
$$\rho (\ln K)^2 + \sigma (\ln G)^2 + \mu \qquad (12)$$

This function reduces to the Cobb-Douglas case if the parameters $\delta, \varepsilon, \phi, \vartheta, \rho, \sigma$ are no different from zero; otherwise, it exhibits non-unitary elasticity of substitution. In summary therefore, this function is quite flexible in approximating arbitrary production technologies in terms of substitution possibilities (Intriligator et al., 1996).

Output/Value added elasticities and private factor productivities with respect to public infrastructure are then derived as follows;

Output/Value added elasticities with respect to public infrastructure

The output/value added elasticity with respect to the public infrastructure input can be calculated from the translog estimates by:

$$\mathrm{E}_G = \frac{\partial \mathrm{Y}}{\partial G} \frac{G}{\mathrm{Y}} = \gamma + \varepsilon \ln L + \phi \ln \mathrm{K} + 2\sigma \ln G \qquad (13)$$

Private factor productivities with respect to public infrastructure

The effect of the public infrastructure input G on private factor productivities, that is

[21] However more degrees of freedom are lost in comparison to the Cobb Douglas production function.

$$\frac{\partial^2 Y}{\partial K \partial G}, \qquad \frac{\partial^2 Y}{\partial L \partial G}$$

can be derived from the estimates of equation (12) as follows;

$$\varepsilon = \frac{\partial^2 \ln Y}{\partial \ln L \; \partial \ln G} \quad and \quad \phi = \frac{\partial^2 \ln Y}{\partial \ln K \; \partial \ln G} \text{ from which } \frac{\partial^2 Y}{\partial K \partial G}, \qquad \frac{\partial^2 Y}{\partial L \partial G}$$

can be computed as $\frac{\partial^2 Y}{\partial K \partial G} = \phi \frac{Y}{KG}$, *and* $\frac{\partial^2 Y}{\partial L \partial G} = \varepsilon \frac{Y}{LG}$ (14)

Since the ratios $\frac{Y}{KG}$ and $\frac{Y}{LG}$ are positive, it is possible to infer from the signs of ε and ϕ whether the effect of G on private factor productivities is positive or negative respectively and hence make conclusions about substitutability or complementarity.

2.2.2.3 Extensions of the Basic Models

Extensions to the above basic models are needed to take into account omitted variables and other unobservable factors. Failure to do so, would cause an omitted variables bias. This necessitates inclusion of regional (district) and firm specific effects.

To take into account regional effects, the error term in the equations is specified in a way that permits each observation to have an unobserved component of the error term representing differences in underlying productivity from location, climate, mineral endowments, etc. Earlier work, e.g. Aschauer (1989a), which applied traditional estimation techniques (such as ordinary least squares) and ignored regional or state specific effects, were criticised for producing biased and inconsistent estimates (see for example Holtz-Eakin, 1992). This is a case of model misspecification.

We remedy this in our work by following the approach of Rovolis and Spence (2002). That is, in one of our functional specifications we introduce regional specific characteristics by applying a least squares dummy variable(s) model (LSDV).[22] In this, a number of dummy variables representing the different regions are added to the

[22] See Wooldridge 2003, pg 284-289 for justification of this approach in capturing unobservable explanatory variables or unavailable key explanatory variables due to lack of data.

simple OLS version linking them to our observations on the basis of individual firm location.

For firm specific characteristics, we introduce firm age and a vector of firm specific dummy variables to capture firm characteristics like ownership. Foreign ownership is hypothesised to have a positive influence on firm value added. The reasons for this is that firms with some degree of foreign ownership would have timely access to inputs, better quality labour and capital, finance, maintenance personnel and sources of information about technology and markets.

Firm age should capture both learning effects as well as the vintage effect. We cannot say "a priori" the direction of impact. While the first is likely to have a positive impact, the latter will have a negative impact.

For labour quality, we follow Hall and Jones (1999), Bils and Klenow (2000) and Söderbom and Teal (2001) in our specification, which allows explicitly for the labour augmenting aspect of human capital on labour input. Hence human capital augmented labour (anti-logged) is $e^{\alpha h}L$.[23]

The new variables to be introduced to the basic models will enter the equations as follows;

(N_i)**:** A vector of regional dummy variables.

(Z_i) : A vector of firm specific dummy variables

(H_i): Human capital - mean number of school years completed in the district for that part of the population over the age of 15 years.

We also make an extension to the translog production function specification, which provides a number of empirical advantages. The translog production function is a second-order approximation to unknown production function derived with a Taylor's expansion. As in Costa et al (1987), each variable in our estimation is expressed as the deviation from a given point of expansion. Since the mean point is generally used in a Taylor's expansion, the translog function can be estimated as;

$$\ln VA_i = \lambda + \alpha(\ln L_i - \ln \overline{L}) + \beta(\ln K_i - \ln \overline{K}) + \gamma(\ln G_i - \ln \overline{G}) + \vartheta(\ln L_i - \ln \overline{L})^2$$
$$+ \rho(\ln K_i - \ln \overline{K})^2 + \sigma(\ln G_i - \ln \overline{G})^2 + \delta(\ln L_i - \ln \overline{L})(\ln K_i - \ln \overline{K})$$
$$+ \varepsilon(\ln L_i - \ln \overline{L})(\ln G_i - \ln \overline{G}) + \phi(\ln K_i - \ln \overline{K})(\ln G_i - \ln \overline{G}) \qquad (15)$$

[23] This would capture labour quality and would be αh in the logged equation.

Where VA_i represents value added for each firm rather than the gross value of production. As argued by Denny and Fuss (1978) this allows technology to be separated into factors of production and intermediate inputs. The factors of production are denoted as in the earlier equations and the mean values by $\overline{()}$. Hence this would be the form of the empirical translog specification. This procedure has an added advantage in that it is like "Centering", a method that reduces multicollinearity in polynomial or interaction-effect models (see Hamilton, 2003, pp.167 and section 5.8 below).

2.2.2.4 Testing procedures

We test the restrictions on the production technology. Within the translog framework, homogenous technology will mean that the sum of the coefficients of the squared terms and the cross-effects will be zero. Linear homogeneity will require that in addition to the above condition, the sum of the linear terms equals one (Chambers, 1988).

These restrictions are tested with an F-test, with the computed F-statistic given by

$$F_{m,n-k_u} = \left[\left(RSS_R - RSS_U\right)/m\right]/\left(RSS_U / n - k_U\right) \qquad (16)$$

Where $RSS_R, RSS_U, m, n, and\ k_U$ stand for sum-of-square errors in the restricted and unrestricted regressions, number of restrictions, number of observations, and number of estimated parameters in the unrestricted model, respectively. The restrictions considered above will be rejected if F-computed > F-critical.

To test for the appropriateness of the functional form and its consistency with empirical data, we apply the RESET test suggested by Ramsey and Schmidt (1976), and discussed in Thomas (1993).[24] Essentially we test the null hypothesis of a linear specification.

We apply a generalisation of the RESET test since we are dealing with multiple regressions. Instead of adding powers of each regressor to an equation as initially presented by Ramsey and Schmidt (1976), the squares of the predicted

[24] This is to deal with the criticism levelled at earlier studies regarding functional form misspecification.

values, $\overline{Y}_i^{\,2}$ obtained from the original estimated equation, are added. If the equation first computed is

$$\overline{Y}_i = \overline{\beta}_1 + \overline{\beta}_2 X_{2i} + \overline{\beta}_3 X_{3i} \qquad i = 1, 2, 3 \ldots n \tag{17}$$

then the RESET test proceeds by estimating

$$Y_i = \beta_1^{'} + \beta_2^{'} X_{2i} + \beta_3^{'} X_{3i} + \gamma \, \overline{Y}_i^{\,2} + \varepsilon_i \qquad i = 1, 2, 3 \ldots n \tag{18}$$

Further powers of $\overline{Y}$ can be added to the equation and the joint significance of the $\overline{Y}$ variables can be tested with the F-test. Significance means that we reject the null hypothesis of a linear specification. One limitation of the RESET test is that it does not specify the precise form of non-linearity expected. The RESET statistic, even if significant, gives no indication, hence making it a test of general misspecification rather than a test of specification (Thomas, 1993, page 144).

In addition, RESET has no power for detecting omitted variables whenever they have expectations that are linear in the included independent variables in the model. It also has the drawback of using up many degrees of freedom if there are many explanatory variables in the original model.

We do take into account the fact that the RESET test is not robust in the presence of heteroskedasticity. We therefore carry out heteroskedasticity-robust procedures to make the RESET test robust to heteroskedasticity.

If we estimate our chosen model equations directly for all firms (that is taking the full sample), we constrain the output elasticities to be the same across all types of firms or sectors. However we test for data pooling by exploring particular sub-samples on the basis of different sectors and firm sizes, which allows us to consider whether estimates of output elasticities should be specific to those sectors and firm sizes (section 2.3.2). We apply the usual “Chow test” (first chow test) to test the null hypothesis of data poolability in the case of firm size sub-samples. However in the case of sectors, we had too few observations to estimate the equation for the agriculture sub-sample. In this case we therefore apply Chow’s second test (see Mukherjee, White and Wuyts, 1998).

The relevant test statistic is also based on the F-statistic, which is:

$$F_{(m, n-k_R-m)} = \frac{RSS_R - RSS_1}{RSS_1} \frac{n - k_R - m}{m} \tag{19}$$

Where RSS_R is the residual sum of squares (RSS) from the estimated equation for the whole sample, RSS_1 is the RSS from the estimated equation for the sub-sample(s) that we can estimate, k_R is the number of regressors (including the constant) in the restricted equation, and n is the number of omitted observations.

Finally, we check for multi-collinearity among our disaggregated public infrastructure capital measures using the variance-inflating factor (VIF).[25] We found severe problems of multi-collinearity when we included individual infrastructure measures in the same regression estimation. This compelled us to develop a composite indicator of infrastructure availability using principal components analysis. This composite indicator was then used as an independent variable in our regressions (see details below).

2.2.2.5 Infrastructure Data Aggregation Method

A daunting challenge that would be expected is how to enter various measures of infrastructure into a regression analysis relating public infrastructure to economic activity. As discussed in the previous section, simultaneously including several public infrastructure measures introduces the problem of multi-collinearity since locations with high levels of one infrastructure type are likely to have a similarly high stock of another infrastructure type. With multi-collinearity, there is a perfect linear relationship among the predictors of a regression model; hence estimates of the coefficients cannot be uniquely computed, that is, they become unstable and the standard errors for the coefficients can get wildly inflated.[26]

We considered a number of procedures that could be undertaken to eliminate or reduce multi-collinearity, especially for our translog function model.

One way is the "Centering" method, which involves subtracting the mean from x variable values before generating polynomial or product terms. The resulting regression fits the same as an uncentered version (Hamilton, 2003).[27]

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[25] The VIF reflects the degree to which other coefficients' variances (and standard errors) are increased due to the inclusion of a particular predictor (Hamilton, 2003). If VIF is greater than 10, then multicollinearity is strongly present in the estimation. Another measure is the condition index (CI) or condition number. It is defined as the square root of the ratio of the largest eigenvalue to the corresponding smallest eigenvalue. Normally if CI is between 10 and 30, there is moderate to strong multicollinearity and if it is greater than 30 there is serious multicollinearity present in the data (Gujurati, 1995, p. 338 – 339).

[26] We cannot reliably estimate their separate effects due to collinearity.

[27] In many cases "Centering" reduces multicollinearity in polynomial or interaction-effect models.

Another way is the use of Ridge regression where a constant is added to the variances of the explanatory variables. This is not normally recommended because of its arbitrariness and mechanical nature. However there are situations under which the ridge regression arises naturally. For example, if a Cobb-Douglas production function has a constant return to scale, an option is the use of Constrained Least Squares where a constant λ is included as the Langragian multiplier (Maddala, 1988). However when the constant returns to scale assumption is rejected, then it may be inappropriate.

A commonly mentioned method is the Instrumental Variable (IV) method. This involves substituting the variable which causes the problem with another variable that is uncorrelated with the error in the equation, and is (partially) correlated with the endogenous explanatory variable. Normally there is considerable difficulty in getting a suitable instrumental variable as it turned out in this study.

Omitting the variable with the least statistical significance is one method often used. However one needs to consider how important the omitted variables are, say from theory. Excluding an important variable, may bias the estimate for the other variables although the estimators might have a smaller variance. This approach is not appropriate in our case because it is our investigative variables that are highly correlated and we need to retain them in our analysis.

Lastly, Principal components and factor analysis which are methods for data reduction can also be used to cope with multi-collinearity by constructing composite indices.

For this research, we use the principal components method because it provides several advantages. Apart from helping in reducing multi-collinearity, improving parsimony and improving the measurement of indirectly observed concepts, it makes economic sense by aiding the re-conceptualization of the meaning of the predictor in our regression model.[28] By capturing the aggregate impact of infrastructure, we take into account the relationships amongst the different types vis-à-vis their combined productive effects. These relationships can be complex in the sense that they can be

[28] However, the problem of multicollinearity may persist within the translog functional form, but "Centering" normally eliminates the problem, which it does in our parsimonious model. However it is worthy-noting that in some cases, despite loss of precision due to multicollinearity, if we can still distinguish the coefficients from zero and the affected model obtains a better prediction than others, multicollinearity may not necessarily mean a great problem, or require a solution. It may just be accepted as one feature of an otherwise acceptable model (Hamilton, 2003).

competitive, complementary or both. For example, a highway system in a country or region does not only add capacity to its transportation system, but also affects the functioning of other parts of the system, like airports (Batten, 1996).

Principal Components Method

The method involves a mathematical procedure that transforms a number of correlated variables into a smaller number of uncorrelated variables called principal components. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible. That is, the method generates those linear combinations of object measures (called eigenvectors), which express the greatest statistical variance over all of the objects under consideration. This is particularly useful when there are hidden dependencies between different object measures.

In practice, n linear combinations (principal components) of the n columns of $X^{'}X$ matrix are created. All principal components are orthogonal to each other. The first principal component p_1 minimizes the trace of $\left(X - p_1 a_1^{'}\right)^{'}\left(X - p_1 a_1^{'}\right)$, where a_1 is the eigenvector of the $X^{'}X$ matrix associated with the largest eigenvalue. p_1 provides the best linear combination of the columns of X in a least squares sense. On the other hand, the $i-th$ principal component $\left(p_i, with\, i > 1\right)$ tries to describe the features of X not captured by p_1 by minimizing:

trace $\left[\left(X - \sum_{j=1}^{i} p_j a_j^{'}\right)^{'}\left(X - \sum_{j=1}^{i} p_j a_j^{'}\right)\right]$, $with\, i = 2,.....,n; where\ a_j$ is the eigenvector associated with the $j-th$ largest eigenvalue (Alesina and Perotti, 1996).

We aggregate our infrastructure measures (Paved roads, All weather roads, Telephones and Electricty) into an infrastructure index using this method as follows. Since our infrastructure variables are in different measurement units, we first standardize the data. Standardization changes the object measures internally to make each measure have a mean of zero and a standard deviation of one. This prevents one measure from predominating over another simply because of the units used to express each measure.

Implementation of the Principal component analysis (PCA) was done using STATA software package. The first principal component of the PCA was then used to derive weights (scores) for the infrastructure index (See Appendix 2 for details).

$$\text{Log (Infraindex)} = 0.25955*(\text{Log Paved roads}) + 0.25278*(\text{Log (Weather roads)}) + 0.25334*(\text{Log (Power)}) + 0.25942*(\text{Log (Telephone)}). \quad (20)$$

Where infraindex is the value of the aggregate infrastructure measure and the score coefficients being regarded as weights.

On the basis of equation 20, we created the infrastructure index for each observation located in any particular district. See table 1.2.

Table 1.2
Factor scores based on coefficients and standardized infrastructure variables

	District	Factor Score		District	Factor Score
1	Kampala	0.68409	14	Mbale	-1.12819
2	Luwero	-1.46926	15	Soroti	-2.00908
3	Masaka	-1.32217	16	Tororo	-1.45095
4	Mpigi	-1.01015	17	Arua	-2.30251
5	Mubende	-1.97431	18	Lira	-2.25621
6	Mukono	-0.89985	19	Bushenyi	-1.68811
7	Nakasongola	-2.62442	20	Hoima	-1.92122
8	Rakai	-1.74792	21	Kabale	-1.15543
9	Kayunga	-1.27091	22	Kabarole	-1.48905
10	Wakiso	-0.73917	23	Masindi	-1.29742
11	Iganga	-1.36838	24	Mbarara	-1.61638
12	Jinja	-0.54448	25	Kyenjojo	-2.23310
13	Kamuli	-2.13892			

The negative score indicates that some firms have access to less infrastructure stocks than the national average available to firms.

2.3 Regression Model Estimation, Empirical Analysis and Results

In our empirical estimation and analysis, we compare alternative models with different functional forms and specifications. After carrying out a number of relevant diagnostic tests, including model specification tests, the findings from our chosen model are that the estimated elasticity between public infrastructure and private sector production/productivity is positive, big in magnitude, and significantly different from zero (at 1% level).

It is also worthy-noting that in all our specifications the results are positive and significant. The log-linear functional form, a common criticism of earlier studies, does not drive the results. After carrying out diagnostic tests, i.e. Wald test, Ramsey regression specification error test (RESET), heteroskedasticity test and a test for multi-collinearity (Mean Variance Inflation Factor, VIF), our parsimonious model, is of the translog production function form.

The results from the more general production function (Translog production function) show that the quadratic terms are collectively significant in almost all the models. This finding supports our use of the more general production function form in our final analysis. However we also report on results from the Cobb Douglas specification for comparison purposes.

2.3.1 Econometric Results

The estimation results are reported for the full sample as well as sub-samples based on sectors. The results for the whole sample and where we use the aggregate infrastructure index as our investigative variable are discussed first (tables 2.2a and 2.2b). The results for individual infrastructure measures are reported later in the sections 2.3.3 and 2.3.4, which elaborate on results from both the Cobb Douglas and Translog Production functions.

There are six versions of models using both the Cobb Douglas and Translog production functions. These are based on functional form, with or without regional specific characteristics (i.e. OLS or Least Squares Dummy Variable model), with or without robust standard errors.

Table 2.2a
Results from the full sample with aggregate infrastructure measure

Model Description	Infrastructure variables	Results
Model 1 - 2: Cobb-Douglas and no regional effects **Model 1:** OLS **Model 2:** With Robust standard errors **Dependent variable**: Log Value Added per worker Multicollinearity not a big problem, with the Variance Inflation Factor (VIF) just above 10 in both models.	Apart from the other input factors and control variables, aggregate infrastructure variable (infraindex) used in model. All models adjust for capacity utilisation	In both cases our infrastructure measures are positive, big in magnitude and significant at 1% level. Infraindex = 0.45 in both cases, R-squared high (0.48). Model with robust standard errors essentially the same as the OLS version. However the Ramsey (Reset) test indicates a case of omitted variables.
Model 3 - 4: Cobb-Douglas and with regional effects **Model 3:** LSDV **Model 4:** With Robust standard errors **Dependent variable**: Log Value Added per worker	Aggregate infrastructure index used in the regression model	(a) Aggregate index significant at 1 % level. Infraindex = 0.48 in both cases and small change in standard errors. R-squared = 0.48 Presence of multicollinearity, with the Variance Inflation Factor (VIF) at 12.16 in both models. The Ramsey (Reset) test indicates a case of omitted variables.
Models 5: **Translog Production Function and no regional effects.** **Model 5**: OLS (Parsimonious model). **Dependent variable**: Log Value Added Multicollinearity eliminated through "Centering"(See Hamilton 2003; pg 166-170). i.e. Standardizing the variables. VIF = 5.42	Aggregate infrastructure index (Infraindex), with squared and cross terms. Model 5 adjusts for capacity utilisation	(1) Infraindex- positive, big magnitude and significant at 1 % level. (2) Squared term: positive and significant at 1% level. (3) Cross term, infraindex and private capital positive and significant at 10% level. (Complementarity). (4) Cross term, infraindex and private labour, negative and significant. (Substitutive). R-squared = 0.77
Models 6: **Translog Production Function and with regional effects.** **Dependent variable**: Log Value Added Multicollinearity eliminated through "Centering"(See Hamilton 2003; pg 166-170). i.e. Standardizing the variables VIF = 7.92	Aggregate infrastructure index (Infraindex), with squared and cross terms.	(1) Infraindex- positive, big magnitude and significant at 1 % level. (2) Squared term: positive and significant at 5% level. (3) Cross term, infraindex and private capital positive and significant at 10% level. (Complementarity). (4) Cross term, infraindex and private labour, negative and significant. (Substitutive) R-squared = 0.77

Table 2.2b
Estimates with Aggregate Infrastructure Measure (full sample)

Variable \ Functional form	**Cobb Douglas Production Funcion** Dependent variable: Log Value Added per worker				**Translog Production Function** Dependent variable: Log Value Added	
	No regional effects		**With regional effects**		**No Regional effects**	**With regional effects**
	OLS	Robust s.errors	LSDV	Robust s. errors	OLS	LSDV
	Model 1	Model 2	Model 3	Model 4	Model 5	Model6
Constant	-0.110*** (0.029)	-0.110*** (0.029)	0.017 (0.141)	0.017 (0.135)	-0.181*** (0.035)	-0.186*** (0.162)
Log Private Employment (Log L)	0.276*** (0.088)	0.276*** (0.091)	0.303*** (0.110)	0.303*** (0.112)	0.334*** (0.024)	0.336*** (0.024)
Log Private Capital						
Log K					0.515*** (0.023)	0.513*** (0.023)
Log (K/L)	0.577*** (0.024)	0.577*** (0.028)	0.576*** (0.025)	0.576*** (0.028)		
Aggregate infrastructure measure						
Infraindex (Log G)					**0.346***** (0.065)	**0.360***** (0.080)
Log (G/L)	**0.451***** (0.113)	**0.451***** (0.118)	**0.488***** (0.143)	**0.488***** (0.144)		
Log (unemployment)	-0.096 (0.087)	-0.096 (0.093)	-0.112 (0.106)	-0.112 (0.107)	-103* (0.055)	-0.100 (0.070)
Foreign Ownership	0.333*** (0.053)	0.333*** (0.052)	0.340*** (0.054)	0.340*** (0.053)	0.230*** (0.036)	0.231*** (0.036)
LogK * Log L					0.047 (0.032)	0.048 (0.032)
Log K* Log infraindex					**0.043*** (0.025)	**0.044*** (0.025)
Log L* Log infraindex					**-0.045*** (0.024)	**-0.046*** (0.025)
$(\text{Log Infraindex})^2$					**0.074***** (0.024)	**0.082**** (0.035)
$(\text{Log K})^2$					0.031 (0.020)	0.030 (0.021)
$(\text{Log L})^2$					-0.032* (0.018)	-0.033* (0.018)
R-squared	0.4773	0.4773	0.4782	0.4782	0.768	0.7681
Adj R-squared	0.4746		0.4738		0.7653	0.7647
SSE(RSS)	502.283		501.471		222.967	222.84
Mean Variance Inflation Factor (VIF)	10.73	10.73	12.16	12.16	5.42	7.92
Ramsey (Reset) test						
$F(m, n\text{-}k_u)$	14.48	14.48	14.91	14.91	1.04	1.14
Prob >F	0.000	0.000	0.000	0.000	0.3741	0.331
Heteroskedasticity test						
Chi2(1)	4.02		4.31		1.35	1.29
Prob >chi2	0.0451		0.0379		0.2458	0.2552
N	962	962	962	962	962	962

*Significant at 10 % level
** Significant at 5 % level
*** Significant at 1% level. Standard errors in parenthesis.

Although we report on results of models in which we included regional specific characteristics, the regional dummies turned out to be jointly insignificant in all models. Models 1 to 4 are of the Cobb Douglas functional form, while models 5 and 6 are of the Translog Production functional form (see table 2.2b).

All models in table 2.2b include a proxy variable for capacity utilisation (i.e. unemployment per district) as a control variable. We take the unemployment rate in the district as a proxy for the degree of capacity underutilization for all firms in the district. It is found to be significant in the full sample (translog formulation) and sub-samples of industrial firms.

As can be deduced from tables 2.2a and 2.2b the main findings that emerge from the estimation of our parsimonious model (model 5) are as follows.

First, we find that public infrastructure makes a positive and highly significant contribution to the value added of firms. This finding endorses the importance of public infrastructure in the production process.

Second, the positive and significant coefficients of the squared term and the interaction term between public infrastructure capital and private capital tends to support the "Public Infrastructure Capital Hypothesis" that emphasises the importance of indirect effects of infrastructure that arise because private capital and public infrastructure are considered to be complementary. That is, public infrastructure raises the productivity of private capital. This is also consistent with investment oriented endogenous models that emphasize complementarities between the development of public infrastructure and the accumulation of private capital.

Third, the magnitudes of our coefficients are particularly interesting given that our unit of analysis is an individual firm. Previous research was mainly carried out at the aggregate level, either at national or regional level. The computed value added elasticity with respect to public infrastructure (standardized coefficients) based on average values is significant at 1% level (see below).

Log Value Added	Coef.	Std.Err	t	P>l t l
(1)	**0.451031**	0.064982	6.94	0.000

Predicted Log value added increases by 0.45 standard deviations with each 1-standard-deviation increase in the infrastructure composite index (Log infraindex). Transforming the standardized coefficients to original values (unstandardized coefficients), a one percent increase in the infrastructure composite index is associated with a 0.382 percent increase in predicted value added (see table below).

Log Value Added	Coef.	Std.Err	t	P>I t I
(1)	**0.382481**	0.084227	4.54	0.000

Unfortunately, we cannot find a similar study within Sub-Saharan Africa with which to compare our results. Nevertheless we draw attention to the big magnitude of impact that is either almost equivalent or higher than many earlier studies that were done in other parts of the world, i.e. North America and Western Europe. Earlier studies with big coefficients were criticised for methodological flaws. However our study takes into account of the criticisms of earlier studies and still findings a positive and big impact of public infrastructure of private sector production. We argue that this can be explained by the following:

(1) Because current public infrastructure provision in Uganda is less than optimal in almost all parts of the country, additional investments will bring significant returns.

(2) In this study, we use actual physical measures of public infrastructure as opposed to public investment expenditures or derived public capital stocks by the perpetual inventory method (PIM). This ensures that we do not unnecessary assume that these investment expenditures actually results in actual investments in public capital, a very unrealistic assumption especially in the case of developing countries where the incidences of corruption are high and there are inefficiencies in the implementation of infrastructure investment projects. This could to some extent explain the results of some studies that have found insignificant and sometimes negative impacts.

(3) Unlike other studies that use national or regional outputs as the dependent variables, we use firm output/productivity (Value added), which we link to the available public infrastructure stock on the basis of firm location, hence providing a more direct linkage.

2.3.2 Differences among Sectors and Firm Sizes

In the previous sections, we assumed data poolability, both on the basis of firm sizes as well as on the basis of sectors. However earlier work was criticised for making this assumption without making the necessary test statistics. Although as argued by Brynjolfsson and Hitt (1995), our use of value added as the dependent variable rather than sales should help to make the production process of, say, a retailing firm more comparable to a manufacturing firm, we nevertheless test for "poolability" of the data on the basis of both firm size and sector composition. Two sub-samples are considered for the firm size analysis. That is micro and small firms (<=24 employees) and medium and large firms (>24 employees). Three sub-samples are considered for the sector analysis, i.e. agriculture, industry and services. However because the agriculture sector has too few observations we consider only two sectors in the final analysis. We apply Chow's second test, which is applied when one of the sub-samples has too few observations (See section 2.2.2.4).

Table 2.3
Test Statistics for Data Poolability

(Translog Production Function)

F - Test		Calculated Value	Critical Value (5% level) (approx.)	Result
Firm Size F(m, n-Ku)	F(12, 938)	1.46	1.75	Accept Null
Sector F(m, n-Kr-m)	F(17, 934)	2.18	1.67	Reject Null

As shown in table 2.3, the results of the chow test suggest that there are differences among sectors but not firm sizes. Table 2.3a below shows that although public infrastructure in aggregate has a positive and significant impact on both sectors, public infrastructure elasticity appears to be stronger for industrial firms than for service firms.

However, the results for the service sector are substantially more consistent with the public infrastructure capital hypothesis with the stock of public infrastructure raising private sector output both directly and indirectly. This is highlighted by the positive and significant coefficients of the squared term and the interaction term between public infrastructure and private capital.

Table 2.3a: Sectoral Analysis of the Impact of Public infrastructure on Firm Value Added

Variable \ Sector	Services		Industry	
	Cobb Douglas	Translog	Cobb Douglas	Translog
Aggregate infrastructure measure Infraindex (standardized coefficients)				
Log infraindex (Log G)		**0.356***** (0.086)		**0.441***** (0.116)
Log (G/L)	**0.443***** (0.147)		**0.706***** (0.198)	
(Log infraindex)^2		**0.064**** (0.032)		**0.069*** (0.039)
Log K * Log infraindex		**0.083***** (0.030)		**-0.044** (0.052)
Log L * Log infraindex		**-0.085**** (0.035)		**0.024** (0.042)
Value added elasticities with respect to public infrastructure capital (unstandardized coefficients)[2]				
Unstandardized coefficients				
Cobb-Douglas - Log (G/L)	**0.349***** (0.116)		**0.557***** (0.156)	
Translog production function (infraindex)		**0.387***** (0.107)		**0.522***** (0.154)
N	639	639	306	306

*** Significant at 1% level ** Significant at 5 % level *Significant at 10 % level
Standard errors in parenthesis
Results taken from Tables 2.3b and 2.4
Note: 1 The dependent variable for the Cobb-Douglas specification is Log Value added per worker while that of the translog specification is Log Value added
2 For the translog function, the value added elasticities with respect to public infrastructure capital are based on average values.

On the other hand, the squared term and the interaction term between public infrastructure and private capital for firms in the industry sector are insignificant. In fact the interaction term between public infrastructure and private capital is negative and insignificant. From the perspective of the public infrastructure capital hypothesis, this points to a surprising lack of complementarity between these factors. However this is not an entirely surprising result if one critically examines the underlying mechanisms of the relationship between public infrastructure and private sector output/productivity, particularly for firms in the industrial sector in Uganda. The main reason that can be advanced for this finding would be as follows;

In Uganda, inadequate provision of public infrastructure and services negatively affects private investment. This comes as a result of firms trying to cope with deficient public infrastructure by investing in complementary capital which minimizes their capacity to invest in productive capital.[29]

Empirical evidence provided by Reinikka and Svensson (2002), using data from the Uganda industrial survey, 1998 found that as many as 77 percent of large firms, 44 percent of medium-sized firms, and 16 percent of small-sized firms owned power generators. On average the cost of generators represented 16 percent of the value of total investment and 25 percent of the value of investment in equipment and machinery in 1997. There findings also suggested that it would cost about three times more to run and own a generator than to buy power from the public grid when available. In addition fifty percent of the firms invested in mobile phones (a privately run service) because of deficiencies in public provision while 77 percent disposed of their own waste.

The above scenario is more likely to be true for firms in the industrial sector than those in the service sector. Service firms are traditionally less capital intensive than industrial (manufacturing) firms. This is also shown by our summary statistics data (tables 2.5b, 2.5c – Appendix 1). Therefore because private capital inputs are relatively less significant for them, their private investment plans are not overly affected when they invest in complementary capital, if at they do at all. The service firm with the least worth of total assets in our sample has total fixed assets worth Uganda Shillings 41, 000 while the median firm’s total assets are worth Uganda shillings 65 million. On the other hand, the industrial firm with the least worth of total assets has total fixed assets worth approximately Uganda Shillings 967,000 while the median firm’s total assets are worth Uganda shillings 322 million.

This is reinforced by the fact that service firms are apparently relatively smaller in size and therefore are less likely to invest in complementary capital. About 62 percent of service firms in our dataset are micro or small while only about 37 percent are medium or large. The situation is reversed in the industrial sector with about 35 percent of firms being micro or small while about 65 percent are medium or large.

[29] Complementary capital in the case of Ugandan firms includes electric generators, mobile telephones and waste disposal facilities, etc.

2.3.3 Elaboration of the Estimates of the Cobb Douglas Production Function

As already noted the Cobb Douglas production framework has a number of limitations in the analysis of the impact of public infrastructure on private sector output/productivity. The results reported here should therefore be read within the caveat of the limitations of this analytical framework and only included here to enable comparisons with earlier studies.

There are five versions of models using the Cobb Douglas production, each with one of the four of our individual infrastructure measures and one with the aggregate infrastructure measure (infraindex). We did estimate a model in which we included the individual infrastructure measures together in one regression. We however do not report on the results because they were bedevilled by multicollinearity with insignificant coefficients but with high R-squared**.**

Models 1 to 4 include one type of infrastructure measure at a time, that is paved roads, electricity, telephone and all weather roads respectively, while Model 5 and 5a includes the aggregate infrastructure measure. The results are of the unconstrained Cobb-Douglas function that is equation 11 (See discussion in section 2.2.2.1).

First, we note that the constant returns to scale assumption made in earlier studies is invalidated by our data. However, we find that individual infrastructure measures as well as the aggregate infrastructure measure (in all models) are positively and significantly associated with the value added of firms in the sectors.

The primary coefficient of interest may be interpreted as the elasticity of value added (output) to public infrastructure intensity. Specifically, the dependent variable measures Log value added per worker while the key independent variable measures the Logarithm of the public infrastructure index per worker (Models 5, 5a and 6a in table 2.3b).

We included control variables in the models that included firm-specific age, human capital, unemployment (for capacity utilisation) and foreign ownership. Human capital was found to be insignificant. In addition it was highly collinear with the infrastructure measures. Firm specific age was also found insignificant as would be expected in a cross sectional analysis. Hence these two variables were dropped from the model. However foreign ownership was found to be positively and significantly associated to firm-level value added in all the models. Unemployment a proxy for capacity utilisation was included in models 5a in each case and found to be significant only in the sub-sample for industrial firms. In all cases it had the effect of increasing the magnitude of our public infrastructure coefficient. However we treat the result with some caution because its inclusion results in some very mild collinearity with our investigative variable. To get a more accurate estimate requires a firm specific capacity utilisation variable.

Because our variables are expressed as standard scores, measured in standard deviations from their means, our standardized coefficients require a different definition of effect size, i.e. standard deviations change per standard deviation.

However to make comparisons with other studies we transform the standard coefficients to original value coefficients. On the basis of model 5a, a one percent increase in the infrastructure index per worker is associated with 0.35 percent increase in value added per worker for service firms. For industry (model 5a), a one percent increase in the infrastructure index per worker is associated with a 0.56 percent increase in value added per worker. In the overall sample (model 6a), a one percent increase in the infrastructure index per worker is associated with a 0.36 percent increase in value added per worker. The magnitudes of all our results are higher than many earlier studies but almost equivalent to the seminal work of Aschauer 1989a whose estimate was approximately 0.39 for public capital in the U.S.

To check the validity of our results several post-regression tests were carried out including checks on model specifications and the assumption of constant error variance.

First we carried out the heteroskedasticity test, to test the assumption of constant error variance by examining whether squared standardized residuals are linearly related to predicted y (see Cook and Weisberg, 1994). Wrongly assuming constant error variance would imply that our standard errors and hypothesis tests might be invalid. Our results as shown in table 2.3b suggest that we can accept the null hypothesis of constant variance for the sub-samples of service firms as well as industrial firms for most of the models. In cases in which we have to reject the null hypothesis, robust standard errors are applied (see also figures 2.2 and 2.3)

Fig. 2.2: Residuals Vs Fitted Values for industrial firms (Model 5)

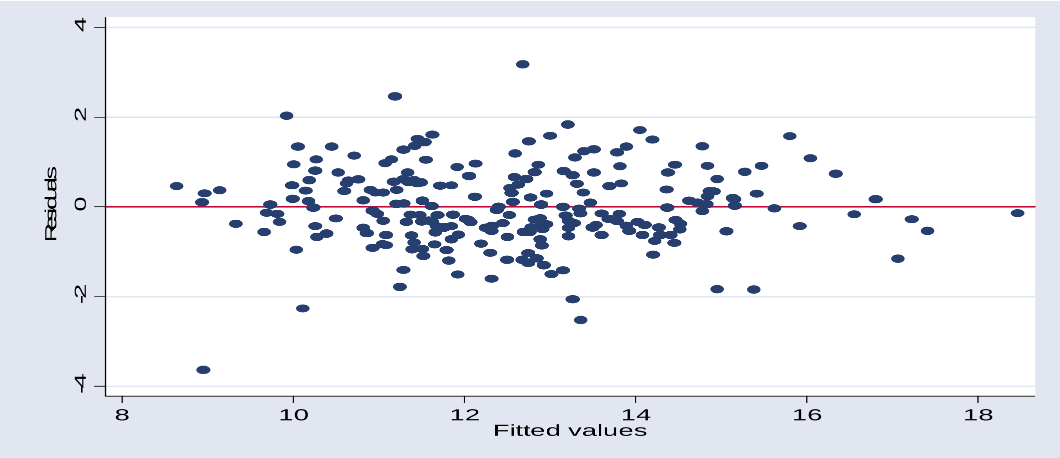
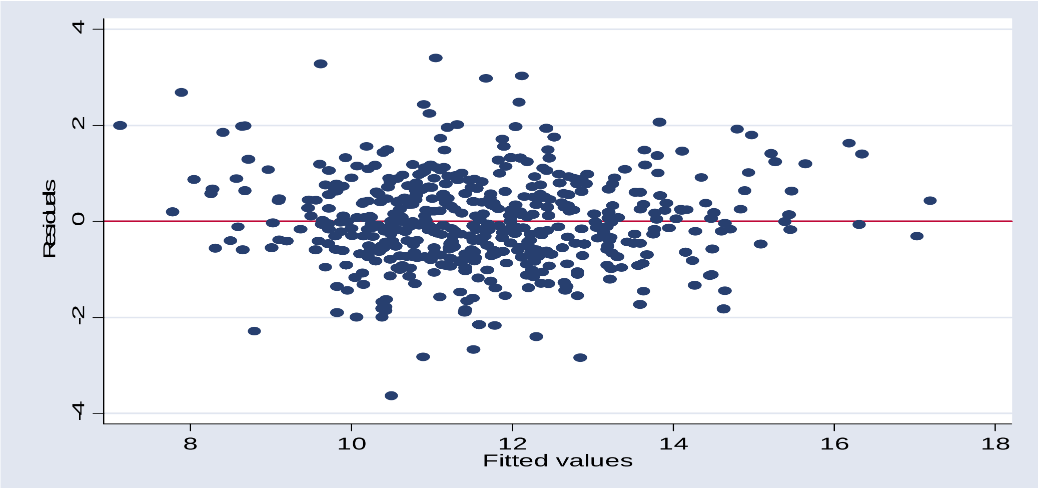


Fig. 2.3: Residuals Vs Fitted Values for service firms (Model 5)



In regard to model specification, we carried out the omitted-variable test, that is, the Ramsey RESET test, by regressing y on the x variables, and also the second, third, and fourth powers of predicted y (after standardizing predicted y to have mean 0 and variance 1) and using an F-test to check the null hypothesis that all three coefficients on those powers of predicted y equal zero. Rejection of the null hypothesis implies that further polynomial terms would improve the model. As shown in table 2.3b, we can reject the null hypothesis for the service sector, but need not reject the null hypothesis for the industrial sector. Hence the Ramsey (Reset) test indicates that the models for one sub-sample have omitted variables. This and the fact that the Cobb-Douglas production function approach restricts the elasticities of input substitution to equal one and does not allow us to investigate interaction effects between factor

Table 2.3b: Estimates of the Cobb Douglas Production Function Models; Dependent Variable: Log Value Added per Worker
Sub-Samples based on sectors

Sector	Services						Industry							Full Sample									
Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 5a	Model 1	Model 2	Model 2a Robust s.errors	Model 3	Model 4	Model 5	Model 5a	Model 1	Model 2	Model 2a Robust s.errors	Model 3	Model 4	Model 4a Robust s.errors	Model 5	Model 5a Robust s.errors	Model 6	Model 6a Robust s.errors
Constant	-0.093**	-0.094***	-0.095***	-0.096***	-0.095***	0.097***	-0.217***	-0.224***	-0.224***	-0.214***	-0.215***	-0.215***	-0.208***	-0.108***	-0.114***	-0.114***	-0.108***	-0.110***	-0.110***	-0.109***	-0.109***	-0.110***	-0.110***
	(0.036)	(0.037)	(0.036)	(0.036)	(0.036)	(0.036)	(0.054)	(0.054)	(0.055)	(0.053)	(0.053)	(0.053)	(0.053)	(0.029)	(0.030)	(0.029)	(0.029)	(0.029)	(0.029)	(0.029)	(0.0290)	(0.029)	(0.029)
Log (K/L)	0.552***	0.549***	0.553***	0.549***	0.551***	0.549***	0.708***	0.707***	0.707***	0.703***	0.710***	0.705***	0.702***	0.560***	0.577***	0.577	0.579***	0.579***	0.579***	0.579***	0.579***	0.577***	0.577***
	(0.029)	(0.029)	(0.029)	(0.029)	(0.029)	(0.029)	(0.050)	(0.051)	(0.053)	(0.050)	(0.050)	(0.050)	(0.050)	(0.024)	(0.025)	(0.028)	(0.024)	(0.024)	(0.028)	(0.024)	(0.028)	(0.024)	(0.028)
Log (G/L)					**0.342*** **	**0.443*** **						**0.281*** **	**0.706*** **							**0.331*** **	**0.331*** **	**0.451*** **	**0.451*** **
(aggregate measure)					(0.040)	(0.147)						(0.052)	(0.198)							(0.031)	(0.031)	(0.113)	(0.118)
Log L	0.070**	0.179***	0.179***	0.161***	0.174***	0.248**	0.134***	0.218***	0.218***	0.225***	0.255***	0.225***	0.547***	0.083***	0.184***	0.184***	0.192***	0.182***	0.182***	0.186***	0.186***	0.276***	0.276***
	(0.034)	(0.042)	(0.040)	(0.040)	(0.040)	(0.111)	(0.047)	(0.060)	(0.053)	(0.057)	(0.057)	(0.057)	(0.155)	(0.027)	(0.034)	(0.034)	(0.033)	(0.032)	(0.033)	(0.032)	(0.033)	(0.088)	(0.091)
Log (unemployment)						-0.079							-0.356**									-0.096	-0.096
						(0.111)							(0.160)									(0.087)	(0.093)
Individual Public infrastructure measures																							
Log (Paved roads/L)	**0.284*** **						**0.225*** **							**0.273*** **									
	(0.034)						(0.044)							(0.026)									
Log (electricity/L)		**0.318*** **						**0.268*** **	**0.268*** **						**0.312*** **	**0.312*** **							
		(0.042)						(0.056)	(0.053)						(0.033)	(0.032)							
Log (Telephone/L)			**0.349*** **							**0.281*** **							**0.337*** **						
			(0.040)							(0.052)							(0.031)						
Log (Allweather roads/L)				**0.329*** **							**0.310*** **							**0.326*** **	**0.326*** **				
				(0.040)							(0.051)							(0.031)	(0.031)				
Foreign Ownership	0.443***	0.467***	0.438***	0.456***	0.445***	0.447***	0.182**	0.195**	0.195**	0.183**	0.169**	0.182**	0.182**	0.329***	0.346***	0.346***	0.328***	0.334***	0.334***	0.331***	0.331***	0.333***	0.333***
	(0.070)	(0.071)	(0.070)	(0.070)	(0.070)	(0.070)	(0.083)	(0.084)	(0.083)	(0.083)	(0.082)	(0.083)	(0.082)	(0.053)	(0.054)	(0.052)	(0.053)	(0.053)	(0.052)	(0.053)	(0.052)	(0.053)	(0.052)
R-squared	0.4862	0.4763	0.4873	0.4829	0.4865	0.4869	0.4821	0.4761	0.4761	0.4863	0.4973	0.4868	0.4951	0.4747	0.4653	0.4653	0.4779	0.4752	0.4752	0.4767	0.4767	0.4773	0.4773
Adj R-squared	0.4830	0.473	0.484	0.4796	0.4832	0.4828	0.4753	0.4691		0.4795	0.4907	0.4800	0.4867	0.4725	0.4631		0.4757	0.4731		0.4745		0.4746	
SSE (RSS)	348.967	355.716	348.27	351.238	348.814	348.535	138.961	140.586		137.84	134.885	137.720	135.489	504.836	513.808		501.744	504.287		502.923		502.283	
Mean Variance Inflation Factor (VIF)	1.13	1.41	1.35	1.32	1.34	10.02	1.29	1.72	1.72	1.63	1.66	1.62	12.83	1.21	1.57	1.57	1.50	1.48	1.48	1.49	1.49	10.73	10.73
Ramsey (Reset) test																							
$F(m, n\text{-}k_u)$	10.36	10.38	10.92	11.21	11.26	11.39	0.03	0.06	0.06	0.17	0.48	0.12	0.04	13.30	13.25	13.25	14.13	14.37	14.37	14.40	14.40	14.48	14.48
Prob >F	0.0000	0.0000	0.000	0.0000	0.0000	0.0000	0.9914	0.9819	0.9819	0.9138	0.6986	0.9454	0.9893	0.000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000	0.000
Heteroskedasticity test																							
Chi2(1)	1.04	1.4	1.05	1.06	1.32	1.20	3.38	4.08		2.88	3.26	3.32	3.61	3.55	4.40		3.38	4.65		4.07		4.02	
Prob > chi2	0.3071	0.2371	0.3057	0.3035	0.2505	0.2743	0.0659	0.0435		0.0895	0.0708	0.0685	0.0574	0.0595	0.0359		0.0659	0.0311		0.0436		0.0451	
N	639	639	639	639	639	639	306	306	306	306	306	306	306	962	962	962	962	962	962	962	962	962	962

*** Significant at 1% level   * *Significant at 5% level   *Significant at 10 % level
Standard errors in parenthesis

inputs led us to apply the more flexible translog production function in our estimations in the next section.

2.3.4 Elaboration of the Estimates of the Translog Production Function

As discussed earlier, the translog production function has a flexible functional form and allows us to account for the direct and indirect effects of public infrastructure on private sector output (value added)/productivity.

There are five versions of models, each with one of the four of our individual infrastructure measures and one with the aggregate infrastructure measure (infraindex). We did estimate the models with regional specific characteristics. However because the regional dummies turned out to be jointly insignificant in all models, we do not include the results of regression estimates in which regional dummies were included. The results of the estimations with and without regional dummies were essentially the same.

Models 1 to 4 include one type of infrastructure measure at a time, that is paved roads, electricity, telephone and all weather roads respectively, while Model 5 includes the aggregate infrastructure measure. The estimation results are reported based on sectors (service and industrial firms), since, as noted earlier, chow's second test suggested that there are differences among sectors.

Our parsimonious model in the two sub-samples is model 5 for both the service and industry sectors. Model 5 applies the aggregate infrastructure measure and also passes our statistical tests as shown in table 2.4

Results for service firms' sub-sample;

$$\begin{aligned}\ln VA = &-151^{***} + 0.341 \ln L^{***} + 0.503 \ln K^{***} + 0.356 \ln G^{***} \\ &+ 0.047 \ln K \ln L + 0.083 \ln K \ln G^{***} - 0.085 \ln L \ln G^{**} + 0.023 \ln^2 K \\ &- 0.022 \ln^2 L + 0.064 \ln^2 G^{**} + 0.291\ Foreign\,ownership^{***} \\ &- 0.114 \ln(unemployment)\end{aligned}$$

$N = 639 \quad Adj.\ R^2 = 0.74 \quad Ramsey\ (\text{Re}set)\ test, \quad F\,(3,\ 624) = 0.77 \quad Mean \quad VIF = 5.23$

$\text{Pr}ob\ > F = 0.5129$

*** *Significant at* 1% *level*, ** *Significant at* 5% *level*, * *Significant at* 10% *level*.

Standard errors are shown in table 2.4

Unlike in the Cobb Douglas case, The Ramsey (Reset) test indicates that the model has no omitted variables, showing that the addition of cross and quadratic terms as in the translog production function model that is applied here should be preferred to the Cobb-Douglas production function.

For the service sector, we find that the impact of infrastructure, G is highly significant. The single (individual), cross and squared terms including infrastructure are all significant at 1 and 5 percent levels. Unlike what would be expected in developed countries, i.e. that the squared term for public infrastructure would be negative and hence exhibiting diminishing returns, the squared term in our estimation is positive and significant. From this we can infer increasing returns in respect to public infrastructure.

With respect to marginal productivities, inputs G and L are substitutes $(\varepsilon = -0.085)$, whereas G and K are complements $(\phi = 0.083)$.

It can be summarised that our empirical analysis finds evidence that public infrastructure has a significant impact on service firms' value added. In addition, we find evidence that the direct effect arising from public infrastructure, i.e. increasing the marginal productivities of private factors is more important than the indirect effects.

A major criticism of results of the translog specifications is that their results need to be interpreted with some caution due to high multicollinearity caused by high correlation between the single with the cross and quadratic terms. However, as discussed in section 2.2.2.3**,** our use of the "Centering" method sufficiently deals with the problem of multicollinearity. The mean variance inflation factor (mean VIF) is well below 10 at 5.23 (see table 2.4) indicating that multicollinearity is not a problem.

**Table 2.4 : Estimates of the Translog Production Function Models:
Sub Samples based on Sectors**

Sectors / Variable	Services					Industry				
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Constant	-0.150***	-0.232***	-0.134***	-0.136***	-0.151***	-0.223***	-0.285***	-0.185***	-0.161***	-0.192***
	(0.042)	(0.048)	(0.046)	(0.046)	(0.047)	(0.056)	(0.063)	(0.061)	(0.057)	(0.058)
Log Private Employment (Log L)	0.342***	0.347***	0.347***	0.341***	0.350***	0.344***	0.348***	0.344***	0.331***	0.343***
	(0.030)	(0.030)	(0.030)	(0.030)	(0.030)	(0.049)	(0.050)	(0.049)	(0.048)	(0.049)
Log Private Capital (Log K)	0.496***	0.488***	0.498***	0.503***	0.492***	0.622***	0.606***	0.624***	0.645***	0.626***
	(0.027)	(0.028)	(0.027)	(0.027)	(0.028)	(0.050)	(0.050)	(0.050)	(0.050)	(0.050)
Infraindex (Log G)					**0.356*** **					**0.441*** **
					(0.086)					(0.116)
Log (unemployment)	-0.127*	-0.161*	-0.110	0.014	-0.114	-0.210**	-0.197*	-0.182*	-0.163**	-0.241**
	(0.068)	(0.086)	(0.069)	(0.046)	(0.070)	(0.105)	(0.113)	(0.095)	(0.075)	(0.104)
Individual Public infrastructure measures										
LogPaved roads	**0.400*** **					**0.428*** **				
	(0.092)					(0.122)				
Log electricity		**0.536*** **					**0.478*** **			
		(0.124)					(0.148)			
LogTelephone			**0.352*** **					**0.362*** **		
			(0.088)					(0.103)		
Log Allweather roads				**0.229*** **					**0.342*** **	
				(0.070)					(0.092)	
LogK * Log L	0.046	0.048	0.046	0.047	0.047	0.155*	0.152	0.154*	0.158*	0.152
	(0.037)	(0.036)	(0.037)	(0.037)	(0.037)	(0.093)	(0.093)	(0.093)	(0.092)	(0.093)
Log K* Log infraindex					**0.083*** **					**-0.044**
					(0.030)					(0.052)
Log K * Log Paved roads	**0.081*** **					**-0.040**				
	(0.030)					(0.053)				
Log K * Log electricity		**0.102*** **					**-0.003**			
		(0.032)					(0.049)			
Log K * LogTelephone			**0.076** **					**-0.051**		
			(0.030)					(0.052)		
Log K * LogAll weather				**0.070** **					**-0.069**	
				(0.028)					(0.051)	
Log L* Log infraindex					**-0.085** **					**0.024**
					(0.035)					(0.042)
Log L * Log Paved roads	**-0.075** **					**0.023**				
	(0.036)					(0.043)				
Log L * Log electricity		**-0.096*** **					**0.004**			
		(0.036)					(0.038)			
Log L * LogTelephone			**-0.082** **					**0.027**		
			(0.036)					(0.043)		
Log L * LogAll weather				**-0.064***					**0.034**	
				(0.035)					(0.040)	
$(\text{Log K})^2$	0.022	0.020	0.023	0.023	0.022	-0.059	-0.052	-0.060	-0.066	-0.059
	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)	(0.060)	(0.060)	(0.060)	(0.059)	(0.059)
$(\text{Log L})^2$	-0.023	-0.022	-0.023	-0.025	-0.022	-0.087**	-0.088**	-0.089**	-0.084**	-0.085**
	(0.022)	(0.021)	(0.022)	(0.022)	(0.022)	(0.039)	(0.040)	(0.040)	(0.039)	(0.039)
$(\text{Log Infraindex})^2$					**0.064** **					**0.069***
					(0.032)					(0.039)
$(\text{LogPaved roads})^2$	**0.075*** **					**0.088** **				
	(0.026)					(0.035)				
$(\text{Log Electiricity})^2$		**0.154*** **					**0.147*** **			
		(0.035)					(0.047)			
$(\text{Log Telephone})^2$			**0.062***					**0.056**		
			(0.032)					(0.040)		
$(\text{Log Allweather roads})^2$				**0.058***					**0.029**	
				(0.033)					(0.037)	
Foreign Ownership	0.289***	0.2998***	0.288***	0.293***	0.291***	0.161***	0.168***	0.154***	0.142**	0.153***
	(0.047)	(0.047)	(0.047)	(0.047)	(0.047)	(0.058)	(0.058)	(0.058)	(0.057)	(0.058)
R-squared	0.7415	0.7432	0.7404	0.7390	0.7411	0.8024	0.8008	0.8025	0.8065	0.8036
Adj R-squared	0.7370	0.7387	0.7359	0.7344	0.7366	0.7950	0.7933	0.7951	0.7993	0.7962
SSE (RSS)	153.194	152.158	153.811	154.660	153.396	61.429	61.929	61.396	60.141	61.049
Mean Variance Inflation Factor (VIF)	5.44	8.13	5.32	4.00	5.23	10.51	11.86	9.63	9.10	10.19
Ramsey (Reset) test										
$F(m, n\text{-}k_u)$	0.77	0.59	0.69	0.84	0.77	1.12	1.38	1.00	2.62	1.22
Prob >F	0.5109	0.6207	0.5593	0.4724	0.5129	0.3414	0.249	0.3937	0.0512	0.3031
Heteroskedasticity test										
Chi2(1)	0.00	0.02	0.00	0.00	0.01	2.07	2.45	1.63	1.35	2.03
Prob >chi2	0.9682	0.8964	0.9767	0.9501	0.9346	0.1507	0.1174	0.2023	0.2446	0.1542
N	639	639	639	639	639	306	306	306	306	306

* Significant at 1% level ** Significant at 5 % level *** Significant at 10 % level
Standard errors in parenthesis

Results for industry firms' sub-sample;

$$\begin{aligned}\ln VA = -0.192^{***} &+ 0.343\ln L^{***} + 0.626\ln K^{***} + 0.441\ln G^{***} \\ &+ 0.152\ln K\ln L - 0.044\ln K\ln G + 0.024\ln L\ln G - 0.059\ln^2 K \\ &- 0.085\ln^2 L^{**} + 0.069\ln^2 G^{*} + 0.153\,Foreign\,ownership^{***} \\ &- 0.241\ln(unemployment)^{**}\end{aligned}$$

$N = 306$ $\quad Adj.R^2 = 0.80$ $\quad Ramsey\,(\mathrm{Re}\,set)\,test,$ $\quad F\,(3,\ 291) = 1.22$ $\quad Mean \quad VIF = 10.19$

$\Pr ob\ > F = 0.3031$

*** *Significant at* 1% *level*, $\quad ^{**}$ *Significant at* 5% *level*, $\quad ^{*}$ *Significant at* 10% *level.*

For the industry sector, we again find that the impact of infrastructure, G is highly significant. However, the cross terms which include public infrastructure are all insignificant. Therefore with respect to marginal productivities, inputs G and L as well as G and K appear not to affect each other. As argued earlier, this is not entirely surprising. Inadequate provision of public infrastructure and services as is the case in Uganda negatively affects private investment. This comes as a result of firms trying to cope with deficient public infrastructure by investing in complementary capital which minimizes their capacity to invest in productive capital. Ultimately this affects their demand for private factor inputs, particularly for firms in the industrial sector given their size composition.

Similar patterns as discussed above are obtained when individual infrastructure measures are used in the different models (table 2.4). Each infrastructure measure is positively and significantly associated with the value added of firms in both sectors. The association appears to be greater between electricity and the value added of firms irrespective of the sector under consideration.

Like in the Cobb Douglas case, we included control variables in the models, i.e. firm-specific age, human capital, unemployment (for capacity utilisation) and foreign ownership. Human capital was found to be insignificant. In addition it was highly collinear with the infrastructure measures. Firm specific age was also found insignificant as would be expected in a cross sectional analysis. Hence these two variables were dropped from the model. However foreign ownership was found to be positively and significantly associated with firm-level value added in all the models.

2.4 Conclusions and Policy Issues

In this paper, we specified and estimated both Cobb Douglas and translog production models to study the impact of physical public infrastructure and private sector output/productivity using firm level data. Diagnostic testing suggests that the empirical results are correctly specified and that the translog production function specification should be preferred to the Cobb-Douglas model. Evidence also shows that data are not poolable between sectors.

The results of our estimations show that public infrastructure has both direct and indirect effects on firm output/productivity. They also suggest that these effects may benefit small firms in particular as they may not have sufficient capacity to substitute for unavailable or inadequate public infrastructure by investing privately in complementary capital.

The signs and significance levels of the coefficients of our investigative variable are consistent with the arguments of endogenous growth theory models that emphasize the role of public infrastructure in the development process. Our empirical analysis finds evidence that public infrastructure is positively and significantly associated with firm value added. In addition, we find evidence that it is complementary to private capital, while substitutive to private labour employment.

The current focus on public infrastructure investments in the current discourse on development strategies may therefore be justified particularly in regard to the stimulation of growth in poor countries especially those in Sub-Saharan Africa where public infrastructure stocks are appallingly low.

These results have important policy implications. Since policies intended to stimulate aggregate economic growth are mainly expected to have an effect through the response of private firms, they provide an important argument for maintaining and extending high quality infrastructure. However decisions about substantially increasing investments in public infrastructure need also to take into account the possibility that public infrastructure may have nonlinear effects on private sector output/productivity. For relatively low levels of public infrastructure, marginal increases may not have an effect on output/productivity growth (and growth rates) until a certain critical mass or “threshold” is attained while for relatively high levels of public infrastructure, increased public infrastructure investments may negatively impact on private sector output/productivity growth/growth rates. The required level of public infrastructure capital at any point in time can therefore be expected to differ across countries, states or districts depending on their different infrastructure stock levels, geographic and economic structures.

In addition, caution need to be taken when substantial and lump-sum spending on public infrastructure is to be made. There is need to assess the possibility of adverse macroeconomic effects depending on the nature and source of financing as well as a need to assess the viability of individual infrastructure projects. These are issues that are left for further study.

2.5 Limitations of the study

We acknowledge the fact that the study investigates the static, or short run impacts of changes in the public infrastructure capital stock on firm performance and hence on economic performance. The pure cross-section regressions only provide the impact of infrastructure on output (value added)/productivity, but not the impact on the growth rate of output/productivity. For further study, we intend to use panel data, to examine impact on the growth rate of output (value added)/productivity.

Our findings are also just indicative of the possible long run link between infrastructure and productivity and do not explicitly deal with the question of the dynamic, or long run effects of public infrastructure on economic growth.

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APPENDICES

Appendix 1: Descriptive statistics

Table 2.5a: Descriptive Statistics - Full sample

Full Sample	Obs.	Mean	Median	Minimum	Maximum	Standard Deviation
Private output						
Gross output (Ug. Shs'000)	962	2,411,450	281,438	945	113,000,000	8,656,416
Log (Gross output)	962	12.72	12.55	6.85	18.54	1.9
Value Added (Ug Shs'000)	962	1,111,915	123,053	202.68	90,500,000	4,928,512
Log (Value Added)	962	11.89	11.72	5.3	18.32	1.86
Private inputs						
Labour (number of employees)	962	70.5	23	1	4560	226.4
Log (Labour)	962	3.26	3.14	0	8.43	1.19
Private capital (K) - (net total assets) (Shs'000)	962	2,798,761	123,301	41.35	914,000,000	31,100,000
Log (Private capital - K)	962	11.74	11.72	3.72	20.63	2.32
Infrastructure measures						
Individual infrastructure measures						
Paved roads (in km. Per sq.km.area)	962	0.37	0.56	0.0003	0.56	0.257
Log (Paved roads)	962	-1.996	-0.585	-8.237	-0.585	2.11
All weather roads(in km. Per sq.km.area)	962	0.204	0.295	0.003	0.295	0.13
Log (All weather roads)	962	-2.064	-1.22	-5.93	-1.222	1.24
Electricity (ratio of households with electricity per district)	962	0.376	0.525	0.003	0.525	0.209
Log (Electricity)	962	-1.370	-0.645	-5.809	-0.645	1.14
Telephone (Mean distance to the nearest public phone per district - inverted)	962	0.464	0.673	0.015	0.673	0.29
Log(Telephone)	962	-1.244	-0.396	-4.17	-0.396	1.229
Aggregate infrastructure measure						
Log (infraindex)	962	-1.710	-0.727	-5.475	-0.727	1.436
Standardized - Log (infraindex)	962	0.0	0.684	-2.624	0.684	1
Quality of Infrastructure						
Road quality (percentage of kms of roads in fair to good condition per district)	962	0.67	0.83	0.09	0.83	0.24
Control variables						
Human capital	962	4.8	5.62	2.46	5.62	1.165
Log (Human Capital)	962	1.53	1.73	0.9	1.73	0.282
Age	720	11.72	7.5	1	91.5	12.23
Log (Age)	720	2.05	2.014	0	4.52	0.896
Capacity utilisation (unemployment+1)	962	3.67	4.49	1	4.49	1.192
Log (unemployment+1)	962	1.23	1.5	0	1.5	0.42

Notes:
1. The aggregate infrastructure variable includes a standardized variable version
2. The other variables are standardized in regression estimations

Table 2.5b: Descriptive Statistics - Industry sector

Industry sector	Obs.	Mean	Median	Minimum	Maximum	Standard Deviation
Private output						
Gross output (Thousand shillings)	306	4,688,611	608,100	4,941.31	113,000,000	12,700,000
Log (Gross output)	306	13.6	13.3	8.51	18.54	1.89
Value Added (Thousand shillings)	306	1,733,391	195,838.9	202.68	90,500,000	6,522,102
Log (Value Added)	306	12.44	12.19	5.312	18.321	1.88
Private inputs						
Labour	306	112.93	35.5	2	4560	341.2
Log (Labour)	306	3.71	3.57	0.693	8.43	1.22
Private capital (K) - (net total assets) (Shs'000)	306	5,792,056	321,590	969.94	914,000,000	53,400,000
Log (Private capital - K)	306	12.7	12.7	6.9	20.6	2.1
Infrastructure measures						
Individual infrastructure measures						
Paved roads (in km. Per sq.km.area)	306	0.36	0.56	0.0003	0.56	0.26
Log (Paved roads)	306	-2.033	-0.585	-8.24	-0.585	2.081
All weather roads(in km. Per sq.km.area)	306	0.2	0.295	0.006	0.295	0.125
Log (All weather roads)	306	-2.078	-1.22	-5.17	-1.222	1.22
Electricity (ratio of households with electricity per district)	306	0.37	0.525	0.01	0.525	0.21
Log (Electricity)	306	-1.36	-0.645	-4.63	-0.65	1.09
Telephone (Mean distance to the nearest public phone per district - inverted)	306	0.452	0.673	0.0154	0.673	0.2904
Log(Telephone)	306	-1.275	-0.3962	-4.17	-0.3962	1.214
Aggregate infrastructure measure						
Log (infraindex)	306	-1.731	-0.727	-5.013	-0.727	1.413
Standardized - Log (infraindex)	306	-0.0154	0.684	-2.302	0.684	0.984
Quality of Infrastructure						
Road quality (percentage of kms of roads in fair to good condition per district)	306	0.652	0.83	0.09	0.83	0.25
Control variables						
Human capital	306	4.785	5.62	2.46	5.621	1.15
Log (Human Capital)	306	1.53	1.73	0.899	1.73	0.28
Age	230	14.75	9	1.5	91.5	14.5
Log (Age)	230	2.32	2.2	0.41	4.5	0.845
Capacity utilisation (unemployment +1)	306	3.7	4.49	1	4.49	1.2
Log (unemployment +1)	306	1.23	1.5	0	1.5	0.394

Notes:
1. The aggregate infrastructure variable includes a standardized variable version
2. The other variables are standardized in regression estimations

Table 2.5c: Descriptive Statistics - Services sector

Services sector	Obs.	Mean	Median	Minimum	Maximum	Standard Deviation
Private output						
Gross output (Thousand shillings)	639	1,341,066	198,373	945.00	74,600,000	5,657,184
Log (Gross output)	639	12.286	12.2	6.85	18.13	1.75
Value Added (Thousand shillings)	639	826,074	101,991.9	667.60	54,600,000	3,995,916
Log (Value Added)	639	11.61	11.533	6.5	17.82	1.79
Private inputs						
Labour (number of employees)	639	49.3	19	1	1726.5	141.3
Log (Labour)	639	3.02	2.94	0	7.5	1.1
Private capital (K) - (net total assets) (Shs'000)	639	1,399,513	64,681	41.35	172,000,000	9,172,449
Log (Private capital - K)	639	11.24	11.08	3.7	18.96	2.27
Infrastructure measures						
Individual infrastructure measures						
Paved roads (in km. Per sq.km.area)	639	0.384	0.56	0.0003	0.56	0.25
Log (Paved roads)	639	-1.92	-0.585	-8.24	-0.585	2.12
All weather roads(in km. Per sq.km.area)	639	0.21	0.295	0.006	0.295	0.124
Log (All weather roads)	639	-2.03	-1.22	-5.17	-1.22	1.24
Electricity						
(ratio of households with electricity per district)	639	0.39	0.525	0.01	0.525	0.21
Log (Electricity)	639	-1.34	-0.645	-4.63	-0.65	1.15
Telephone						
(Mean distance to the nearest public phone per district - inverted)	639	0.48	0.673	0.0154	0.673	0.282
Log(Telephone)	639	-1.188	-0.3962	-4.17	-0.3962	1.22
Aggregate infrastructure measure						
Log (infraindex)	639	-1.659	-0.727	-5.013	-0.727	1.439
Standardized - Log (infraindex)	639	0.035	0.684	-2.303	0.684	1
Quality of Infrastructure						
Road quality						
(percentage of kms of roads in fair to good condition per district)	639	0.683	0.83	0.12	0.83	0.23
Control variables						
Human capital	639	4.842	5.62	2.46	5.621	1.17
Log (Human Capital)	639	1.54	1.73	0.899	1.73	0.28
Age	478	10.3	6.5	1	75.5	10.74
Log (Age)	478	1.92	1.87	0	4.3	0.893
Capacity utilisation (unemployment +1)	639	3.72	4.49	1	4.49	1.2
Log (unemployment +1)	639	1.24	1.5	0	1.5	0.427

Notes:
1. The aggregate infrastructure variable includes a standardized variable version
2. The other variables are standardized in regression estimations

Appendix 2: Principal components and factor analysis

These methods seek a few underlying dimensions that account for patterns of variation among the observed variables. The underlying dimensions imply ways to combine variables to replace many original variables in a regression, thus simplifying subsequent analysis. Principal components and factor analysis obtain the regression of observed variables on a set of underlying dimensions called components or factors and provide estimates of values on these dimensions (Hamilton 1992).

In algebraic form, this can be illustrated as follows.[30] Information of K variables, $Z_1, Z_2, Z_3, ..., Z_k$ can be reexpressed in terms of K principal components $F_1, F_2, F_3, ..., F_k$. The first principal component, F_1, is that linear combination of original variables having the largest sample variance (λ_1)

$$F_1 = a_{11}Z_1 + a_{21}Z_2 + a_{31}Z_3 + ... + a_{k1}Z_k$$

This is based on the constraint $\sum_{k=1}^{K} a_{k1}^2 = 1.$ Imposition of this constraint is important, to avoid situations in which variances can be made arbitrarily large by increasing the magnitudes of the a_{kj} coefficients.

The second principal component, F_2, is then that linear combination uncorrelated with F_1 having the largest variance (λ_2)

$$F_2 = a_{12}Z_1 + a_{22}Z_2 + a_{32}Z_3 + ... + a_{k2}Z_k$$

given the constraint $\sum_{k=1}^{K} a_{k2}^2 = 1.$

The third principal component is that linear combination uncorrelated with F_1 *and* F_2 having the largest variance (λ_3), and so forth. The a_{kj} in these equations represent coefficients from the regression of the jth component on the kth variable.

As is shown below, correlation between our infrastructure variables is quite high.

The correlation matrix of our standardized values shows a high correlation between the variables (see table 2.6).

[30] This section borrows substantially from Hamilton 1992.

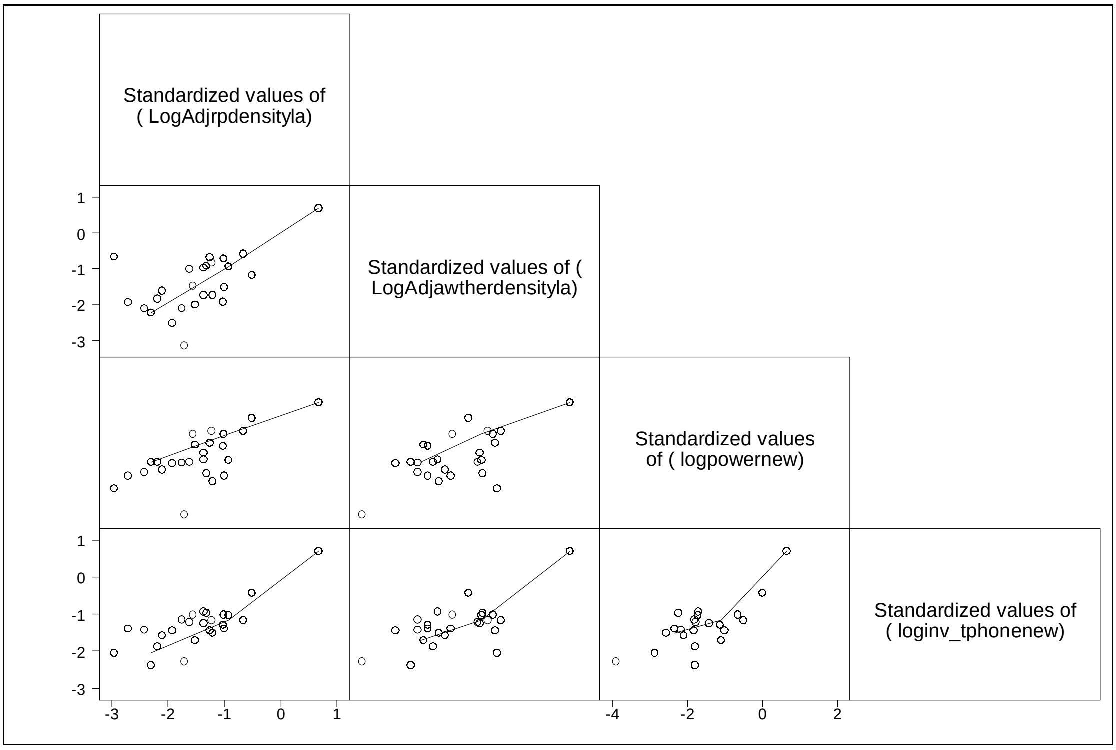
Table 2.6
Correlation matrix of infrastructure variables

Correlations among infrastructure variables
(Obs = 962)

	Paved roads	Weather roads	Power	Telephone
Paved_roads	1			
Weather_road	0.9297	1		
Power	0.9476	0.882	1	
Telephone	0.9761	0.9426	0.9328	

Figure 2.4, a scatterplot matrix with exploratory band regression curves, confirms these relations graphically.

Fig. 2.4
Scatterplot matrix of infrastructure variables, with band regression lines



We can therefore generate a composite variable that reproduces the maximum possible variance of our four observed variables.

Table 2.7
Principal component analysis of infrastructure measures

(obs=962)

(principal component factors; 1 factor retained)

Factor	Eigenvalue	Difference	Proportion	Cumulative
1	3.80598	3.6859	0.9515	0.9515
2	0.12009	0.06803	0.03	0.9815
3	0.05206	0.03019	0.013	0.9945
4	0.02187	.	0.0055	1.0000

Variable	Factor Loadings 1	Uniqueness
Paved roads	0.98784	0.02418
Weather roads	0.96207	0.07442
Power	0.96421	0.07029
Telephone	0.98735	0.02513

Table 2.7 shows the results from the principal component analysis which begins by deriving four principal components, labelled as factors 1 – 4. The Eigenvalues are variances of the original components. The first principal component (Factor 1) has the highest eigenvalue or variance (λ_1), the second component (Factor 2) has the second highest eigenvalue (λ_2), etc. The sum of the eigenvalues equals the number of variables, i.e. $\lambda_1 + \lambda_2 + ... + \lambda_k$ where k is the number of variables. This is so since standardized variables have variances of 1; hence the number of variables also equals the total variance of all variables.

The proportions as shown in table 2.7 are therefore computed as fraction of the total variance. That is for the jth component, we have $\frac{\lambda_j}{K}$. The first component, for example, explains over 95% of the total variance, i.e. $\frac{3.80598}{4} = 0.9515$.

The four components explain 100% of the combined variance of the original four variables. Since the first component explains over 95% of the combined variance, the remaining three components contribute relatively very little (see proportions). We can therefore reconstruct most of the information of the four original variables from just the first component and disregard the remaining components.

Factor loadings are standardized coefficients in the regression of variables on components (or factors). Each observed variable could be expressed as a linear function of K uncorrelated principal components:

$$Z_k = l_{k1}F_1 + l_{k2}F_2 + ... + l_{kK}F_K$$

Here l_{k1} is the loading of variable Z_k on standardized component F_1, and so on. Factor loadings reflect the strength of relations between variables and components.

The uniqueness of each variable equals the proportion of its variance not explained by the retained components or factors. Only approximately 2.4% of the variance of paved roads, 7.4% of the variance of weather roads, 7% for power (electricity) and 2.5% for telephone are not explained by the first component**.**

The eigenvalues provide a criterion with which we judge the components to keep.[31] A common rule of thumb is to disregard principal components with eigenvalues of less than 1. This is so, since each standardized variable has a variance of 1, a component with an eigenvalue of less than one account for less than a single variable's variation – and is therefore useless for data reduction (Hamilton 1992).

However use of only the eigenvalue-1 rule, could lead to arbitrary distinctions between components in some cases. For example one may keep one component with $\lambda = 1.01$ and drop the next one with $\lambda = 0.99$ yet they may have similar importance. This therefore suggests use of another criterion for confirmatory purposes. One such criterion is the use of a scree graph, which plots eigenvalues against component or factor number. Despite the fact that there is some degree of subjectiveness in scree graph inspection, they provide useful guidance and may suggest more natural cutoffs. Our particular case is illustrated in figure 2.5 below.

In figure 2.5, we look for a point at which eigenvalues stop falling steeply and begin to level off. In this case the levelling off begins after component one. Components two, three and four account for relatively little additional variance, reinforcing the conclusion we draw from the eigenvalue-1 criterion.

In the case of more than one component being retained, a third criterion may need to be applied to ease interpretation. It considers the meaningfulness or interpretability of the components, since an uninterpretable component may have limited analytical use despite a large eigenvalue. This is not necessary for our case since we retain one component.

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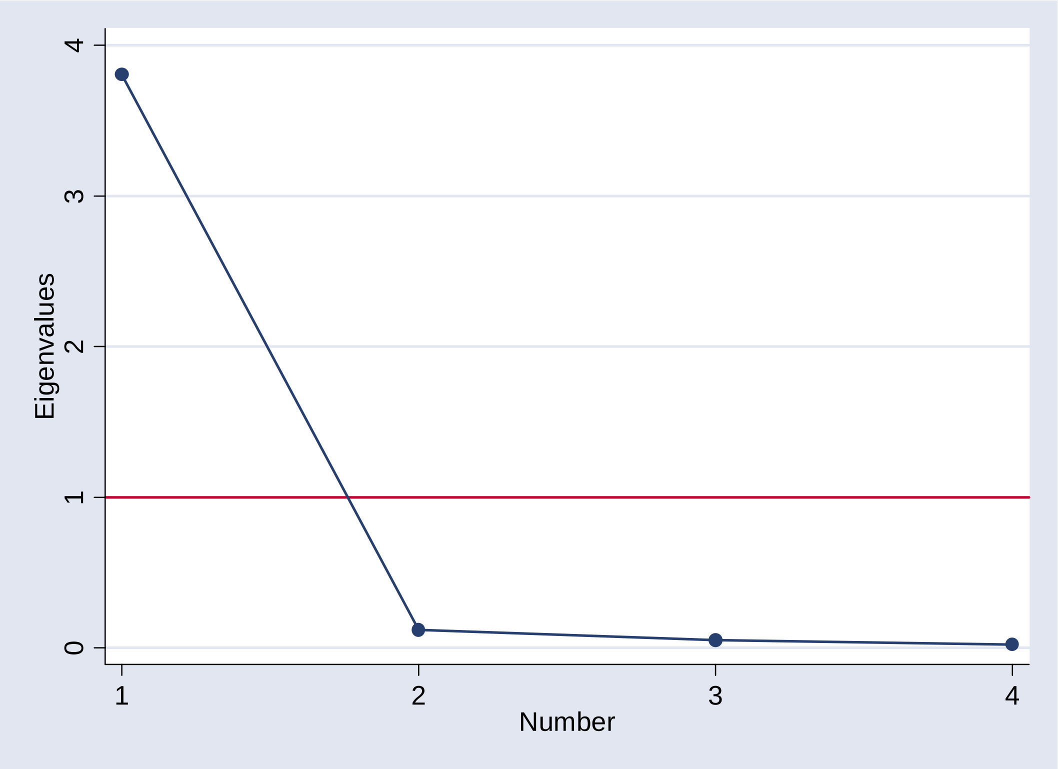
[31] Eigenvalues are variances of the original components

Fig. 2.5
Scree graph for Principal Components Analysis of infrastructure measures



To check for the reliability of our retained first principal component, we calculate a reliability coefficient called theta (θ). This coefficient can be viewed as a special case of Cronbach's α, which measures how, well a set of items (or variables) measures a single unidimensional latent construct (i.e. it is a coefficient of reliability or consistency). When data have a multidimensional structure, Cronbach's alpha will usually be low.

A reliability coefficient of 0.80 or higher is considered as "acceptable". As in Hamilton (1992:266), our reliability coefficient (θ) is calculated as follows:

$$\theta = \left(\frac{K}{K-1}\right)\left(1 - \frac{1}{Eigenvalue_1}\right)$$

Where K equals the number of variables included.

In this case θ equals 0.98, which is quite high and confirms the reliability of our aggregate infrastructure measure.

Since we retain a single component, which is substantively meaningful and interpretable, we don't need "Rotation[32]" so we proceed directly to factor scores. Factor scores are composites, which are combinations of our individual investigative variables. They are derived from factor score coefficients, which are themselves obtained from the regression of factors on variables. Algebraically, this can be illustrated as follows;

$$\tilde{\tilde{F}}_j = c_{1j}Z_1 + c_{2j}Z_2 + ... + c_{kj}Z_k$$

Where

c_{kj} are the factor score coefficients for the jth factor.

Factor scores $(\tilde{\tilde{F}}_j)$ are estimates of the unknown true values of the factors (F_j).

Table 2.8 below shows the derived factor score coefficients for our infrastructure composite index.

Table 2.8
Factor score coefficients

(based on unrotated factors)

Variable	Scoring Coefficients 1
Paved roads	0.25955
Weather roads	0.25278
Power	0.25334
Telephone	0.25942

[32] The case of two or more components retained may make interpretation difficult, hence the need for rotation to make initial loadings come closer to a "simple structure". A "simple structure" might mean that each variable loads strongly (either positively or negatively) on only one factor, and near zero on the other factors. The rotated factors are then easier to interpret.