Underinvestment in Public Infrastructure Capital and Private Sector Output and Productivity in Uganda

Implications for Economic Growth

A thesis submitted by

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(Uganda)

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> If I have been able to see further, it was only because I stood on the shoulders of giants.
>
> (Isaac Newton, quoted in Easterly, 2001: 178)

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Aldret Albert Musisi
2007

Abstract

This thesis analyses the relationship between public infrastructure capital and private sector output/productivity and growth in the specific context of poor sub-Saharan countries like Uganda. It argues that while gross under-investment in public infrastructure capital before the 1980s was mainly due to poor economic management and political instability, continued under-investment after the 1980s can largely be attributed to the economic models underlying economic reform policy design. The neoclassical analysis of fiscal policy and growth vis-à-vis public spending in the models which guide macroeconomic stabilisation and structural adjustment programmes of the International Monetary Fund (IMF) and World Bank tends to focus on either public consumption goods or transfer payments. It largely overlooks the productivity-enhancing effects of public spending as well as its crowding-in effects on private investment with serious implications for long-term growth. This study highlights the correlation between fiscal adjustment and a decline in both public investment in infrastructure capital, and the consequent decline in productive private investment (both as per cent of GDP). In Uganda's case it finds that, despite significant increases in foreign aid, there has been a persistent decline in public investment as a percentage of GDP since the onset of economic reforms. Public investment fell from about 8.6 per cent of GDP in 1987/88 to 3.6 per cent in 2004/05, negatively impacting on private productive capital. Although there was some modest growth in total private investment, it was largely driven by construction of private residential buildings while productive investments in machinery and equipment saw a downward trend.

On the basis of old and new economic growth theory as well as economic development theory, the study argues that investments in infrastructure capital can be a major factor in initiating and facilitating economic growth in developing countries. This is, first, through the role of infrastructure capital as an intermediate input, and second as a major factor in the generation of positive vertical externalities and increasing returns to scale, and through these, on the process of economic structural change, which is the major channel through which developing countries can escape from low-growth development traps. However, there is considerable ambiguity regarding its positive effects in the empirical literature. This thesis therefore determines the quantitative significance of the impact of public infrastructure capital on different production sectors and tests the following hypotheses:

- that there is a strong linkage between public infrastructure capital and private sector output and productivity performance given Uganda's underdeveloped public infrastructure;
- that there are threshold effects (nonlinearities) in the output/productivity effect of public infrastructure capital on the private rates of return and hence in the stimulation of private capital formation;
- that there are differences in impact of the various types of public infrastructure capital on the output and productivity performance of different sectors;
- that there is complementarity between public infrastructure capital and private capital.

These hypotheses are examined in light of the need to contribute to the debate on the current dilemmas relating to the creation, availability and exploitation of fiscal space for additional infrastructure investments in sub-Saharan countries like Uganda.

Unlike much of the literature, the study' adopts a microeconomic perspective in its empirical analysis, with the analytical model linking individual production-unit output and productivity to key physical public infrastructure on the basis of location. To avoid the disadvantages of using public investment expenditures on infrastructure as proxies for public infrastructure capital, an inventory of the quantity and quality of physical stocks of public infrastructure by district was compiled, using a Geographical Information System in addition to secondary data sources. In estimation, the study applies flexible functional forms, allowing explicit analysis of the indirect effects as well as the derivation of output and scale elasticities while spline regression models are applied to test the threshold effects hypothesis.

The empirical results show that public infrastructure capital has significant positive direct and indirect effects on output and productivity, and that there are increasing returns to scale. It provides evidence that there is complementarity between public infrastructure and private capi-

tal which is consistent with the presence of positive production externalities. The study also shows that there are differences in the impact of public infrastructure on different sectors. Output elasticity appears to be stronger for service firms than for industrial firms, which is at odds with the findings of many other studies. The study argues that in relative terms, the less capital-intensive service firms are more likely to be incapable of providing their own infrastructure and are therefore more dependent on inadequate public provision. Hence, they benefit more from increased or improved public provision. The more capital-intensive industrial firms benefit relatively less from public infrastructure since they are less captive to an inadequate public service. However, as they try to cope with deficient public infrastructure by investing in complementary capital, they minimise their capacity to invest in other productive capital, such that underinvestment in public infrastructure capital results in complementary capital substituting for productive private capital. In general the study corroborates the finding of perception studies that the physical infrastructure showing the most significant association with the value added of firms is electricity for both service and industrial firms, reflecting the gross underinvestment in electricity infrastructure. For the agricultural sector, the results show that it is only dry-weather roads (which are mainly feeder roads) and all-weather roads that have a positive and significant association with agricultural output and productivity through its complementarity with agricultural land.

The results of the threshold analysis show that there are only eight districts (about 19.5 per cent of all districts in the sample), which are above the threshold level. All other districts have too low levels of public infrastructure capital for it to have any significant output or productivity effects. The study estimates that the investment required to bring public infrastructure capital stocks to at least the minimum critical mass in all districts amounts to about 24 per cent of GDP. However, there are major challenges with regard to creation of fiscal space for the additional public infrastructure investments. Among those major challenges are limited absorptive capacity and the possibilities or risk of the 'Dutch disease' if investments are aid-financed.

Nevertheless, comparison of total present-day values for the benefits and costs of investments in different physical infrastructure categories shows that benefits are significantly higher than costs. Considering the

large positive effects, there are potentially large medium- and long-term gains which maybe sufficient to offset short-run 'Dutch disease' effects.

The study finds it inconceivable that public infrastructure capital is not productive in Africa, as results from some studies have shown. It argues that the evidence they provide is a likely result of poor proxies for public capital stocks. Continued underinvestment will not only compromise economic growth but may even hamper fiscal stability in the long run. Therefore, investment in public infrastructure should be among the top expenditure priorities since it affects all sectors and may also result in the removal of some of the capacity constraints faced in several other sectors.

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List of Acronyms

AfDB	African Development Bank
BMP	Black Market Premium
C-D	Cobb-Douglas
CGE	Computable General Equilibrium
COBE	Census of Business Establishments
DfID	Department for International Development
DVRM	Dummy Variable Regression Model
EDA	Exploratory Data Analysis
ERA	Electricity Regulatory Authority
GDP	Gross Domestic Product
GIS	Geographical Information System
IMF	International Monetary Fund
IPP	Independent Power Producers
kW	Kilowatts
MFPED	Ministry of Finance, Planning and Economic Development
MTN	Mobile Telephone Network
MW	Megawatts
MWHC	Ministry of Works, Housing and Communications
NBS	National Biomass Study
NFA	National Forestry Authority
ODA	Overseas Development Assistance
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares
PCA	Principal Components Analysis
PCO	Public Call Offices

PFP	Policy Framework Paper
PPA	Power Purchase Agreement
PPP	Public-private partnership
PRSP	Poverty Reduction Strategy Paper
RAFU	Road Agency Formation Unit
RESET	Regression Specification Error Test
ROCKS	Road Costs Knowledge System
SNO	Second National Operator
SSA	Sub-Saharan Africa
TFP	Total Factor Productivity
Translog	Transcendental Logarithmic
UBI	Uganda Business Inquiry
UBOS	Uganda Bureau of Statistics
UCC	Uganda Communications Commission
UEB	Uganda Electricity Board
UEDCL	Uganda Electricity Distribution Company Limited
UEGCL	Uganda Electricity Generation Company Limited
UETCL	Uganda Electricity Transmission Company Limited
UNCTAD	United Nations Conference on Trade and Development
UNHS	Uganda National Household Survey
UPL	Uganda Posts Limited
UPTC	Uganda Posts and Telecommunications
UTL	Uganda Telecom Limited
VIF	Variance Inflation Factor

A typical unpaved road in Katwe,
a part of Kampala with many informal and formal enterprises/firms

1 Introduction

1.1 Introduction

While productivity growth in developed countries is driven by technological innovation, changing the structure of production towards activities with higher levels of productivity can still be the major channel through which developing countries escape from low-growth development traps. This entails adopting and adapting existing technologies, entering world markets for manufacturing goods and services, and accumulating physical and human capital (United Nations, 2006). Capital accumulation is therefore an essential factor in their growth process, both as a major carrier of technological change and productivity increases and through its role in the development of infrastructure. Thus it can be a catalyst in the process of economic structural change. The founding fathers of development economics, such as Rosenstein-Rodan, Nurkse, Kurt Martin and others, recognised infrastructure as one of the major factors needed to generate positive vertical externalities and increasing returns to scale (Vos, 2002). However, despite the fact that 'new' growth theories also emphasise the important role of infrastructure in the growth process, many developing countries in Africa and Latin America have failed to sustain infrastructural investments, with infrastructure stocks either remaining constant or declining (United Nations, 2006). This has serious repercussions for current and future economic growth.

In many sub-Saharan African countries including Uganda, underinvestment was caused by poor economic management, political instability and wars, especially before the 1980s. However, from the mid-1980s, one of the main reasons for this has been the dominance of the uniform liberal economics paradigm, which, on the one hand, has advocated a greater role for the private sector in infrastructure provision, and on the other, promoted macroeconomic policies that focus on short-term stabilisation.[1] These policies have restricted the pursuance of broader developmental policies. Although a number of countries implementing IMF/World Bank-type policies have managed to restore economic stability and growth during the 1990s, there are doubts whether that can be sustained. The main concern is that the policies have also resulted in excessive reductions in public investment, leading to underinvestment in public infrastructure capital stocks, a necessary complement to private capital and thus an important determinant of long-run growth (Dessus and Herrera, 2000).[2] This is supported by studies such as Collier and Gunning (1999) and Grier (2005) which find that investment is too low in Africa. Others, like DfID (2002) and World Bank (1994) specifically point to the extremely low infrastructure capital stocks in sub-Saharan Africa as a major obstacle to private investment and growth. These studies suggest the need for significant increases in investment if growth is to be sustained. However, there are a number of dissenting voices to this hypothesis.

Easterly and Levine (2001) argue that it is total factor productivity[3] rather than factor accumulation which accounts for most of the cross-country and cross-time variation in growth, although they agree that factor accumulation may be critical for some countries at specific junctures. The findings of studies such as Calamitsis et al. (1999), Devarajan et al. (1996) and Devarajan et al. (2001) cast doubt on whether the latter is the case in sub-Saharan African countries like Uganda. Devarajan et al. (2001) in particular, who applied cross-country growth regressions of African countries as well as micro-data from Tanzania, find no evidence that private or public capital is productive in Africa.[4] They also argue that investment in Africa is actually too high rather than too low when the bad investment climate in the region is taken into account. These seem to be surprising conclusions given that the levels of public infrastructure capital stock in Africa are so low that one would expect significant returns to new infrastructure investments.

In addition, a number of other studies provide evidence that would seem to support the argument of Easterly and Levine (2001) that it is not factor accumulation that should be targeted as the driving force in economic growth. Berthélemy and Söderling (1999), for example, examine the sources of growth for adjusting countries since the 1960s, using growth accounting methods and panel data estimation of the production function. Their empirical evidence shows that recent improvements in economic performance in several African countries, including Uganda, were driven by the removal of market distortions and to a lesser extent by structural change, while there was no significant progress in terms of higher investment rates.[5]

This thesis contends that the results and conclusions of most of these studies, which are mainly macro/cross-country (especially in the case of sub-Saharan Africa) have major methodological limitations and so caution is required when interpreting them for policy purposes. As will be argued in detail in Chapter 2, the orthodox growth theories and models upon which most of these studies are based focus on the traditional inputs (labour and private capital) as well as technological factors but generally ignore public infrastructure capital and non-technological factors that are more important for growth processes relevant to developing countries. Although some growth accounting studies, for example Berthélemy and Söderling (1999) attempt to account for some of these factors, an important factor that is often omitted, or at least whose contribution is not explicitly accounted for, is public infrastructure capital. This is a major limitation because, apart from its direct effect on output and growth as an intermediate input, it is associated with significant spillover externalities. As Easterly and Levine (2001) admit, factor accumulation, especially infrastructure capital, could ignite productivity growth and overall growth even though it does not account for much of the cross-country differences in growth rates or in the level of GDP per capita as computed with the growth accounting approach.

On the other hand, a major limitation of many econometric empirical studies, for example Devarajan et al. (2001) is that they ignore the significant heterogeneity of public capital and use inappropriate proxies of public infrastructure capital such as public investment expenditures as a share of GDP or 'public capital stocks' compiled using the perpetual inventory method (PIM). This may be producing misleading results, especially in regard to developing countries where corruption and significant inefficiencies in public investments exist to such an extent that there is a discrepancy between public investments and actual physical accumulation of public capital (see details in sub-section 1.3.1).

Furthermore, the contextual determinants of the economic impact of public infrastructure investments are hardly taken into account (see

Chapter 3).[6] For example, the studies ignore the possibility that output/productivity effects of infrastructure may be subject to a threshold, not in the context of a 'saturation point' or 'overcapacity point' as is common in studies on developed countries,[7] but in the context of a critical minimum mass, which is more relevant for low-income countries with less than optimal infrastructure stocks. Since infrastructure is characterised by indivisibilities, a minimum level of stocks may be required to make a difference to economy-wide productivity growth.

To take the above issues into account, this study adopts a different approach. As detailed in Chapter 4, it applies flexible function forms, particularly the unrestricted Cobb-Douglas and translog production functions, with the latter enabling the capture of both direct and indirect effects; uses different types of actual physical public infrastructure capital stocks instead of aggregated public investment expenditures; applies spline regression models in relation to the analysis of the threshold hypothesis; and uses micro/sectoral analyses in the econometric empirical investigation. One objective of the study is to provide a rationale for increased public investment in infrastructure at a time when, for macroeconomic reasons, there is continuing pressure for reductions in public expenditure in many sub-Saharan African countries implementing IMF/World Bank-type reforms. However, before we proceed to discuss the research problem, the research questions and hypotheses in detail, it is important to delineate precisely what infrastructure capital is and the types that are relevant to this study.

1.1.1 What is infrastructure?

Infrastructure and 'social overhead capital' are encompassing terms which have been used by development economists such as Paul Rosenstein-Rodan, Ragnar Nurkse and Albert Hirschman to refer to several activities (services) that play a crucial role in the development of an economy. The terms are used interchangeably, but neither term is precisely defined. 'Social overhead capital' is used in a wider sense and is considered to include all those services without which primary, secondary and tertiary production activities cannot function (Hirschman, 1958). In this broader sense, it also encompasses the social sectors, which include services that are basic to human development such as education, health and housing. The common characteristic of the two terms is that they 'both comprise activities that share technical features (such as economies of scale) and economic features (such as spillovers from users to non-users)' (Gowda and Mamatha, 1997).

Traditionally, 'core' infrastructure has been defined to include economic infrastructure (also referred to as physical infrastructure). Gowda and Mamatha (1997) classify it to include three broad categories:

- public utilities, including power, telecommunications, drinking water supply, sanitation and sewerage, solid waste collection and disposal, gas supply, and storage and warehousing;
- public works, including roads, dams, canal works and tanks for irrigation and drainage;
- other transport sectors, including roads, railways, ports and waterways and airports.

This study focuses on 'core' or economic infrastructure (that is, physical infrastructure and the services it provides), although the other infrastructure services such as education are included in the empirical analyses as control variables whenever possible and appropriate. As will be detailed in Chapter 3, the focus on economic infrastructure was partly motivated by results of perception firm surveys carried out by the World Bank (Reinikka and Svensson, 2001) which identified poor economic infrastructure such as electricity as among the most binding constraints on private sector investment and growth. The focus of the thesis is therefore on public infrastructure that acts as productive input for private producers, that is, public intermediate goods or public inputs assumed to be productivity increasing as opposed to public infrastructure considered to be welfare improving.

1.2 Problem and Research Questions

In most of the growth literature, reference to economic performance focuses on the growth 'miracle' in East Asia and the growth 'disaster' in sub-Saharan Africa (SSA). The poor performance in SSA has been attributed to several causes, with more recent studies pointing to low factor accumulation (reflected in the falling stock of physical capital) as a major reason (Grier, 2005). Collier and Gunning (1999), for example, found a 20 per cent decline in the stock of private capital per worker since 1980. The underlying causes for this are identified as being connected to the unfavourable investment environment due to political and economic factors such as wars, economic mismanagement and poor inadequate infrastructure, which discourage private sector investment.

Uganda is among the strongest and most persistent reformers in sub-Saharan Africa and has substantially improved its investment environment (both politically and economically) for more than a decade, but the hoped-for private sector investment response has been modest at best. Apparently, this can be attributed to the remaining structural impediments, particularly poor provision of public infrastructure (Reinikka and Svensson, 2001 and 2002; Rudaheranwa, 2000; Gauthier, 2001).

As discussed previously, some analysts have argued that fiscal adjustment may be curtailing public investment in infrastructure capital (Belloc and Vertova, 2006). The models that guide the IMF and World Bank policies and programmes tend to assume that public expenditure always crowds out the private sector. Khan et al. (1990) have developed a model merging the IMF and World Bank approaches, which highlights several contentious assumptions that are made by the two organisations.

First, in the crowding-out hypothesis higher public expenditure leads to a reduction in private investment. Hence, governments have to reduce expenditure and set expenditure ceilings to meet growth objectives. When expenditure has to be decreased, public investment is an easier item to cut than elements of the recurrent budget, which includes items such as wages. Hicks (1991)'s analysis of expenditure patterns in 24 developing countries during the 1980s details the kinds of expenditures that were cut and those that were protected. In general, he finds that capital expenditures were reduced more than current expenditures. Social expenditures and defence were relatively protected, while the directly productive and infrastructure sectors bore a relatively larger burden of the adjustments.[8] Implicitly, therefore, this approach trades off public investment against the expectation of private sector investment growth. Belloc and Vertova (2006) argue that even if public investment is included in the government budget constraint, the crowding-out hypothesis is still brought to bear with the assumption that government expenditure competes with the private sector in the use of scarce physical and financial resources. Thus, higher government demand for goods and services can raise interest rates, making capital more expensive and therefore a disincentive to private investment. On the basis of this, cutting back public investment can stimulate private investment decisions and can have a positive impact on growth. This impact depends on whether public investment crowds out private investment more than proportionally or, in the case of the crowding-out being less than on a one-to-one basis, public investment being significantly less productive than private investment.

A second assumption highlighted in the Khan et al. (1990) model is that the public sector will not engage in investment, meaning that public expenditure does not contribute to capital accumulation. Therefore, in the basic IMF/World Bank approaches as depicted by the model,[9] a reduction in public spending decreases borrowing by the public sector. When this is combined with an increase (by a smaller amount) in the supply of private credit to the private sector, it is possible to improve the balance of payments through a reduction in overall domestic borrowing while at the same time promoting economic growth through the increase in domestic investment.[10]

The approach described above is quite controversial but continues to guide economic adjustment policies and in turn to influence public investment trends in many countries. FitzGerald (2006) argues that this is due in large part to its analytical simplicity, which makes it suitable for developing countries with their limited macroeconomic data.

Although the Poverty Reduction Strategy Papers (PRSP) show an apparent 'change' in focus from the original Policy Framework Papers, with an emphasis on increasing expenditure on poverty alleviation programmes vis-à-vis directly productive sectors, the macroeconomic strategies in the PRSP of many countries still emphasise macroeconomic stability, narrowly defined in terms of price stability and fiscal balance (Gottschalk, 2005). Hence, the underlying assumptions in regard to the role of the public sector vis-à-vis the private sector are no different from those of earlier economic policy strategies, with similar implications for public investment and public infrastructure capital stocks. The empirical evidence in Chapter 3 of this study shows a continued decline in public investment as a percentage of GDP from 1987/88 to date.

This thesis, therefore, addresses the general problem area of the relationship between public infrastructure capital and private sector output, productivity and growth in the context of countries like Uganda, which have underdeveloped infrastructure but are implementing 'good' macroeconomic policies.[11] These countries face development policy dilemmas, confronted on one hand by the commitment to implement IMF/World Bank-type economic reforms which entail reduction in public expenditure, and on the other by the need to deal effectively with absorptive capacity constraints such as lack of sufficient critical physical infrastructure. At the same time, political considerations prevent reductions in recurrent expenditure, meaning that productive and especially infrastructure sectors bear a larger burden of expenditure adjustments, which results in underinvestment in public infrastructure capital. This study argues that excessive emphasis on stabilisation and lack of sufficient attention to underinvestment in productive capital, particularly public infrastructure capital, may frustrate attempts at economic take-off. To investigate this problem in detail, the thesis attempts to answer the following questions:

- Is there a strong linkage between public infrastructure capital and private sector output and productivity performance, given Uganda's underdeveloped public infrastructure?
- Are there threshold effects (non-linearities) in the output/productivity effect of public infrastructure capital on the private rates of return and hence in the stimulation of private capital formation?

The specific research questions are:

- What are the underlying mechanisms through which public infrastructure capital impacts on private sector output and productivity?
- Are there differences in impact of the various types of public infrastructure capital and the output and productivity performance of different sectors?
- Is there substitutability or complementarity between public infrastructure capital and private capital? Will an increase in public infrastructure raise the marginal product of private capital and therefore induce private investment?
- What are the implications for public sector provision vis-à-vis private sector provision in the context of sub-Saharan African countries like Uganda?

In the context of the above research problem and questions, the hypotheses of the research are:

- There is interdependence between public infrastructure capital and private capital. Public infrastructure raises the expected return of private capital and therefore induces private investment, which is vital if output growth is to be sustained.

- Public infrastructure produces positive externalities and has both direct and indirect effects on the output and productivity of the private sector. Its adequate availability is a necessary condition for economic growth.
- The impact of infrastructure development on private sector output, productivity and economic growth is more significant when a bottleneck exists in the economy as a result of an underdeveloped infrastructure.
- There are sectoral differences in the relationship between public infrastructure and private output and productivity. Public infrastructure investments need to take into account the benefits that will accrue to the various sectors of economic activity.
- There are non-linearities in the relationship between public infrastructure capital and economic output and productivity. Threshold externalities associated with public infrastructure capital may result in an area or country being stuck in a low-output growth trap until a minimum critical mass is attained.

1.3 Objectives and Significance of the Study

Both the objectives and significance of this study lie in the questions asked and in the methods used to answer them.

Although the literature on the relationship of public infrastructure capital to output, productivity and growth is voluminous and remains controversial, empirical analyses have mainly focused on industrial countries, partly because of the unavailability of data for other countries, especially those in sub-Saharan Africa. It is important to put the results from these empirical analyses in context before relating or applying them to economic environments in developing economies. For example, the stock of infrastructure in developed economies had already reached a reasonable level of development in most of the periods covered by most of the studies, unlike in sub-Saharan African countries, which have underdeveloped infrastructure. In general there is a dearth of empirical evidence for this group of countries. Little attention (in terms of empirical work) has been paid to the impact public infrastructure capital could have on the growth process in sub-Saharan Africa countries, including Uganda,[12] yet poor and inadequate public infrastructure is always highlighted as one of the main factors curtailing growth (see, for example, DfID, 2002; World Bank, 1994). The objective of the study is to contribute to filling this gap by providing some new empirical evidence for Uganda.

From a policy point of view, various studies (for example, Gottschalk, 2005) have noted that in most Poverty Reduction Strategy Papers broad-based growth (pro-poor growth) is put at the centre of countries' development strategies with the objective of achieving both growth and poverty reduction. However, the sources of growth are not always identified. Studies like the current one should provide an important input into these strategies. Although the thesis does not explicitly analyse the relationship between public infrastructure and poverty, the non-exclusionary nature of public infrastructure makes it possible for the poor and non-poor to benefit from investment in it. Therefore, it should have a positive impact on the quality of life of the poor and, to some degree, facilitate the alleviation of poverty, especially if public infrastructure that is crucial for sectors in which most of the poor are engaged is emphasised.

In addition, the findings of this study could be an important input into the macroeconomic debates as to the nature of responses to aid-financed public infrastructure investments. The conclusions of these debates hinge on, first, whether there are positive or negative output/productivity effects of public infrastructure investments, and second, the magnitude of impact if positive. The simulation studies in the literature depend on estimates and sensitivity analyses for the possible supply responses (Adam, 2005).

While it was not the objective of this study to test the validity of the predictions of endogenous growth theory, it did aim to assess whether the conditions deemed necessary in endogenous growth models (that is, increasing returns to scale and complementarity between public infrastructure capital and private capital) are met. If this were to be the case, it would imply a big impact on output and productivity growth, which would make an important input into fiscal policy decisions.

Generally, therefore, the policy relevance of this study lies in the implications of its findings for fiscal policies of aid-recipient countries like Uganda to enhance and sustain economic growth. The research results should provide some of the answers to current dilemmas in development policy relating to the creation, availability and exploitation of fiscal space for additional infrastructure investments.[13]

1.3.1 Methodological issues, caveats and limitations of the study

Like more recent studies, this thesis takes into account the limitations of the analytical frameworks used in earlier studies in which only the direct effects of public infrastructure capital were accounted for (see Chapter 2 for details of the limitations of methodologies used in earlier studies). It applies more flexible functional forms, which allow explicit analysis of the indirect effects. A combination of exploratory data analysis and econometric modelling, including spline function approaches, is applied to identify threshold value(s) and to test the threshold effects hypothesis empirically.

Another unique feature of the study lies in its use of micro production functions instead of state, regional or national production functions as has been the case in many other studies. The advantage of this is that it enables a more direct linkage between physical public 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. In addition, returns are estimated at the level of particular sectors instead of at the aggregate national level, allowing a more direct estimation and analysis of the impact on particular production processes. This approach means that the study focuses on a particular country and avoids the problems of cross-country studies, which draw comparisons between highly disparate economies. Therefore, more directed development policies may benefit from the disaggregated analysis of the relationship between public infrastructure capital and the performance of different sectors in the economy.

Most studies, (for example, Aschauer, 1989a) use public capital variables measured in monetary terms, that is, adding up past public investments using the perpetual inventory method of estimation, as measures of public infrastructure capital over time. This method has a number of disadvantages, especially in the context of developing countries like Uganda. First, due to factors such as corruption and inefficiency, all expenditures designated as investment expenditure may not result in increases in the public infrastructure capital stock. That is, the level of expenditures may not be reflected in the actual infrastructure investments that are made, resulting in overvaluation of the public infrastructure capital stock series that are constructed (Pritchett, 1996; Sanchez-Robles, 1998). Second, there are no 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. Third, the heterogeneity of public capital is ignored. There are portions of public capital which private production units may not use at all, at least not directly.

The alternative approach applied here takes inventory of the quantity, and where possible quality, of public infrastructure stocks or their proxies by measuring available physical stocks at district level. However, because it is very difficult and expensive to measure/obtain physical measurements of public infrastructure stocks over time, this study had to be cross-sectional.[14]

Therefore, one limitation of this approach is that it does not explicitly show the long-run link between public infrastructure and economic performance. However, because the study applies a functional form of a higher-order degree, it is possible to assess the conditions necessary for endogenous growth theory, that is, increasing returns to scale and complementarity between public infrastructure capital and private capital. The findings are therefore indicative of the possible long-run link.

There is one more limitation. While focusing the investigation on a single country as described above has advantages, it means that we are unable to take into account international spillovers of infrastructure investment, which can be substantial for land-locked countries like Uganda. This would require a study that covers public infrastructure networks between African countries at a regional level.

1.4 Organisation of Thesis

Chapter 2 establishes the theoretical basis for the role of public infrastructure in enhancing private output, productivity and growth. Old development theory, neoclassical growth theory and endogenous (new) growth theory all give it a role in the growth process. The chapter argues that although there are differences in the way neoclassical and endogenous growth theories view the role of public infrastructure, they both contribute to our understanding of its role and together provide a good basis for empirical analysis. Neoclassical growth theory provides the methodological tools to measure the rate of technological progress while endogenous growth theory can provide an explanation for its evolution. Therefore, as the distinction between them is more to do with aggregate returns to capital and the implications for long-run productivity, they need not be mutually exclusive. From the neoclassical perspective, the extension of the investment concept to include investment in human capital, research and development, and public infrastructure, improves the measurement of inputs, allowing technological progress to be measured accurately, while from the point of view of endogenous growth, a broader concept of capital means constant returns may be possible and realistic (Stiroh, 2001).

The chapter also outlines the different mechanisms through which public infrastructure impacts on the output and productivity of the private sector and concludes that the impact of public infrastructure can be direct or indirect through its being an intermediate input or through its impact on the marginal productivity of private inputs respectively. It also reviews models used in earlier studies as well as empirical approaches and evidence, with a view to identifying their major limitations and related conceptual problems, and suggests possible remedies. A growth model with infrastructure capital is derived on the basis of the review. This model is used as a basis for empirical analyses in later chapters.

The importance of taking into account the context within which public infrastructure investments are made becomes clear in Chapter 2. Building on this, Chapter 3 discusses the state of public infrastructure in Uganda and the role of the public sector in infrastructure provision. It discusses the opportunities and complexities of public and private partnerships in the context of sub-Saharan Africa (SSA) and Uganda in particular. It concludes that although the current discourse on the role of infrastructure in the growth process has shifted from infrastructure stock accumulation to efficiency in provision with an emphasis on an increased role for the private sector, a number of factors indicate that the public sector still has a major role to play in provision, public policy and financing. Among them are under-investment and difficulties of attracting private investors in SSA countries, scale economies in the production of infrastructure services, consumption externalities and non-exclusivity (Jimenez, 1995).

Chapter 4 lays the foundation for the analytical approach of the study, including the empirical approach to testing of the public capital (infrastructure) hypothesis. It addresses the technical aspects of the research framework that are important for the analysis and outlines the study's approach, which draws on insights from macro studies to analyse the relationship between public infrastructure and economic output and productivity and growth. The chapter also provides information on the sources, coverage and strengths and weaknesses of the data used in the study. In summary, it sets the foundation for investigation of the research hypotheses.

In Chapters 5, 6 and 7, the research hypotheses are tested using a combination of exploratory data analysis, econometric modelling and spline function theory. Chapter 5 presents the analytical model linking individual production-unit output and productivity to key physical public infrastructure on the basis of location. It tests parameter stability (data 'poolability') on the basis of both firm size and sector composition. The reasoning is that the effect of public infrastructure may differ across sectors and firm sizes, which may be important for economic policy. Two production function models are applied to take into account the serious deficiencies in models used in previous studies: the Cobb-Douglas production function model, used in most of the earlier studies (to allow comparisons with earlier studies) and the more flexible transcendental logarithmic (translog) specification.

The uniqueness of the agricultural sector in Uganda, that is, its being mainly smallholder and to a great extent characterised by subsistence forms of production, necessitates a separate analysis from that of the industrial and service sectors covered in Chapter 5. Using district-level agricultural output and productivity data, Chapter 6 examines the relationship between different types of physical public infrastructure and agricultural output and productivity. It provides estimates of the magnitude of the association.

The results from Chapters 5 and 6 set the stage for Chapter 7. The basic argument in this chapter is that public infrastructure investments are 'lumpy' in nature, such that in countries or underdeveloped areas with infrastructure stocks below a certain minimum threshold, the concept of marginal productivity of capital may be rendered difficult to apply. The chapter empirically tests the hypothesis that marginal increments in infrastructure stocks will not have a significant effect unless a critical mass or threshold level of infrastructure stocks has been attained. As previously discussed, the alternative scenario is one in which infrastructure stocks have reached a 'saturation point' where, too, increases in stocks will not have a significant effect. Since the latter scenario is more relevant to advanced countries with already developed infrastructure, the study's focus is on the former. Exploratory and econometric modelling techniques (based on spline function theory) are used to test the threshold effects in infrastructure provision empirically. To check the robustness of results, separate regressions for samples of firms below and above the threshold value are used to confirm the hypothesis empirically. The results show that only when public infrastructure capital reaches a certain threshold does increase in public infrastructure capital start to have a significant impact on value added. The chapter also includes estimates of the investment required to bring public infrastructure stocks to the threshold level and analyses the marginal effects and elasticities of marginal investments made after the threshold point has been reached.

On the cost side, it is important to assess whether the returns from increasing infrastructure investment would outweigh the costs of provision. Therefore, benefit-cost ratios for different public infrastructure investments for different sectors are calculated. The conclusion is that the returns are not only positive and significant, but also substantial. Given that the current infrastructure stocks are very low, it is shown that significant public investment in infrastructure would need to be sustained over a prolonged period of time, providing support to the idea of a 'big push' as envisaged in the United Nations 2015 Millennium Development Goals.

Finally, Chapter 8 summarises the main conclusions and policy contributions and implications of the study. It also provides some suggestions for future research.

Notes

1. Stabilisation being narrowly defined as low inflation and avoidance of major fiscal and external imbalances.
2. The implication of this is that there has been an adverse effect on both productive public and private capital accumulation.
3. In their study, total factor productivity is defined as that 'something else' besides physical factor accumulation that accounts for growth differences.
4. The impact of public investment and public infrastructure capital on output or productivity and growth is a subject of continuing debate not only for sub-Saharan African countries but also for other regions of the world (see Chapter 2).
5. It should be noted, however, that they differ from Easterly and Levine (2001) in that they argue that while earlier attempts by the countries under

study to achieve economic take-off largely failed due to low productivity levels, current attempts may be frustrated by lack of capital accumulation. See also Fischer et al. (1998) who express major concerns over the lack of investment recovery in sub-Saharan Africa.

6. While some studies, such as Devarajan et al (2001) attempt to control for some of these problems (for example, the policy environment) they come to the same conclusions.
7. Chapter 2 provides a review of the studies.
8. Oxley and Martin (1991) and De Haan et al. (1996) noted similar behaviour in some OECD countries in the 1970s and 1980s.
9. The macroeconomic projections made with these models are in many cases supplemented with 'informed judgement'. It also worth noting that although this remains the underlying framework of the orthodox approaches, specific policies have been evolving over time. In addition, some recent work in this school of thought (for example, Agénor, 2000) now allows for the possibility of public investment crowding-in private investment.
10. This objective can also be achieved by increasing tax revenues, although increases in tax revenues are more difficult to achieve. Essentially, when higher tax revenue is possible, public saving increases in combination with a smaller reduction in private saving, such that total investment rises, but less than proportionally (Belloc and Vertova, 2006).
11. 'Good' in the context of IMF/World Bank stabilisation and structural adjustment policies.
12. This could be explained by lack of country-level data on public infrastructure stocks, especially for African countries.
13. Fiscal space is defined as 'the availability of budgetary room that allows a government to provide resources for a desired purpose without any prejudice to the sustainability of a government's financial position' Heller (2005a: 3).
14. In any case, time series estimation was not possible. The research evidence shows that public infrastructure stocks have hardly increased in Uganda over time (see Chapter 3).

2 Economic Theories, Public Infrastructure Capital and Private Sector Output and Productivity

2.1 Introduction

This chapter provides a succinct review of different economic theories on the role of public infrastructure, particularly its relationship with private sector output, productivity and growth. It also serves as a background against which to build the economic model and select empirical approaches for use in later chapters. It therefore reviews empirical models and approaches used in earlier studies with a view to identifying their major limitations and related conceptual problems and suggest possible remedies. A growth model with infrastructure capital is derived on the basis of the review.

As discussed in Chapter 1, a number of studies, (for example, Easterly and Levine, 2001) found that traditional inputs do not account for an important fraction of output growth. Growth accounting, which is firmly rooted in economic theory and is the centre-piece of the approaches used in these studies, illustrated that the measured residual referred to as total factor productivity (TFP) accounted for half or more of the growth in most of the cases.[1] Hence, these studies argue that it is TFP rather than factor accumulation that is most important in the growth process. As argued by Harberger (1998), many economists think of TFP or 'the residual in growth accounting terminology', as representing technical change, which makes one think of inventions, research and development and technical innovations. However, determinants of TFP can also be thought of as externalities of different kinds vis-à-vis economies of scale, spillovers and systematic complementarities, especially when one considers developing-country economies.[2] The theoretical literature on growth and economic development has particularly associated infrastructure investment with significant spillover externalities (Rosenstein-Rodan, 1943; Hirschman, 1958). Endogenous growth theory also sees externalities as the source of endogenous feedback effects on output growth (Hulten et al., 2005). Therefore, in addition to treating public infrastructure as a productive intermediate input, this study also focuses on externality-based models with a broad concept of capital in which private returns to scale may be diminishing, but in which social returns that reflect spillover externalities can be constant or increasing. Examples of externality-based models in endogenous growth theory include Lucas (1988), Romer (1986), Barro (1990) and Barro and Sala-i-Martin (1995). For Lucas (1988) externalities arise from human capital accumulation: the higher the productivity of each worker in production of the final good, the higher the average level of human capital. In Romer (1986), knowledge is a production input with increasing marginal productivity. In Barro (1990) and Barro and Sala-i-Martin (1995), productive public services (particularly infrastructure) as inputs in private production, create the positive linkage between government and growth and can be viewed as effects on the efficiency coefficient A (see below). On the basis of the above, the empirical analysis in Chapters 5, 6 and 7 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) as shown below. In addition, it is augmented with relevant control variables, as will be illustrated later.

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

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.

As a basis for the empirical assessment that will be done later, the next section of this chapter looks at what different economic theories say about the relationship between public infrastructure capital and private sector output and productivity by reviewing its role in development theory, old and new economic growth theories. Section 2.3 identifies the underlying mechanisms in order to highlight some of the most likely direct as well as indirect effects (spillover externalities) of infrastructure investments, while section 2.4 offers a review of empirical models, approaches and evidence with a view to highlighting the major limitations and related conceptual problems and suggests possible remedies. On the basis of these sections, section 2.5 derives a growth model with infrastructure capital as one of the explanatory variables. This model is later re-adapted to the micro and sectoral analyses in Chapters 5, 6 and 7. Concluding remarks are made in section 2.6.

2.2 Economic Theory and Role of Government Policy Actions Relating to Public Infrastructure in the Growth Process

In traditional macroeconomic neoclassical growth theory, steady-state growth is driven by exogenous factors, that is, the dynamics of population and of technological progress. This does not allow sufficient analysis of how firms' strategic behaviour as well as government policy actions (for example, government investment in public infrastructure) may affect long-term growth through the impact on technological progress. As a result, the role of government in the growth process was underestimated in economic theory (Van Sinderen and Roelandt, 1998). However, as discussed below, both development theory and new growth theory give a much greater role to the government and public infrastructure in the growth and development process.

2.2.1 Neoclassical growth theory and role of public infrastructure capital

In the orthodox neoclassical growth model, steady-state growth is driven by exogenous factors implying that fiscal policy and public infrastructure in particular can only affect the rate of growth during the transition to the steady state. It can only be an important determinant of the level of output and is unlikely to have an important effect on the rate of growth, (Easterly and Rebelo, 1993a). More generally, broadly defined capital generates only internal and diminishing returns. Therefore, in the neoclassical view, the accumulation of capital impacts on growth in the short run, with long-run productivity growth entirely driven by exogenous technical progress.

Nonetheless, the basic form of the neoclassical model is a useful tool for understanding the proximate factors that are associated with growth of output and productivity. Solow (1956, 1957) provides the framework and methodology to assess the importance of different factors. This is on the basis of assumptions of competitive markets and input exhaustion with Hicks-neutral technology. In this framework, output is modelled as follows:

$$Y_t = A_t . f(K_t, L_t) \tag{2.1}$$

Technical progress, which is equivalent to the Solow residual or TFP, is then defined as the difference between output growth and the share-weighted growth rates of the traditional inputs of capital and labour:[3]

$$\Delta \ln A = \Delta \ln Y - \alpha \Delta \ln K - (1-\alpha) \Delta \ln L \tag{2.2}$$

where
Δ represents a first difference
α is the share of capital in national income
$(1-\alpha)$ is the share of labour in national income

From this formulation, the sources of productivity growth can then be ascertained. Taking labour productivity growth, which is defined as output per worker, ($\frac{Y}{L}$), equation 2.2 can then be written as:

$$\Delta \ln\left(\frac{Y}{L}\right) = \alpha \Delta \ln\left(\frac{K}{L}\right) + \Delta \ln \mathrm{A} \tag{2.3}$$

The sources of labour productivity growth are therefore identified as follows:

- $\Delta \ln\left(\frac{K}{L}\right)$ - capital deepening (increase in capital per worker)
- $\Delta \ln A$ then captures the growth in TFP.

In this standard neoclassical growth accounting framework with only private inputs, any effect of public infrastructure will be included in TFP growth. Public infrastructure is therefore an accumulated input which is missed and contributes to an overstatement of true technical change. The neoclassical implications hold as long as diminishing returns to all capital exist (Stiroh, 2001).

If neoclassical assumptions are invalid, it means that the Solow residual does not only measure technical change. For example, if there are increasing returns to scale but no technical change, input shares will not equal output elasticities and the Solow residual will be measured to be positive even if there is no technical change. Neoclassical economists have come up with 'neo-classical growth fixes' with the argument that growth equations may not be limited to capital and labour as conventionally measured and can be augmented by other factors. Nonetheless, their effect on the per capita growth rate is still seen to be short term.

In neoclassical growth models, if infrastructure is considered to be a public good (that is, non-rival and non excludable) any increases in its amount can be thought of as upward shifts of the production function, thereby raising the steady-state level of output as well as the growth rate of the economy in the transition to the steady state.

2.2.2 Endogenous growth theory and role of public infrastructure capital

Endogenous growth analysis provides an endogenous mechanism for long-run productivity growth. This is either through the removal of diminishing returns to capital or by analysing specific actions that explain technical change. Therefore, factors affecting total factor productivity could include distortions from imperfect competition, externalities and production spillovers, omitted inputs, non-constant returns to scale and reallocation effects (ibid.).

Following the route set by the pioneering work of Uzawa (1965) and Conlisk (1969) in which they attempted to endogenise the rate of technological progress in the neoclassical model, new theories of economic growth amend the orthodox neoclassical theory by introducing an endogenous formulation of technical change. At the core of endogenous growth models is the proposition that investment in capital (broadly defined) and the production of new processes and products is important for growth, if growth is to be continued without being affected by diminishing returns. The definition of capital is expanded to include many reproducible factors of production, such as accumulation of human capital through training, build-up of know-how through Research and Development, spending on public infrastructure and other public goods, and so on (Van der Ploeg, 1994). This makes the assumption of constant (increasing) returns to scale with respect to the broad measure of capital quite plausible and it is through this channel that the important role that infrastructure can play in economic growth is highlighted (see also Barro, 1990; Barro and Sala-i-Martin, 1992, 1995). These models therefore take into account the important role that government policy can play in long-run growth outcomes through its impact on several growth inducing factors such as physical infrastructure, human capital formation and enhancement of the functioning of markets(Crafts, 1996; van Sinderen and Roelandt, 1998).

In the benchmark model of Barro (1990), the increase in the stock of infrastructure increases the steady state growth rate of output per capita. The performance of the model is similar to the 'AK' model in which production is with constant returns to a broad concept of capital and anything that changes the level of the baseline technology (A) affects the long-run per capita growth rate. Barro and Sala-i-Martin (1995), show that various government activities, including provision of infrastructure services,[4] can be viewed as effects on A and hence on the growth rate, since government investment in public infrastructure is assumed to enhance the productivity of private capital.

A limitation of endogenous growth models like the standard 'AK' type models is that they focus on the steady state growth rate of output per capita. This is in line with the criticism that AK models do not predict absolute or conditional convergence; yet conditional convergence appears to be an empirical regularity (ibid.).

Further, the macro evidence of endogenous growth so far (for example, Jones, 1995) shows little relationship between policy variables and long-run growth. Jones (1995) also notes that despite the increase in investment shares in the countries belonging to the Organization for Economic Cooperation and Development (OECD), there has not been persistent acceleration in growth. However, he does find that policy variables affect the levels of output and productivity, though not long-term growth rates.

2.2.3 Development theory and role of public infrastructure

Development theory links public infrastructure to economic growth by presenting it as one of the factors that can explain an old question of development theory: why some countries tend to get caught up in an underdevelopment trap. As in the big push theory in the literature, lack of or too low stocks of public infrastructure may cause underdevelopment to persist in some countries or regions.

This relates to the arguments presented by Rosenstein-Rodan (1943, 1984) in which public infrastructure (social overhead capital) is viewed as a major indivisible block which must be built and sponsored because private market initiative would not increase it in time. He cites the example of the textile industry in India in the post-Napoleonic era, arguing that,

> Low wages should have been a sufficient incentive to create a textile industry in India in the post-Napoleonic era and not in Lancashire, England. Indian wages were 50 or 60 percent lower than the low wages in England. There was no danger of currency manipulation or trade obstacles under British control; the prospect of building a textile mill in Bombay instead of Manchester or Coventry seemed most attractive. Further analysis revealed, however, that in order to build a factory one would have to build a bridge or finish a road or a railway line or later an electric power station. Each of these elements in the so-called social overhead capital requires a minimum high quantum of investment, which could serve say fifty factories but would cost far too much for one. The necessary minimum capital outlay outside of the textile mill would more than compensate for the advantage of cheaper labour. Lower wages were not a sufficient incentive for investment. (Rosenstein-Rodan, 1984: 208)

The market mechanism would not result in creation of the relevant social overhead capital; therefore sponsorship, planning or programming through public investment would be necessary. In addition, to take advantage of external economies (due to indivisibilities) required an 'optimum' enterprise size to be brought about by simultaneous planning of several complementary industries (Rosenstein-Rodan, 1984). The failure of the public sector to build or to facilitate the building of relevant infrastructure would make industrialisation, and hence growth, unlikely. Early development theorists therefore justified a greater public sector role in provision with the argument that infrastructure investments are associated with significant spillover externalities. Marglin (1963) criticised continued use of models in which decreasing returns to scale obtained, in spite of empirical reality exhibiting increasing returns.

More recent growth literature (for example, Murphy et al. (1989) formalises these ideas in a model showing that each industrialising firm that uses a shared infrastructure contributes to the large fixed cost of building it and thus indirectly helps other users, making their industrialisation more likely. In one of the equilibria analysed in the model, infrastructure makes money on its first-period investment if the economy industrialises, but incurs a large loss if no industrialisation takes place and there are no users of the infrastructure. The possibility of an insufficient number of firms industrialising results in the infrastructure not being built, and that in turn could ensure that firms would not make the large-scale investments needed to industrialise. This would be a case of an underdevelopment trap caused by co-ordination failure (see Bardhan, 1995). In such a case, it would seem plausible to argue that infrastructure would need to be built ahead of demand, which would necessitate public sector provision, public subsidies towards the construction of the infrastructure or an attempt at co-ordination of investments by enough private users of the infrastructure to get to the industrialisation equilibrium. This kind of public investment may facilitate the industrialisation of different sectors of the economy because it makes it profitable to industrialise, and may send a signal to firms in different sectors to anticipate widespread industrialisation (Anderson and Lakshmanan, 2004).

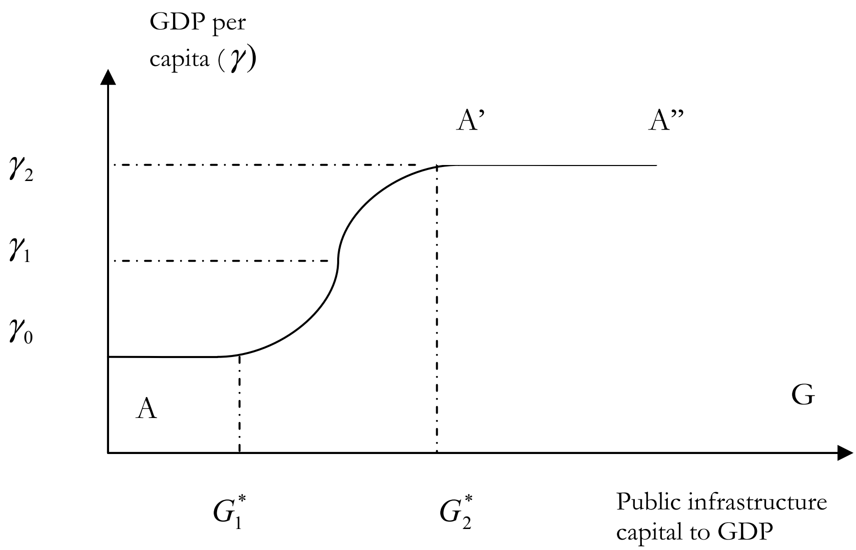
To examine how threshold externalities impact on growth, neoclassical models of economic growth have been augmented with a feature that is sufficient to produce multiple, locally stable balanced growth paths in equilibrium. That is, technological externalities with a 'threshold' property that permits returns to scale to rise very rapidly whenever economic state variables, such as the quality of labour, or infrastructure capital take on values in a relatively narrow 'critical mass' range.

Among the types of externalities considered are spillovers from stocks of different types of capital (to capture the notion of 'infrastructure') as well as the labour-augmenting outcomes of externalities arising in the process of creating human capital.

The growth experiences of different countries show that developed and less developed countries exhibit substantial differences in development patterns. While some manage to sustain high growth rates over long periods of time, others advance at acceptable, if not spectacular, rates and a good number stagnate in low-growth 'traps' recording low rates of growth or relatively low levels of economic development, or both (Azariadis and Drazen, 1990).

Azariadis and Drazen (1990) perceive threshold effects and non-linearities in growth and development as occurring in sectors and contexts where network effects and externalities are large. They apply an Overlapping Generation model of physical and human capital accumulation to explain why certain underdeveloped countries appear stuck in a 'poverty trap' where neither type of capital is accumulated and personal income stagnates even though they are in possession of the same technology that allows other countries to grow steadily.

Figure 2.1
Threshold Public Infrastructure Capital Accumulation, Threshold Externalities and Growth



Source: Adapted from Azariadis and Drazen (1990: 519)

Their study, which is based on threshold externalities in the accumulation of human capital, suggests that there are multiple locally stable stationary states that arise due to the existence of increasing social returns to scale which become particularly pronounced when economic state variables attain a critical mass or 'threshold' values.

This reasoning can be extended to the particular case of physical public infrastructure. Figure 2.1 illustrates the characteristics of the development process that would be observed if the threshold externalities associated with (infrastructure) capital accumulation were important in explaining the differences in growth. All other things being equal[5], economies on opposite sides of the threshold G_1^* will have substantial differences in growth rates. Essentially, economies to the right of the threshold invest far more heavily in infrastructure capital and accumulate it faster than those to the left of the threshold.

The productivity of infrastructure will be higher in those economies with infrastructure stocks between the threshold G_1^* (that is, critical minimum mass) and the saturation point G_2^*. For various reasons (for example, budgetary constraints) some countries, regions or districts keep infrastructure investments too low (for example, below the critical minimum mass) such that the productivity of infrastructure may be essentially zero. These output-infrastructure relationship scenarios can therefore be theoretically represented with a cubic function specification (see equations 2.4 - 2.6 below) to capture the possibility of the existence of multiple equilibria. As can be deduced from the equations below, for both infrastructure supply and its marginal productivity (the slope) to be positive, 'a' is set to equal zero (a = 0) and G would have to range from 0 to 2c/3d (G = 0 to G = 2c/3d). Productivity of infrastructure would reach its maximum value at G = c/3d. Therefore, marginal productivity of extra infrastructure investment in public infrastructure capital is a quadratic and positive as long as G < 2c/3d (that is, economies of scale over this range).

$$\gamma = a + bG + cG^2 - dG^3 > 0 \tag{2.4}$$

$$\frac{\partial \gamma}{\partial G} = b + 2cG - 3dG^2 \geq 0 \tag{2.5}$$

$$\frac{\partial^2 \gamma}{\partial G^2} = 2c - 6dG \tag{2.6}$$

Hence equation 2.4 forms the basis of our empirical analysis in Chapter 7. However, as will be elaborated in that chapter, polynomial regression in the form of equation 2.4, that is, regressing G, G^2, G^3, performs poorly as a modelling approach because it generally suffers from crippling multicollinearity problems (see also Marsh and Cormier, 2001). This problem is solved by the use of spline models (in this case, cubic spline functions) which are seen as extensions of or restricted versions of polynomial regressions rather than an alternative to them (ibid.). Spline regression models are more flexible and less likely to generate perfect multicollinearity in higher dimensions. Another alternative would be kernel regression, but Welsh et al. (2002) provide evidence that suggests that spline methods are more efficient than kernel methods.

The spline function can be modelled in general terms by piecewise polynomials of any degree, say order k (in this case it is 3), which are specified by dividing the range of the independent variable into several intervals by a set of points called knots (in this case, representing the threshold point and saturation point) and introduction of dummy variables that are defined by the intervals. Introduction of appropriate constraints to the model ensures the function is continuous, guaranteeing continuity of the first and second derivatives; that is, there are k-1 derivatives (see details in Chapter 7).

As argued earlier, our main interest and focus is on the threshold (G_1^*) or the minimum critical mass required for productivity effects to be realised.

However, in the literature that attempts to empirically test the efficacy of these arguments, the focus is on the saturation point, for example, $(G)_2^*$, with the assumption that for relatively low levels of public infrastructure capital, increased public investment raises the economic growth rate, but for relatively high levels of public infrastructure capital stocks, increased public investment has no positive impact on growth. That is, once a particular 'stage' has been reached, as in the case of economies such as A' and A'' in Figure 2.1, the economies should converge, at least temporarily, to a given balanced growth path.

For example, Sanchez-Robles (1998) views services provided by the stock of public infrastructure capital as being subject to congestion (see also Barro and Sala-i-Martin, 1992 and Cashin, 1995). In his study, the 'saturation' or 'overcapacity' point is thought of as a ratio of public infrastructure capital to output, like $(G)_2^*$ in Figure 2.1. When the saturation point is surpassed, marginal increments in the public infrastructure stock cease to have an impact on productivity since they no longer cause a reduction in congestion. On the other hand, a positive and significant effect of public infrastructure capital on growth implies that public infrastructure capital has not yet reached the saturation point, meaning that subsequent increases alleviate congestion, resulting in a positive impact. An example of this phenomenon would be a case in which more vehicles on the same road lead to lower productivity of the road. An increase in roads reduces congestion, improving productivity; however, the marginal increments (roads) cease to have a positive impact beyond a certain saturation point. Therefore, congestion gives rise to non-linearities in the relationship between public infrastructure capital and economic growth.

Fernald (1999) also illustrates this phenomenon, but from the perspective of network externalities that introduce economies of scale in the provision of infrastructure services (World Bank, 1994). This characteristic implies that public infrastructure services are supplied through a networked delivery system such that building an interstate network might be very productive but building a second network might not be so. Hence, there would be non-linearities in the public infrastructure capital and economic growth relationship. Using data on inputs and outputs for 29 sectors of the U.S. economy for the years 1953-89, Fernald (1999) finds that before 1973 the interstate road system was highly productive, but after 1973, when the interstate system was completed, roads offered a normal (or even zero) rate of marginal return. His findings seem consistent with the argument that, while the massive road-building exercise of the 1950s and 1960s in the U.S. led to a one-time boost in productivity, new investments in roads would not yield the same marginal productivity growth as before1973. The above scenarios have led some researchers to incorporate infrastructure not as a third factor in the production function, but as part of the technological constraint. In the theoretical model developed by Dugall et al. (1999), technological growth rate is specified as a non-linear function of infrastructure and a time trend, the latter capturing the effect of all other variables on the growth rate in technology. Public infrastructure increases total productivity by lowering production costs. By increasing the technological index, public infrastructure shifts the production function upwards, and therefore increases the marginal products of factor inputs.

However, Sturm et al. (1998) criticise Dugall et al.'s approach. They argue that when the Cobb-Douglas function (estimated in log levels) is applied as by Dugall et al. (1999), it does not make any difference whether public infrastructure capital is treated as a third production factor input or as part of the technological constraint. Either way of modelling the public infrastructure-output relationship yields similar equations to be estimated, such that the explicit measurement of the direct and indirect impact of public infrastructure capital is not possible (Romp and de Haan, 2005).

As will be discussed in detail in Chapter 7, the current study differs from the studies mentioned above by considering the threshold point G_1^* or 'under-capacity point', which is more relevant to the level and state of public infrastructure capital stocks in sub-Saharan African countries in general and Uganda in particular.

2.3 The Underlying Mechanisms Linking Public Infrastructure to Output, Productivity and Growth

Public infrastructure not only affects production and consumption directly, it also produces many positive and negative externalities. In addition it involves large flows of expenditure, making its linkages to private sector output and productivity and the economy as a whole multiple and complex (Kessides, 1993). Our interest in this study is in the ways investments in public infrastructure capital would support the growth of a country's productive sectors such as agriculture, services and industry; hence, the focus is on linkages with private sector output and productivity.[6]

The impact of public infrastructure capital on output, productivity and growth can be argued to be through two broad channels (see Figure 2.2).

First, public infrastructure can be seen to be a direct input into the production function for private output. It affects private sector output/productivity because private production units purchase intermediate goods and services, which include, for example, transportation services and electricity. An increase in the stock of roads or electricity would lower the production cost of the corresponding services and decrease the price paid for road transport and electricity by the private sector (Hulten et al., 2005). Moreover, a reduction in the costs of intermediate inputs to production would result in increased profitability of production, encouraging higher levels of output; income and/or employment.

The second impact channel is through the efficiency-enhancing externalities of public infrastructure, which may lead to an increase in private output through its effect on the level of productivity as envisaged in endogenous growth theory and new economic geography. An increase in the stock of public infrastructure capital would, in the case of roads, result in the reduction of transport costs, which could facilitate and promote specialisation and trade. This might result in economies of scale and possibly agglomeration, with consequent productivity benefits. As argued by Anderson and Lakshmanan (2004), the importance of public infrastructure or road infrastructure in this particular case arises because specialisation and trade occur when there is a positive trade-off between efficiency gains from trade and transport costs. In other words, public infrastructure contributes to 'Smithian growth.[7] In output equation 2.3, Smithian growth would be an increase in A.

From another perspective, reduction in transport costs could lead to better inventory management (inventory minimisation) resulting in savings in non-transportation cost elements such as storage, interest and insurance. That is, the optimal level of inventory would depend on the trade-off between procurement and transportation costs and carrying costs. Taking the example of a firm's output, when goods are delivered more frequently, the firm saves on inventory carrying costs if it has access to better and reliable transport services (Anderson and Lakshmanan, 2004).

Furthermore, public infrastructure influences the process of the diffusion of technological growth because it is complementary and plays a role in raising the productivity of other factors. In the case of an increase in, say, electricity generation and distribution capacity, the result would be continuous supply and more stable voltage, which would not only allow the use of more sophisticated machinery but also minimise the need for individual production units to provide their own generating capacity (Hulten et al., 2005) and (Lee and Anas, 1992).

Lastly, the availability of public infrastructure in a given location may attract flows of additional resources ('crowding-in' of domestic/foreign private investment), which could lead to a reduction in factor costs and transaction costs at that particular location (see Figure 2.2).

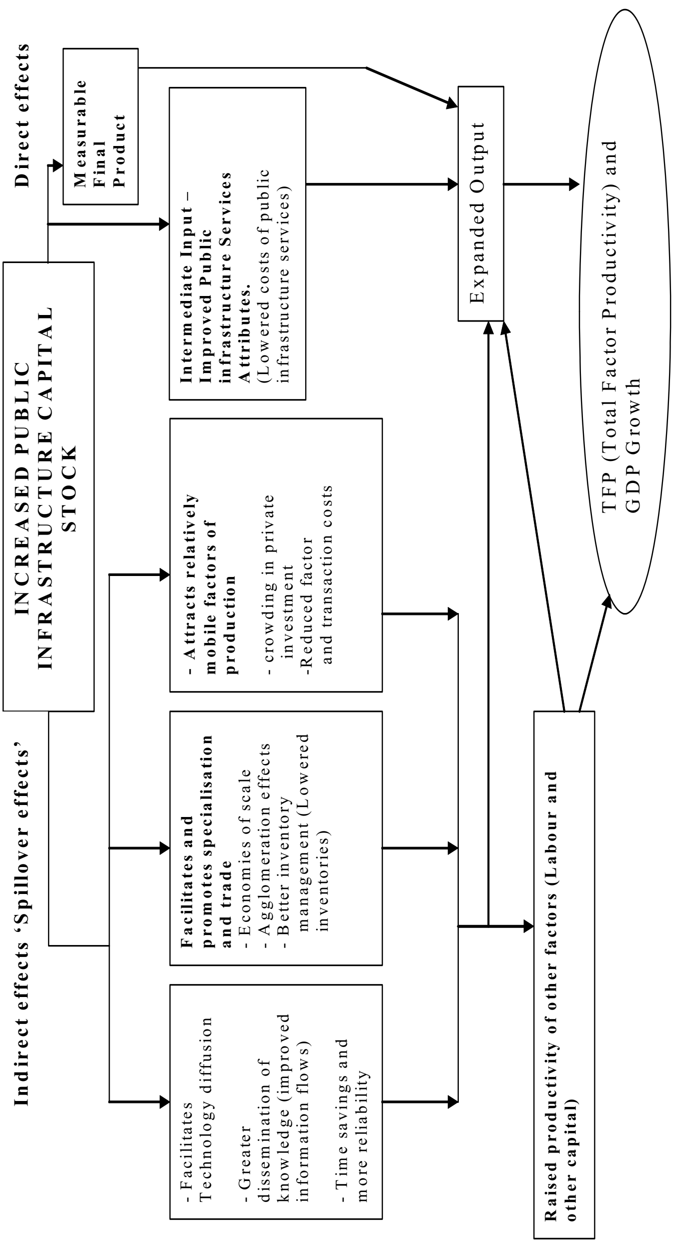
All these cost reduction effects of public infrastructure capital stock can be captured in the cost functions of production units (see details of cost-function approach in section 2.4). They can be reconciled or made comparable with the production-function approach by using Hotelling's Lemma to obtain supply functions, which enables the calculation of output elasticities (Demetriades and Mamuneas, 2000).

In conclusion, we can say that here we have focused on the supply-side effects, which are our main interest in this study. However, there are demand-side effects that result from the flows of expenditure on investment in public infrastructure capital (Kessides, 1993). First, there are important economic effects originating from the multiplier effects of the expenditure on wages and inputs used in construction as well as the derived demand generated for the output of other sectors. In addition, depending on market conditions, for example, existence or otherwise of labour market rigidity, the cost of labour and other inputs may increase and 'crowd-out' private investment.

Second, depending on the way infrastructure investments are financed, the availability of financial capital for others as well as the fiscal balance and external creditworthiness, and therefore macroeconomic stability, may be affected (ibid.). However, it can be argued that both the multiplier effect and financial crowding-out may apply to any form of government expenditure, so long as the expenditure is financed by taxation or borrowing rather than revenues from services generated (ibid.).

A more likely scenario for sub-Saharan African countries like Uganda is aid-financing. This gives rise to the possibility of trade-offs between short-run effects related to relative price adjustments in the form of 'Dutch disease', and long-run effects on productivity and crowding-in of private investment. This study does not explicitly focus on this aspect. However, a number of simulation-based studies (for example, Adam and Bevan, 2006),[8] which focus on whether the scaling up of aid to finance such investments would result in sufficient returns in terms of sustained growth in comparison with the negative effects, conclude that the supply-side responses to the aid-financed public expenditures are key to the evolution of the aggregate economy. This partly motivated the current study.

Figure 2.2
Causal Relationship Between Infrastructure and Economic Output



Source: Author's construction

2.4 Review of Empirical Models and Evidence

With a view to highlighting the major limitations of empirical work on the effects of public infrastructure capital on private output and economic growth, this section reviews results and empirical approaches of past studies. Because of the voluminous amount of studies, this review is in no way exhaustive and is intended to summarise approaches and their main limitations as identified in the literature thus far. More recent studies specific to individual sectors are discussed in the later empirical chapters.

Studies that analyse the link between public infrastructure capital and private output and growth can generally be classified into two groups: microeconomic studies that try to identify the link between public infrastructure investments and the productivity of individual production units, and macroeconomic studies that try to analyse the contribution of public infrastructure investment (capital) to the economy in terms of increases in output or reductions in the cost of production using econometric analytical tools. For the former, the economic tool of analysis is usually cost-benefit analysis, which seeks to predict economic benefits to both households and firms adjusted for project, operational, external and other costs. Examples of this are World Bank analyses of rates of return on infrastructure projects. However, ex-post econometric analyses have also been done, using firm or household survey data.

Given the ex-post nature of analysis in this study, this review focuses on the pros and cons of studies that apply econometric analytical tools.[9] In general, three approaches have been used:

i. the production function approach
ii. the duality approach, in which either the cost function or the profit function approach is utilised
iii. the dynamic system approach, in which several methods are used, including the Vector Auto-regression model, the error correction model, and estimation of the Euler equations obtained from an optimisation problem.

These studies are carried out at different levels of aggregation, with some done at the individual firm level, an industry, a region of a country, the economy as a whole or a group of economies, depending on the data available (Batina, 2004).[10]

Several problems that could bias results have been identified in the approaches of many of the studies in the literature, especially the earlier studies, including the seminal Aschauer (1989a). The problems are mainly methodological and include simultaneity bias, omitted variable bias, not taking into account the direction of causality, measurement problems, and ignoring of fixed effects as well as the stationarity properties of the data used. The empirical models and approaches are detailed below, highlighting the problems mentioned above,[11] which will then inform the approach of the current study. It must be emphasised here that most of the econometric problems that are highlighted can now be resolved by modern econometric techniques. Indeed, many recent studies manage to deal with most of the problems; to deal with problems such as endogeneity, for example, they use instrumental variables or the GMM dynamic panel data approach (see Chapter 5). Therefore, the discussion that follows focuses more on the appropriateness of functional forms applied in analysis than on problems that can be resolved with standard econometric techniques. That is, when the study discusses the remedies required for the identified shortcomings, the focus is more on the appropriateness of functional forms. The standard econometric remedies that are required are discussed in Chapters 4, 5, 6 and 7, where the econometric approach and estimations of the study are spelled out.

a. *Duality approach: Profit or cost function approaches, 'behavioural approaches'*

In the duality approach, the public infrastructure capital stock is assumed to be externally provided by the public sector as a free input and enters into the cost or profit function of the firm as in equations 2.7 and 2.8 respectively (see Sturm et al., 1998). This enables the capture of the cost reduction effects as discussed in section 2.3.

$$C(p_t^i, q_t^i, A_t, G_t) = \min_{q_t^i} \sum_i p_t^i q_t^i \text{ subject to } Q_t = f(q_t^i, A_t, G_t) \quad (2.7)$$

and

$$\Pi(p_t^Q, p_t^i, A_t, G_t) = \max_{Q_t, q_t^i} p_t^Q Q_t - \sum_i p_t^i q_t^i$$

subject to

$$Q_t = f(q_t^i, A_t, G_t) \quad (2.8)$$

Firms are assumed to minimise private cost (C) for a given level of output. Since input prices (p_i) are exogenously determined, quantities of the private inputs (q_i) become the instruments of the firm. For the profit function, firms are assumed to maximise their profits (Π) given the output prices (p^Q) and input prices. Optimising firms also take into account environmental variables, that is, the state of technical knowledge (A) and the amount of public infrastructure capital available (G) (Sturm et al. 1998; Romp and de Haan, 2005).

Duality theory and the optimising behaviour of the firm are used to derive input demand functions that in part depend on the services of the public infrastructure capital stock (Batina, 2004). In duality theory, the profit and cost approaches are dual to one another and dual to the production function such that a production function can be recovered from information on cost. Examples include Deno (1988) and Lynde and Richmond (1992).

The role public infrastructure capital plays is expressed by its shadow price in the cost function; that is, the effect an additional unit of public infrastructure capital has on overall cost. However, many of the early studies in the literature using these approaches did not resolve some of the problems identified in regard to the production function approach; for example, time series characteristics of the data and the direction of causation problem. They also still applied the Cobb-Douglas production function form, hence maintaining its drawbacks. More recent studies apply the Translog cost function, which generalises the Cobb-Douglas form and allows for differential effects across inputs and for complementarity across inputs to occur.

A major difference between the duality and production function approaches is that the duality approach involves a more complicated hypothesis. This can be regarded as a disadvantage. While the production function approach only requires that the firm be technologically efficient, the duality approach involves the additional assumption that the firm behaves optimally by choosing inputs to minimise cost, or to maximise profit when estimating cost shares that stem from cost minimisation (ibid.).

b. Dynamic system approach: Vector Auto-Regression approach

Studies that apply this approach estimate a system of equations with the intention of capturing direct and indirect interaction between several variables over time. It involves the use of advanced techniques, for example, Vector Auto-regression (VAR) or the Error Correction Model (ECM) to control for econometric problems like simultaneity bias or autocorrelation. The most common in the literature is the VAR.

The VAR approach, as coined by Sturm et al. (1998), is primarily data oriented (see, for example, Clarida (1993) and Sturm et al. 1995 which apply some variant of this approach). It imposes as few economic restrictions as possible and tries to solve some of the problems raised by the approaches mentioned earlier. It has the advantage of not imposing *a priori* causality directions and does not need other identifying conditions derived from economic theory. Indirect effects of public capital are also taken into account. In this case, a number of variables are explained by their own lags and lags of the other variables such that variables are treated as jointly determined.

However, the VAR approach has the disadvantage of not completely revealing the underlying production process. It is also somewhat harder to get elasticity estimates. The only way to get specific elasticity estimates is via the impulse-response functions, which result in estimates of the long-run effects of different shocks (Sturm et al., 1998).

From the perspective of developing countries, another disadvantage is that this approach requires a long series of data if any meaningful analysis is to be conducted.

c. Public capital in cross-section models

The impact of public capital on economic growth in most of the models discussed above is measured mainly through the use of a time series framework. Most of the more recent empirical literature on the relationship between public capital and growth is dominated by cross-country cross-section regressions mainly based on the theory of endogenous economic growth (Barro, 1991; Mankiw et al., 1992). Due to lack of relevant data, most of the studies employ government investment expenditures as an explanatory variable. This may be problematic because public investment may not be a true reflection of public infrastructure capital stocks due to corruption and implementation inefficiencies, especially in the case of developing countries.

In addition, although many of the studies are now well aware of the problems associated with these cross-section regressions, for example, biases due to omitted variables and reverse causation (Levine and Renelt, 1992; Levine and Zervos, 1993) and sample selection, several studies do not, or are unable to, deal with them sufficiently. Often the results are not robust, especially in a cross-section of heterogeneous countries. Further, growth regressions are mainly single-equation models, yet economic theory may indicate and economic data may not reject that there is more than one endogenous variable in the system (see Crihfield and Panggabean, 1995). In this case a more structural approach (which also reduces the problem of multi-collinearity) is called for (Sturm et al., 1998)

d. Public capital in structural models

Modelling of this type is reduced-form modelling and has the advantage of addressing the problems highlighted in single equation models, for example, problems of causation and multicollinearity (by introducing some endogeneity). However, many studies that use this approach and are designed to illustrate the role of government investment assume a positive relationship between government investment and the performance of the economy simply by referring to studies like that of Aschauer (1989a), ignoring the criticisms of methodologies used in such studies as highlighted above (see, for example, Toen-Gout and Van Sinderen, 1995). Westerhout and Van Sinderen (1994) are an exception as they try to estimate the marginal productivity of public capital. Using a small-linearised macroeconomic model (consisting of four reduced-form equations) for the Netherlands, they assess the indirect effect of both government policies and external factors on economic growth through their effect on private investment. The rate of output growth depends on the private gross investment rate, whereas the private gross investment rate is assumed to be positively related to the rate of growth of public investment with causality running from public to private investment (ibid.).

e. Production function approach: Empirical models with the production function specification

The production function applied in many studies (for example, Aschauer, 1989a) is assumed to be of the Cobb-Douglas type. It relates the output or value added of an economy or industry, Y, to the quantities of labour input L, private capital input K, public (infrastructure) capital G and time (t) which represents the possibility that the technology may change over time. That is,

$$Y = F(L, K, G, t)$$

The function F describes the technological possibilities available to the economy or industry. The assumptions made are that factor markets are characterised by perfect competition, and that public infrastructure capital is a pure public good in the sense of Samuelson (1954) and therefore can be approximated as an unpaid factor (Hakfoort, 1996).

Estimation of the contribution of public capital to growth is mainly done with single equations and time series data with an imposition of the Cobb-Douglas function in logarithmic form (for example, Aschauer, 1989a). However, there are some exceptions, especially in regard to the specifications applied, with some studies imposing the Cobb-Douglas form but using first differences of logs instead of logs (for example, Aaron, 1990; Hulten and Schwab, 1991; Tatom, 1991), with the contention that the data are not stationary. There are also differences in regard to data used, with some studies using cross-section data instead of time series (for example, Costa et al., 1987).

A number of limitations have been identified in these studies. They relate to the assumed causality between public capital and output, the specification and restrictiveness of the estimated models in the case of Cobb-Douglas production functions and the characteristics of the data used in the case of time series data. In regard to the characteristics of the data, the way to proceed is to explore whether the data are stationary or cointegrated. However, in cases where the variables are only cointegrated in first differences, this specification eliminates the ability to estimate the underlying long-term relationship between production and factor inputs.

To deal with the restrictiveness of the Cobb-Douglas functional form, recent studies impose the Translog production function, which is deemed to be a more flexible specification. In essence, it is a second-order Taylor's series approximation of an unknown production function that nests the Cobb-Douglas function. Our empirical implementation uses this approach and takes into account important econometric issues that were neglected in previous studies. This specification has the advantage of enabling the capture of both direct and indirect effects of public infrastructure capital on the level of output or output growth. Therefore, it makes it possible to examine the total effect, including spillover externalities associated with investments in infrastructure capital stocks. Increasing returns to scale at the firm level are reconciled with the assumption of perfect competition, with the assumption that increasing returns are external to the firm.

In addition, unlike the dual cost function approach, it requires neither a behavioural (minimising or maximising) assumption nor data on factor prices (Chambers, 1988; Stephan, 2003).

2.4.1 Empirical evidence

Results from most of the earlier studies in the literature point to a positive contribution of publicly provided infrastructure to private sector output and growth (for example, Ratner, 1983; Aschauer ,1989a; Munnell, 1990). However, a number of studies that followed Aschauer (1989a) show the opposite and there has been continuing controversy, with some studies supporting the public capital hypothesis while others find no impact.

As shown in Appendix A, in our selected sample of studies which was based on methodology applied and results of magnitude of impact, estimates of output elasticity range from negative 0.11 to positive 0.73.[12] Although these studies are not directly comparable, for example, due to differences in infrastructure measures and countries, the size of the magnitudes of impact and the wide range in the estimates raised doubt about their validity.[13]

In most of the literature, methodological flaws are put forward as the reason for such discrepancies. However, more recent studies which apply more sophisticated functional forms and statistical methods show that the conflicting results may not only be attributable to methodological deficiencies. Apparently there are contextual determinants of public infrastructure capital productivity that need to be taken into account. As already highlighted in the previous sections, the magnitude of the economic impact may depend on the 'context' in which the public infrastructure investment is made. For example, if public infrastructure investments are made as additions to an already well-developed large network the effects may be minimal, while they may be large and significant if the opposite is true. There may also be threshold effects such that the levels of public infrastructure capital stocks become a contextual factor in economic impact.

2.4.2 Summary of limitations in empirical studies and related conceptual issues

In general, the main elements of criticism are flaws in the models and methodologies used as well as the inappropriate proxies used for public capital (infrastructure).[14] The methodological flaws mainly relate to econometric problems of unit roots, spurious correlation, endogeneity of public capital, and measurement errors in the public capital proxies. This could also partly explain the disparity in results from different studies. Like many recent studies, this thesis endeavours to eliminate or at least minimise the methodological flaws through proper exploratory data analysis and selection of the relevant models.

There are other limitations which are not methodological. They relate to the assumptions made and raise important conceptual questions. These include: the assumption that infrastructure is a pure public good, the question of optimality of infrastructure capital, the assumption (with the exception of theoretical models) that infrastructure is an unpaid factor and the neglect of the possibility of international spillovers of infrastructure investment.

Most of the empirical models in the literature make the unrealistic assumption that infrastructure is an unpaid factor. However, infrastructure is paid through a variety of taxes, licence fees, levies and user charges and their omission in the analysis implies that the models may overestimate the effects of infrastructure investment (Hakfoort, 1996; Winston, 1991). This study assesses whether the returns from increasing infrastructure investment outweigh the costs of provision.

There is also need for flexibility in regard to the assumption of a pure public good, as most government activities/services including provision of infrastructure are subject to congestion and hence impure public goods (see Barro and Sala-i-Martin, 1992). In the analysis of public goods, therefore, a distinction has to be made between pure public goods and congestible public goods. A pure public good, also referred to as 'factor augmenting' or 'atmospheric', is not subject to congestion by the number of firms, quantities of output or traditional primary inputs; hence it is non-rival and non-excludable and available to all firms and industries. In this case it is plausible to make the assumption of constant returns to scale in primary inputs, since, when the traditional primary inputs of capital and labour are both doubled, output would be expected to double given that the availability of the public good(s) is in undiminished quantity. On the other hand, congestible public goods are characterised by rivalness but are non-excludable. In this case, as output within an industry increases, the congestible good would be expected to be used more and we would expect diminishing returns to scale in primary factors and constant returns to scale in all factors (Feehan and Batina, 2003).

Whether a public good is 'pure' or 'congestible' then becomes an empirical question. If the returns to scale are found to be constant in all inputs, then the public good is 'congestible', while if the returns to scale in the primary inputs are constant then the public good can be considered to be 'pure' (ibid.). Table 2.1 summarises this classification system and the related characteristics.

Table 2.1
*A Classification System for Public Goods**

Type	**Pure Public Good**	**Congestible Public Goods (unpaid factor)**
Characteristics 1. Returns to scale	Private-goods production functions exhibit constant returns to scale in primary inputs Increasing returns in all inputs	Private-goods production functions exhibit decreasing returns to scale in primary inputs Constant returns in all inputs
2. Amount of public good (G) available to an industry or firm i	Gi = G due to non-congestibility	Gi < G due to intra- and inter-industry congestion, except in the special case of a semi-public input.[15]
3. Impact on industries	Affects at least one industry	Affects at least one industry
Examples	Knowledge-related inputs, e.g. literacy, basic research & development and weather forecasts	Public infrastructure, e.g. roads

Note: * Another type of public good is what is referred to as 'firm-augmenting'.[16] However we exclude it here because it is of limited practical interest.

Source: Modified from Feehan and Batina (2003).

Because of the nature of our analysis, we do not explicitly deal with the question of optimality of public infrastructure capital or the possibility of international spillovers. Nonetheless, international spillovers can be of great relevance, particularly for landlocked countries like Uganda, although countries that provide the gateway to the rest of the world also benefit substantially. Capturing these effects would require a study covering transport networks between African countries. Adenikinju et al. (2002) found that in Senegal and Côte d'Ivoire transportation was perceived as a greater obstacle to exports within Africa than outside Africa, a perception they linked to the poor quality of roads and other transport networks. Hence, there are likely to be substantial benefits even from improvements in individual country infrastructure which can be coordinated at a regional level.

2.5 Derivation of a Stylised Growth Model with Infrastructure Capital[17]

From a theoretical perspective and on the basis of the transmission mechanisms discussed in the previous sections, it can be argued that the impact of public infrastructure can be direct or indirect. The direct impact could be construed to take place during the transition to the steady state, while the indirect effect is through its impact on the marginal productivity of private inputs.

Therefore the growth model applied here differs from the standard 'AK' type endogenous growth models like that of Barro (1990) which focuses on the impact of public infrastructure on the steady state growth rate of output per capita. This thesis follows Sanchez-Robles (1998) by allowing for transitional dynamics in the model approach, which is elaborated below.

The starting point is the production function in intensive form as in equation (2.9), where y denotes output per worker (Y/L), α the capital share in production, and A the level of productivity (level of technology).

$$y = \mathrm{A}k^{\alpha} \quad \alpha < 1 \tag{2.9}$$

The description of the evolution (dynamics) of A and k is as follows:

$$\Delta k = s_k y - (\delta + n)k \tag{2.10}$$

$$\frac{\Delta k}{\mathrm{k}} = s_k \, {}^{y}\!/_{k} - (\delta + n) \qquad (2.11)$$

where

k is capital in per capita terms

$s_k y$ are savings or share of output devoted to private investment.

n is population growth or increase in labour supply

δ is depreciation.

Δ denotes the variable's time derivative.

$$\frac{\Delta A}{A} = \phi(G / y) \quad \phi' \geq 0 \qquad \mathrm{G/y} < (\mathrm{G/y})^* \qquad (2.12)$$

where

G is public infrastructure capital stock

${}^{G}\!/_{y}$ is public infrastructure capital stock as a share of GDP.

(G/y)* is the threshold level.

From equation (2.12), if it is assumed that the threshold level (G/y)* is a 'saturation point', then greater levels of public infrastructure capital as a share of GDP bring about higher rates of growth of efficiency by reducing congestion (see Sanchez-Robles, 1998). Beyond the threshold level, any marginal increments of the public capital stock will not have an impact on output. That is, they do not lead to any further reductions in congestion.

Alternatively, the threshold level (G/y)* can be an under-capacity point', which would imply that if stocks are below this point then their impact would be essentially zero. This is a likely occurrence in developing countries like Uganda. This scenario is empirically explored in Chapter 7.

If we denote the growth rate in (2.9) and (2.11) by γ and substitute, we get

$$\gamma_y = \gamma_A + \alpha \gamma_k \qquad (2.13)$$

then,

$$\gamma_y = \phi(G/y) + \alpha s_k \, {}^{y}\!/_{k} - \alpha(\delta + n) \tag{2.14}$$

The relationship between GDP per capita growth and a proxy of public infrastructure capital is established in equation (2.14). The last term of the equation is net private investment.

From equation (2.14), the following specification can be utilised in estimation:

GDP per capita growth =
$\beta_0 + \beta_1$infrastructure/GDP + β_2Private investment + β_3 X + ε (2.15)

As in other empirical research studies on the determinants of economic growth, X is a vector of regressors representing other explanatory variables to proxy for the deviation from the steady state. These may include proxies for the macroeconomic environment (for example, inflation, exchange rates – black market premium), human capital, the political environment, external factors (export growth, external debt, terms of trade).

Chapters 5, 6 and 7 re-adapt this macro-level formulation to the mcro-/sectoral-level analyses. The analytical framework in this regard is detailed in Chapter 4.

2.6 Concluding Remarks

Although there are differences in the way neoclassical and endogenous growth theories view the role of public infrastructure in the growth process, they both contribute to our understanding of that role and together provide a good basis for empirical analysis. Neoclassical growth theory provides the methodological tools to measure the rate of technological progress while endogenous growth theory can provide an explanation for its evolution. They need not be mutually exclusive, as the distinction between them is more to do with aggregate returns to capital and the implications for long-run productivity. From the neoclassical view, the extension of the investment concept to include investment in human capital, research and development and public infrastructure improves the measurement of inputs, allowing technological progress to be measured accurately, while from the point of view of endogenous growth, a broader concept of capital means constant returns may be possible and realistic (Stiroh, 2001).

In the orthodox neoclassical growth model, steady-state growth is driven by exogenous factors, implying that fiscal policy and public infrastructure in particular can only affect the rate of growth during the transition to the steady state. Therefore the accumulation of public infrastructure capital impacts on growth in the short run, with long-run productivity growth entirely driven by exogenous technical progress.

From the point of view of endogenous growth theory, various activities of government, including provision of infrastructure services, can be viewed as effects on baseline technology, and hence on the growth rate since government investment in public infrastructure capital is assumed to enhance the productivity of private capital.[18] However, a limitation of endogenous growth models like the standard 'AK' type models is that they focus on the impact of public infrastructure on steady-state growth rate of output per capita, which is more relevant to developed than to most developing countries which are producing inside their production possibility frontiers.

On the other hand, classic development theory links public infrastructure to economic growth by presenting it as one of the factors that can explain an old question of development theory: why some countries tend to be caught up in an underdevelopment trap. As in the big push theory in the literature, lack of or too low stocks of public infrastructure may cause underdevelopment to persist in some countries or regions. Development theorists therefore suggest the possibility of non-linearities in the relationship between public infrastructure capital and output growth. This implies that in some circumstances large increases of public investment in infrastructure capital may be required if increases in private investment and higher growth rates are to be achieved. Nonetheless, public infrastructure is seen to be a necessary but not sufficient condition for growth, highlighting the need for policy complementarities.

The review of economic theories and empirical models in this chapter indicates that the role and impact of public infrastructure on output growth could be contextual. As argued in the World Economic and Social Survey (United Nations, 2006) and in development theory, economic growth in sub-Saharan countries, for example, is more about structural change than about investing in technological progress. For these countries, therefore, public infrastructure development can be an essential factor in the growth process since it can play a major role in the process of economic structural change.

Before the presentation of the econometric analyses, the next chapter examines the state of public infrastructure capital in Uganda, analyses the composition and evolution of both private and public fixed capital formation and discusses the role of the public sector in infrastructure provision.

Notes

1. As discussed in Chapter 1, the contribution of TFP is sensitive to whether the quality of labour and capital is included in the analysis.
2. Attempts have therefore been made to explain the determinants of TFP on the basis of different conceptions. Aghion and Howitt (1998), Grossman and Helpman (1991b) and Romer (1990) focus on technological change, Parente and Prescott (1994) on impediments to the adoption of new technologies, Romer (1986) and Lucas (1988) on externalities, Kongsamut et al. (2001) on changes in the sector composition of production, and Harberger (1998) focuses on the adoption of lower-cost production methods (Easterly and Levine, 2001). As discussed earlier, those that focus on non-technological factors are of particular relevance to developing countries.
3. For simplicity, time subscripts are left out.
4. The basis of their argument is that government investments in both the material (for example, roads and railways) and immaterial infrastructure (for example, education and property rights) are essential to economic growth.
5. Hence, public infrastructure is thought of as a necessary but not sufficient pre-condition for growth.
6. Hence, linkages with ,say, the environment are not examined in this study.
7. The term 'Smithian growth' refers to Adam Smith and describes growth that occurs as a result of specialisation and trade.
8. Their study uses a recursive dynamic real computable general equilibrium model of a small open economy with the principal features of a low-income aid-dependent country like Uganda. In fact the underlying social accounting matrix is loosely based on data from Uganda. This is used to simulate the effect of a year-on-year increase in net aid flows. The study concludes that 'the macroeconomic impact of aid depends closely on the underlying microeconomics of the associated public expenditures it finances' (Adam and Bevan, 2006: 289).
9. See Gramlich (1994) for a more extensive review including a discussion of other methods: cost-benefit analyses, engineering needs assessments, and so on.

10. Aggregation of the data at industry, state or country level assumes that firms are identical so that it is possible to aggregate across all firms to obtain the aggregate production function, cost function or profit function. The behaviour of firms is hypothesised to be similar enough to allow aggregation to occur. It is possible that if the public infrastructure capital hypothesis fails, the reason could be failure of the aggregation assumption.
11. The next sub-sections borrow from Sturm et al. (1995, 1998), Batina (2004) and Romp and de Haan (2005).
12. For more examples, see Sturm et al. (1995), Hakfoort (1996) and World Bank (1994).
13. A number of studies (for example, Gramlich, 1994; World Bank, 1994; OECD, 1993; and Hakfoort, 1996) have questioned the validity of research results such as those listed in Appendix A, mainly on the basis of methodological flaws.
14. See Munnell (1992) for a discussion of criticisms and counter-criticisms of methodologies used in the various studies.
15. A public good that is non-rival between industries but congestible and therefore rival within an industry. For example, 'Industries may use G at different times of the year in which case one industry's use may not affect the others' (Feehan and Batina, 2003).
16. A firm-augmenting public input can be used simultaneously by more than one firm within an industry. The public input provides a service to firms regardless of their size. Specifying a public good like this, however, has the unboundedness property, which is problematic. When firm-augmenting public inputs are employed, assumptions that avoid the unboundedness problem have to be invoked, like an exogenously fixed number of firms or a fixed set-up in establishing a firm (Feehan et al. 2004).
17. This section borrows substantially from Sanchez-Robles (1998).
18. The basis of the argument put forward by proponents of the endogenous growth theory is that government investments in both the material (for example, roads and railways) and immaterial infrastructure (for example, education and property rights) are essential to economic growth.

3 Public Infrastructure, Economic Reforms and Growth in Uganda

3.1 Introduction

Chapter 2 established that development theory and new growth theory predict a significant impact of public infrastructure investment on private output, productivity and growth. However, the review of the empirical evidence showed that it is important to take into account the different contexts or environments in which public infrastructure is created, since they may vary significantly to such an extent that the types and magnitudes of economic impacts may differ between countries. Relevant examples of such contextual determinants include the macroeconomic policy climate, level of economic development and developmental stage of the public infrastructure network. An unfavourable macroeconomic policy climate with severe macroeconomic distortions may mean that even investments in 'core' infrastructure may not be productive. The implication is that in countries that have these kinds of macroeconomic problems, investments have to be made in tandem or be preceded by macroeconomic structural adjustment.

With regard to the level of development, when a country or region is at a particular stage of development public infrastructure investments can enhance growth and stimulate significant changes in the structure of production, leading to acceleration of the growth process. Kelly (1997) illustrated this for China in his model of dynamic Smithian growth. As far as the developmental stage is concerned, investments will not have as much impact in countries or regions that already have large stocks of infrastructure capital as it will in those with underdeveloped infrastructure, other things remaining constant.

All this has implications for the appropriate institutional framework for infrastructure provision. Viable private provision depends on whether market structures, technology or the nature of property rights facilitate feasibility of exclusion (Feehan et al., 2004). While most types of infrastructure are rival, that is, congestible, which is an attribute shared with private inputs, there are significant problems with exclusion. While exclusion for some public infrastructure such as electricity is feasible in developed economies, enforcement of exclusion is more difficult in less-developed economies like Uganda, so they are better categorised as congestible public inputs. There is a high cost of excluding economic agents, and in cases where the exclusion costs become manageable, for example due to technological improvements, a natural monopoly tends to arise. Monopolies lead to inefficiency because they are profit-maximisers and may reduce output so that price is higher than marginal cost. All these justify a greater role for the public sector, especially in sub-Saharan Africa.

Before the quantitative econometric analyses are done in Chapters 5, 6 and 7, this chapter assesses and compares the stock of public infrastructure capital in Uganda with that in other countries, particularly those at the same level of development, and traces the evolution of both public and private fixed capital formation over the last 20 years with a view to assessing the implications for future growth. The detailed exploratory data analysis is done as follows.

In the next section, the levels of public infrastructure capital stocks in Uganda are compared with stocks in other countries, first with other East African countries, then with other sub-Saharan African countries, and finally with low-income countries. Section 3.3 analyses trends in selected physical measures of 'core' public infrastructure capital and corroborates them with results from firm perception surveys carried out to determine the major constraints to firm investments. It then assesses whether there is a correlation between the implementation of economic reforms and the composition and trends in public fixed capital formation, and discusses the implications for private investment and current and future output and growth. Section 3.4 discusses the existing institutional frameworks for the provision of different types of infrastructure and assesses the institutional options for provision vis-à-vis the role of the public sector. Lastly, concluding remarks are made in section 3.5.

3.2 The State of Infrastructure and Trends in Selected Physical Measures

Public infrastructure capital stocks in Uganda are very low even when compared with those in other low-income countries. Table 3.1 uses some selected measures of 'core' infrastructure to show that stocks in low-income countries are in general much lower than those in middle- and high-income countries in per capita terms. However, what is more important is that Uganda's stocks are considerably lower than the average stocks of other low-income countries. Comparison with other sub-Saharan African countries shows that poor and inadequate infrastructure is not unique to Uganda;[1] the problem is only more serious in Uganda, whose infrastructure stocks in 1999 were less than half the average for sub-Saharan Africa even with the exclusion of South Africa. For example, Uganda's electricity-generating capacity was 0.008 kW per capita, compared with 0.04 kW per capita for sub-Saharan Africa (excluding South Africa).

Table 3.1 also shows that Uganda's teledensity was just 2.6 mainlines per 1000 persons in 1999, which was about one-third the average for sub-Saharan Africa (excluding South Africa) and about one-tenth the average for other low-income countries. Comparison with East African countries highlights the extent of the underinvestment. Kenya and Tanzania had 10.3 and 4.7 mainlines per 1000 persons respectively in 2002, while Uganda had 2.4, a decline from 1999. However, there is significant growth in mobile telephony as shown in sub-section 3.4.3, although access is very limited, especially in rural areas.

Per capita stocks have also declined over time, with the 1999 level of stocks of some major types of infrastructure being lower than in the 1970s (see Tables 3.1 and 3.2). Obviously there have been no significant increases in infrastructure provision in per capita or per square kilometre terms for a long time. This assessment is corroborated by other studies, for example, Deininger and Okidi (2003). Table 3.2 shows that Uganda's stocks have fallen far behind those of Kenya and Tanzania.

Table 3.1

Selected Measures of Infrastructure Provision: Uganda Compared with Sub-Saharan Africa (excluding South Africa), and Low-, Middle- and High- income Countries

Year	UGANDA 1980	1992	1999	Sub-Saharan Africa (excluding South Africa) **(1996-2000)**	Low-income countries 2000	Middle-income countries 2000	High-income countries 2000
Paved roads (km/1000 person)	0.3	0.1	0.1	0.4	1.1	1.1	10.5
Paved roads in km/Sq.Km (000s)	19.6	12.3	14.2				
Telephone Mainlines (per 1000 persons)	2.0	1.7	2.6	8.0	28.0	127.0	584.0
Electricty-generating capacity (kilowatts per capita)	0.01	0.01	0.01	0.04	116.0	406.0	2,031
Percentage of households with access to electricity		7.0	7.0				
Mean district-level distance to nearest public telephone (kms)		30.06	30.27				

Notes:

1. The figure for paved roads in sub-Saharan Africa (SSA) is for 1996, computed from *World Bank Africa Database* (2001).
2. The figure for telephone mainlines in SSA is for 1996–2002, from *World Bank Africa Database*.
3. The figure for electricity-generating capacity in SSA is for 1997, computed from US Energy Information Administration data.

Sources:

1. Own computations based on *World Bank Africa Database* (2004), World Bank (1994, 2001), World Bank (2003).
2. Fay and Yepes (2003).
3. *Uganda National Household Survey*, 1992/93 and 1999/2000.
4. Uganda Bureau of Statistics, *Statistical Abstract* (2003).
5. US Energy Information Administration, http://www.eia.doe.gov/neic/historic/hinternational.htm

Table 3.2
Physical Measures of Infrastructure in Uganda, Kenya and Tanzania

Country	Year	Telephone Mainlines (per 1000 persons)	Mobile phones (per 1000 persons)	Paved roads (road density) (km per 1000 persons)	Electricity production (millions of kilowatt-hours) per million persons
Uganda	1970	1.4		0.2	79.0
	1980	1.5		0.3	51.0
	1990	1.7		0.1	35.0
	1999	2.6	3.2	0.1	55.0
	2002	2.4	20.6	n.a	69.0
Kenya	1970	3.4		0.2	51.0
	1980	4.5		0.3	90.0
	1990	7.9		0.3	130.0
	1999	10.6	1.6	0.5	n.a
	2002	10.3	41.5	n.a	143.0
Tanzania	1970	1.1		0.2	35.0
	1980	2.1		0.2	38.0
	1990	3.1		0.1	35.0
	1999	4.7	0.8	0.1	66.0
	2002	4.7	19.5	n.a	81.5

Notes:

1. The 1999 figure for paved roads in Kenya is for 1991; the1999 figure for paved roads in Tanzania is for 1994.
2. The 1999 figures for electricity production in Uganda and Tanzania are for 1998.

Sources: Own calculations based on data from International Telecommunications Union, Uganda Communications Commission, World Bank (1994, 2001) and *World Bank Africa Database* (2001, 2004).

3.2.1 Perceptions of firm managers – 1994 and 1998 firm surveys

World Bank studies reviewed by Reinnika and Svensson (2001) corroborate the above evidence, which suggests that the existing stocks of physical infrastructure are less than optimal. Firms place infrastructure high on the list of constraints to investment in Uganda. Two enterprise surveys conducted in 1994 and 1998 enabled an examination of the dynamics of the business environment and constraints as perceived by the private sector. They covered firms with five or more employees with the following size breakdown: small (5 to 20 employees), medium (21 to 100 employees) and large (more than 100 employees). The 1998 survey covered the manufacturing sector, which was divided into agro-processing and other manufacturing, tourism, commercial agriculture, and construction. The 1994 survey included firms from more sub-sectors.

While in 1994 infrastructure was ranked as a 'moderate' constraint, in 1998 it was ranked at the top as a 'major' constraint, with unreliable and inadequate electricity supply being the most binding constraint. The analysis of the constraints by firm category in the 1998 survey indicated little difference in the relative rankings by small and large firms. However, higher perception scores by the large firms indicated that the constraints were generally more binding for large firms than for small ones. For Kampala-based firms,[2] access to infrastructure (utility) services was not as binding as in other districts. The results also indicated that infrastructure services such as electricity are characterised by high costs and frequent supply interruptions. In order to mitigate the deficiencies and gaps in the publicly supplied infrastructure services, firms invest in complementary capital; for example, they may install power generators to circumvent unreliable and inadequate electricity or may hire messengers to bypass unreliable telephone services.

However, firms deal with infrastructure deficiencies in different ways. Some opt for self-sufficiency while others blend public and own provision or remain captive to an inadequate public service.[3] Those firms that remain captive to the inadequate infrastructure are likely to incur the higher costs associated with public service deficiencies, depending on the production technology used. Some firms may be so sensitive to fluctuations in power supply when they are in the 'captive' regime that any interruption in supply forces them to shut down. This has negative effects on productivity as well as amount and quality of output, let alone the firms' investment rates. Firms that opt for self-sufficiency or blending incur high unit costs because of scale economies in comparison with public provision, which should have an effect on their expansion plans (investment). Hence, self-provision of infrastructure could crowd out private investment and negatively affect output growth.

3.3 Fiscal Adjustment and Fixed Capital Formation: Implications for Output and Productivity Growth

As observed in Chapter 1, a combination of increased aid inflows and implementation of economic reforms in the late 1980s and throughout the 1990s had a positive impact on growth in some countries like Uganda.[4]

However, as shown below, recovery of domestic private investment has been modest and public investment as a percentage of GDP has declined. Researchers like Rodríguez (2006) argue that fiscal adjustment is resulting in contractions in public investment expenditures relative to GDP, with serious implications for the accumulation of public infrastructure capital and productive private capital. Before discussing fiscal adjustment in relation to trends in private and public fixed capital formation, we shall examine the extent to which underinvestment in infrastructure is reflected in the composition of aid flows to Uganda (a major source of public investment funds) by assessing trends in the composition of official development assistance by purpose (sector) as well as the composition of government expenditure during the period of economic reform.

Table 3.3 shows official development assistance (ODA) flows to Uganda from 1985 to 2004. It summarises bilateral donor aid commitments to Uganda and their intended purpose as classified by the Organisation for Economic Co-operation and Development (OECD).[5] The table contains broad classifications and the constituents of each category are as follows.

a. Social and infrastructure services

This is aid aimed at developing human resource potential as well as ameliorating living conditions. It includes educational infrastructure and services; health and population; water supply, use and sanitation; and river development. It excludes irrigation systems for agriculture.

b. Economic infrastructure and services

This constitutes aid for the type of infrastructure investments that are the focus of this study. It covers assistance to networks, utilities and services that facilitate economic activity. It includes energy (its production and distribution, including peaceful use of nuclear energy) and transport and communications (equipment or infrastructure for road, rail, water and air transport, and for television, radio and electronic information networks).

c. Production sectors

This covers contributions to directly productive sectors. It comprises agriculture, industry, mining and construction, and trade and tourism.

d. Multisector

This includes support to projects that cross-cut several sectors, with a concentration on the environment, gender projects, and urban and rural development.

e. Programme assistance

This includes developmental contributions other than debt reorganisation (for example, balance of payments and budget support) as well as funds made available for capital projects of the recipient's choice. It mainly includes sector-unallocated structural adjustment assistance and food aid.

f. Action relating to debt

This covers debt forgiveness, rescheduling, refinancing, and so on.

g. Emergency aid

Under this heading comes emergency and distress relief in cash or kind, including relief food and aid to refugees.

h. Other and unallocated/unspecified

This is aid that cannot be assigned to another part of the table, and in the case of project or sector assistance, commitments for which the sectoral destination had not been specified. It includes aid to non-governmental organisations and administrative costs.

As Table 3.3 shows, social and infrastructure services take a large share of bilateral aid. Although as low as 5 per cent in the 1985–89 period, it increases substantially to 34.7 per cent and 43.8 per cent during 1990–94 and 1995–99 respectively and declines slightly to 38.3 per cent during 2000–04. Another important area is programme assistance, which rises from 2 per cent to 27.7 per cent between 1985–89 and 2000–04, reflecting the response of aid donors to Uganda's perseverance in implementing economic reforms given that this aid is in support of structural adjustment programmes.

However, aid for economic infrastructure and services as well as production sectors declines substantially over these periods. For production sectors it falls from 39 per cent to 7.1 per cent while for economic infrastructure and services it falls from 34 per cent to just 4.3 per cent of total bilateral ODA commitments. Although bilateral ODA is only part of total ODA, it constitutes more than half of total ODA (as shown in Table 3.3) and therefore provides a fair reflection of percentage shares of ODA financial flows to the different sectors.

As argued by Schwartz et al. (2004), aid to post-conflict countries like Uganda tends to peak immediately after the conflict as a result of increased attention from the international community. However, it is during this time that the country faces political and administrative constraints that limit absorptive capacity and so aid is not used as productively.

Unfortunately, as the country builds up its capacity to absorb aid productively in the middle phase of the post-conflict period, aid begins to decline as donor interest wanes due to disillusionment with slow reconstruction processes or emergence of new post-conflict situations. Collier and Hoeffler (2002) demonstrate that the aid profile pattern is an initial burst followed by a gradual decline. Although Uganda has continued to be a focus of aid donors, Table 3.3 reveals a similar pattern. Total net ODA as a percentage of GDP increases from 12 per cent during 1985-89 to 19.9 per cent during 1990-94 but gradually declines to 13.4 per cent during 2000-04. As noted before, economic infrastructure and services suffer a disproportionate decline. As argued in Chapter 1 and section 3.2 of this chapter, there is an obvious need for substantial infrastructure investments to sustain the country's growth performance, but aid trends are inconsistent with this need.

Table 3.3
Official Development Assistance (ODA) to Uganda (1985-2004), by Purpose

		(Million US Dollars)		
Bilateral ODA commitments by purpose				
Purpose	**1985-89**	**1990-94**	**1995-99**	**2000-04**
1. Social and infrastructure services	n.a	545.8	929.9	1097.6
2. Economic infrastructure and services	n.a	229.8	232.8	122.6
3. Production sectors	n.a	329.0	146.3	204.0
4. Multisector	n.a	84.7	105.7	108.4
5. Programme Assistance	n.a	304.3	281.3	793.0
6. Action relating to Debt	n.a	47.0	264.7	197.3
7. Emergency Assistance	n.a	5.5	66.3	265.7
8. Unallocated/Unspecified	n.a	28.5	94.0	76.5
Total Bilateral ODA commitments		**1574.6**	**2121.0**	**2865.1**
Bilateral ODA commitments by purpose		**Percentage shares by purpose**		
Purpose	**1985-89**	**1990-94**	**1995-99**	**2000-04**
1. Social and infrastructure services	5	34.7	43.8	38.3
2. Economic infrastructure and services	34	14.6	11.0	4.3
3. Production sectors	39	20.9	6.9	7.1
4. Multisector	0	5.4	5.0	3.8
5. Programme Assistance	2	19.3	13.3	27.7
6. Action relating to Debt	2	3.0	12.5	6.9
7. Emergency Assistance	1	0.3	3.1	9.3
8. Unallocated/Unspecified	0	1.8	4.4	2.7
9. Technical co-operation	17			
Total	**100**	**100**	**100**	**100**
	1985-89	**1990-94**	**1995-99**	**2000-04**
Total ODA NET (Million US Dollars)	**1552.9**	**3427.9**	**3557.6**	**4460.5**
Total ODA NET (% Real GDP)	**12**	**19.9**	**14.3**	**13.4**
Bilateral ODA commitments(% of Total ODA NET)		45.93	59.62	64.23

Note: For 1985–1989, the OECD reports the figures only in percentage terms.
Source: Author's calculations based on OECD data on geographical distribution of financial flows to aid recipients (various years).

The composition of government expenditure should to some extent mirror the bilateral donor aid patterns highlighted above. This is because net aid as a percentage of public expenditure has been a little more than 50 per cent for the last several years (Collier and Reinikka, 2001a). Table 3.4 (sectoral composition of recurrent expenditure as percentage of total public expenditure), Table 3.5a (sectoral composition of development expenditure as percentage of total public expenditure) and Table 3.5b (sectoral composition of development expenditure as percentage of GDP) provide some indication of the government's expenditure priorities. Although Table 3.3 is not directly comparable with these tables, it can be seen that, as in Table 3.3, social sectors (including education and health) take a substantial share while economic infrastructure and services such as roads and production sectors such as agriculture have a very small share. Consistently with the analysis in Hicks (1991), which was discussed in Chapter 1, it is apparent that social sectors and defence are the priority sectors in addition to public administration.

In 1994/95, for example, recurrent expenditure on education and health constituted about 15.7 per cent of total public expenditure, defence 11.3 per cent and roads and works 1.1 per cent.

In 2003/04, for which there is relatively better disaggregated data, including foreign aid flows to the different sectors, total (including recurrent and development) expenditure on education and health constituted about 24 per cent of total public expenditure, public administration had 17 per cent, defence 9.4 per cent, roads and works 7.3 per cent and agriculture 1.1 per cent. After 1999/00, when policy focused heavily on the need for road improvement, expenditure on the sector did increase somewhat, but the expenditure emphasis still remained on the sectors identified by Hicks (1991). This was particularly due to donor preferences and conditions in regard to education and health expenditure.

Table 3.4
Sectoral Composition of Uganda Government Recurrent Expenditure as Percentage of Total Public Expenditure, 1994/95-2003/04

Sector	1994/95	1995/96	1996/97	1997/98	1998/99	1999/00	2000/01	2001/02	2002/03	2003/04
Roads and Works	1.06	0.79	0.99	0.87	1.59	1.46	1.33	1.47	1.45	1.24
of which:										
Works, Housing and Communications	0.99	0.75	0.62	0.71	0.88	0.87	0.62	0.74	0.72	0.21
Road Maintenace	0.07	0.04	0.37	0.16	0.71	0.59	0.71	0.73	0.73	1.03
of which:										
Trunk Roads	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43
District Roads	0.07	0.04	0.37	0.16	0.71	0.59	0.71	0.61	0.59	0.50
Urban Roads	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.14	0.10
Agriculture	1.09	0.52	0.46	0.41	0.35	0.44	0.37	0.34	0.43	0.37
Education	11.25	10.61	12.72	14.72	15.58	12.50	10.93	11.51	12.69	12.15
Health	4.40	5.28	3.67	3.80	3.59	3.16	3.32	4.48	5.11	4.70
Water						0.24	0.08	0.06	0.07	0.08
Public Administration	12.18	13.35	12.65	15.76	13.07	12.18	10.95	11.36	11.34	11.12
Justice/law and order	5.02	5.45	4.95	5.33	4.79	4.05	3.10	3.67	3.76	5.06
Econ'c functions & social services	2.18	1.06	1.08	0.98	0.66	0.58	0.57	0.76	0.94	0.87
Security (Defence)	11.33	10.76	10.46	9.77	13.28	9.10	7.68	7.43	7.84	9.11
Interest Payments	4.78	5.04	4.23	4.47	4.32	4.62	4.70	4.91	4.55	6.91
of which:										
Domestic Interest	0.49	1.01	1.12	2.08	1.45	1.47	2.33	2.88	2.32	5.18
External Interest	4.29	4.03	3.11	2.39	2.86	3.14	2.38	2.03	2.23	1.73
Total	58.07	57.91	55.44	60.57	61.55	52.95	47.74	50.89	52.73	58.52

Note: Figures for 1998/99 and 2000/01 are provisional outturns, while for 2002/03 they are from the approved budget. The remaining years are budget outturns.
Source: 'Medium-term Expenditure Framework Tables' in *Background to the Budget* (various years). Kampala: Ministry of Finance, Planning and Economic Development.

Table 3.5a

Sectoral Composition of Public Development Expenditure as Percentage of Total Public Expenditure, 1994/95-2003/04

Sector	1994/95		1995/96		1996/97		1997/98		1998/99	
Source of Funds	Local	Foreign Aid	Local	Foreign Aid	Local	Foreign Aid	Local	Foreign Aid	Local	Foreign Aid
Roads and Works	1.54	n.a	1.79	n.a	3.10	n.a	2.00	n.a	2.43	n.a
of which:										
Works, Housing and Communications	1.05	n.a	1.39	n.a	2.23	n.a	1.41	n.a	2.43	n.a
Trunk Road Maintenance		n.a		n.a		n.a		n.a		n.a
District Road Maintenance		n.a		n.a		n.a		n.a		n.a
Urban Road Maintenance	0.50	n.a	0.40	n.a	0.87	n.a	0.59	n.a		n.a
Agriculture	0.52	n.a	0.39	n.a	0.39	n.a	0.26	n.a	0.33	n.a
Education	0.70	n.a	0.49	n.a	0.49	n.a	0.51	n.a	1.93	n.a
Health	0.43	n.a	0.56	n.a	0.83	n.a	0.51	n.a	0.61	n.a
Water		n.a		n.a		n.a		n.a		n.a
Public Administration	0.49	n.a	0.16	n.a	0.76	n.a	0.34	n.a	1.00	n.a
Justice/law and order	0.37	n.a	0.38	n.a	0.30	n.a	0.20	n.a	0.42	n.a
Economic functions and social services	3.44	n.a	2.62	n.a	2.85	n.a	2.63	n.a	1.97	n.a
Security (Defence)	0.41	n.a	0.48	n.a	0.63	n.a	0.62	n.a	0.45	n.a
Total % of Total Govt Expenditures	**9.44**	**32.49**	**8.66**	**33.43**	**12.44**	**32.12**	**9.06**	**30.37**	**11.56**	**26.89**
Local % of Total Development funds		22.51		20.58		27.92		22.98		30.08
Aid % of Total Development funds		77.49		79.42		72.08		77.02		69.92

Notes:

1. For 1994/95 – 1998/99 the figures for foreign aid are only available in aggregate.
2. Figures for 1998/99 and 2000/01 are provisional outturns, while for 2002/03 they are from the approved budget. The remaining years are budget outturns.
3. Because of the nature of budget reporting, development expenditure includes some recurrent expenditure.

Source: 'Medium-term Expenditure Framework Tables' in *Background to the Budget* (various years). Kampala: Ministry of Finance, Planning and Economic Development.

Table 3.5a *(continued)*

Sector	1999/2000		2000/2001		2001/2002		2002/2003		2003/2004	
Source of Funds	Local	Foreign Aid	Local	Foreign Aid	Local	Foreign Aid	Local	Foreign Aid	Local	Foreign Aid
Roads and Works	3.44	6.20	3.37	6.77	3.55	6.14	3.28	5.23	2.84	3.18
of which:										
Works, Housing & Communications	3.44	6.20	3.37	6.77	3.55	6.14	3.28	5.23	1.65	2.78
Trunk Road Maintenance	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	1.19	0.40
District Road Maintenance	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
Urban Road Maintenance	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
Agriculture	0.44	2.66	0.48	2.99	1.02	2.72	1.04	2.72	0.91	1.74
Education	3.25	1.52	3.09	1.61	3.08	1.46	3.20	1.44	2.25	1.95
Health	0.81	5.59	0.74	5.16	0.74	2.63	1.05	4.47	1.08	4.88
Water	0.66	3.07	1.30	3.73	1.51	3.38	1.46	2.43	1.40	1.13
Public Administration	0.57	0.29	0.72	0.47	1.04	0.43	0.86	0.64	1.46	5.07
Justice/law and order	0.37	0.10	0.50	0.18	0.41	0.16	0.72	0.17	0.43	0.17
Economic functions & social services	2.19	6.03	2.25	8.51	3.16	7.81	3.78	5.90	2.58	4.13
Security (Defence)	0.21	0.00	0.27	0.00	0.19	0.00	0.39	0.00	0.24	0.02
Total % of Total Govt Expenditures	**15.39**	**31.67**	**16.08**	**36.19**	**18.23**	**30.88**	**19.05**	**28.22**	**16.02**	**25.46**
Local % of Total Development funds		32.70		30.76		37.13		40.31		38.63
Aid % of Total Development funds		67.30		69.24		62.87		59.69		61.37

Notes:
1. Figures for 2002/03 are from the approved budget. The remaining years are budget outturns.
2. Because of the nature of budget reporting, development expenditure includes some recurrent expenditure.

Source: 'Medium-term Expenditure Framework Tables' in *Background to the Budget* (various years). Kampala: Ministry of Finance, Planning and Economic Development.

Table 3.5b

Sectoral Composition of Public Development Expenditure as Percentage of GDP, 1994/95– 2003/04

Sector	1994/95		1995/96		1996/97		1997/98		1998/99	
Source of Funds	Local	Foreign Aid	Local	Foreign Aid	Local	Foreign Aid	Local	Foreign Aid	Local	Foreign Aid
Roads and Works	0.30	n.a	0.33	n.a	0.63	n.a	0.37	n.a	0.50	n.a
of which:									0.00	
Works, Housing & Communications	0.20	n.a	0.25	n.a	0.46	n.a	0.26	n.a	0.50	n.a
Trunk Road Maintenance		n.a		n.a		n.a		n.a		n.a
District Road Maintenance		n.a		n.a		n.a		n.a		n.a
Urban Road Maintenance	0.10	n.a	0.07	n.a	0.18	n.a	0.11	n.a		n.a
Agriculture	0.10	n.a	0.07	n.a	0.08	n.a	0.05	n.a	0.07	n.a
Education	0.13	n.a	0.09	n.a	0.10	n.a	0.09	n.a	0.40	n.a
Health	0.08	n.a	0.10	n.a	0.17	n.a	0.09	n.a	0.13	n.a
Water		n.a		n.a		n.a		n.a		n.a
Public Administration	0.09	n.a	0.03	n.a	0.16	n.a	0.06	n.a	0.21	n.a
Justice/law and order	0.07	n.a	0.07	n.a	0.06	n.a	0.04	n.a	0.09	n.a
Economic functions & social services	0.66	n.a	0.48	n.a	0.58	n.a	0.49	n.a	0.41	n.a
Security (Defence)	0.08	n.a	0.09	n.a	0.13	n.a	0.11	n.a	0.09	n.a
Total (all sectors)	**1.80**	**6.21**	**1.57**	**6.07**	**2.54**	**6.57**	**1.67**	**5.60**	**2.40**	**5.57**

Notes:

1. Because of the nature of budget reporting, development expenditure includes some recurrent expenditure.
2. Includes donor-financed development projects.

Source: 'Medium-term Expenditure Framework Tables' in *Background to the Budget* (various years). Kampala: Ministry of Finance, Planning and Economic Development.

Table 3.5b *(continued)*

Sector	1999/2000		2000/2001		2001/2002		2002/2003		2003/2004	
Source of Funds	Local	Foreign Aid	Local	Foreign Aid	Local	Foreign Aid	Local	Foreign Aid	Local	Foreign Aid
Roads and Works	0.79	1.42	0.88	1.77	1.08	1.87	0.89	1.41	0.77	0.87
of which:										
Works, Housing & Communications	0.79	1.42	0.88	1.77	1.08	1.87	0.89	1.41	0.45	0.76
Trunk Road Maintenance	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	0.32	0.11
District Road Maintenance	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
Urban Road Maintenance	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
Agriculture	0.10	0.61	0.13	0.79	0.31	0.83	0.28	0.73	0.25	0.47
Education	0.75	0.35	0.81	0.42	0.94	0.45	0.86	0.39	0.61	0.53
Health	0.19	1.28	0.19	1.35	0.23	0.80	0.28	1.21	0.29	1.33
Water	0.15	0.70	0.34	0.98	0.46	1.03	0.39	0.66	0.38	0.31
Public Administration	0.13	0.07	0.19	0.12	0.32	0.13	0.23	0.17	0.40	1.38
Justice/law and order	0.08	0.02	0.13	0.05	0.12	0.05	0.19	0.05	0.12	0.05
Economic functions & social services	0.50	1.38	0.59	2.23	0.96	2.38	1.02	1.59	0.70	1.13
Security (Defence)	0.05	0.00	0.07	0.00	0.06	0.00	0.11	0.00	0.06	0.01
Total (all sectors)	**3.53**	**7.26**	**4.22**	**9.49**	**5.56**	**9.42**	**5.14**	**7.62**	**4.36**	**6.93**

Notes:
1. Because of the nature of budget reporting, development expenditure includes some recurrent expenditure.
2. Includes donor-financed development projects.

Source: 'Medium-term Expenditure Framework Tables' in *Background to the Budget* (various years). Kampala: Ministry of Finance, Planning and Economic Development.

In development expenditure, which is 70 per cent financed by foreign aid on average (see Table 3.5a), roads and works seems to have a relatively reasonable share compared with other items. However, it was only about 1.6 per cent of total GDP in 2003/2004, a drop from about 2.2 per cent in 1999/2000.[6] It is also important to note that, due to the way budget reporting is done in Uganda, almost all of this is actually expenditure on rehabilitation, upgrading, and a good part of maintenance as well as administrative costs. After a long period of ignoring expenditure on maintenance and the consequent decline in stocks (particularly prior to 1999/2000) as illustrated previously, the government's expenditure priorities focused not on construction of new roads but on rehabilitation, improvement and maintenance (Ministry of Works, Housing and Communications, 2002). However, a clear distinction between recurrent and development budgets is difficult to make, even between these expenditure types. Apparently the distinction is made on the basis of whether it is periodic maintenance (which is included in the development budget) or routine maintenance (placed in the recurrent budget). Thus, there are likely to be some discrepancies with national accounts data. To obtain a clearer picture, this study conducts further analysis using aggregate and disaggregated national accounts data on trends and composition of private and public fixed capital formation.

Nevertheless, the total share devoted to road maintenance (in both, recurrent and development budgets) for 2003/04, for which there is complete data, is 0.7 per cent of GDP. This compares well with the required minimum annual average expenditure on maintenance estimated by Fay and Yepes (2003) at about 0.73 per cent of GDP for sub-Saharan countries. However, it is important to note that in Uganda's case maintenance comprises more than just routine maintenance; it includes periodic maintenance. Assuming that what is in the recurrent budget is routine maintenance, the figure drops to just 0.28 per cent of GDP, which is substantially lower than Fay and Yepes (2003)'s estimate.

This, coupled with no new investments in road construction, implies significant underinvestment given the already very low existing stocks. However, as discussed previously, the decline in public investment is not unique to Uganda. The adverse effect of fiscal deficit targets on public investments is continually coming to the centre of policy discourses between developing countries and the international financial institutions. This has prompted the International Monetary Fund (IMF) to undertake studies in a sample of countries including Brazil, Chile, Colombia, Ethiopia, Ghana, India, Jordan and Peru. The study's conclusions are that public investment had indeed declined during the period of adjustment (IMF, 2005).[7] Table 3.6 compares the performance of public investment and private investment in the sample countries and Uganda. It shows that the decline in public investment in Uganda was more than the group average during the period studied, dropping from 4.95 per cent of GDP for 1994/95 - 1998/99 to 3.85 per cent of GDP for 1999/00 - 2003/04. There was also a slight drop in private investment as a percentage of GDP, from 11.9 per cent to 11.72 per cent. Public investment as a percentage of GDP for the countries in the IMF (2005) study was 6.9 per cent (group average for the first period) and dropped to 5.8 percent in the subsequent period. Similar trends are observed in private investment (see Table 3.6).

Table 3.6
Public and Private Investment as Percentage of GDP (annual averages), 1994-2003

	1994 - 1998			1999 - 2003			Change		
Country	**Private**	**Public**	**Total**	**Private**	**Public**	**Total**	**Private**	**Public**	**Total**
Brazil	17.4	2.6	20.0	17.0	1.8	18.7	-0.4	-0.9	-1.3
Chile	22.1	3.8	25.9	18.4	2.6	21.0	-3.7	-1.2	-5.0
Colombia	13.7	7.6	21.3	7.2	6.2	13.4	-6.5	-1.4	-7.9
Ethiopia	7.6	9.0	16.5	9.1	9.9	19.0	1.5	0.9	2.5
Ghana	8.9	13.1	22.0	13.7	9.7	23.4	4.8	-3.4	1.4
India	17.0	7.3	24.3	17.4	6.1	23.5	0.4	-1.2	-0.8
Jordan	20.7	6.9	27.6	15.5	6.8	22.3	-5.2	-0.1	-5.3
Peru	18.5	4.6	23.0	15.6	3.4	19.0	-2.9	-1.2	-4.0
Group average	15.7	6.9	22.6	14.2	5.8	20.0	-1.5	-1.0	-2.5
Group median	17.2	7.1	22.5	15.6	6.1	20.0	-1.6	-1.2	-2.6
	1994/95 - 1998/99			**1999/00 - 2003/04**			**Change**		
Country	**Private**	**Public**	**Total**	**Private**	**Public**	**Total**	**Private**	**Public**	**Total**
UGANDA	**11.9**	**5.0**	**16.8**	**11.7**	**3.9**	**15.6**	**-0.2**	**-1.1**	**-1.2**

Source: IMF (2005) and own calculations based on National Accounts data from Uganda Bureau of Statistics.

3.3.1 Trends in fixed capital formation in Uganda during the period of economic reform, 1981/82–2004/05

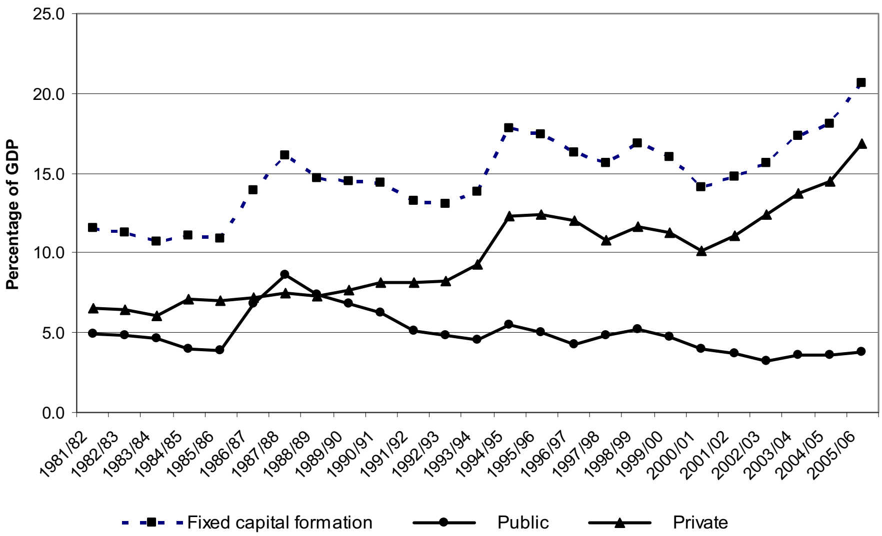
It is important to assess whether there is a relationship between the implementation of economic reforms and trends in fixed capital formation, and to analyse the implications for output and productivity growth. Figures 3.1 and 3.2 show that despite significant increase in foreign aid at the beginning of the 1980s, public investment as a percentage of GDP fell from 1981/82 to 1985/86, coinciding with the period of Uganda's first attempt at stabilisation and structural adjustment. The decline in public investment seems to have been a result of the reforms, which included ceilings on the budget deficit (Uganda, 1983).[8]

The reform programme was abandoned in 1984 after disagreements with the IMF over the levels of public expenditure. The government wanted to increase military expenditure to counter escalating insurgency as well as to increase public sector wages in view of the forthcoming elections. It was also a time when the civil war that had been going on since 1981 had reached its peak. The government was overthrown in 1986 and public investment increased between 1985/86 and 1987/88.

In 1987, the new government adopted the IMF/World Bank policies, which was the second attempt at stabilisation and structural adjustment. Although a number of slippages occurred, especially between 1987 and 1988, the required reforms were implemented with unprecedented commitment. Public investment as a percentage of GDP has seen a persistent decline since the onset of the economic reforms, falling from about 8.6 per cent in 1987/88 to 3.6 per cent in 2004/05, again despite the significant increases in aid from the late 1980s.

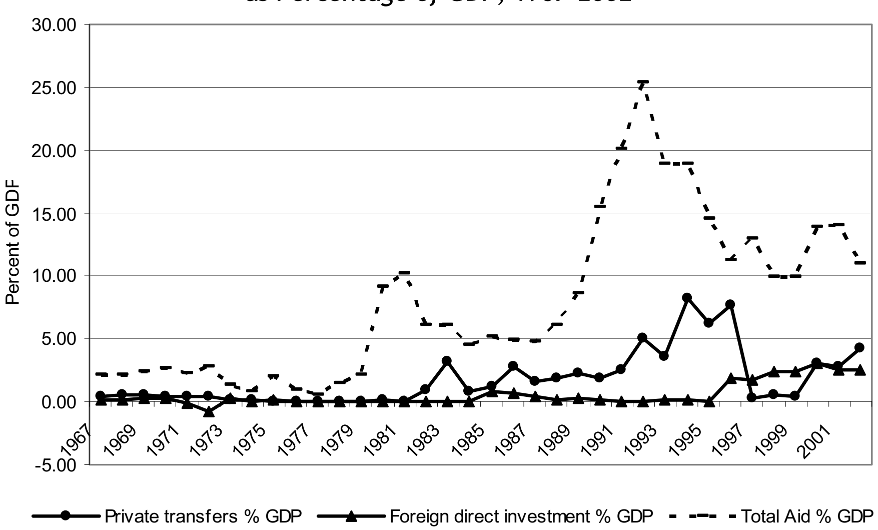
The proponents of the reform policies would argue that strengthening of expenditure controls as well as 'prioritisation' of public expenditures, among other reform measures, resulted in a steady improvement in economic performance, including growth in private investment, which augurs well for future growth. However, a more disaggregated analysis of both public and private investment paints the opposite picture (see subsection 3.3.2 below). Private investment is driven by construction financed by private transfers from abroad and foreign aid inflows (Figures 3.1 and 3.2). In addition, as argued by Collier and Reinikka (2001b) Uganda's good economic growth performance must be seen from the perspective of the conditions that prevailed before implementation of the 1987 reform programmes. The economic growth can be attributed to

Figure 3.1
Evolution of Fixed Capital Formation, 1987/88—2004/05



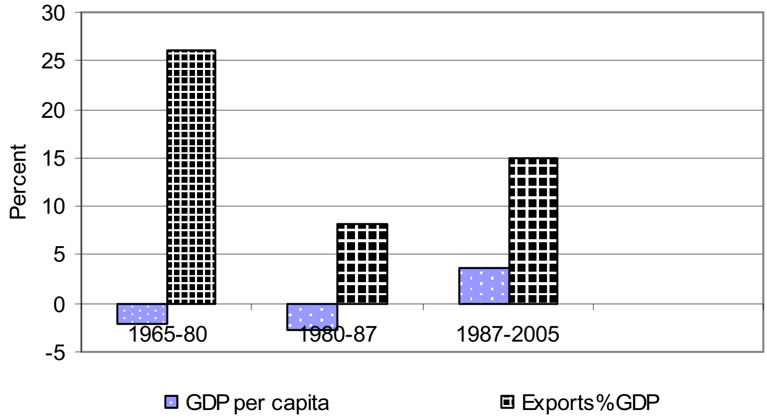
Source: Primary data from Ministry of Finance, Planning and Economic Development and Uganda Bureau of Statistics.

Figure 3.2
Foreign Aid, Private Transfers and Foreign Direct Investment as Percentage of GDP, 1967-2002



Source: World Bank Africa Database (2004).

Figure 3.3
*Uganda's GDP per Capita Growth and Exports as Percentage of GDP, 1965–2005***



	1965 - 80	1980 - 87	1987 - 2005
Per capita GDP growth	-2.1	-2.7	3.6
	1965	**1987**	**2005**
Exports % GDP	26	8.2	14.9

Note: **The figures for exports as % GDP are for one calendar year as shown in the table.
Sources: Helleiner (1992), World Bank (2006) and Ministry of Finance, Planning and Economic Development.

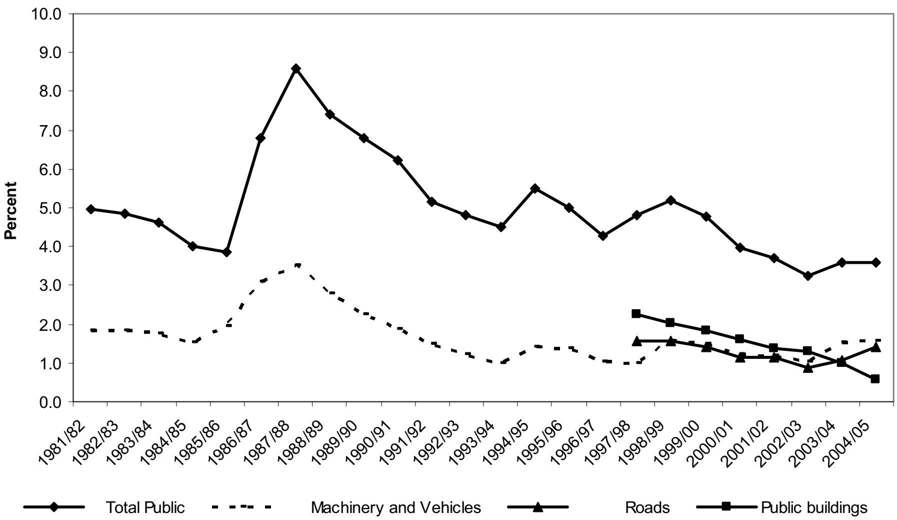
recovery from civil wars in different years during 1966-86 as well as to improvements in economic management during the reform period. With significant improvements in regard to these two aspects over the last several years, the opportunities for growth through recovery are gradually being exhausted. The growth trends shown in Figure 3.3, with negative growth during the troubled years, suggest that this may well be the case.

3.3.2 Trends in components of public and private investment in Uganda, 1981/82–2004/2005

For the period for which data are available, public investment comprises several subcategories of investment classified under two major headings:

Plant, Machinery and Vehicles, and Construction. Construction consists of public buildings and roads. Similarly, private investment comprises Plant, Machinery and Vehicles, and Construction. Construction comprises private buildings and informal housing. Analysis of the composition and evolution of public investment shows that declining investment in both public buildings and roads contributed to the general decline in public investment (see Figure 3.4 and Table 3.7).

Figure 3.4
Trends in Components of Public Investment as Percentage of GDP, 1981/82—2004/05

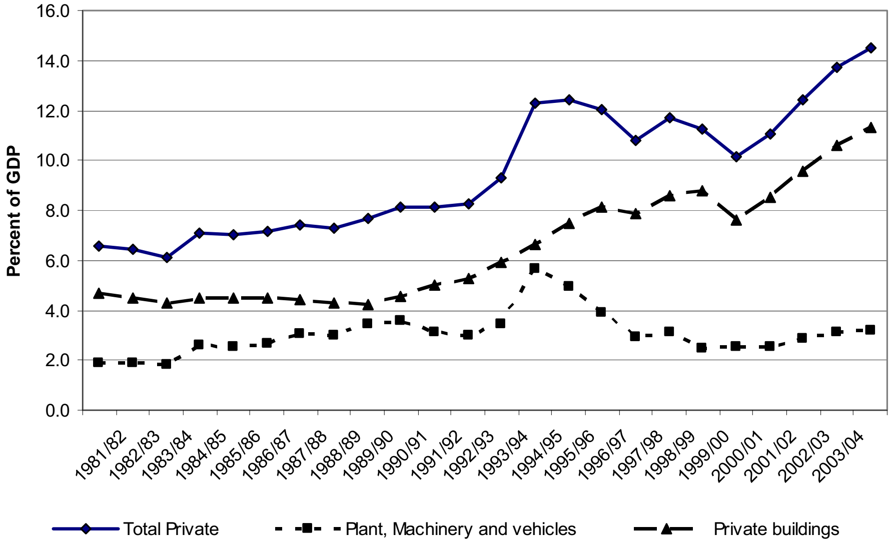


Sources: Primary data from Ministry of Finance, Planning and Economic Development and Uganda Bureau of Statistics.

A further analysis of the Ministry of Works, Transport and Communications data on roads constructed during the period shows that most of the investments were actually major rehabilitation of old roads rather than construction of new roads, which is consistent with the road density statistics in Table 3.1.

On the other hand, analysis of both the composition and evolution of private investment shows that private investment growth has mainly been driven by private building construction, while the sum of plant, machinery and vehicles has been declining since 1994/95 (see Figure 3.5). Table 3.8 shows that from 1997/98 onwards investments in private buildings constituted more than 70 per cent of total private investment for each of the years and increased from 73 per cent in 1997/98 to 78 per cent in 2004/05. Plant, machinery and vehicles fell from 27 per cent to 22 per cent in 2004/05. It was not possible to further disaggregate private buildings to separate residential from non-residential buildings, but given the declining trends in plant and machinery there are likely to be more residential and commercial (business) buildings. Reviewing empirical studies, UNCTAD (2003) suggests that growth is predominantly caused by investment in machinery and equipment, and less so by construction, say, of residential buildings. It is also worth noting that another likely factor that drove private investment growth, in addition to foreign aid and private transfers, was the coffee boom of 1994/95.

Figure 3.5
Trends in Components of Private Investment as Percentage of GDP, 1981/82—2004/05



Sources: Primary data from Ministry of Finance, Planning and Economic Development and Uganda Bureau of Statistics.

Table 3.7
Evolution of Disaggregated Public and Private Investment in Percentages, 1981/82—2004/05 (1997/98=100)

PUBLIC INVESTMENT					PRIVATE INVESTMENT		
Year	Plant ,Machinery and Vehicles	Buildings	Roads	Total	Plant,Machinery and Vehicles	Buildings	Total
1981/82	81			46	29	26	27
1982/83	87			48	31	27	28
1983/84	83			46	29	26	27
1984/85	70			39	41	26	30
1985/86	91			38	40	27	30
1986/87	148			69	44	28	32
1987/88	181			94	54	29	36
1988/89	153			86	57	30	38
1989/90	132			84	69	32	42
1990/91	117			81	76	36	47
1991/92	95			70	69	41	49
1992/93	86			70	71	47	54
1993/94	74			70	87	56	64
1994/95	117			94	160	70	94
1995/96	125			94	153	87	105
1996/97	98			85	127	98	106
1997/98	100	100	100	100	100	100	100
1998/99	169	98	108	124	115	118	117
1999/00	169	94	103	120	95	127	118
2000/01	146	86	86	105	103	116	112
2001/02	147	78	94	104	110	137	130
2002/03	138	76	76	95	129	162	153
2003/04	211	62	97	112	151	189	179
2004/05	234	39	135	119	164	215	201

Notes: The original figures used in computing the figures for this table were in real terms (constant 1997/98 prices) as provided by the Uganda Bureau of Statistics (UBOS). Different deflators are used by UBOS for the various components of expenditure as appropriate. They include the underlying consumer price index as well as an ‘external index’ based on the manufacturing unit value index and the official exchange rate.
Sources: Primary data from Ministry of Finance, Planning and Economic Development and Uganda Bureau of Statistics.

Table 3.8
Trends in the Percentage Composition of Public and Private Investment in Uganda, 1997/98—2004/05

	PUBLIC INVESTMENT				PRIVATE INVESTMENT		
Year	Plant ,Machinery and Vehicles	Buildings	Roads	Total	Plant,Machinery and Vehicles	Buildings	Total
1997/98	21	46	33	100	27	73	100
1998/99	30	39	30	100	27	73	100
1999/00	31	39	30	100	22	78	100
2000/01	31	41	29	100	25	75	100
2001/02	32	37	31	100	23	77	100
2002/03	32	40	28	100	23	77	100
2003/04	42	28	30	100	23	77	100
2004/05	44	16	40	100	22	78	100

Sources: Primary data from Ministry of Finance, Planning and Economic Development and Uganda Bureau of Statistics.

Following the successful deregulation and stabilisation of the economy, an important constraint driving these trends in private investment could be underinvestment in public physical infrastructure capital, which could be influencing firms' investment decisions and private sector production in general. Gauthier (2001), Reinikka and Svensson (2001) and Rudaheranwa (2000) argue that with the substantial progress made through economic liberalisation, the impact of infrastructural costs on private sector investment and growth in Uganda has gained significance. Given the trends in different types of private investment (increases in private buildings and decline in plant, machinery and vehicles) and that public infrastructure development in Uganda lags behind that in most countries even in sub-Saharan Africa, continued underinvestment could have serious repercussions for current and future economic growth.

Although the question we are concerned with here is whether there is a shortage of infrastructure and its impact on productivity, an equally important one is whether the government should change its infrastructure investment policies in regard to institutional arrangements for providing infrastructure.[9] This is another wide area of research, which requires a study of its own. The current thinking is that there has been a failure of pure public infrastructure provision in sub-Saharan Africa, characterised by low investment and the consequent inadequate quality of service and access. On the other hand, as discussed earlier, the nature of infrastructure makes sole market provision unsuitable. Other factors such as 'lumpy' investment requirements, spillover effects and non-excludability in consumption create a legitimate public interest. Torero and Chowdhury (2005) point out that attempts at market provision in the 1980s and 1990s were not a resounding success, making it necessary to look for new institutional arrangements appropriate to sub-Saharan Africa.

The next section reviews existing institutional frameworks for the three major infrastructure types that are the focus of this study, that is, roads, electricity and telephones in Uganda, with a view to assessing the roles that the private and public sectors can play in provision. The new institutional options are meant to allow greater involvement of the private sector in the provision of infrastructure, with the overall objective of achieving improved efficiency and attracting private investment.

3.4 Institutional Framework for Infrastructure Provision in Uganda[10]

3.4.1 Institutional framework for Uganda's road system

Uganda's road network comprises paved (tarmac) roads, all-weather roads (murram, gravel), and dry-weather roads (dirt roads). Motorable tracks also constitute a good part of the network (see descriptions of each type in Chapter 4). Less than 10 per cent of the total road network is paved. This compares poorly with other low-income countries in Africa.[11] The average for conflict-affected sub-Saharan African countries is 13 per cent, and for non-conflict-affected sub-Saharan countries (excluding South Africa) 27 per cent (Schwartz et al., 2004). Moreover, 22 of Uganda's 56 districts have no paved roads whatsoever (see Table 3.10).

Roads are also classified in terms of institutional responsibilities. The central government, through the Ministry of Works, Housing and Communications is responsible for national or classified (main) roads, while district and urban roads are the responsibility of districts and cities/municipalities respectively. District and community access roads constitute the largest proportion of the total network. About 25 per cent of the national roads are paved, virtually all district roads are unpaved, 45 per cent of urban roads are paved and all community access roads are unpaved (Table 3.9). In general, classified roads are considered to be in good condition on average, but district and urban roads are in poor condition.

Table 3.9
Ugandan Road Network, 2000

Category of Roads	Proportion of Total	Comments
National	14.7%	25% paved
District	34.5%	virtually all unpaved
Urban	4.3%	45% paved
Community Access	46.5%	all unpaved
Private	Unknown	mainly unpaved

Source: Ministry of Works, Housing and Communications, 2002

There are no direct charges for using public roads. Therefore, the central government provides grants to districts, cities and municipalities for maintaining and developing district and urban roads. There is no official ownership of community roads and little or no funding is provided for their maintenance, which is left to local initiatives.

The institutional arrangements for the sector are in transition. As a first step towards the creation of a Roads Agency, the Government established the Road Agency Formation Unit (RAFU) in 1998, to which operational functions of road sector management were divested from the Ministry of Works, Housing and Communications.

RAFU is to be expanded into a Road Agency and take responsibility for district, urban and community access roads, with the Ministry retaining responsibility for policies, planning, regulation and institutional building.

The reason for having one agency manage all roads is that it will facilitate cost decisions involving trade-offs between capital expenditure and maintenance costs as well as allow greater economies of scale in procurement to be achieved (World Bank, 2001). Currently most of RAFU's financing is from foreign donors.

Private sector participation is limited to executing contracts relating to design, construction and maintenance. However, there is poor or lack of local capacity in terms of both skilled personnel and plant and equipment. The potential for the private sector to fund roads is limited because the potential for road tolls is very small due to the low levels of traffic outside Kampala. In the foreseeable future, the public sector will have to continue to play a major role in the provision of road infrastructure, especially with funding continuing to be sought from foreign donors as it is currently. However, the government would not necessarily need to be involved in all aspects of provision.

3.4.2 Existing institutional arrangements for the provision of electricity infrastructure services

Electricity provision is less than satisfactory, with less than 9 per cent of the country's population currently having access to electricity. Urban access is about 21% per cent, while access in the rural areas is very much lower at about 3 per cent (Ministry of Energy and Mineral Development, 2004).Current installed generation capacity is about 320 MW altogether, but it falls short of demand, necessitating frequent load shedding. In addition, reliability is poor and distribution losses amount to about 35 per cent, mainly due to illegal connections but also because of the generally poor condition of the distribution system.

Before 2001 this sector was monopolised by a publicly owned parastatal, the Uganda Electricity Board (UEB) which performed all the roles of generation, transmission and distribution. Electricity was generated entirely from one facility, the Owen Falls Power Station on the River Nile. Now there are some other small hydro and diesel generation facilities with a total capacity of less than 20 MW. Until recently, the Ministry of Energy and Mineral Development was responsible for the sector and it exercised significant control over all the operations of the UEB.

Table 3.10
Length of Roads by Type, District and Region (Kilometres)

	Region & District	Paved (tarmac)	All weather (murram, gravel)	Dry weather (dirt road)	Motorable Track	Road Total
	Central Region					
1	Kalangala	0	0	0	91	0
2	Kampala	121	64	5	27	190
3	Kayunga	27	109	64	753	200
4	Kiboga	0	118	160	550	278
5	Luweero	56	462	1028	988	1546
6	Masaka	147	111	353	1164	611
7	Mpigi	90	403	262	1001	755
8	Mubende	116	286	393	1233	795
9	Mukono	111	356	681	1200	1148
10	Nakasongola	120	87	213	621	420
11	Rakai	28	78	284	650	390
12	Sembabule	0	32	163	165	195
13	Wakiso	173	322	279	961	774
	Total	**989**	**2428**	**3885**	**9404**	**7302**
	Eastern region					
14	Bugiri	31	37	93	222	161
15	Busia	29	44	40	226	113
16	Iganga	56	273	331	377	660
17	Jinja	137	87	102	144	326
18	Kaberamaido	0	130	49	226	179
19	Kamuli	33	380	311	1128	724
20	Kapchorwa	0	26	82	52	108
21	Katakwi	0	249	145	814	394
22	Kumi	66	223	151	503	440
23	Mayuge	9	0	104	144	113
24	Mbale	67	136	119	199	322
25	Pallisa	0	184	161	610	345
26	Sironko	12	82	48	69	142
27	Soroti	32	319	104	682	455
28	Tororo	51	102	194	869	347
	Total	**523**	**2272**	**2034**	**6265**	**4829**
	Nothern Region					
29	Adjumani	0	113	50	81	163
30	Apac	83	494	222	587	799
31	Arua	2	425	435	190	862
32	Gulu	9	405	386	490	800
33	Kitgum	0	291	199	296	490
34	Kotido	0	392	344	969	736
35	Lira	45	345	314	303	704
36	Moroto	0	279	164	101	443
37	Moyo	0	49	92	41	141
38	Nakapiripirit	0	259	10	248	269
39	Nebbi	0	88	302	172	390
40	Pader	0	203	45	142	248
41	Yumbe	0	44	139	41	183
	Total	**139**	**3387**	**2702**	**3661**	**5634**
	Western Region					
42	Bundibugyo	0	90	19	186	109
43	Bushenyi	97	138	244	417	479
44	Hoima	10	108	246	267	364
45	Kabale	41	234	123	120	398
46	Kabarole	66	80	220	340	366
47	Kamwenge	0	41	67	123	108
48	Kanungu	0	150	77	53	227
49	Kasese	125	70	128	339	323
50	Kibaale	0	38	352	320	390
51	Kisoro	0	41	102	79	143
52	Kyenjojo	4	106	248	276	358
53	Masindi	82	415	222	651	719
54	Mbarara	129	254	773	893	1156
55	Ntugamo	55	71	125	185	251
56	Rukungiri	0	179	4	70	183
	Total	**609**	**2015**	**2950**	**4319**	**5574**
	UGANDA TOTAL	**2260**	**10102**	**11571**	**23649**	**23339**

Note: Road total excludes motorable tracks.
Source: Data collected using the Geographical Information System (GIS) with maps. Assistance from the National Biomass Study project of the National Forestry Authority is acknowledged. Data are for 1999.

The UEB was restructured in 2001 with the objective of enabling private sector participation, in the hope that the private sector would bring greater efficiency as well as new investments. An Electricity Regulatory Authority had been established in 2000 and given the responsibility of licensing operators and approving tariffs.

Three different companies were established, to which the functions of generation, transmission and distribution were transferred: Uganda Electricity Generation Company Ltd (UEGCL) which owns the two major hydro-power plants at Nalubaale and Kiira; Uganda Electricity Transmission Company Ltd (UETCL) which owns and operates the transmission infrastructure; and Uganda Electricity Distribution Company Ltd (UEDCL) which owns and operates the distribution network. With privatisation, long-term (20-year) concessions have been granted to Eskom Uganda Ltd[12] and Umeme Ltd[13] to maintain and operate the assets of UEGCL and UEDCL respectively. UETCL is still government owned, but it is envisaged that it will be passed on to the private sector under some form of management contract or concession. The company given the 20-year concession for the assets owned by UEGCL is expected to maintain and operate the two major power stations and is committed to an agreed investment programme. The company given a 20-year concession to maintain and operate the distribution network owned by UEDCL is required to make minimal annual investments in system rehabilitation.

In addition to these, competition through licensing of independent power producers (IPPs) was introduced and a number of IPPs obtained permits from the Electricity Regulatory Authority.[14] Although there seem to be prospects for IPPs, as evidenced by the acquisition of permits to carry out feasibility studies on sites with potential to generate electricity with mini-hydropower stations, attempts at attracting the private sector to participate in additional generation capacity by building, financing and operating relatively large dams at Bujagali Falls (200 MW) and Karuma Falls (150 MW) have encountered a number of funding-related difficulties.[15] A notable IPP was the US-based AES Corporation, which was to build, 'finance' and operate the Bujagali Power Project with a World Bank loan (which was conditional on the government giving guarantees to purchase the generated power). However, disagreements over the terms of the Power Purchase Agreement significantly delayed the project, making it unviable for AES, which resulted in its pulling out.

These new institutional arrangements aim at the withdrawal of the public sector from operational activities, with the government's role to be limited to preparation of legislation, development of policy and drawing up of indicative generation plans. However, private investors holding concessions may be unwilling to invest in rural areas because of concerns regarding the financial viability of electricity supply there arising from the need to purchase and install equipment as well as high operational costs of supplying the sparse population in comparison with more densely populated urban areas. It is premature to talk about the performance of the sector under the new institutional arrangements; evaluation will have to be done over a longer period of time. However, since the least-cost option in Uganda is large-scale generating plants (that is, on a cost per kWh basis) rather than thermal energy provided by the private sector on a small scale, it is apparent that the public sector will continue to take significant responsibility for funding new investments. This is because, even in the case of private sector investment in large-scale generating plants, the government would remain responsible under the terms of the Power Purchase Agreements (PPAs). Long-term projects in many African countries are construed to be potentially very risky projects; therefore, under the terms of the PPAs, a government-owned electricity utility usually needs to guarantee that it will buy all the power produced. This was the case with the Bujagali AES agreement in which the guarantee from the electricity utility was to be underwritten by a government guarantee. The government guarantee would then help the IPP investors to raise finance, even though IPPs are in many cases presented as new sources of finance for investment in electricity generation.

3.4.3 Existing institutional arrangements for the provision of telecommunications infrastructure services

Like the electricity sector, the telecommunications sector has undergone reform and divesture to enable private sector participation in the hope that it would bring greater efficiency and new investment. Before the reforms, provision was by a publicly owned monopoly, Uganda Posts and Telecommunications Corporation (UPTC). As discussed earlier, there was virtually no expansion in access during the 1990s. Installed capacity, subscriber lines and public phones were heavily concentrated in the capital city. Although Kampala had less than 10 per cent of the population in 1997, it had 70 per cent of all subscriber lines, while the eastern and western regions of the country, with more than 50 per cent of the population, had only 20 per cent of the subscriber lines (Shirley et al., 2002).

The Communications Act was passed in 1997 to provide a legal framework for the reforms (Ministry of Finance, Planning and Economic Development, 2001). In 1998, the UPTC was unbundled into three separate limited liability companies: Post Bank (U) Ltd, Uganda Posts Ltd, and Uganda Telecom Ltd. While the others remain wholly publicly owned, 51 per cent of the shares of Uganda Telecom Ltd were sold to a consortium of private companies including Detecon, Telecel and Orascom. Subsequently, UTL formed a subsidiary to provide mobile phone services, which began operations in 2001.

An independent regulatory agency, the Uganda Communications Commission, was also established under the Act, its remit being sector regulation, the rights and obligations of operators, licensing, interconnection, performance obligations and fair competition. It is also responsible for ensuring the protection of subscribers' and investors' interests.

As part of the reforms, Celtel, a mobile phone operator, was licensed in 1993 and became operational in 1995. In addition, in order to introduce competition in all major telephony services (including fixed and mobile phones), a second national operator, Mobile Telephone Network, was licensed in 1998 to provide both mobile and fixed-line telecommunications services.

Table 3.11

Selected Telecommunications Sector Indicators, 1996–2005

Services Provided	1996	1998	1999	2001	2002	2003	2004	2005
Fixed phone lines								
Number	45,145	56,196	58,261	56,149	59,472	65,793	82,495	100,777
Per 1000 persons	2.2	2.6	2.6	2.3	2.4	2.6	3.1	3.7
Mobile cellular subscribers								
Number	3,000	12,000	72,602	276,034	505,627	777,563	1,165,035	1,525,125
Per 1000 persons	0.1	0.5	3.2	11.5	20.6	30.6	44.3	56.1
Pay Phones								
Number	1,258	1,433	1,680	3,310	3,200	3,456	4,634	10,263
Per 1000 persons	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.4

Source: Uganda Communications Commission

Competition in the sector has resulted in improved price, quality and coverage of the service as well as expansion of private sector investment. Table 3.11 shows significant increases, particularly in mobile telephones, which has resulted in an increase in telephone density from only about three lines per 1000 persons in 1998 to over 47 lines per 1000 persons in 2004. (This includes both mobile and fixed phones.)

Although competition has resulted in some success, there are dangers and risks in pursuing a purely commercial approach. As argued by Tusubira et al. (2003), most developed countries liberalised and privatised their telecommunications sectors after they had achieved high levels of access (based on a universal service approach).[16] The Uganda Communications Commission's review of the performance of the sector concludes that the achievements have been modest, with a significant fraction of the population still lacking basic telephony services and the existing backbone infrastructure capacity being inadequate. Therefore, there is inadequate availability of and access to voice and data communication infrastructure in rural and urban areas respectively. In terms of general penetration of services, there is hardly any fixed line service in homes, although mobile voice telephony is beginning to fill this gap. The principal means of communication for the majority of people remains public and private pay phones. Only about 2 per cent and 16.6 per cent of the rural and urban populations respectively own mobile phones. Fixed phones are mainly in offices or high-income residential areas in urban centres (Uganda Communications Commission, 2005).

Obviously, resources will have to be committed to ensure penetration, especially in less viable and unviable rural areas of the country, which may be contributing a significant portion of the country's output. And even if not, communication services may play a role in stimulating the development of these rural areas. Therefore, government involvement, for example through public-private partnerships, may be required for installation of a national telecommunications backbone with adequate bandwidth and installation of pay phones and public call offices in rural areas.

3.5 Concluding Remarks

The review in this chapter suggests that there is inadequate infrastructure in Uganda, at least of the three core types: paved roads, electricity and telephones. Apparently, the need to restrain fiscal imbalances has inadvertently resulted in the curtailing of public infrastructure investments. The persistent decline during the period of economic reform could partly explain current underinvestment, which, in turn, could be negatively impacting on private productive capital.

The current thinking is to allow greater involvement of the private sector in provision of infrastructure services. However, due to lack of confidence in African economies, at least in the short-to-medium term, there is still some doubt as to whether private investors would have interest in large long-term investments (see AfDB, 1997). The main factors that explain this are higher political and economic risks, lack of counterpart agents, greater investment needs and lower payment capacity of consumers (Schwartz et al., 2004). The problem is exacerbated by the competition for strategic investors as several sub-Saharan countries are privatising their publicly owned infrastructure companies almost at the same time. However, telecommunications infrastructure, especially mobile telephony, has had more success in attracting private investment than electricity or roads. Apparently this is because the cost recovery period in mobile telephony is short, just as in non-infrastructure industries (ibid.). In the power sector, no significant new (actual) investments have been undertaken in Uganda so far (Engurait, 2005).

Nonetheless, depending on the macroeconomic environment, properly formulated incentives and possibility of sovereign or multilateral support, success in attracting private sector participation may differ between countries and there may be room for private investors in operational aspects as well as in making new investments. However, a purely commercial approach may not address development objectives since private investors would not be interested in less viable and unviable rural areas of the country, which may have the greatest need and where infrastructure investments may potentially play a role in stimulating development.

In addition, promotion of public-private partnerships, especially independent power producers, as a source of funds for new infrastructure investment may be overemphasised. The terms in power purchase agreements between private investors and governments are quite stringent in order to provide a hedge against perceived risks associated with long-term projects in Africa. In many cases, government guarantees are required by private investors before they raise the necessary finance. This makes governments indirectly responsible for raising the necessary funds on the basis of their guarantee. The Bujagali project agreement between the Government of Uganda and AES Power was a clear example of this.

In conclusion, the existing infrastructure stocks and the results from the perception surveys suggest that new public infrastructure investments should be a key policy priority. However, as suggested on the basis of the empirical literature review, it is not obvious that new investments would result in significant returns.

Chapter 4 elaborates on the analytical framework and data used in this study, before Chapters 5, 6 and 7 estimate the possible output and productivity effects of public infrastructure capital in Uganda.

Notes

1. Stein (1995) compares the state of infrastructure in East Asian countries with that in sub-Saharan Africa (SSA) and concludes that there can be no doubt about the need for increases in infrastructural spending in SSA. Brautigam (1995) shows that the density of transport infrastructure (roads and railways) was more extensive in Taiwan in 1952 than in many African countries in the 1990s. Taiwan had 434 m. of highway per square km compared with 165 m. in Côte d'Ívoire, 134 m. in Nigeria, and 94 m. in Kenya.
2. Kampala is the capital city of Uganda
3. Similar behaviour was found in Indonesia and Thailand by Anas et al. (1996).
4. In broad terms and compared with other sub-Saharan African countries, Uganda's economic performance has been impressive, with real GDP growth averaging about 6 per cent over the last 14 years and annual inflation being maintained at below 5 per cent for most of the second half of the 1990s.
5. Although aid commitments may differ from disbursements, it should be possible to assess sectoral trends.
6. The only physical infrastructure that the government spent money on was roads during the period up to 1999/2000, although there was some expenditure on electricity in the subsequent years. This is corroborated by national accounts data.
7. Other empirical studies (for example, Clements et al., 2003 and Savvides, 1992) bear this out. Their evidence shows that debt service crowded out public investment spending in a number of low-income countries (Belloc and Vertova, 2006).

8. The main objective was to achieve an overall increase in economic efficiency through an improvement in allocation of the country's scarce resources as well as maintenance of macroeconomic stability through 'responsible' monetary and fiscal policies.
9. This refers to the factors affecting the relationship between actors (especially the government and private parties) and the structure of incentives.
10. This review substantially draws from the country framework report, World Bank (2001).
11. However, this has to be put in perspective because the percentage depends on the length of the total road network. A country with a small network may have a higher percentage of paved roads.
12. Eskom Uganda Ltd is a subsidiary of Eskom Enterprises (Pty) Ltd of South Africa.
13. Umeme Ltd is jointly owned by Globeleq and Eskom Enterprises of South Africa.
14. A notable IPP was the US-based AES Corporation, which pulled out due to delays in project implementation resulting in lower returns. Other companies for smaller hydropower projects, like Kakira Sugarworks (1985) Ltd and Nile West Rural Electrification Company Ltd, have also been licensed. Others, like S.N. Power Invest of Norway, have been given permits to carry out feasibility studies on mini-hydropower sites in western Uganda.
15. Hydropower potential is estimated at 2,000 MW along the River Nile. Another large potential source is geothermal energy, estimated at 450 MW in the Rift Valley belt in western Uganda but yet to be verified. It is argued that this could be a more reliable supply because, unlike hydropower, it would not be affected by problems such as drought. However, its unit cost vis-à-vis hydropower also needs to be assessed.
16. In Uganda this is defined in terms of access to a minimum of one voice and data network point by the year 2010 for a specified number of people. For public access points, the target is one access point per 1000 people.

4 Framework for Analysing Impact of Physical Public Infrastructure on Output and Productivity in Uganda

4.1 Introduction

This chapter addresses the technical aspects of the research framework and outlines the study's analytical approach, which draws on insights from macro studies. However, the assessment of impact differs from the macro/cross-country studies, in that it is done from a microeconomic perspective with the analytical model linking individual production-unit output and productivity to key physical public infrastructure on the basis of location. This raises the question of what aggregate value can be obtained from effects on individual production units if the analysis is extended to the economy as a whole. This question has been answered to some extent by studies that have focused on the effect of public infrastructure using aggregate production functions and in many cases found a positive effect. As argued by Christ and Green (2004), the positive effects must arise via uncountable small effects on individual production units throughout the economy. Whatever the magnitude of these effects, if they exist, they would support the theory that public infrastructure has positive external effects on private output and productivity. However, this study does not merely assume that the micro effects necessarily add up to reflect the macro outcomes; it identifies the channels and transmission mechanisms as a way of bridging the gap between micro- and macroeconomic impacts.

The analysis is made possible by the construction of a data series of public infrastructure stocks at district level. This has a number of advantages that are discussed in the sections that follow. This chapter also provides information on data sources, coverage of the data and its strengths and weaknesses. In sum, it sets the foundation for the investigation of the research hypotheses.

Section 4.2 provides an exposition of the study's approach and then section 4.3 presents information about the sources of data and the sampling method for the main data set. Section 4.4 deals with data coverage and details all the data variables. Section 4.5 highlights data problems, limitations and the ways in which they are ameliorated. Concluding remarks are made in section 4.6.

4.2 Approach to Analysing Impact of Public Infrastructure on Private Sector Output and Productivity

As stated earlier, this study's approach differs from that of most of the literature by taking into account the contextual determinants of the impact of public infrastructure. Therefore, the empirical analysis does more than estimate the magnitude of the impact of public infrastructure on private sector output and productivity, it also tests the threshold effects hypothesis. This is done by using a combination of exploratory data analysis, econometric modelling and spline regression models. In addition, the impact of public infrastructure on output and productivity is viewed from a microeconomic perspective through its association with individual production units in particular sectors. Most of the earlier studies assumed parameter stability on the basis of both firm size and sector composition. This study tests the assumption because it is important to assess whether there are differences in impact between sectors (which turns out to be the case). Paul et al. (2001) argue that many studies that have examined the aggregation problem have come to the conclusion that estimating the impact on a particular sector has resulted in more plausible estimates which are more interpretable, allowing a more direct estimation and analysis of the impact of public infrastructure on a particular production process.

The macro model equation derived in Chapter 2 is re-adapted to the micro approach. Data on district-level public infrastructure stocks are assigned to individual firms located in that district. The infrastructure is sufficiently diverse by district to capture the productivity effects of variations in infrastructure, which is not the case at national level and over time. Equation 4.1 (below) illustrates the perceived linkage. It should be noted that the model below is only intended for illustrative purposes, to highlight the framework applied. Extensions made include taking into account the efficiency of public infrastructure provision by adjusting infrastructure variables for quality, not on the basis of maintenance costs but on the basis of physical measures that essentially capture the level of infrastructure maintenance as detailed in sub-section 4.4.3 (part d) of this chapter. The function specification is allowed flexibility in order to assess whether there are decreasing, constant or increasing returns to scale and to capture interaction between inputs and hence analyse whether there is complementarity or substitutability between them. As stated in Chapter 2, it is assumed that increasing returns to scale are external to a firm and hence we reconcile increasing returns to scale at the firm level with the assumption of perfect competition.

Equation 4.1 illustrates the way firm-level variables are linked with infrastructure variables at district level.

$$Y_i = A(G_j)f(L_i, K_i, G_j) \tag{4.1}$$

where

Y_i is the value of firm i's output or value added

A is an efficiency parameter

K_i is a measure of the firm's private capital input

L_i is a measure of the firm's labour input

G_j is a measure of public infrastructure stock in district j in which the firm is located

In addition, extensions to this general specification are made to include a vector of firm-specific dummy variables capturing the age and ownership characteristics of the firm and a vector of district dummy variables to take into account district/regional specific characteristics. Following the theoretical discussion in section 2.1 of Chapter 2, human capital is also included as a district-level variable as an externality. The derivation of the formal models used in actual estimation and analysis is discussed in detail in Chapter 5.

As can be deduced from the above model, although the unit of analysis is the firm, the variable of interest for the study (public infrastructure) is common to all firms within a district. However, public infrastructure intensity can vary within a district. Potentially, a firm within a district could be located in an area that has little access to public infrastructure, which means that a more finite matching up of public infrastructure intensity and firm location would be required. Such detailed matching up of firms with public infrastructure was not feasible for this study. This is unlikely to be a major limitation in the case of Uganda, though, as firms tend to cluster around public infrastructure in any particular district.

Besides, there is an advantage in measuring public infrastructure variables in this way. As argued by Deaton (1998), it avoids a situation where the measurement error in the independent variable(s) may be correlated with the measurement error in the dependent variable, resulting in bias and inconsistency in the estimated coefficients (see discussion below).

In other words, in terms of the study's investigative variable (public infrastructure), this turns out to be a richer and more appropriate specification. An example provided by Deaton (1998: 100-1) is adapted here to show why this is the case. Consider a model like

$$y_{ic} = \alpha + \beta x_{ic} + \gamma G_c + \mu_{ic} \tag{4.2}$$

where

i is a firm in village c

y_{ic} is an outcome variable

x_{ic} and G_c are firm- and village-level explanatory variables respectively

y is a measure of firm output or value added

x is a set of firm variables

G is a measure of public infrastructure in the village.

In practice, we may not have village-level data on G, but only broader measures, say at district level as is the case in this study.

If we write G_d – for the broad measure – d for district, so that

$$G_d = n_d^{-1} \sum_{c \varepsilon d} G_c \tag{4.3}$$

where n_d is the number of villages in the district, we then have

$$G_c = G_d + \varepsilon_c \tag{4.4}$$

It can be seen that G_d is orthogonal to the measurement error, because the measurement error in equation (4.4) is the deviation of the village-level G from its district mean, and it is orthogonal to the observed G_d by construction. Therefore, regressing district data instead of village data avoids the correlation between the explanatory variable(s), and the error term and the ordinary least squares are unbiased and consistent.

What is required, however, is checking, and if necessary correction, of standard errors for group effects. This necessity arises from the fact that firms or households in the same location will usually be more homogeneous than between districts,[1] and hence errors may be correlated within sub-groups or clusters of the data. This is easily done in the STATA software package. If the error terms in the regressions are correlated across observations, ordinary least squares regression is not efficient (ibid.).

Another important point to note in relation to the above is that, given that the public infrastructure variables are at district level, there is a need to scale them down to make them relevant at the firm level. There are two possibilities for doing this: measuring on a per capita basis or using a variable that measures the relative spatial intensity. This study uses the latter since it is investigating the impact of public infrastructure on the basis of physical location. This facilitates factoring in of the geographic element. As argued by Antle (1983), deflating public infrastructure with land area is preferable to applying population or aggregate production values, because distance seems crucial in regard to the infrastructure problem, especially if one is interested in capturing the effect of, say, infrastructural constraints on productivity in a sector like agriculture.

However, there is likely to be high correlation between public infrastructure intensity variables and population density. If the estimated public infrastructure coefficient is positive, the question arises as to whether it is public infrastructure input that is positively impacting on labour output/productivity or whether the effect is the result of operating in a densely populated area. This uncertainty can be dealt with by introducing dummy variables to control for district characteristics such as population density. The study restricts the degree of freedom by applying regional dummies. The assumption is that districts in the same region will have similar characteristics, which will be adequately captured by the dummies.

To take into account the serious deficiencies in models used in previous studies, different formulations and functional specifications are applied. A generalised Cobb-Douglas (CD) production function model is used, but only to enable comparison of the results with those of earlier studies, most of which utilised the Cobb Douglas production function (the limitations of using this framework are explained in Chapters 2 and 5). This study adopts the trans-log production function specification because it allows flexibility and enables the analysis of complementarity and substitutability between production inputs, which is key in assessing the direct and indirect effects of public infrastructure.

The outcomes of the empirical analyses in Chapters 5 and 6 will provide the magnitude of supply-side responses to increased public infrastructure stocks for different sectors. That will set the stage for Chapter 7, in which threshold effects of public infrastructure and its implications for growth are discussed and analysed. Using both exploratory and econometric modelling techniques (based on spline function theory), the chapter empirically tests the hypothesis that there are threshold effects in infrastructure provision. Many of the issues that arise relating to threshold externalities at the country level also pertain to performance of firms, so the rigorous empirical work done in this study on Uganda uses micro firm-level data to assess the existence of threshold effects. Chapter 7 also includes estimates of the investments required to bring public infrastructure stocks to the threshold level and analyses the possible marginal effects and elasticities of infrastructure capital after the threshold point has been reached. On the cost side, benefit-cost ratios for different public infrastructure investments for different sectors are calculated, providing an indication of the extent of underinvestment in those types of public infrastructure. Chapter 8 sets out the conclusions of the study as well as their policy relevance, including the implications of making large infrastructure investments on the basis of the results in Chapters 5, 6 and 7. This is done from the perspective of the availability, exploitation and creation of fiscal space for additional infrastructure investments.

Table 4.1 Data Variables and Sources

Sector	Variables	Sources		Public Infrastructure Stocks	Sources
Service firms Industrial firms Agricultural farm enterprises (data not representative of agricultural sector)	**Production Data** Gross output Value Added Labour Capital (Total Assets)	Uganda Business Inquiry, 2000/01 by UBOS	**Linked on the basis of Production unit location (District)**	Paved roads density per district All-weather roads density per district Dry-weather roads density per district Public infrastructure composite variable (From Principal component analysis - PCA)	Primary data collected using the GIS method to retrieve lengths of roads by each spatial location (i.e. each district) from maps.
	Capacity utilisation (unemployment per district) Human capital	Uganda National Household survey 1999/2000			
	Firm Characteristics Firm ownership Firm Age	Uganda Business Inquiry, 2000/01 by UBOS		Quality measures of infrastructure (condition of roads)	Ministry of Works, Housing and Communications. District and Sub-County Local Governments
Sector	**Variables**	**Sources**			
Agriculture - farming households (data representative)	Agricultural land (cultivable land) Labour Fertilisers Human capital (crop farmers) Research and extension (improved varieties)	Agriculture (crop) survey - a core module of the Uganda National Household survey 1999/2000		Indicator of electricity stocks per district Indicator of telephone stocks per district	Derived from the Uganda National Household survey 1999/2000

4.3 Sources of Data and Sampling Method for Main Data Set

The data used for the research were obtained from different sources and comprise both primary and secondary data. The major sources of data are the Uganda Business Inquiry 2000/01 (Uganda Bureau of Statistics, 2004), which is a census of business establishments and covers formal and informal enterprises from various sectors;[2] Uganda National Household Survey 1999/2000,[3] including the socio-economic, community and agricultural (crop) surveys, all conducted by the Uganda Bureau of Statistics; and data on infrastructure stocks by district. When data from these sources are linked, they provide a good data set for the analysis in the study (see Table 4.1).

4.3.1 Censuses of business establishments in Uganda

The firm-level data used in the study are from a survey of business establishments for the financial year 2000/01 carried out by the Uganda Bureau of Statistics. Business surveys were conducted annually from 1964 to 1971, with the exception of 1970.[4] The political and economic difficulties that the country underwent from 1972 to 1988 prevented such surveys. After a long gap, the Census of Business Establishments was conducted in 1989. After another period of more than 10 years came the Uganda Business Inquiry 2000/01. It is far more comprehensive in its coverage than the previous surveys. For all the surveys, classification was according to the United Nations International Standard Industrial Classification of Economic Activities (ISIC). ISIC Revision Three was used for the Uganda Business Inquiry 2000/01 at 4-digit level.

The Uganda Business Inquiry (UBI) was conducted for several purposes, including computation of value added for estimating GDP; obtaining information for estimating capital formation and updating input-output tables and compiling a social accounting matrix for Uganda; and using value added for re-basing indices of industrial production and establishing a producer price index (Uganda Bureau of Statistics, 2004). Therefore, it yields considerable useful detailed data on firm-level variables.

Unlike earlier surveys, which covered only formal establishments employing 10 people and more and then later five or more, the Uganda Business Inquiry 2000/01 covered establishments with fixed premises engaging at least one person in all districts except Kitgum and Pader, which were affected by the war in the north of the country. It covered formal as well as informal enterprises in the following sectors: agriculture; manufacturing; trading; services; hotels and restaurants; finance and banking; insurance; education and health; mining and quarrying; construction; small mining and manufacturing; small trading and services. The data were mainly collected from account books of the businesses and included, among others, gross output, intermediate consumption, fixed assets, and employment (see Chapter 5). Value added was obtained by deducting intermediate consumption from total output.

4.3.2 Sampling design of UBI 2000/01

The sampling frame for the Uganda Business Inquiry (UBI) comprised a comprehensive list of all businesses in the country, creating a Uganda Business Register 2001/2002 with a total of more than 160,000 establishments from which establishments to be covered were selected (Uganda Bureau of Statistics, 2004). The selected sample was designed to:

- include all large businesses (with more than 20 employees).
- ensure that the sample included all the defined employment size bands and industry groups (1-4; 5-9; 10-19; 20-49; 50-99 and 100 plus; see Table 4.2 for the weights used).

Systematic sampling was used and 4300 businesses were selected. The systematic sampling method was chosen over others because it was easier to conduct than a simple random sample and therefore could be implemented with minimal mistakes (ibid.). In addition, it had the advantage of spreading the sample more evenly over the population and hence was more precise than simple random sampling. This ensured that the sampled firms were representative of the population in the different industrial categories (sectors), accounted for a substantial share of national output in each of the categories, were sufficiently diverse in terms of firm size, and had a wide geographical coverage even though location was not a criterion.

The first unit in the sample was selected using a random sampling method and the remaining units were selected following a predetermined rule. Table 4.2 shows the industrial categories, employment size bands and sampling fractions used as a basis to generate the total sample. Businesses with a population of, say, size N were numbered 1 to N (sorted by Activity Code, then Total Employment in the Business Register). If the required sample was of n units, a unit was taken at random from the first k units and every kth unit thereafter. For example, if k was 15 and if the first establishment drawn was number 11, the subsequent establishments were numbers 26, 41, and so on.

Table 4.2
Sample Intervals for Each Industry Group by Employment Size Band, 2002

Activities	Employment Size Band					
	1-4	5-9	10-19	20-49	50-99	100+
Agriculture	10	10	1	1	1	1
Fishing	8	3	1	1	1	1
Mining & quarrying	200	1	1	1	1	1
Manufacturing	100	5	3	1	1	1
Electricity, gas & water	4	1	1	1	1	1
Construction	4	3	1	1	1	1
Trade	320	5	3	1	1	1
Hotels & restaurants	130	5	2	1	1	1
Transport	10	4	1	1	1	1
Post & telecommunications	2	2	1	1	1	1
Finance & insurance	4	1.5	1	1	1	1
Real estate & business service	15	4	1	1	1	1
Community & social services	70	4	1	1	1	1

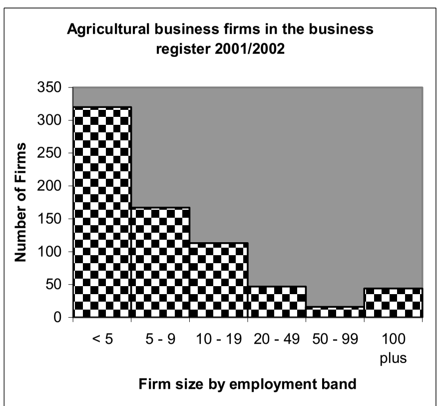
Source: Uganda Bureau of Statistics (2004)

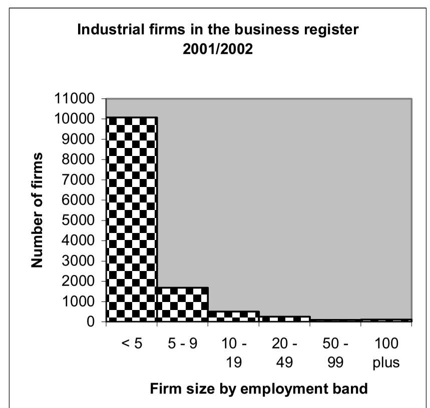
The sampling fractions in Table 4.2 were determined using the population of businesses in each size band. They can be interpreted as follows: a factor of ‘10’ in column 2, row 3 meant that an enterprise employing fewer than five persons in the agriculture sector had a probability of selection of 1/10. A factor of 2 meant the probability of selection was ½, and a factor of 1 meant all enterprises in this employment size band were selected.

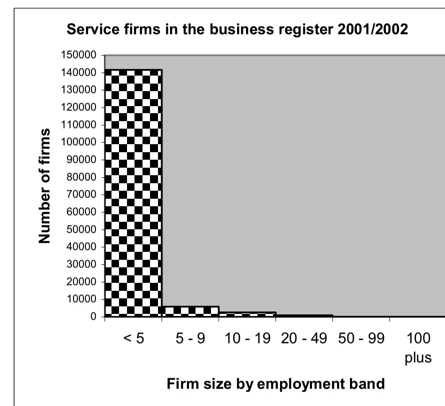
Table 4.3

Profile of Firms by Size and Sector in Business Register 2001/02

Firm Size	Agriculture		Industry		Services		Total	
	Number	%	Number	%	Number	%	Number	%
< 5	320	45.3	10067	79.1	141596	93.6	151983	92.3
5 - 9	167	23.6	1678	13.2	5929	3.9	7774	4.7
10 - 19	113	16.0	508	4.0	2570	1.7	3191	1.9
20 - 49	47	6.6	255	2.0	917	0.6	1219	0.7
50 - 99	16	2.3	99	0.8	187	0.1	302	0.2
100 plus	44	6.2	112	0.9	114	0.1	270	0.2
Total	**707**	**100.0**	**12719**	**100.0**	**151313**	**100.0**	**164739**	**100.0**
% of Total	**0.4**		**7.7**		**91.9**		**100.0**	





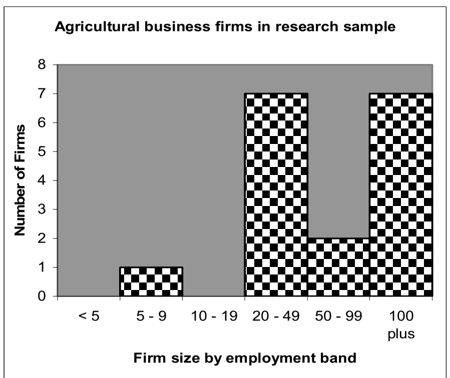


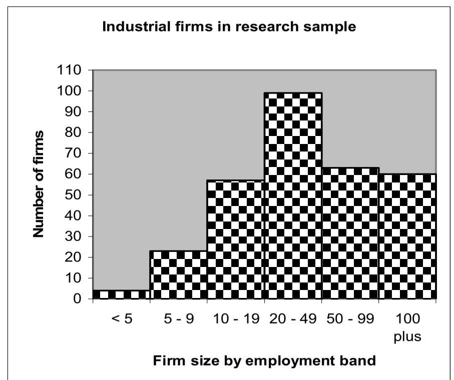
Source: Own computations from Uganda Business Inquiry 2000/01 data.

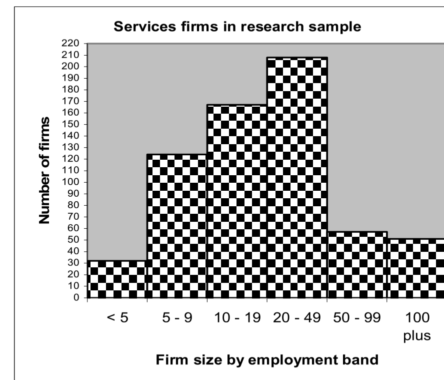
Table 4.4

Profile of Firms by Size and Sector in Research Sample

Firm Size	Agriculture		Industry		Services		Total	
	Number	%	Number	%	Number	%	Number	%
< 5	0	0.0	4	1.3	32	5.0	36	3.7
5 - 9	1	5.9	23	7.5	124	19.4	148	15.4
10 - 19	0	0.0	57	18.6	167	26.1	224	23.3
20 - 49	7	41.2	99	32.4	208	32.6	314	32.6
50 - 99	2	11.8	63	20.6	57	8.9	122	12.7
100 plus	7	41.2	60	19.6	51	8.0	118	12.3
Total	**17**	**100.0**	**306**	**100.0**	**639**	**100.0**	**962**	**100.0**
% of Total	**1.77**		**31.81**		**66.4**		**100.0**	







Source: Own computations from Uganda Business Inquiry 2000/01 data.

4.4 Data Variables and Coverage of Data Set Used in Research

4.4.1 Comparison of Business Register data and study sample data

Although the survey covered both formal and informal enterprises, the data set used in the analysis here comprises only those enterprises that provided information on fixed assets. Some, especially small and informal sector enterprises, did not provide the information on fixed assets and/or details on expenditure that was required for the analysis.

The study therefore utilised 962 firms in the analysis. Still, this sample is superior to many others that are used in similar analyses, because to some degree it covers micro and small firms with fewer than 10 employees and is not overly biased towards large firms unlike many data sets used in those analyses considering firms with 10 or more employees. Nonetheless, comparison of the size and sector distribution of firms in the Business Register (Table 4.3) and the sample in this study (Table 4.4) shows that micro and small firms are under-represented. This is, of course, partly due to the fact that the business register included sole proprietorships and firms employing at least one person, while the research sample used in this analysis contains only a few firms employing only one person. Most of the micro firms do not keep proper account books, making it difficult to collect the necessary data, and others did not provide some important variables such as fixed assets. In terms of this analysis, therefore, it was important to check whether there are significant differences in the relationship between public infrastructure and firm output and productivity on the basis of firm size. As will be shown by the results in Chapter 5, there are no significant differences in the impact of public infrastructure capital on output and productivity of firms of different sizes. Hence, the firm size bias in the sample does not unduly bias the conclusions of this study. The characteristics of the firms are set out by firm size, sector and location in Table 4.5.

Although the sampling was not done on the basis of districts or regions, the data set in the sample used in this study includes firms found in 25 of the existing 56 districts and from all four regions of the country. This is a wide geographical coverage given that the concentration of firms is in seven districts found in the central, west and eastern regions of the country. These seven districts (Kampala and Mukono in the central region, Jinja-Iganga and Mbale-Tororo in the eastern region, and Mbarara in the western region) contribute more than 70 per cent of manufacturing output (Uganda Bureau of Statistics, 2004). Nevertheless there is concentration of public infrastructure and firms in Kampala district which could unduly influence our results. As is shown in chapter 7, exclusion of Kampala from the analysis does not change the study's conclusions.

Table 4.5
Characteristics of Firms in Business Register and Research Sample

CATEGORIES		BUSINESS REGISTER				RESEARCH SAMPLE			
		Enterprises		Employment		Enterprises		Employment	
		Number	Share per cent	Number	Share per cent	Number	Share per cent	Number	Share per cent
By firm size									
Micro	< 5	154958	94.1	252,125.0	51.3	58	6.0	221.0	0.3
Small	5 - 24	8526	5.2	86,171.0	17.5	449	46.7	6,233.5	9.2
Medium	25 - 99	985	0.6	42,614.0	8.7	337	35.0	15,699.0	23.1
Large	100 plus	270	0.2	110,097.0	22.4	118	12.3	45,712.5	67.4
	Total	**164739**	**100.0**	**491,007.0**	**100.0**	**962**	**100.0**	**67,866.0**	**100.0**
By sector									
Agriculture		707	0.4	26,381.0	5.4	17	1.8	1,805.0	2.7
Industry		12719	7.7	99,893.0	20.3	306	31.8	34,556.0	50.9
Services		151313	91.9	364,733.0	74.3	639	66.4	31,505.0	46.4
Total		**164739**	**100.0**	**491,007.0**	**100**	**962**	**100.0**	**67,866.0**	**100.0**
By Location									
Central region		99724	60.5	306,614.0	62.4	732	76.1	56,551.5	83.3
Eastern region		30446	18.5	76,127.0	15.5	101	10.5	6,346.5	9.4
Western region		24726	15.0	83,832.0	17.1	81	8.4	3,835.0	5.7
Northern region		9843	6.0	24,434.0	5.0	48	5.0	1,133.0	1.7
Total		**164739**	**100.0**	**491,007.0**	**100.0**	**962**	**100.0**	**67,866.0**	**100.0**

Source: Own computations from Uganda Business Inquiry 2000/01 data.

Table 4.5 shows that although there is a firm size bias, especially against micro and small firms, the sample is still diverse in terms of firm size, with micro and small enterprises constituting about 52.7 per cent and large firms a little over 12 per cent. In terms of geographical coverage, they are from all the four regions of the country, with the central region having about 76.1 per cent as would be expected as it constitutes the capital city. In terms of sector composition, services constitute quite a large proportion of enterprises, with over 66 per cent, industry has 31.8 per cent and agriculture 1.8 per cent. To some extent this reflects the structure in the Business Register. However, the agricultural sector is under-represented in both the Business Register and the study sample. This is because agricultural production is mainly carried out by small-holder, family-based household farming units mostly engaged in subsistence agriculture. To address this data limitation, as detailed in Chapter 6, the study utilises a separate data set for the agricultural sector, obtained from the Crop Survey 1999/2000 which was carried out by the Uganda Bureau of Statistics. The Survey covered about 8400 farming households.

4.4.2 Agriculture (Crop) Survey 1999/2000

The Uganda National Household Survey 1999/2000 included the Agriculture Crop Survey as a core module. The data collected included estimated output of crops grown nationwide, characteristics of crop-farming households, labour and non-labour inputs, other inputs such as fertilisers, pesticides, seeds, and information on the use of agricultural extension services.

4.4.3 Public infrastructure: Quantity and quality variables

The analysis uses both primary and secondary data on public infrastructure stocks at district level. Some of the variables were obtained by aggregation from the Uganda National Household and Community Surveys of 1999/2000 conducted by the Uganda Bureau of Statistics, and from various other sources including the Ministry of Works, Housing and Communications, and district local governments and municipalities. Other data, for example length of different types of roads, were obtained by measurement of road distances from topographical and administrative maps. The focus was restricted to three key public infrastructure stocks in Uganda: electricity, telephones and roads of various types. These were also ranked as some of the most binding constraints to investment in firm-manager perception surveys (Reinikka and Svensson, 2001).

a. Road distances and densities, by district

Unlike many studies that view all roads as one type of infrastructure, this study takes into account the fact that different types of roads may have different impacts on the output and productivity of production units in different sectors of the economy. Three types of roads, defined on the basis of descriptions provided by the Ministry of Works, Housing and Communications, are considered.

- Paved roads – These are referred to as tarmac or tarred roads and are sealed with tar. They are mainly national roads (owned and managed by the central government) and feed into cities from border posts and towns.
- All-weather roads – These are gravel roads, their surface comprising small stones mixed with sand. An upgrade from dry-weather roads, they are sometimes referred to as murram roads.
- Dry-weather roads – These are dirt roads and passable by motorised vehicles, although with difficulty in wet weather and in some cases only during the dry period. Institutionally, dry-weather roads are mainly owned and managed by district governments with assistance from the central government, and are functionally referred to as district roads. While this type of road is also found in urban centres and cities, the majority are feeder roads in rural areas and link rural communities to commercial and socio-economic centres.

The lengths of the above types of roads per district were obtained by measuring distances from topographical and administrative maps, using two methods:

i. With the help of two physical planners, the lengths of roads in each district were manually measured from topographical and administrative maps depicting spatial data as of 1998.

ii. For increased accuracy, a computer-based Geographical Information System (GIS) method was later used to retrieve distances of roads in each district. The author took advantage of the state of the art technology of the National Biomass Study Project of the National Forestry Authority. The project already had spatial data collected between 1992 and 1996, which was updated until 1999 and later entered into computers using digitising and scanning methods. With the help of project staff and using GIS, the author retrieved the lengths of different types of roads.[5] The road distances per district captured through this method are quite accurate.

Finally, the road density per district was computed by dividing district data on road lengths of different types of roads by the corresponding district land area.

b. Mean distance to the nearest public telephone (telephone call box/booth), by district

The community survey portion of the Uganda National Household Survey 1999/2000 recorded the availability of, or access to, general infrastructure by individuals living within a particular village or community. The distance to the nearest public telephone from the centre of the village or community was estimated. This study uses the average for the district in the analysis. To have a positive coefficient in the econometric estimation (that is, being closer to a telephone being associated with higher productivity) the original variables were inverted. The study uses this as a proxy for the stock of telephone infrastructure per district. The variable excludes fixed line connections in households, which is not a major limitation because there are very few such connections (see Chapter 3). As discussed earlier, there are hardly any fixed line services in homes and the principal means of communication for the majority of people remains public and private pay phones.[6] In 2001, tele-density (fixed lines) was very low in Uganda, at 0.25 lines per 100 persons compared with the average of 0.5 for sub-Saharan Africa and 2.8 for low-income countries.

c. Proportion of households with electricity, by district

To measure the stock of electricity infrastructure, the study uses data capturing the degree of electrification per district (see also Teruel and Kuroda, 2005). It uses the availability of electricity at the household level to calculate the households with electricity as a proportion of the total number of households per district. This variable is derived from the National Household Survey 1999/2000 and is used as a proxy for the stock of electricity infrastructure per district.[7]

d. Public infrastructure quality, by district

The measurement and inclusion of quality in the analysis is important since it is typically related to efficiency. Public infrastructure variables are therefore adjusted accordingly; for example, in the case of roads, on the basis of the percentage of kilometres of national, district or urban roads in good, fair or bad condition. This essentially takes into account the level of infrastructure maintenance as follows:

$$G_t = G_{t-1}(1-\delta) + I_g \tag{4.5}$$

where

G_t is stock of public infrastructure capital

G_{t-1} is stock of public infrastructure capital in a previous period

δ is depreciation

I_g is 'investment' in public infrastructure capital.

However, as discussed in Chapter 3, hardly any new investments were made over time. Hence I_g captures major rehabilitations (particularly for road infrastructure) that were made and which should be reflected in the current stock of public infrastructure capital.

Road quality

For road infrastructure, the study uses the percentage of kilometres of roads in fair to good condition by district as the quality measure. This is on the basis of the assessment by central government, district and urban council engineers. Road classification takes into account the time taken per kilometre given the maximum speed allowed on a particular road (see Tables 4.6 a, b and c).

Because the road network is classified into several administrative categories and is managed by different levels of government, that is, national, district and urban authorities, the roads are also classified as national roads (managed by the central government), district roads (managed by district authorities) and urban roads (managed by urban authorities). All three types of roads are to be found in any particular district.

Road conditions are assessed at the different levels of government. Hence, the study uses the percentage of kilometres of national, district or urban roads in good, fair or bad condition. The study takes the average ratio representing those kilometres of roads in good and fair condition per district. The total kilometres of roads per district is multiplied by the average ratio to get the length of kilometres of roads in fair or good condition per district.

Table 4.6
Road Condition Classification

a. Access Level of District Roads (Unpaved Roads)

S/No	Road Condition	Description
1	Very poor	Impassable to all traffic
2	Poor	Impassable to 2-wheel drive
3	Poor to fair	Impassable to 2-wheel drive when wet
4	Fair	Often closed to 2-wheel drive when wet
5	Fair to good	Passable to 2-wheel drive all year
6	Good	Reliable access all year round to all vehicles

Note: This was the basis of determining road quality before introducing time taken per kilometre.
Source: Ministry of Works Housing & Communications – District Urban Community Access Roads Division.

b. Access Level - Driving Vehicle at Maximum Speed Allowed on Road (Urban Roads)[8]

Survey Rating	Paved road	All-weather road
Very good	>80 km per hour	>70 km per hour
Good	61 – 80 km per hour	51-70 km per hour
Fair	50 - 60 km per hour	40-50 km per hour
Poor	Not motorable	Not motorable
Very Poor	Not motorable	Not motorable

Source: Interviews with local government engineers.

c. Access Level - Driving Vehicle at Maximum Speed Allowed on Road (Paved and Unpaved National Roads)

S/No	Road Condition	Description using speed of the car
1	Very poor	10 – 20 km/hr
2	Poor	21 – 30 km/hr
3	Poor to fair	31 – 40 km/hr
4	Fair	41 – 50 km/hr
5	Fair to good	51 – 60 km/hr
6	Good	>60 km/hr

Source: Ministry of Works Housing & Communications.

Quality of telephone and electricity infrastructure

For the other two key infrastructure variables, the relevant quality measures would be: for telephone infrastructure, unsuccessful local calls (percentage of total) or waiting time for installation of main lines; for energy infrastructure, electricity transmission and distribution losses as a percentage of total output or days without electric power.

However, these are unavailable at district level and it is unlikely that they would vary substantially between districts since they are centrally supplied. However there are quality differences in the case of mobile phones, but given that our reference year for infrastructure variables was 1999/00, they had not yet become important as public or private pay phones (see Table 3.11).

4.4.4 Control variables

a. Human capital

To take into account the effect of quality of labour as derived from endogenous growth theory, that is, that there is significant relationship between human capital and firm output and productivity, the study introduces human capital into the analysis as an externality. Externalities arise from human capital accumulation; the higher the productivity of each worker in producing the final good, the higher the average level of human capital. The study uses the mean number of school years completed by the population over the age of 15 years to represent human capital endowment in the district.

b. Capacity utilisation

As in many developing countries, many firms in Uganda produce below their maximum capacity. However, data on individual firm capacity utilisation are unavailable. Therefore, the study controls for this aspect by using unemployment rates in each district derived from the Uganda National Household Survey 1999/2000.

4.5 Data problems and limitations

Data collected and compiled by authorities in developing countries are often subject to unknown but probably substantial errors. However, as discussed earlier, most of the public infrastructure data were collected with the assistance of sophisticated computer techniques and thus are substantially accurate. In regard to the firm-level data, effective quality control procedures were implemented, for example built-in questionnaire checks and computer editing of data (see Appendix C).

For the Household Survey data 1999/2000, from which some public infrastructure variables as well as control variables were derived, reasonable quality can be inferred in comparison with earlier surveys, partly due to the significant financial and technical support provided to the Uganda Bureau of Statistics by several donor countries. Several studies, for example Deininger and Okidi (2003) and Reinikka and Collier (2001), use data from this survey and it is argued to be of relatively good quality.

Despite the above, there are still a number of limitations:

- Incomplete information/missing data for some firms, especially the small and informal ones. Notably missing is information on fixed assets, particularly for small firms and those in the informal sector. This limited the analysis to mainly formal sector firms.
- In the firm survey data, the coverage of the agricultural sector was far from comprehensive. It covered large farms engaged in market gardening and horticulture, mixed farming and animal husbandry and excluded forestry and small-holder household-based farming units mainly engaged in subsistence agriculture (see Table 4.4). This necessitated a search for a different data set for the sector. Eventually the author obtained the Agricultural (Crop) Survey data, which were collected as a core module of the Uganda National Household Survey 1999/2000 by the Uganda Bureau of Statistics (UBOS). However, the Survey data had their own problems. Because of the way agricultural production units are organised, there are hardly any records of farm output. Hence, the output is estimated, with possible errors in measurement. The reliability of the data was checked by UBOS using coefficients of variation for selected crops.[9] Big variations from the 1995/96 survey as well as other sources meant further data checks had to be carried out. This affected the research study schedule, meaning substantial delays before analysis could be done. UBOS carried out a Post Enumeration Survey to cross-check the information obtained earlier and correction factors were applied. Nevertheless, this did not necessarily rule out the possibility of errors in measurement, especially for the output figures which would be the dependent variable in this study's econometric analysis. However, as argued by Benziger (1996), the implication for the econometric results would be

that while errors in measurement of the dependent variable could be expected to lower the significance levels, ordinary least squares estimation would remain unbiased. Thus, if there were any significance in the results, it would not be because of the errors but despite them. Of course, errors in the independent variable(s) can lead to bias, but given the presumed accuracy of the investigative variable, that is, public infrastructure, the chances of bias in the study results due to errors are minimal.

- In addition to public infrastructure, some control variables, for example, capacity utilisation, are not firm-specific. Although this has its advantages as discussed earlier, to an extent it reduces the precision of the estimated coefficients (Deaton, 1998: 101).
- A limitation in the empirical implementation is that the data are cross-sectional and the study is testing whether there is a relationship between public infrastructure capital and the level of output or productivity for different sectors of the economy as well as the magnitude of that impact. However, the findings of the study can be indicative of the possible long-run link between public infrastructure, output, productivity and growth. It is also possible to assess whether the necessary conditions hypothesised for endogenous growth, that is, increasing returns to scale over all inputs and complementarity between public infrastructure capital and private capital, are met. In addition, it is possible to determine whether there are non-linearities in public infrastructure provision. These are all-important for economic policy, especially for a country like Uganda which must be producing from inside its production possibility frontier.

4.6 Concluding Remarks

This chapter has discussed the technical aspects of the research framework and outlined the study's approach. In addition, it has provided information on data sources, the coverage of the data and its strengths and weaknesses and it has laid the foundation for the investigation of the research hypotheses.

Unlike the frameworks in much of the literature, the adopted framework is designed to analyse the impact of public infrastructure capital on private sector output and productivity at the micro level and by sector.

This allows a more direct linkage and analysis of the impact of public infrastructure on particular production processes.

The study's approach also allows flexibility in functional specifications, enabling analysis of complementarity and substitutability between production inputs. This is important in testing the crowding-in/crowding-out hypothesis and the assessment of direct and indirect effects of public infrastructure capital. In addition, the possibility that output/productivity effects of public infrastructure are subject to a threshold is taken into account. Econometric modelling techniques based on spline function theory are used to test empirically whether there are threshold effects in infrastructure provision. In contrast to most studies, the focus is not on the optimal level or 'saturation point' but on the critical minimum mass of infrastructure required to have productivity effects. This is of more relevance to developing countries like Uganda which have underdeveloped infrastructure.

An important aspect ignored in most empirical literature is the heterogeneity of public capital in terms of different types of infrastructure and productive and unproductive public investments. Ignoring the heterogeneity of public capital can result in misleading empirical outcomes, as different types of public capital are most likely to have different effects not only on output/productivity but also on the accumulation of private capital. Therefore, the study's approach allows for differences in infrastructure capital and, as shown in Chapters 5 and 6, for the differences in impact on different sectors.

Lastly, the data variables that are used in this study are actual physical measures of public infrastructure capital collected with the use of a computer-based Geographical Information System which provides accurate data on existing physical infrastructure stocks. This avoids use of the wrong and inaccurate proxies normally utilised, particularly public investment expenditure, and thus increases reliability of the results as well as the conclusions that are drawn.

In the next chapter, empirical analyses are conducted to assess the effects of different types of public infrastructure capital on the output (value added) and productivity of firms in the industrial and services sectors.

Notes

1. The reason for this is that there may be neighbourhood effects such that ''local eccentricities are copied by those who live near one another and become more or less uniform within a village' (Deaton, 1998: 73). This is particularly the case in the agricultural sectors of poor countries where there may be more similarities within villages than between them, for example due to different crops and cropping patterns.
2. Micro enterprises, that is, those with fewer than five employees, were considered to be informal.
3. The household survey is large and comprehensive in that it covers over 10,000 households. It includes a socio-economic survey of households, a community survey and a household enterprise survey. The community surveys from which some of the infrastructure variables are derived involve about 1000 communities across the country. At the community level, information on productive structure and access to infrastructure can be obtained. These surveys cover all districts except some in the north of the country, which were affected by the war.
4. The history of business surveys in Uganda dates back to the 1960s, when the first survey of industrial production was conducted in 1964/65, with 1963 as the reference year.
5. 'A Geographical Information System (GIS) is a computer system capable of capturing, storing, analyzing, and displaying geographically referenced information; that is, data identified according to location (United States Geological Survey, http://erg.usgs.gov/isb/pubs/gis_poster/).
6. Private payphones include mobile phones. However for the research period (that is the reference year for the infrastructure variables 1999/00), mobile phones were not extensively used as private pay phones, although they became more important in subsequent years.
7. This should be a good proxy for the stock of electricity infrastructure capital in a district because, for example, it is reflective of the number of electric transformers in a district.
8. The general speed limit on national highways is 100km/h and in urban built-up areas 65 km/h, unless otherwise stated.
9. Coefficient of variation measures the dispersion of data points around the mean and is computed as ratio of the standard deviation to the mean. It is useful when comparing the degree of variation between data series.

5 Quantitative Analysis: Impact of Physical Public Infrastructure on Private Sector Output and Productivity in Uganda

5.1 Introduction

Chapter 2 established from a theoretical perspective that investments in public infrastructure capital should have a positive and significant effect on output and productivity. However, there is confusion in the empirical evidence about whether it has significant economic benefits. As argued in Chapter 2 and 3, the proposition of this study is that the impact would depend on a number of contextual determinants, including the macroeconomic policy environment, level of economic development and developmental stage of the infrastructure network. Given the macroeconomic achievements in regard to stabilisation and structural adjustment in Uganda since the mid-1980s and the underdeveloped public infrastructure, new investments should have significant productivity effects.

Chapters 1 and 3 argued that fiscal adjustment has inadvertently resulted in underinvestment in public infrastructure capital, which may undermine the adjustment objectives of achieving higher and sustainable output growth and may even hamper fiscal stability in the long run. To provide a rationale for increased public investment in public infrastructure capital, this chapter assesses the extent to which physical public infrastructure is a determinant of private sector output and productivity in Uganda. In addition it assesses the interdependence between public infrastructure capital and private capital, which contributes to understanding of the way inadequate public infrastructure constrains firms' decisions to invest. This is complemented and corroborated by results from firm perception studies. Understanding the link between underinvestment in public infrastructure capital and the way it affects productive private capital should provide insights into the crowding-in and crowding-out hypotheses and has important economic policy implications.

Using firm-level data, this chapter examines three hypotheses: that the impact of infrastructure development on private sector output and productivity is more significant when a bottleneck exists in the economy as a result of underdeveloped infrastructure; that it crowds-in private investment, meaning that underinvestment may reduce or discourage private capital formation; that there are significant positive infrastructure externalities – the chapter does this by testing for conditions necessary for endogenous growth, that is, increasing returns and complementarity between public infrastructure capital and private capital.

The literature has produced many estimates of the impact of public infrastructure on output/productivity, mainly for developed countries, especially the United States of America and various western European countries, but hardly any for sub-Saharan African countries. The results of these studies have not been without controversy. At one extreme are studies that suggest that there are high rates of return to infrastructure investment; for example, Albala-Bertrand and Mamatzakis (2004), Aschauer (1989a), Munnell (1990) and Rovolis and Spence (2002). Then there are those that suggest that the impact is essentially zero or negative; for example, Björkroth and Kjellman (2000)[1] and Holtz-Eakin (1994). The argument of the latter studies is that the large, positive effects found in some studies appear to be the artefact of an inappropriately restrictive econometric framework. However, they have also been criticised for applying difference methods that destroy any long-term relationship in the data, leaving only short-term impact to be captured in the model (Hsiao, 1986; Munnel, 1992) even though 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.

This chapter argues 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 Africa. High rates of return to infrastructure may depend on a country's particular characteristics, for example, having much less infrastructure stock to begin with.[2] 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 the types of public infrastructure that provide productive spillovers and the sectors in which the effects are the largest.[3]

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, the extra costs normally associated with this kind of strategy, that is, the distortions involved in raising taxes to fund the investments, would be avoided.[4] 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 kinds of subsidies may be 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 magnitude 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 various approaches, particularly the production function approach, profit or cost function approach, cross-country approach, structural model approach and vector autoregressions.

There are advantages to each approach. Given that this study is at the firm level, it applies the production function approach because it is more straightforward and does not require vast amounts of data, unlike the other possible alternative, the cost function approach. This is particularly appealing when the research focus is on developing countries, where in many cases data are difficult to gather. The cost function approach, which is preferred by some researchers, requires much more detailed data and does not in itself help resolve problems concerning non-stationarity of the time series and the issue of causality (Sturm et al., 1998).

The study minimises the problems associated with the production function approach as follows.

a. Problems related to the time series properties of the data, that is, 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 made in first differences. However, the estimates then become difficult to interpret, as they no longer take economically meaningful values. Also, using first differences implicitly assumes that a change in the capital stock affects the level of production in the same year (*ibid.*). Because of the nature of the data, this is a cross-section study, making these problems less of a concern in the analysis.

b. Most studies use the Cobb-Douglas production function, which is a restrictive functional form. This study circumvents its limitation by checking the data vis-à-vis the constant returns to scale assumption, and in addition applies an alternative, more complex but flexible translog production function specification. The translog production function also allows assessment of substitutability and complementarity between different production inputs, including public infrastructure capital. The multicollinearity problem normally associated with the translog production function specification is dealt with in two ways: by the large size of the sample and by the econometric techniques described in sub-sections 5.3.3 and 5.3.5.

c. The study uses standard techniques to check and control for unobserved, firm- and region-specific characteristics that may be captured by the public infrastructure coefficients.

d. 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 why some researchers argue 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 minimise this limitation, for example by using instrumental variables, identifying the direction of causality through the GMM dynamic panel data approach[5] or estimating simultaneous equation models, this study suggests that endogeneity may not be a problem because:

   i. Few, if any, additions have been made to infrastructure stocks in Uganda for a long time, and most certainly not prior to the period covered by this study. Questions on community-level infrastructure access between 1992 and 1999/2000 asked retrospectively in the 1999/2000 National Household Survey revealed relatively little change over time (see Chapter 3). In addition, it is unlikely that reverse causality would hold for a single firm.

ii. As argued by Fan and Chang-Kang (2005), the use of actual physical infrastructure stock variables in the production function minimises the possibility of reverse causality because they are a result of past investments over many years, while the dependent variable in this study, that is, output or productivity, is a function of the current infrastructure capital stock. Zhang and Fan (2001) provide empirical evidence to support this argument. They analysed the endogeneity problem in a study on rural India by testing the two directions of causality between productivity growth and road capital. They compared results from two different approaches, the instrumental variable (IV) approach and the original model, and found little difference in the road capital stock coefficients. They argue that the reason was that road capital at the current level was a result of past government investments.[6] However, reverse causality may still be of concern if the growth potential of each region is taken into account in the decision-making of investors or policy-makers. Inclusion of regional dummies to capture region-specific characteristics, as done in this study, should minimise potential bias in this regard.

iii. Another perception which also has some credence, especially in the case of developing countries, is that infrastructure development is at least in part 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: 195). In the case of Uganda we can even argue that, because of low levels of coverage, political pressures rather than economic ones could be more important (Deininger and Okidi, 2003).[7] Therefore, the infrastructure coefficient in this study could actually be biased downwards. These arguments are supported by the empirical evidence provided by Belloc and Vertova (2006) for countries in the region. They implement a variance decomposition analysis on seven countries mainly drawn from east and central Africa and find that public investment is in general highly economically exogenous as variance is mostly explained by itself. They argue that their results support the idea that public investment is mostly dependent on autonomous policy decisions that do not necessarily reflect the economic cycle.

These circumstances minimise the possibility of any feedback effect of firm output/value added growth on public infrastructure capital.

In the remainder of this chapter, the next two sections (5.2 and 5.3) present the econometric models linking private firm production and public infrastructure capital as well as extensively discuss the estimation strategy and econometric methods used. The discussion is partly motivated by the controversies in the literature on econometric methods used by different studies. Section 5.4 presents regression model estimations, empirical analysis and results. Concluding remarks are made in section 5.5.

5.2 Econometric Model Linking Private Firm Production and Public Infrastructure Capital

The applied model reflects a formulation in which the technical relationship is about applying alternative combinations of all conceivable inputs of factors of production to attain maximum output.[8]

On the basis of the discussion in Chapter 2, the empirical investigation treats public infrastructure capital as, first, a third input which enters the production function directly, and second, 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)[9] in the basic model equation (5.1).

$$\mathrm{Y}_i = A(G_i)\, f(L_i\ \mathrm{K}_i\ G_i\ ) \tag{5.1}$$

In most studies in the literature, a generalised Cobb-Douglas form of technology, which yields a more specific relationship between inputs and outputs as in equation 5.2, is assumed.

$$\mathrm{Y}_i = \mathrm{A}_i L_i^{\alpha} \mathrm{K}_i^{\beta} G_i^{\gamma} e^{\mu_i} \tag{5.2}$$

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 (5.2) produces a linear function that can be estimated (see equation 5.6 below). Taking into account the cross-section study, the stochastic disturbance term μ_i accounts for variations in the technical or productive capabilities of the i th firm.[10].

However, in addition to the many other limitations (which will be discussed later) a major drawback of this approach is that a Cobb-Douglas function estimated in log levels does not allow explicit measurement of the direct and indirect impacts of public infrastructure capital. For this reason, this study explores alternative functional specifications.

5.3 Estimation Strategy and Testing Procedures

The empirical work is based on cross-sectional firm-level data and quality measures of public infrastructure and physical infrastructure stocks (various types of roads, electricity and telephones) in Uganda. The unit of analysis is the firm and the study links the firm's value added and inputs to key physical public infrastructure assets in Uganda on the basis of firm location (details about all the data were given in Chapter 4).

Alternative production function specifications were explored, but the starting point was the introduction of the stock of public infrastructure in the Cobb-Douglas production function.[11] The 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 analysis of both the direct and indirect effects given the quadratic and interaction terms. However, the study tests for the appropriateness of each of the functional specifications and selects the appropriate form (preferred functional form) on the basis of statistical performance and consistency with theory.

The production functions in their basic form can be estimated as:[12]

a. The Cobb-Douglas (C-D) model with several inputs:

$$\ln(\textit{firm value added}_i) = a_0 + \sum_{i=1}^{k} b_i \ln X_i \tag{5.3}$$

b. The Cobb-Douglas model with constant returns to scale:

$$\ln(firm\ value\ added_i) = a_0 + \sum_{i=1}^{k} b_i \ln X_i, where \sum_{i=1}^{k} b_i = 1 \quad (5.4)$$

c. The translog model: Generally for k inputs, the translog function is

$$\ln(firm\ value\ added_i) = a_0 + \sum_{i=1}^{k} b_i \ln X_i + \sum_{i=1}^{k}\sum_{j=1}^{k} c_{i,j} \ln X_i \ln X_j \quad (5.5)$$

where X_i is the ith input and the term $\ln X_i \ln X_j$ represents the product/interaction between two factor inputs or variables, hence $c_{ij} = c_{ji}$.

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.

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

5.3.1 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. This study measures them as the amount of input utilised 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. The capital inputs are total fixed assets. Other inputs could be included in the production function. As discussed earlier, the study includes physical public infrastructure as a separate input.

Since the Cobb-Douglas is linear in the logarithms of variables, equation (5.2) above can be rewritten in log-linear form as:

$$\ln \mathrm{Y} = \lambda + \alpha \ln L + \beta \ln \mathrm{K} + \gamma \ln G + \mu \quad (\lambda = \ln \mathrm{A}) \tag{5.6}$$

As previously discussed in Chapter 2, the classical approach to estimating the Cobb-Douglas production function at the macro level is to assume perfect competition and profit maximisation 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 to exhibit constant returns to scale (see Intriligator et al., 1996). Following the formulation of Aschauer (1989a), many researchers have tried to estimate the impact of public infrastructure on private sector output/productivity with the assumption of constant returns to scale. This study assumes that increasing returns to scale are external to a firm and thus reconciles the increasing returns to scale at the firm level with the assumption of perfect competition. In order to test the validity of these assumptions with the data, three other formulations are considered.

In the second formulation, the function F (.) in equation (5.2) 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 $\alpha+\beta<1$) so that equation 5.6 would be reformulated to equation 5.8:

$$\ln \mathrm{Y} = \lambda + (1-\beta-\gamma)\ln L + \beta \ln \mathrm{K} + \gamma \ln G \tag{5.7}$$

$$\ln\left(\frac{Y}{L}\right) = \lambda + \beta \ln\left(\frac{\mathrm{K}}{L}\right) + \gamma \ln\left(\frac{G}{L}\right) + \mu \tag{5.8}$$

If the assumption of constant returns to scale is valid, equation (5.8) can be estimated, using the Aschauer (1989a) formulation.[13]

In the third 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 $\alpha+\beta+\gamma >1$) so that equation 5.6 would alternatively be reformulated to equation 5.10:

$$\ln \mathrm{Y} = \lambda + (1-\beta)\ln L + \beta \ln \mathrm{K} + \gamma \ln G \tag{5.9}$$

$$\ln Y = \lambda + \ln L - \beta \ln L + \beta \ln \mathrm{K} + \gamma \ln G$$

$$\ln Y - \ln L = \lambda - \beta \ln L + \beta \ln K + \gamma \ln G$$

$$\ln\left(\frac{Y}{L}\right) = \lambda + \beta \ln\left(\frac{\mathrm{K}}{L}\right) + \gamma \ln G + \mu \tag{5.10}$$

In the fourth formulation, no *a priori* restrictions regarding returns to scale are assumed. Equation 5.8 is reformulated to equation 5.11:

$$\ln\left(\frac{Y}{L}\right) = \lambda + \beta \ln\left(\frac{\mathrm{K}}{L}\right) + \gamma \ln\left(\frac{G}{L}\right) + (\alpha + \beta + \gamma - 1)\ln L + \mu \tag{5.11}$$

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 (5.11) reduces to equation (5.8).

We therefore have four different formulations for estimating the parameters of the Cobb-Douglas production function and they involve alternative assumptions and econometric problems. The first (equation 5.6) 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 5.8). Although this method reduces the problems of multicollinearity and heteroskedasticity,[14] 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 a possible problem of endogeneity.

The third formulation (equation 5.10) 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.

The fourth formulation (equation 5.11) also reduces the problems of multicollinearity and heteroskedasticity and does not require the 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.

This study uses the less restrictive equation 5.11 as its basic model for estimation and makes extensions to it (see sub-section 5.3.3 below).

Despite some of the problems of the Cobb-Douglas formulations having been resolved, the approach still has the limitation of restricting the elasticity of input substitution to equal one and it does not allow an explicit analysis of the possibilities of interaction between factor inputs. That is, it does not allow us to disentangle the direct and indirect impacts of public infrastructure capital. To overcome these limitations, the study's second approach is based on a translog production function, which is elaborated in the next section.

5.3.2 Elaboration of the translog production function with infrastructure capital

The second approach is based on the production function formulation of Christensen et al. (1971, 1973). It is a more general functional form and it helps minimise any biases that might result from using the more restrictive Cobb-Douglas specification. It also has the advantages of enabling the testing of interactions between factor inputs, derivation of output and scale elasticities with respect to public infrastructure capital; allowing a variable elasticity of substitution; and being easily estimable. 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.[15] That is, it has sufficient parameters to make it possible for its first and second derivatives to be equal to those of any arbitrary function (Thomas, 1993).

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

$$\ln \mathrm{Y} = \lambda + \alpha \ \ln L + \beta \ \ln \mathrm{K} + \gamma \ln G + \delta \ln L \ln \mathrm{K} + \varepsilon \ln L \ \ln G + \phi \ln \mathrm{K} \ \ln G + \vartheta \ (\ln L)^2 \rho (\ln K)^2 + \sigma (\ln G)^2 + \mu \qquad (5.12)$$

This function reduces to the Cobb-Douglas case if the parameters $\delta, \varepsilon, \phi, \vartheta, \rho, \sigma$ are not 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:

a. 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

$$E_G = \frac{\partial Y}{\partial G}\frac{G}{Y} = \gamma + \varepsilon \ln L + \phi \ln K + 2\sigma \ln G \tag{5.13}$$

b. Private factor productivities with respect to public infrastructure

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

   $\frac{\partial^2 Y}{\partial K \partial G}$, $\frac{\partial^2 Y}{\partial L \partial G}$ are derived from the estimates of equation (5.12)

   as follows:

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

   from which

   $\frac{\partial^2 Y}{\partial K \partial G}$, $\frac{\partial^2 Y}{\partial L \partial G}$ can be computed as

$$\frac{\partial^2 Y}{\partial K \partial G} = \phi \frac{Y}{KG}, \quad \text{and} \quad \frac{\partial^2 Y}{\partial L \partial G} = \varepsilon \frac{Y}{LG} \tag{5.14}$$

   $\frac{Y}{KG}$ and $\frac{Y}{LG}$ are positive, so from the signs of ε and ϕ

   it is possible to infer whether the effect of G on private factor productivities is positive or negative, respectively, and hence make conclusions about substitutability or complementarity.

5.3.3 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.

Therefore the econometric approach adopted has several advantages. It

i. controls for the impact of district/regional differences in firm output/productivity by employing a 'regional effects' specification;
ii. controls for individual firm differences in productivity by employing a 'firm effects' specification;
iii. controls for the quality of public infrastructure;
iv. tests for the possibility of difference among sectors and among different firm sizes; and
v. minimises endogeneity problems, given the nature of the public infrastructure stocks data in this study.

To avoid high multicollinearity, the principal components analysis (PCA) method is applied to get a composite infrastructure variable, which reduces the number of correlated explanatory variables.

As discussed previously, earlier work that applied traditional estimation techniques (such as ordinary least squares) and ignored region- or state-specific effects was criticised for producing biased and inconsistent estimates. The current study remedies this by following the approach of Rovolis and Spence (2002). That is, in one of the functional specifications it introduces region-specific characteristics by applying a dummy variable regression model.[16] In this, a number of dummy variables representing the different regions are added to the simple OLS version, linking them to the study's observations on the basis of individual firm location, capturing differences in underlying productivity from location, climate, mineral endowments, and so on.

For firm-specific characteristics, the study introduces firm age and ownership. Foreign ownership is hypothesised to have a positive influence on firm value added. The reason 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* what the direction of impact will be. While the first is likely to have a positive impact, the latter will have a negative impact.

For labour quality, the study follows Bils and Klenow (2000), Hall and Jones (1999) and Söderbom and Teal (2001) in its specification, which allows explicitly for the labour-augmenting aspect of human capital on labour input. Hence, human capital-augmented labour (anti-logged) is $e^{\alpha h}L$.[17] As established in Chapter 4, human capital is defined as mean number of school years completed for that part of the population in the district over the age of 15 years, and it is treated as an externality, which follows from the theoretical discussion in section 2.1 of Chapter 2.

As regards the capital input, we need to take into account the extent of its utilisation. That is, there is a need to deal with the problem of capacity utilisation. However, since data on capacity utilisation are difficult to obtain, the study follows the Solow (1957) approach, which assumes that the percentage of capital utilised is the same as the percentage of labour utilised. Hence the study uses the unemployment rate as a proxy for capacity utilisation.

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

(N_i): A vector of district-/region-specific characteristics.

(Z_i): A vector of firm-specific characteristics.

The study also makes an extension to the translog production function specification, which provides a number of empirical advantages. As in Costa et al. (1987), each variable in the estimation is expressed as the deviation from a given point of expansion. Since the mean point is generally used in a Taylor's expansion,[18] the translog function can be estimated as

$$\begin{aligned}\ln VA_i = {} & \lambda + \alpha(\ln L_i - \ln \overline{L}) + \beta(\ln K_i - \ln \overline{K}) + \gamma(\ln G_i - \ln \overline{G}) + \vartheta(\ln L_i - \ln \overline{L})^2 \\ & + \rho(\ln K_i - \ln \overline{K})^2 + \sigma(\ln G_i - \ln \overline{G})^2 + \delta(\ln L_i - \ln \overline{L})(\ln K_i - \ln \overline{K}) \\ & + \varepsilon(\ln L_i - \ln \overline{L})(\ln G_i - \ln \overline{G}) + \phi(\ln K_i - \ln \overline{K})(\ln G_i - \ln \overline{G}) \qquad (5.15)\end{aligned}$$

where VA_i represents value added for each firm rather than the gross value of production. As argued by Denny and May (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 a dash (-). Hence this would be the form of the empirical translog specification. This procedure has an added advantage in that it is like 'centring', a method that reduces multicollinearity in polynomial or interaction-effect models. The resulting regression fits the same as an uncentred version (see Hamilton, 2003:167 and section 5.3.4 below).

5.3.4 Testing procedures

The study tests restrictions on the production technology. Within the translog framework, homogeneous 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

$$F_{m,n-k_u} = [(RSS_R - RSS_U)/m]/(RSS_U / n - k_U) \tag{5.16}$$

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, the study applies the RESET test suggested by Ramsey and Schmidt (1976) and discussed in Thomas (1993).[19] Essentially it tests 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 values $\overline{Y}_i^2$ obtained from the original estimated equation are added.[20] If the equation first computed is

$$\overline{Y}_i = \overline{\beta}_1 + \overline{\beta}_2 \mathrm{X}_{2i} + \overline{\beta}_3 \mathrm{X}_{3i} \quad \mathrm{i} = 1, 2, 3 \ldots \mathrm{n} \tag{5.17}$$

then the RESET test proceeds by estimating

$$Y_i = \beta_1^{'} + \beta_2^{'} X_{2i} + \beta_3^{'} X_{3i} + \gamma \overline{Y}_i^2 + \varepsilon_i \quad i = 1, 2, 3 \ldots n \qquad (5.18)$$

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: 144).

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

The study does take into account the fact that the RESET test is not robust in the presence of heteroskedasticity. It therefore carries out heteroskedasticity-robust procedures to make the RESET test robust to heteroskedasticity.

If the chosen model equations are estimated directly for all firms (that is, taking the full sample) the output elasticities are constrained to be the same across all types of firms or sectors. Therefore, the study tests whether it is acceptable to pool the data by exploring particular subsamples 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 (sub-section 5.4.2). The study applies 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, there were too few observations to estimate the equation for the agriculture sub-sample. In this case, therefore, the study applies Chow's second test (see Mukherjee et al., 1998).

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

$$F_{(m, n-k_R-m)} = \frac{RSS_R - RSS_1}{RSS_1} \frac{n - k_R - m}{m} \qquad (5.19)$$

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, the study checks for multicollinearity among the disaggregated public infrastructure capital measures using the variance-inflation factor (VIF).[21] There were severe problems of multi-collinearity when individual infrastructure measures were included in the same regression estimation. This compelled development of a composite indicator of infrastructure availability using principal components analysis. This composite indicator was then used as an independent variable in the regressions (see details below).

5.3.5 Infrastructure data aggregation method

A daunting challenge to be expected is how to enter various measures of infrastructure into a regression analysis relating public infrastructure to economic activity. As discussed above, simultaneously including several public infrastructure measures introduces the problem of multicollinearity since locations with high levels of one infrastructure type are likely to have a similarly high stock of another infrastructure type. With multicollinearity, there is a perfect linear relationship among the predictors of a regression model; hence estimates of the coefficients cannot be uniquely computed.[22] That is, they become unstable and the standard errors for the coefficients can become wildly inflated.

A number of procedures that could be undertaken to eliminate or reduce multicollinearity, especially for the translog function model, were considered.

One way is the 'centring' method,[23] which involves subtracting the mean from x variable values before generating polynomial or product terms. The resulting regression fits the same as an uncentred version (Hamilton, 2003).

A commonly mentioned method is the instrumental variable method. This involves substituting the variable that 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, and it turned out that way in this study.

Omitting the variable with the least statistical significance is an often-used method. 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 the study because it is the investigative variables that are highly correlated and they need to be retained in the analysis.

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

The study uses the principal components method because it has several advantages. Apart from helping to reduce multicollinearity,[24] improve parsimony and improve the measurement of indirectly observed concepts, it makes economic sense by aiding the re-conceptualisation of the meaning of the predictor in the regression model. By capturing the aggregate impact of infrastructure, we take into account the relationships between the different types vis-à-vis their combined productive effects. These relationships can be complex, in that they can be competitive, complementary or both. For example, a highway system in a country or region does not only add capacity to its transportation system, it also affects the functioning of other parts of the system, such as airports (Batten, 1996).

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 minimises 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 p_i, with i > 1 tries to describe the features of X not captured by p_1 by minimising: 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).

The study aggregates the infrastructure measures (paved roads, all-weather roads, telephones and electricity) into an infrastructure index using this method as follows.

Since the infrastructure variables are in different measurement units, we first standardise the data. Standardisation 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 the STATA software package. The first principal component of the PCA was then used to derive weights (scores) for the infrastructure index (See Appendix E for details).

Log (Infraindex) = 0.25955*(Log Paved roads) +
0.25278*(Log (All-weather roads)) + 0.25334*(Log (Power)) +
0.25942*(Log (Telephone)) (5.20)

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

The infrastructure index for each observation located in any particular district (Table 5.1) was created on the basis of equation 5.20.

Factor scores represent the infrastructure composite variable per district. As shown in Table 5.1, they are a good reflection of the stock of infrastructure since districts with relatively higher stocks come at the top of the list. Kampala and Jinja are the capital city and the second-largest city respectively.

Table 5.1
Factor Scores Based on Coefficients and Standardised Infrastructure Variables

No.	District	Factor Score	No.	District	Factor Score
1	KAMPALA	0.6859547	14	KABAROLE	-1.592573
2	JINJA	-0.5391751	15	MBARARA	-1.620306
3	WAKISO	-0.7475896	16	RAKAI	-1.744796
4	MUKONO	-0.8730775	17	BUSHENYI	-1.791116
5	MPIGI	-0.9583244	18	HOIMA	-1.887673
6	KABALE	-1.131595	19	SOROTI	-1.967977
7	MBALE	-1.175943	20	MUBENDE	-1.97524
8	KAYUNGA	-1.20345	21	KAMULI	-2.082494
9	MASINDI	-1.283412	22	KYENJOJO	-2.142226
10	MASAKA	-1.370844	23	ARUA	-2.189271
11	IGANGA	-1.39133	24	LIRA	-2.235029
12	LUWERO	-1.444474	25	NAKASONGOLA	-2.813355
13	TORORO	-1.466247			

5.4 Regression Model Estimation, Empirical Analysis and Results

Like many research results in the literature, the results in Tables 5.2 and 5.3 have a limitation, in that validity to pool the data is assumed. As discussed in detail in Chapter 4, the firms in the full sample are from three sectors, that is, services, industry and agriculture (commercial and large farms but not farm households) and are of different sizes (micro and small, medium, and large). Later in this chapter, we shall test whether it is valid to pool the data. The results reported here are only meant to facilitate comparison with the results of some recent studies.

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

It is also worth-noting that the results are positive and significant in all the specifications. After carrying out diagnostic tests, that is, Wald test, Ramsey regression specification error test (RESET), heteroskedasticity test and a test for multicollinearity (Mean Variance Inflation Factor – VIF), the 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 the study's use of the more general production function form in the final analysis. However, the results from the Cobb-Douglas specification are also reported for comparison purposes.

5.4.1 Econometric results

The estimation results are reported for the full sample as well as subsamples based on sectors. The results for the whole sample and for where the aggregate infrastructure index is used as the investigative variable are discussed first (Tables 5.2 and 5.3). The results for individual infrastructure measures are reported later in sub-sections 5.4.3 and 5.4.4, which elaborate the 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 region-specific characteristics (that is, OLS or dummy variable regression model – DVRM), with or without robust standard errors.

Although the results of models in which region-specific characteristics were included are reported, the regional dummies turned out to be jointly insignificant in all models. First, the study focused on the four geographically recognised regions, that is, North, South, West and Central. Then, it considered the capital city, Kampala, as a separate region. In all cases the regional dummies turned out to be individually and jointly insignificant (see p-values in Table 5.3). Other variables included in the models were firm age, human capital, unemployment (for capacity utilisation) and foreign ownership. Human capital, Firm age and unemployment (capacity utilisation) were all insignificant. Hence, these three variables were dropped from subsequent estimations. However, foreign ownership was found to be positively and significantly associated to firm-level value added in all the models.

Table 5.2
Results from the Full Sample with Aggregate Infrastructure Measure

Model Description	Infrastructure Variables	Results
Model 1—2: Cobb-Douglas with regional effects **Model 1:** Dummy Variable Regression Model (DVRM) **Model 2:** With robust standard errors **Dependent variable**: Log Value Added per worker	In addition to the other input factors and control variables, aggregate infra-structure variable (infraindex) used in model.	In both cases the regression coefficients for the infrastructure measures are positive, and significant at 1% level. Coefficient for Infraindex = 0.385 in model 1 but with presence of multicollinearity. Proxy for capacity utilisation, that is, log (unemployment) insignificant. R-squared (0.48). Model 2 with robust standard errors and log (unemployment) dropped. Essentially the results are the same as in model 1 but with infrastructure coefficient slightly smaller in magnitude. Coefficient for infraindex = 0.275. Multicollinearity not a problem, in model 2 with all variables having a Variance Inflation Factor (VIF) below 10 with mean VIF at 3.53. However, the Ramsey (RESET) test indicates a case of omitted variables in both models.
Model 3—4: Cobb-Douglas and with no regional effects since regional dummies were insignificant in models 1 and 2. **Model 3:** OLS **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. Coefficient for Infraindex = 0.261 in both cases and small change in standard errors. R-squared = 0.48 Multicollinearity not a problem, in both models with all variables having a Variance Inflation Factor (VIF) below 10 with mean VIF at 1.49. The Ramsey test (RESET) indicates a case of omitted variables.

***Table 5.2** (Continued)*

Model Description	**Infrastructure Variables**	**Results**
Models 5: **Translog production function and no regional effects.** **Model 5**: OLS (Parsimonious model). **Dependent variable**: Log Value Added	Aggregate infrastructure index (Infraindex), with squared and cross terms.	(1) Infraindex- positive 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. This result is, however, sensitive to sectoral composition (see sub-section 5.4.2) (4) Cross term, infraindex and private labour, negative and significant at 10% level. (Substitutive). R-squared = 0.77 Multicollinearity not a problem, with all variables having a Variance Inflation Factor (VIF) below 10 with mean VIF at 3.3. Multicollinearity minimised.
Models 6: Translog Production Function and with regional effects. Dependent variable: Log Value Added	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 Multicollinearity minimised through 'centring"(See Hamilton, 2003: 166-70). VIF = 7.92

In Table 5.3, models 1 to 4 are of the Cobb-Douglas functional form, while models 5 and 6 are of the translog production functional form.

As can be deduced from Tables 5.2 and 5.3 the main findings that emerge from the estimations are as follows.

First, unlike some of the literature which finds no evidence of a significant effect of infrastructure on private output and productivity, this study finds that public infrastructure makes a positive and highly significant contribution to the value added of firms and this is consistent whichever functional specification is applied. This finding validates the importance of public infrastructure in the production process in Uganda.

Second, the positive and significant coefficients of the squared term and the interaction term between public infrastructure capital and private capital in the translog specification tend to support the 'public infrastructure capital hypothesis', which emphasises the importance of indirect effects of infrastructure. The positive and significant squared term provides evidence of increasing returns to scale. The positive and significant coefficient of (Log L) in the Cobb-Douglas specification is also consistent with increasing returns.

In addition, the interaction term confirms complementarity of public and private capital. (That is, public infrastructure raises the productivity of private capital). These results are consistent with arguments of investment-oriented endogenous models that emphasise complementarities between the development of public infrastructure and accumulation of private capital.

The problem usually encountered in translog production function models, that is, multicollinearity, is sufficiently dealt with by this study's empirical approach which is analogous to the 'centring' approach. The large sample size also helps to deal with the problem. The variance inflation factors (VIF) for all variables in the different models (with the exception of model 1) were below 10.[25]

Third, the magnitudes of this study's coefficients are particularly interesting given that its unit of analysis is the individual firm. Previous research was mainly carried out at the aggregate level, either at national or regional level. Using model 5, the computed value added elasticity with respect to public infrastructure evaluated at the mean is equivalent to 0.442 and is significant at 1% level. Therefore a 1 per cent increase in the infrastructure composite index is associated with a 0.442 per cent increase in predicted value added.

Table 5.3

Estimates with Aggregate Infrastructure Measure – Full Sample

Dependent Variable	Cobb Douglas Production Function Log Value Added per worker				Translog Production Function *Log Value Added*	
	With Regional Effects		No Regional Effects		No Regional Effects	With Regional Effects
	DVRM	DVRM	OLS	OLS	OLS	DVRM
	Model 1	Model 2[a]	Model 3	Model 4[a]	Model 5	Model 6
Constant	6.275***	5.646***	5.502***	5.502***	11.571***	11.435***
	(0.657)	(0.245)	(0.164)	(0.184)	(0.066)	(0.280)
Labour (Log L)	0.322***	0.211***	0.198***	0.198***	520***	0.524***
	(0.117)	(0.045)	(0.035)	(0.030)	(0.038)	(0.038)
Private Capital (Log K)					0.415***	0.413***
					(0.018)	(0.018)
Log (K/L)	0.421***	0.421***	0.423***	0.423***		
	(0.018)	(0.026)	(0.018)	(0.025)		
Infrastructure (Log G)					**0.442*** **	**0.484*** **
					(0.053)	**(0.071)**
Log (G/L)	**0.385*** **	**0.275*** **	**0.261*** **	**0.261*** **		
	(0.113)	**(0.035)**	**(0.025)**	**(0.023)**		
Log (unemployment)	-0.336					
	(0.321)					
Foreign Ownership	0.430***	0.430***	0.418***	0.418***	0.424***	0.432***
	(0.068)	(0.030)	(0.067)	(0.039)	(0.067)	(0.067)
LogK * Log L					0.031	0.032
					(0.021)	(0.023)
Log K* Log G					**0.032***	**0.035***
					(0.020)	**(0.020)**
Log L* Log G					**-0.064***	**-0.068***
					(0.039)	**(0.039)**
$(\text{Log G})^2$					**0.123*** **	**0.152** **
					(0.044)	**(0.066)**
$(\text{Log K})^2$					0.011	0.010
					(0.007)	(0.007)
$(\text{Log L})^2$					-0.041*	-0.044*
					(0.023)	(0.023)
Regional Dummies						
East (P-value)	(0.219)	(0.161)				(0.606)
West (P-value)	(0.480)	(0.842)				(0.265)
Central (P-value)	(0.387)	(0.368)				(0.716)
R-squared	0.4782	0.4776	0.4767	0.4767	0.7672	0.7677
SSE(RSS)	802.558		804.881		774.694	773.081
Mean (VIF)	12.16	3.53	1.49	1.49	3.3	5.01
RESET (test) Prob >F	0.000	0.000	0.000	0.000	0.414	0.320
Heteroskedasticity test Prob >chi2	0.0379		0.0436		0.2323	0.2488
N	962	962	962	962	962	962

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

[a] Robust standard errors. Standard errors in parentheses

A direct comparison of results from various studies on the relationship between public infrastructure and private sector output and productivity is not possible due to differences not only in the measurement of infrastructure variables but also in the methodologies used.

It is also unfortunate that the author has not been able to find similar research within sub-Saharan Africa with which to compare the study's results.[26] In general, the more recent studies suggest that the impact is much lower than that found by Aschauer (1989a), generally considered to be the first and seminal study in this line of research (see the recent survey by Romp and De Haan, 2005). As previously highlighted, he found output elasticity with respect to public infrastructure capital to be equivalent to 0.39, albeit using the restrictive Cobb-Douglas production function. The current study's results from the Cobb-Douglas production (without the constant returns to scale assumption) provide an output elasticity of 0.261 (model 3) which is less than Aschauers'. Table 5.4 shows output elastcities from some of the more recent studies. A number of them apply the Cobb-Douglas production function framework despite its limitations. Output elasticities range from 0.08 to 0.65.[27] Compared with these, the current study's results from the Cobb-Douglas production function estimations seem quite plausible. Coupled with the several post-regression tests that were carried out, it confirms that the study dealt sufficiently with the methodological flaws identified in earlier research and that its results are quite robust. However, as discussed earlier, it is the results from the translog production function estimates that are used for further analysis. These are higher in magnitude and are consistent with the study's proposition that higher returns would be expected in countries with underdeveloped infrastructure. As argued at the beginning of this chapter, it is apparent that outcomes depend on a number of contextual determinants, which may partly explain some of the differences in the results of even the more recent research.

This study takes into account the criticisms of earlier studies and still finds a positive and relatively high impact of public infrastructure on private sector production when compared with the most recent studies, even though some of the recent studies have higher coefficients. This can be explained by the following:

a. Current public infrastructure provision in Uganda is less than optimal in almost all parts of the country, so additional investments will bring significant returns.

Table 5.4
Results from Recent Studies of the Relationship Between Infrastructure and Private Sector Output and Productivity

Study	Country and Sample	Type of Estimation	Public Infrastructure	
			Type/ measure	Output Elasticity
Everaert & Heylen (2004)	Belgian regions (regional) (1965 - 96)	Translog production function. They analyse labour market effects of public investment using a general equilibrium model. Then they estimate the output elasticity as a by-product.	Public investment	**0.31**
Kamps (2004)	22 OECD countries (1960 -2001)	Panel estimation Aschauer (1989a) model for individual countries	Public capital stock	**0.22** in panel much higher in time series models for individual countries. **0.40 to 0.86.** However possible multicollinearity with negative coefficients for both private capital and labour
Everaert (2003)	Belgian regions (1953 - 1996)	Vector error correction models (VECMs)	Public capital stock	**0.14**
Pineda and Rodríguez (2006)	Venezuela (1996 -2 001) Manufacturing firms	Cobb-Douglas production function	Public investment in infrastructure	**0.2 to 0.3**
Calderón & Servén (2002)	101 countries (1960 - 1997)	Cobb-Douglas production function	Different types of infrastructure as separate factor	**0.16**
Cadot *et al*. (2006)	France regions	Cobb-Douglas production function combined with policy equation for transport infrastructure.	Infrastructure capital stock (transportation)	**0.08**
Stephan (2003)	West-German regions (11)	Cobb-Douglas production function	Public capital stock	**0.38 (first differences) to 0.65 (log levels)**

Source: Own literature survey and Romp and De Haan (2005).

b. As discussed previously, this study uses 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 it does not unnecessarily assume that these investment expenditures result in actual investments in public capital, a very unrealistic assumption, especially in the case of developing countries where the incidence of corruption is high and there are inefficiencies in implementing infrastructure investment projects. This could to some extent explain the results of some studies that have found insignificant and sometimes negative impacts.

c. Unlike other research that uses national or regional outputs as the dependent variables, this study uses firm output/productivity (value added), which is linked to the available public infrastructure stock on the basis of firm location, hence providing a more direct linkage.

5.4.2 Differences among sectors and firm sizes

In the previous sections, we assumed that data pooling was allowed both by firm size and by sector. However, earlier studies have been criticised for making this assumption without obtaining the necessary test statistics. As argued by Brynjolfsson and Hitt (1995), the use of value added rather than sales as the dependent variable in this study should help to make the processes of, say, a retailing firm more comparable with those of a manufacturing firm. Nonetheless, this study tests for parameter stability on the basis of both firm size and sector composition. Two sub-samples are considered for the firm-size analysis. The study distinguishes between micro and small firms (<=24 employees) and medium and large firms (>24 employees). Three sub-samples are considered for the sector analysis, that is, agriculture, industry and services. However, because the agriculture sector has too few observations, only two sectors are considered in the final analysis. Therefore, for the sector analysis, the study applies Chow's second test, which is used when one of the sub-samples has too few observations (see sub-section 5.3.4).

Table 5.5
Test Statistics for Parameter Stability (Data Poolability

(Translog Production Function)

F - Test		Calculated Value	Critical Value (5% level) (approx.)	Result
Firm Size F(m, n-K_u)	F(11, 940)	1.31	1.79	Accept Null
Sector F(m, n-Kr-m)	F(17, 934)	1.92	1.67	Reject Null

As shown in Table 5.5, on a sectoral level the calculated value is greater than the critical value at 5 per cent, so we reject the null hypothesis that it is valid to pool our data. The opposite is the case in regard to firm size. Therefore, the results of the Chow test suggest that there are differences among sectors but not among different firm sizes. Table 5.6 (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 service firms than for industrial firms. Most of the previous studies find the opposite. So the follow-on question is: Why do service firms seem to benefit more than industrial firms from public infrastructure? This study contends that private sector firms that are incapable of, or unwilling to, provide their own infrastructure are more dependent on public provision, possibly because they are liquidity constrained. In addition, firms that have greater access to capital are less likely to be liquidity constrained; thus it can be hypothesised that more capital-intensive firms benefit relatively less from public infrastructure. Service firms are traditionally less capital-intensive than industrial (manufacturing) firms, so they are likely to be more captive to an inadequate public service than industrial firms. The payoff from increased and improved public provision will therefore be higher for service firms. The summary statistics (Tables D.2 and D.3 in Appendix D) confirm that service firms are less capital-intensive, at least in the study sample. The service firm with the lowest total assets in the 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 lowest 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 not unique to Uganda. Pineda and Rodríguez (2006) found in Venezuela that more capital-intensive manufacturing firms benefited less from public investment in infrastructure.

The results for the service sector are also 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.

On the other hand, the squared term and the interaction term between public infrastructure and private capital for firms in the industrial 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 in light of the underlying mechanisms of the relationship between public infrastructure and private sector output/productivity, particularly for firms in the industrial sector in Uganda (see below).

The main reason that can be advanced for this finding is as follows.

In Uganda, inadequate provision of public infrastructure and services negatively affects private investment (see Chapter 3). This is a result of firms trying to cope with deficient public infrastructure by investing in complementary capital,[28] which minimises their capacity to invest in productive capital. In other words, underinvestment in public infrastructure capital results in productive private capital being substituted by complementary capital. Reinikka and Svensson (2002), using data from the 1998 Uganda industrial survey, found that as many as 77 per cent of large firms, 44 per cent of medium firms, and 16 per cent of small firms owned power generators. On average the cost of generators represented 16 per cent of the value of total investment and 25 per cent of the value of investment in equipment and machinery in 1997. Their findings also suggested that it cost about three times more to run and own a generator than to buy power from the public grid when available. In addition, 50 per cent of the firms invested in mobile phones (a privately run service) because of deficiencies in public provision while 77 per cent disposed of their own waste.

Table 5.6
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**				
Log infraindex (Log G)		0.438*** (0.075)		0.346*** (0.086)
Log (G/L)	**0.270*** (0.032)**		**0.222*** (0.041)**	
(Log infraindex)^2		0.109* (0.061)		0.079 (0.073)
Log K * Log infraindex		0.061*** (0.024)		-0.038 (0.042)
Log L * Log infraindex		-0.129** (0.055)		0.054 (0.065)
Value added elasticities with respect to public infrastructure capital evaluated at the mean				
Translog production function (infraindex)		**0.446*** (0.075)**		**0.346*** (0.086)**
N	639	639	306	306

Notes:
1. *** Significant at 1% level **Significant at 5% level * Significant at 10% level
2. Standard errors in parentheses.
3. Results taken and calculated from Tables 5.7, 5.8, and 5.9.
4. The dependent variable for the Cobb-Douglas specifications is Log value added per worker while that of the translog specification is Log Value added.
5. For the translog function, the value added elasticities with respect to public infrastructure capital are evaluated at the mean.

This scenario is more likely to be true for firms in the industrial sector than those in the service sector.

In addition, because service firms are apparently relatively smaller in size, they are less likely to invest in complementary capital. About 62 per cent of service firms in the data set of this study are micro or small and only about 37 per cent are medium or large. The situation is reversed in the industrial sector, with about 35 per cent of firms being micro or small while about 65 per cent are medium or large.

5.4.3 Elaboration of the estimates of the Cobb-Douglas production function

As already noted, the Cobb-Douglas production function has a number of limitations in analysing the impact of public infrastructure on private sector output/productivity. The results reported here are only intended to enable comparison with other studies in the literature and should be read with this caveat in mind.

In Table 5.7, there are five versions of models using the Cobb-Douglas production function, four with one of this study's individual infrastructure measures and one with the aggregate infrastructure measure (infraindex). A model including the individual infrastructure measures together in one regression was estimated, but the results are not reported because they were bedevilled by multicollinearity with insignificant coefficients but high R-squared.

Models 1 to 4 include one type of infrastructure measure at a time, that is, paved roads, electricity, telephones or all-weather roads, while model 5 includes the aggregate infrastructure measure. The results are of the unconstrained Cobb-Douglas function, that is, equation 5.11 (see discussion in sub-section 5.3.1).

The positive and significant coefficients of Log L in the Cobb-Douglas production function models show that the null hypothesis of constant returns to scale is rejected. Hence the constant returns to scale assumption made in earlier studies is invalidated by the data. In fact, there are increasing returns to all inputs. In addition, 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 with coefficients of almost similar magnitudes. This was also reflected by the weights in the infrastructure composite variable and reflects the high correlation and relationships between the different types, which has implications for investment planning and implementation.

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 (model 5 in Table 5.7) or the individual infrastructure measures.

Figure 5.1
Residuals vs Fitted Values for Industrial Firms (Model 5)

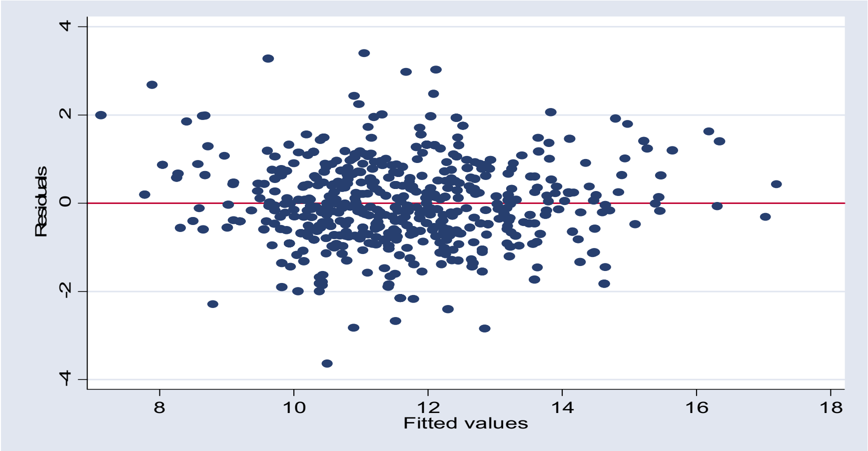


Figure 5.2
Residuals vs Fitted Values for Service Firms (Model 5)

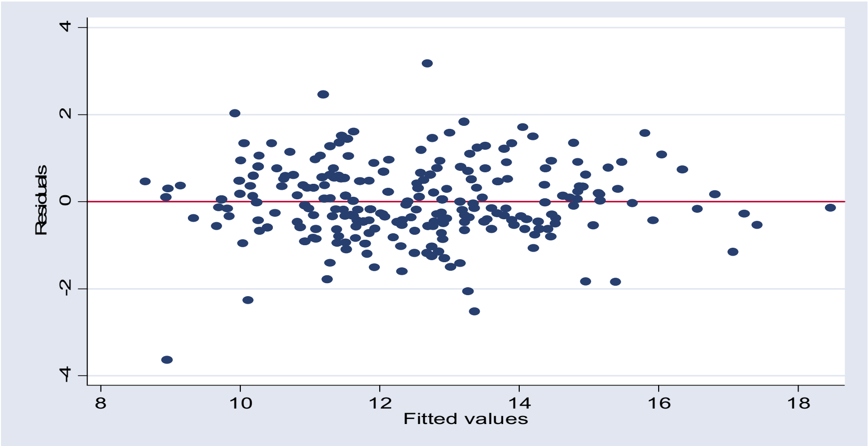


Table 5.7 *Estimates of the Cobb-Douglas Production Function Models: Full Sample and Sub-samples Based on Sectors*

Sector / Variable	Service Firms				
	Dependent Variable: Log Value Added per Worker				
	Model 1	Model 2	Model 3	Model 4	Model 5
Constant	5.671*** (0.198)	5.69*** (0.203)	5.70*** (0.199)	5.93*** (0.211)	5.774*** (0.202)
Log (K/L)	0.403*** (0.021)	0.401*** (0.021)	0.404*** (0.021)	0.401*** (0.021)	0.403*** (0.021)
Log (G/L) (aggregate measure)					**0.270*** (0.032)**
Log L	0.075** (0.037)	0.190*** (0.045)	0.191*** (0.043)	0.171*** (0.042)	0.185*** (0.043)
Log (Paved roads/L)	**0.157*** (0.018)**				
Log (electricity/L)		**0.260*** (0.034)**			
Log (Telephone/L)			**0.275*** (0.032)**		
Log (All-weather roads/L)				**0.260*** (0.032)**	
Foreign Ownership	0.561*** (0.089)	0.591*** (0.089)	0.554*** (0.089)	0.577*** (0.089)	0.562*** (0.089)
R-squared	0.4862	0.4763	0.4873	0.4829	0.4865
SSE (RSS)	558.488	569.29	557.373	562.124	558.244
Mean Variance Inflation Factor (VIF)	1.13	1.41	1.35	1.32	1.34
RESET (test) Prob >F	0.0000	0.0000	0.000	0.0000	0.0000
Heteroskedasticity test Prob > chi2	0.3071	0.2371	0.3057	0.3035	0.2505
N	639	639	639	639	639

***Significant at 1% level **Significant at 5% level * Significant at 10% level.
(Continued)

Table 5.7 *(Continued)*

Sector / Variable	Industrial Firms					
	Dependent Variable: Log Value Added per Worker					
	Model 1	Model 2	Model 2a Robust s.errors	Model 3	Model 4	Model 5
Constant	4.157*** (0.332)	4.228*** (0.338)	4.228*** (0.374)	4.221*** (0.332)	4.381*** (0.333)	4.261*** (0.334)
Log (K/L)	0.517*** (0.037)	0.516*** (0.037)	0.516*** (0.039)	0.513*** (0.037)	0.518*** (0.036)	0.515*** (0.037)
Log (G/L) (aggregate measure)						**0.222*** (0.041)**
Log L	0.142*** (0.050)	0.232*** (0.064)	0.232*** (0.057)	0.240*** (0.060)	0.271*** (0.061)	0.240*** (0.060)
Log (Paved roads/L)	**0.124*** (0.024)**					
Log (electricity/L)		**0.219*** (0.046)**	**0.219*** (0.043)**			
Log (Telephone/L)				**0.222*** (0.041)**		
Log (All-weather roads/L)					**0.245*** (0.041)**	
Foreign Ownership	0.230** (0.106)	0.247** (0.106)	0.247** (0.105)	0.232** (0.105)	0.213** (0.104)	0.230** (0.105)
R-squared	0.4821	0.4761	0.4761	0.4863	0.4973	0.4868
SSE (RSS)	222.394	224.995		220.6	215.871	220.407
Mean Variance Inflation Factor (VIF)	1.29	1.72	1.72	1.63	1.66	1.62
RESET (test) Prob >F	0.9914	0.9819	0.9819	0.9138	0.6986	0.9454
Heteroskedasticity test Prob > chi2	0.0659	0.0435		0.0895	0.0708	0.0685
N	306	306	306	306	306	306

***Significant at 1% level **Significant at 5% level *Significant at 10% level
(Continued)

Table 5.7 *(Continued)*

Sector / Variable	Full Sample							
	Dependent Variable: Log Value Added per worker							
	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
Constant	5.401*** (0.162)	5.456*** (0.165)	5.456*** (0.180)	5.431*** (0.162)	5.649*** (0.169)	5.649*** (0.181)	5.502*** (0.164)	5.502*** (0.179)
Log (K/L)	0.424*** (0.018)	0.421*** (0.018)	0.421*** (0.021)	0.423*** (0.018)	0.423*** (0.018)	0.423*** (0.021)	0.423*** (0.018)	0.423*** (0.021)
Log (G/L) (aggregate measure)							**0.261*** (0.025)**	**0.261*** (0.024)**
Log L	0.089*** (0.029)	0.196*** (0.036)	0.196*** (0.036)	0.204*** (0.035)	0.193*** (0.035)	0.193*** (0.035)	0.198*** (0.035)	0.198*** (0.035)
Log (Paved roads/L)	**0.151*** (0.014)**							
Log (electricity/L)		**0.256*** **(0.027)	**0.256*** (0.026)**					
Log (Telephone/L)				**0.265*** (0.025)**				
Log (All-weather roads/L)					**0.258*** (0.025)**	**0.258*** (0.024)**		
Foreign Ownership	0.416*** (0.068)	0.438*** (0.068)	0.438*** (0.066)	0.415*** (0.067)	0.423*** (0.067)	0.423*** (0.066)	0.418*** (0.067)	0.418*** (0.066)
R-squared	0.4747	0.4653	0.4653	0.4779	0.4752	0.4752	0.4767	0.4767
SSE (RSS)	807.943	822.301		802.994	807.064		804.881	
Mean Variance Inflation Factor (VIF)	1.21	1.57	1.57	1.50	1.48	1.48	1.49	1.49
RESET (test) Prob >F	0.000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Heteroskedasticity test Prob > chi2	0.0595	0.0359		0.0659	0.0311		0.0436	
N	962	962	962	962	962	962	962	962

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

The other variables included in the models, encompassed firm age, human capital, unemployment (for capacity utilisation) and foreign ownership. Human capital, an important variable to firm productivity was surprisingly found to be insignificant. A possible explanation for this outcome could be that there is insufficient variation between districts and hence between firms in the research sample. Firm-specific age was also found to be insignificant. 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.

On the basis of model 5, a 1 per cent increase in the infrastructure index per worker is associated with 0.27 per cent increase in value added per worker for service firms. For industry (model 5), a 1 per cent increase in the infrastructure index per worker is associated with a 0.22 per cent increase in value added per worker. In the overall sample (model 5), a 1 per cent increase in the infrastructure index per worker is associated with a 0.26 per cent increase in value added per worker.

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

First was the heteroskedasticity test, to check the assumption of constant error variance by examining whether squared standardised residuals are linearly related to predicted y (see Cook and Weisberg, 1994). Wrongly assuming constant error variance would imply that the standard errors and hypothesis tests might be invalid. The results, shown in Table 5.7, 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 where we have to reject the null hypothesis, robust standard errors are applied (see also Figures 5.1 and 5.2).

In regard to model specification, the omitted-variable test, that is, the Ramsey RESET test, was carried out by regressing y on the x variables, and also the second, third, and fourth powers of predicted y (after standardising 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 5.7, we can reject the null hypothesis for the service sector but need not reject the null hypothesis for the industrial sector. Hence the 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 inputs led to the application of the more flexible translog production function in the estimations in the next sub-section.

5.4.4 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. The indirect effect is through the impact of public infrastructure on the marginal productivities of private factors, which in turn influence the quantities of private inputs that are chosen (see Chapter 2).

There are five versions of models, each with one of the four individual infrastructure measures developed in this study, and one with the aggregate infrastructure measure (infraindex). The study estimated the models with region-specific characteristics, but, because the regional dummies turned out to be jointly insignificant in all models, the results of the regression estimates in which regional dummies were incorporated are not 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, telephones and all-weather roads respectively, while model 5 includes the aggregate infrastructure measure. The estimation results are reported on the basis of sectors (service and industrial firms) since, as noted earlier, Chow's second test suggested that there are differences among sectors.

The 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 the statistical tests as shown in Tables 5.8 and 5.9. Unlike in the Cobb-Douglas case, the Ramsey (RESET) test shows that the model has no omitted variables, indicating 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.

Table 5.8

Estimates of the Translog Production Function Models: Service Sector

	Service Firms				
Variable	Model 1	Model 2	Model 3	Model 4	Model 5
Constant	11.328***	11.206***	11.336***	11.300***	11.298***
	(0.071)	(0.076)	(0.082)	(0.079)	(0.086)
Log Private Employment (Log L)	0.538***	0.536***	0.542***	0.533***	0.545***
	(0.049)	(0.049)	(0.049)	(0.049)	(0.049)
Log Private Capital (Log K)	0.387***	0.384***	0.387***	0.388***	0.384***
	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)
Infraindex (Log G)					**0.438*** **
					(0.075)
LogPaved roads	**0.215*** **				
	(0.033)				
Log electricity		**0.517*** **			
		(0.073)			
LogTelephone			**0.347*** **		
			(0.062)		
LogAll-weather roads				**0.366*** **	
				(0.060)	
LogK * Log L	0.031	0.031	0.030	0.032	0.031
	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)
Log K* Log infraindex					**0.061*** **
					(0.024)
Log K * LogPaved roads	**0.028** **				
	(0.011)				
Log K * Log electricity		**0.060*** **			
		(0.021)			
Log K * LogTelephone			**0.045** **		
			(0.020)		
Log K * LogAll-weather				**0.045** **	
				(0.018)	

***Significant at 1% level **Significant at 5% level * Significant at 10% level.
(Continued)

***Table 5.8** (Continued)*

	Services				
Variable	Model 1	Model 2	Model 3	Model 4	Model 5
Log L* Log infraindex					**-0.129****
					(0.055)
Log L * LogPaved roads	**-0.052****				
	(0.027)				
Log L * Log electricity		**-0.120****			
		(0.048)			
Log L * LogTelephone			**-0.100****		
			(0.046)		
Log L * LogAll-weather				**-0.081***	
				(0.044)	
$(\text{Log K})^2$	0.008	0.007	0.008	0.008	0.008
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
$(\text{Log L})^2$	-0.034	-0.030	-0.032	-0.033	-0.030
	(0.029)	(0.028)	(0.029)	(0.029)	(0.029)
$(\text{Log Infraindex})^2$					**0.109***
					(0.061)
$(\text{LogPaved})^2$	**0.021****				
	(0.009)				
$(\text{Log Electiricity})^2$		**0.159*****			
		(0.038)			
$(\text{Log Telephone})^2$			**0.059**		
			(0.038)		
$(\text{Log All-weather})^2$				**0.075****	
				(0.037)	
Foreign Ownership	0.534***	0.547***	0.535***	0.547***	0.539***
	(0.088)	(0.087)	(0.088)	(0.088)	(0.088)
R-squared	0.7401	0.7418	0.7394	0.7390	0.7401
SSE (RSS)	533.334	529.776	534.727	535.589	533.23
Mean (VIF)	2.78	3.09	2.93	2.95	2.92
RESET (test) Prob >F	0.5711	0.6296	0.601	0.4643	0.5596
Heteroskedasticity test Prob >chi2	0.956	0.9912	0.9802	0.9518	0.9765
N	639	639	639	639	639

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

Results for service firms sub-sample

$$\ln VA = 11.298^{***} + 0.545\ln L^{***} + 0.384\ln K^{***} + 0.438\ln G^{***}$$
$$+0.031\ln K\ln L + 0.061\ln K\ln G^{***} - 0.129\ln L\ln G^{**} + 0.008\ln^2 K$$
$$-0.030\ln^2 L + 0.109\ln^2 G^{*} + 0.539\,Foreignownership^{***}$$

$N = 639$ $Adj.\ R^2 = 0.74$ $Ramsey(\text{Reset})\ test, F(3,\ 625) = 0.69$ $Mean\ \ VIF = 2.92$

$\text{Prob} > F = 0.5596$

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

Standard errors are shown in Table 5.8

In the service sector, the impact of infrastructure G is highly significant. The single (individual), cross and squared terms including infrastructure are all significant at 1 and 5 per cent levels. In contrast to what would be expected in developed countries, that is, that the squared term for public infrastructure would be negative and hence exhibiting diminishing returns, the squared term here is positive and significant. From this we can infer increasing returns with respect to public infrastructure. This is consistent with the Cobb-Douglas results (that is, positive and significant coefficient of Log L for all equations in Table 5.7). With respect to marginal productivities, inputs G and L are substitutes, whereas G and K are complements. In summary, the empirical analysis finds evidence that public infrastructure has a positive and significant association with the value added of service firms.

Public infrastructure being a complement to private capital stock, while the opposite is true for labour, may imply that public infrastructure favours processes that are capital intensive as opposed to traditional labour-intensive production, thus supporting modernisation of the service sector.

A major criticism of results of the translog specifications is that the results need to be interpreted with some caution due to high multicollinearity caused by high correlation between the single and the cross and quadratic terms. However, as discussed previously, the large sample size and use of the 'centring' method sufficiently deals with the problem of multicollinearity. The variance inflation factors for all variables were well below 10, indicating that multicollinearity is not a problem.

Table 5.9

Estimates of the Translog Production Function Models: Industrial Sector

Variable	Industry Firms				
	Model 1	Model 2	Model 3	Model 4	Model 5
Constant	12.257*** (0.106)	12.187*** (0.104)	12.298*** (0.117)	12.385*** (0.108)	12.294*** (0.113)
Log Private Employment (Log L)	0.520*** (0.067)	0.526*** (0.068)	0.517*** (0.067)	0.509*** (0.066)	0.518*** (0.067)
Log Private Capital (Log K)	0.509*** (0.038)	0.503*** (0.038)	0.512*** (0.038)	0.521*** (0.038)	0.511*** (0.038)
Infraindex (Log G)					**0.346*** (0.086)**
LogPaved roads	**0.176*** (0.039)**				
Log electricity		**0.401*** (0.086)**			
LogTelephone			**0.266*** (0.066)**		
LogAll-weather roads				**0.238*** (0.067)**	
LogK * Log L	0.063 (0.063)	0.105* (0.063)	0.102 (0.063)	0.107* (0.062)	0.102 (0.063)
Log K* Log infraindex					**-0.038 (0.042)**
Log K * LogPaved roads	**-0.018 (0.021)**				
Log K * Log electricity		**-0.009 (0.036)**			
Log K * LogTelephone			**-0.039** (0.035)		
Log K * LogAll-weather				**-0.045 (0.034)**	

Table 5.9 *(Continued)*

Variable	Industry Firms				
	Model 1	Model 2	Model 3	Model 4	Model 5
Log L* Log infraindex					**0.054** **(0.065)**
Log L * LogPaved roads	**0.027** **(0.032)**				
Log L * Log electricity		**0.015** **(0.054)**			
Log L * LogTelephone			**0.047** **(0.055)**		
Log L * LogAll-weather				**0.056** **(0.051)**	
(Log K)^2	-0.019 (0.021)	-0.019 (0.021)	-0.020 (0.021)	-0.023 (0.021)	-0.020 (0.021)
(Log L)^2	-0.109** (0.052)	-0.114** (0.053)	-0.111** (0.052)	-0.108** (0.052)	-0.109** (0.052)
(Log Infraindex)^2					**0.079** **(0.073)**
(LogPaved)^2	**0.024*** **(0.013)**				
(Log Electiricity)^2		**0.143***** **(0.054)**			
(Log Telephone)^2			**0.049** **(0.050)**		
(Log All-weather)^2				**-0.003** **(0.043)**	
Foreign Ownership	0.291*** (0.108)	0.295*** (0.107)	0.281*** (0.108)	0.252** (0.107)	0.280*** (0.108)
R-squared	0.7997	0.7987	0.8	0.8035	0.8000
SSE (RSS)	215.582	216.652	215.225	211.532	215.2532
Mean (VIF)	5.47	5.63	5.45	5.51	5.51
RESET (test) Prob >F	0.2322	0.1846	0.2105	0.0819	0.1941
Heteroskedasticity test Prob >chi2	0.1232	0.1184	0.1514	0.1485	0.1255
N	306	306	306	306	306

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

Results for industrial firms sub-sample

$$\ln VA = 12.294^{***} + 0.518\ln L^{***} + 0.511\ln K^{***} + 0.346\ln G^{***} + 0.102\ln K\ln L - 0.038\ln K\ln G + 0.054\ln L\ln G - 0.020\ln^2 K - 0.109\ln^2 L^{**} + 0.079\ln^2 G + 0.280\,Foreignownership^{***}$$

$N = 306$ $Adj.R^2 = 0.79$ *Ramsey*(Re*set*) *test*, $F(3, 292) = 1.58$ $Prob > F = 0.1941$ *Mean* $VIF = 5.51$

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

In 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. In regard to G and K, this is not entirely surprising. As discussed previously, 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 minimises their capacity to invest in productive capital. Ultimately this affects their demand for private factor inputs, particularly for firms in the industry sector given their size composition. This is corroborated by the evidence from firm perception surveys (see Chapter 3).

Similar patterns are obtained when individual infrastructure measures are used in the different models (see Table 5.9). Each infrastructure measure is positively and significantly associated with the value added of firms in both sectors. However, in the case of electricity and paved roads the squared terms are significant at 1 and 5 per cent levels respectively. From this we can infer increasing returns, especially in the case of electricity. It is also consistent with the results of the perception surveys (see Chapter 3), which identified electricity as the most binding constraint for industrial firms.

In general, the association between electricity and the value added of firms appears to be greater than that of other types of physical infrastructure, irrespective of the sector under consideration, reflecting the gross underinvestment in electricity infrastructure.

As with the Cobb-Douglas model, the study included control variables in the translog models, that is, firm age, human capital, and foreign ownership. Human capital was found to be insignificant. Firm-specific age was also found to be 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, indicating that foreign ownership does seem to grant firms some specific benefits. These could be, for example, timely access to inputs, better-quality labour and capital, finance, maintenance personnel and sources of information about technology and markets.

5.5 Conclusions and Policy Issues

This chapter 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 is preferable to the Cobb-Douglas model.

The results show that public infrastructure has a very significant effect on firm value added in both the service and industrial sectors. The estimates indicate that a 1 per cent increase in the public infrastructure composite variable generates an increase of 0.442 and 0.346 per cent in firm value added of the service and industrial sectors respectively. This has important policy implications from both economic growth and fiscal viewpoints. Taking the service sector, which accounts for 40 per cent of GDP in Uganda, a 0.442 per cent increase in the value added of services would imply an increase of 0.18 per cent of GDP. At the current Value Added Tax (VAT) of 18 per cent, this would mean additional tax revenue of approximately 0.03 per cent of GDP. Similarly, in the industry sector, which accounts for 19 per cent of GDP, a 0.346 per cent increase in the value added of industry would imply an increase of 0.07 per cent of GDP. This would mean additional VAT revenue of approximately 0.01 per cent of GDP. Given that the revenue to GDP ratio has increased by only 2 per cent over the last 10 years in Uganda, these are very significant revenue increases.

The findings also show that public infrastructure has both direct and indirect effects on firm output/productivity, with the direct effect more dominant. The signs and significance levels of the coefficients of the investigative variable are supportive of the crowding-in hypothesis and a positive association between public infrastructure capital and firm value added. They are also in accordance with the necessary conditions for endogenous growth, that is, increasing returns and complementarity between public infrastructure capital and private capital, which is consistent with the presence of positive production externalities.

The estimated coefficients of the different types of public physical infrastructure (roads, electricity and telephones) are quite close in magnitude, reflecting the high correlation between them as indicated in the principal components analysis. Hence, investments may need to be made in tandem, which has implications for investment policy, planning and implementation. Nevertheless, the association between electricity and the value added of firms appears to be greater than that of other types of physical infrastructure for both service and industrial firms, reflecting the gross underinvestment in electricity infrastructure.

Further, the evidence suggests that public infrastructure investments may benefit service firms in particular as they may not have sufficient capacity to substitute for unavailable or inadequate public infrastructure by investing privately in complementary capital. However, because of the nature of production of industrial firms, infrastructure could be a more binding constraint, forcing them to blend public and own provision. Underinvestment and subsequent inadequate provision of public infrastructure capital compels private (individual production unit) provision, which in turn could be crowding out productive private investment and so negatively impacting on output performance, especially for industrial firms.

The 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. Since policies intended to stimulate aggregate economic growth are mainly expected to have an effect through the response of private firms, the findings in this chapter provide an important argument for maintaining and extending high-quality infrastructure.

The analysis and results in this chapter suggest that the relationship between public infrastructure capital and private sector output and productivity may not be constant across the sample. Chapter 7 will investigate whether there are nonlinearities in the output/productivity effect of public infrastructure capital on private rates of return. Before that, Chapter 6 analyses the impact of public infrastructure capital on the agricultural sector. Its uniqueness of organisation in Uganda, being mainly smallholder and to a great extent characterised by subsistence production, necessitates a separate analysis from that of the industry and service sectors.

Notes

1. However, Björkroth and Kjellman (2000) find some evidence of causation running from public capital to private sector output. They argue that, if correctly targeted, public capital investment could affect private sector performance.
2. We need to take into account other contextual determinants, like policy environment or whether the productivity effects are subject to a threshold.
3. Many studies lump all types public capital together, which may partly explain why estimates employing aggregate public capital are insignificant.
4. 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.
5. See Arellano and Bover (1995) and Blundell and Bond (1998). However, the GMM dynamic panel data approach has also been criticised. For example, the Arellano-Bover (1995) approach assumes 'weak' exogeneity instead of 'strong' exogeneity in the link between variables, which for practical purposes remains 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., 2002).
6. See also Fernald (1999), discussed in detail in Chapter 2.
7. See also Calderón and Chong (2004), Dixit and Londregan (1996) and Rogoff (1990) regarding 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.
8. 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 via a production function.
9. The value of output minus the value of all intermediate inputs, representing therefore the contribution of, and payments to, primary factors of production.
10. The stochastic disturbance term is additive on the assumption that it is multiplicative in the original formulation of equation (5.1). 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 use 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.

11. As noted earlier, the Cobb-Douglas function formulation does not disentangle the direct and indirect effects of public infrastructure capital.
12. A number of extensions to these are discussed later in sub-section 5.3.3.
13. Aschauer (1989a) included a trend variable and a capacity utilisation rate to control for the influence of the business cycle.
14. Intriligator et al. (1996: 136-9, 289) demonstrate that the use of ratios helps to reduce these problems, particularly heteroskedasticity.
15. However, more degrees of freedom are lost than with the Cobb-Douglas production function.
16. See Seddighi et al. (2000) for justification of this approach in capturing unobservable explanatory variables or unavailable key explanatory variables due to lack of data.
17. This would capture labour quality and would be αh in the logged equation.
18. As discussed previously, the translog production function is a second-order approximation to unknown production function derived with a Taylor's expansion.
19. This is to deal with the criticism levelled at earlier studies regarding functional form misspecification.
20. This is because $\bar{Y}_i^2$ depends on the squares of both X_{2i} and X_{3i} and also on their product.
21. The VIF reflects the degree to which other coefficients' variances (and standard errors) are increased due to inclusion of a particular predictor (Hamilton, 2003). If VIF is greater than 10, 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: 338-9).
22. We cannot reliably estimate their separate effects due to collinearity.
23. In many cases 'centring' reduces multicollinearity in polynomial or interaction-effect models.
24. However, the problem of multicollinearity may persist within the translog functional form. 'Centring' normally eliminates the problem, and it does so in the parsimonious model. However, it is worth 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 cause a great problem or require a solution. It may just be accepted as one feature of an otherwise acceptable model (Hamilton, 2003).

25. Chatterjee et al. (2000) suggest that the presence of multicollinearity is depicted by whether the largest VIF is greater than 10.
26. A somewhat similar study on Ethiopia (Abrar, 2001) focuses on agriculture (see Chapter 6). He provides evidence of a significant and high impact of infrastructure on agricultural output, with an output elasticity equivalent to 0.56.
27. Excluding the results of Kamps (2004) which exhibits clear signs of multicollinearity.
28. In the case of Ugandan firms, complementary capital comprises electricity generators, mobile telephones, waste disposal facilities, and so on.

6 Public Infrastructure and Agricultural Output and Productivity

6.1 Introduction

Chapter 5 provided empirical evidence that public infrastructure is positively and significantly associated with output and productivity (value added) in both the industrial and service sectors in Uganda. We also found complementarity between public infrastructure and private capital and substitutability between public infrastructure and private labour employment, especially in the service sector.

This chapter aims to provide similar evidence for the agricultural sector, where the role of public infrastructure may be seen as particularly influential not only in regard to productivity enhancement but also because of its potential impact on the many poor people who still depend heavily on agriculture for their livelihood. In general its impact on productivity is expected to be quite significant given the sector's heavy dependence on public infrastructure such as roads. This is perhaps one reason why public infrastructure investments are hypothesised to affect productivity growth positively and significantly even under conditions of no technical change and constant returns to scale (Mamatzakis, 2003). This assumed growth-enhancing nature of public infrastructure necessitates rigorous testing and analysis, given that it could be one of the important factors explaining differences in district and regional agricultural productivity and that such differences could be important for economic policy.

There are hardly any empirical econometric studies on sub-Saharan African countries that test this hypothesis and estimate the magnitude of the relationship. Apparently, the scarcity of data has been and continues to be a major constraint (see literature review in Chapter 2).

As would be expected, there is also a dearth of information as to the productivity effects of public infrastructure on Ugandan agriculture even though it is the largest sector of the economy,[1] accounting for about 41 per cent of GDP and over 80 per cent of employment.[2] Although the agricultural liberalisation policies that were implemented in the 1990s reduced marketing system inefficiencies to a great extent, the sector is still largely characterised by subsistence production, entirely rain-fed and relying on poor and outdated farming technology.[3] The 1990s policy reforms virtually comprised liberalisation of the trade regime, that is 'getting the prices right' by liberalising domestic and export produce marketing and processing, and elimination of export taxes, restrictive tariff and non-tariff barriers, leaving some non-price factors such as public infrastructure as the main constraints to productivity improvements in the sector.

This chapter uses district-level data from various sources on agricultural output and productivity, physical public infrastructure and other relevant explanatory variables to examine the relationship between different types of physical public infrastructure and agricultural output and productivity in Uganda, and provides estimates of the magnitude of the association. As discussed previously, this avoids the limitations of earlier studies that, instead of directly measuring the stock of the available infrastructure, estimate this relationship using monetary values of expenditure on infrastructure, which in some studies are used as indicators of the flow of infrastructure services.[4] Although some studies construct infrastructure stocks from the public infrastructure investment expenditures, using the perpetual inventory method, they do not accurately take into account the quality of capital accumulated over the years as well as the inefficiencies in investment, corruption, and so on, which are crucial issues to consider in most developing countries like Uganda.

By applying a more flexible functional form, this study also avoids or at least minimises methodological flaws, for example, model misspecifications and unchecked restrictions, which are associated with studies that applied simple techniques and implicitly assumed that factors do not interact in the determination of agricultural output and productivity.

As discussed in detail in Chapter 5, the problem of endogeneity with regard to public infrastructure capital stock variables is minimised, since the public infrastructure variables used in estimation are results of past investments over many years while output/value added or productivity is a function of the current public infrastructure capital stock. In this study, the stocks are of a preceding period and no new investments of note have been made.[5] However, reverse causality may still be of concern if the growth potential of each region is taken into account in the decision-making of investors or policymakers. As argued by Fan and Chang-Kang (2005), inclusion of regional dummies, as done in this study, should minimise potential bias in this regard. Zhang and Fan (2001) analysed the endogeneity problem in rural India by testing the two directions of causality between productivity growth and road capital. They used an instrumental variable (IV) approach and found very little difference in the coefficients of roads in the original and IV models because road capital at current level was a result of past government investments.

The remainder of the chapter is organised as follows. Section 6.2 presents and discusses the theoretical arguments about the ways in which public infrastructure can affect agricultural output/productivity. Section 6.3 discusses the empirical model, the data used and the estimation method. Section 6.4 discusses the main empirical findings and compares them with results from other agricultural sector studies. Finally, section 6.5 presents conclusions and discusses economic policy implications on the basis of the empirical findings.

6.2 Underlying Mechanisms in the Relationship between Public Infrastructure and Agricultural Output and Productivity

As discussed in detail in Chapter 2, from a theoretical perspective the overall effect of public infrastructure on agricultural productivity can be divided into direct and indirect effects. The channels through which these effects are transmitted to agricultural output and productivity can be hypothesised in several ways:

Some types of public infrastructure can be seen as intermediate inputs, hence impacting on productivity, while others can connect production and consumption areas, hence facilitating market access and availability of agricultural inputs in addition to enabling acquisition and diffusion of new technology.

6.2.1 Facilitating technology diffusion

Public infrastructure, especially transportation infrastructure, affects farmers' incentives to learn about and use new technologies. For example, important sources of information such as extension contacts may be functions of the availability or cost of transportation. Also affected are the cost of inputs and the market price of outputs, since the existence, quality of, or lack of road infrastructure determines the 'rest of the world's' demand for local products (Antle, 1984). The shadow price of resources not traded in markets, such as time spent in gaining access to markets, may also be affected by poor, or lack of, road infrastructure (ibid.). Felloni et al. (2001) consider roads and electricity to be critical if agricultural activities are to become more specialised or if it is to be economically advantageous to have agricultural processing plants close to production areas. The lack of infrastructural capital, among other factors, is therefore seen as a constraint to farmers' choice of technology and hence their productivity.[6]

Antle (1984) presents a model which differs from the usual production function models, with the production function parameters being viewed as choice variables and therefore specified as functions of variables that influence the farmer's choice of technology. Hence the input technology combination chosen, other fixed physical capital and the farmer's human capital determine the productivity of each farmer's production process.

6.2.2 Stimulation of investment and other multiplier effects

Particular types of public infrastructure, for example, roads or irrigation dams, can have multiplier effects. Construction of a road or an irrigation dam can result in more land being brought under cultivation. This could, in turn, stimulate more fertiliser consumption, which could also necessitate expansion of reserve capacity in fertiliser industries or require new investment in new fertiliser units (Ahmed and Hossain, 1990). For example, Ahmed and Hossain found that in Bangladesh road quality increased the use of fertilisers.

Electricity, too, can have direct and indirect effects. As an intermediate input, for example, in the form of power machinery such as water pumps or milking machines, it can affect production directly. In addition, it facilitates rural industrialisation and dissemination of technology in agricultural areas, which in turn can stimulate higher demand for agricultural products. Felloni et al. (2001), using cross-country data for 1991 from 83 countries, found that the gross product in the energy and transport sectors individually and in combination are statistically significant in determining the aggregate value of agricultural production. They also found electricity and roads to be significant determinants of land productivity.[7] However a limitation of their study is that the infrastructure variables used, that is, output of the transportation, communication and energy sectors per unit of land, are annual expenditures and do not directly measure the stock of available physical infrastructure.

6.2.3 Reduction in the cost of production

Public infrastructure may not only enhance agricultural production and productivity, it may also reduce the marginal cost of production. Public infrastructure such as roads and telephones is also expected to increase the efficiency of both marketing and production since it reduces transaction costs. Transaction costs that are not costs of input prices can be substantial components of the total cost of production in the agricultural sector of developing countries, mainly due to lack of or poor public infrastructure. As argued by Venkatachalam (2003) the absence of proper transportation facilities may substantially increase the transportation costs of inputs and outputs incurred by farmers in a particular area. If the relevant public infrastructure investments are made, then the total marginal cost of production may be considerably reduced, which would benefit the farmers either through increased 'producer surplus' or through freeing of resources which can be used for other productive activities, enhancing the overall output and income of the area or region.

Public infrastructure may also impact on the cost of communication because it facilitates supply of technical and market information, hence lowering transaction costs. A familiar case is acquisition of technical and market information from radio broadcasts and newsletters, which may reduce the cost to farmers of acquiring information from both private and public sectors. Also, availability of telephony infrastructure in a rural village may provide the comparative advantage of up-to-date price information over another village that does not have that infrastructure. Such access to price information could reduce the marketing margin otherwise enjoyed by middlemen who take advantage of the absence of correct information about market prices. There can be other advantages, too. Bayes et al. (1999) found not only a lowering of transaction costs for villages in Bangladesh with telephone access, but also that phones offer additional non-economic benefits such as improved law enforcement.

Agricultural productivity can be regarded as a function of public infrastructure, which supplements other factors such as agricultural research, extension and education.

It is therefore possible to utilise a production model that incorporates public infrastructure, traditional inputs and other factors, for example, human capital, to estimate their differential impacts on agricultural output/productivity. This approach is followed in a number of studies; for example, Antle (1983, 1984), Binswanger et al. (1993), Craig et al. (1997) and Easter et al. (1977).

6.3 Empirical Model and Estimation Method

6.3.1 Data and empirical model

At the minimum, measurement of the productivity effects of public infrastructure requires cross-section data on production units and different quantities of public infrastructure stocks. The empirical analysis is done within a cross-section framework using district-level agricultural data obtained from the Crop Survey 1999/2000 conducted by the Uganda Bureau of Statistics. The survey included both food and cash crops, whose output values are aggregated by district in the analysis. However, the data do not cover all the districts as some districts were left out of the survey due to the ongoing war in the north of the country, while missing data for some of the important explanatory variables, particularly fertilisers, resulted in several districts (observations) being left out of the analysis. While this is a limitation, the 23 remaining districts are from all the regions of the country.

The theoretical basis of the model follows from the model derivations in Chapter 2, the follow-on presentations and applications in Chapter 5 and the more directly relevant theory discussed in section 6.2 of this chapter. On the basis of Antle (1983, 1984),[8] the production technology is represented by the following production function.[9]

$$Y = f\,(\textit{Cultivable Land } (K_L), \textit{Labour } (L), \textit{Infrastructure } (G), \textit{Fertilizer } (F), \textit{Research and Extension } (IV), \textit{Education } (H)) \qquad (6.1)$$

The description of the variables in the model follows below. Descriptive statistics are in appendix D 4.

a. Agricultural value added

Y, the dependent variable, denotes output (in value added). Agricultural value added is aggregate output values per district minus the value of intermediate inputs. Aggregate output is gross crop production value per district derived. Hence, agricultural output in this case excludes livestock and fisheries, which are not included in the crop survey. However, given that livestock and fisheries constitute a small proportion of total GDP (4.8 per cent) as well as agricultural GDP (11.8 per cent) it is unlikely to be a major limitation in the analysis. This division of total output into its crop and animal components also has the advantage of allowing consideration of the contribution of public infrastructure to a specific production process instead of to a broader aggregation.

b. Public infrastructure

The details of the public infrastructure data and their sources were presented in Chapters 4 and 5, so only the definitions are given here. G in equation 6.1 variously represents the following different types of public infrastructure as well as the public infrastructure composite variable.

c. Dry-weather roads

Dry-weather roads are sometimes referred to as dirt roads and are passable by motorised vehicles, although with difficulty in wet weather and in some cases only during the dry period. This study takes kilometres of dry-weather roads per square kilometre per district, adjusted for quality. As discussed in Chapter 4 and also argued by Antle (1983), deflating by land area was preferred to measures such as population or aggregate production values because distance seems to be the most important dimension of the infrastructure problem.[10]

Institutionally, dry-weather roads are mainly owned and managed by district governments with assistance from the central government, and are functionally referred to as district roads. Although these roads are also found in urban centres and cities, the majority of them are feeder roads linking rural communities to commercial and socio-economic centres and are therefore important for delivering farm inputs, marketing agricultural produce and delivering social and administrative services. Hence, the coefficient for dry- weather roads is expected to be positive.

d. All-weather roads

All-weather roads are sometimes referred to as murram roads. They are gravel roads, that is, an upgrade from dry-weather roads, their surface comprising small stones mixed with sand. This study takes kilometres of all-weather roads per square kilometre per district, adjusted for quality. As with dry-weather roads, the coefficient of all-weather roads is expected to be positive.

e. Paved roads

Paved roads are also referred to as tarmac or tarred roads and are sealed with tar. They are mainly national roads (owned and managed by the central government) and feed into cities from various border posts and towns.[11] This study takes kilometres of paved roads per square kilometre per district. The coefficient for paved roads is expected to be positive.

f. Telephone

The study uses the mean distance to the nearest public telephone per district as a proxy for the stock of telephone infrastructure per district. To enable easy interpretation of impact, the original variables are inverted.

g. Electricity

The study uses the proportion of households with electricity per district as a proxy for stock of electricity infrastructure per district.

h. Cultivable land

This relates to the total cultivable land in acres in a district. It includes all arable land except land under permanent pasture, wood or forest, and all other non-agricultural land put to residential use or used for other enterprise activities. It is taken from the Crop Survey 1999/2000 of the Uganda Bureau of Statistics.

i. Fertiliser

The study derives aggregate value of fertiliser used for crop production per district from the Crop Survey 1999/2000. This includes both locally obtained fertilisers, for example, composite manure, and inorganic fertilisers (manufactured fertilisers) for example, nitrogen fertilisers.

j. Labour

Labour encompasses the number of persons engaged in crop farming. This is derived from the Uganda National Household Survey 1999/2000 by the Uganda Bureau of Statistics. Since this survey and the Crop Survey 1999/2000 cover the same households, its use presents no problems.

k. Education (human capital)

The mean number of school years completed by crop farmers in the district is utilised to capture the hypothesised relationship between education (human capital) and agricultural value added.

l. Research and extension

District-level data on research and extension are not readily available. There are data on agricultural research expenditure, but only at the national level. To capture the relationship between research and extension and agricultural value added output/productivity, the study uses information on the use of agricultural extension services derived from the Crop Survey 1999/2000. The Survey reports the percentage of staple food crop area that was planted with improved varieties in 1992, 1994, 1996 and 1998. The average for these years per district is used in estimation. Although this average can be considered to be a research output, it is of preceding years and should be a good proxy as a stock variable for agricultural research and extension.

m. Regional dummies

As was done in Chapter 5, the study introduces regional dummies to capture region-specific characteristics by applying a dummy variable model. In this, a number of dummy variables representing the different regions are added to the simple OLS version.

However, in the final analysis, only the Northern dummy is significant, possibly capturing the peculiarities of the Northern region whose production was affected by the ongoing war in that region. The coefficient for the Northern dummy was expected to be negative.

6.3.2 Empirical functional form

A number of econometric studies that estimate the relationship between infrastructure and the agriculture sector (for example, Antle, 1983, 1984; and Benziger, 1996) assume that the underlying production function is a Cobb-Douglas one. They justify their selection with the argument that it has proved to be a useful representation of agricultural production processes and is linear in the parameters. However, the Cobb-Douglas production function has a number of limitations, especially in regard to its lack of flexibility (see Chapters 2 and 5). Antle (1984) applies a more variable coefficient Cobb-Douglas model that can be interpreted as a special case of the more general translog production function; however, he still assumes constant returns to scale.[12] Other studies, for example, Mamatzakis (2003) and Teruel and Kuroda (2005) use a more flexible framework that incorporates the underlying economic mechanism of cost minimisation, that is, applying a translog cost function model. However, as discussed in Chapter 2, this framework has the disadvantage of requiring a considerable amount of data and retaining several problems identified in the production function approach.

This study applies a more flexible functional form, but it opts for the translog production function as in the earlier estimations in Chapter 5. Some studies that use this formulation simultaneously estimate the production function and factor share functions, that is, the private capital share function and labour share function. One reason advanced for this is that multicollinearity poses serious problems when a single-handed estimation of the production function is done (Yoshino and Nakahigashi, 2000, 2004). However, Yoshino and Nakahigashi (2000) also found that in Thailand it is difficult to identify compensation for labour share in the agricultural sector accurately because it is largely family-based. Thus, this and other data difficulties still abound.

The estimation method adopted by this study, which follows Costa et al. (1987), avoids the usual multicollinearity problems associated with this functional form. In this method, each variable is expressed as the deviation from a given point of expansion, (that is, the mean) as was done in chapter 5. The procedure has the advantage of being analogous to 'centring', a method that reduces multicollinearity in polynomial or interaction-effect models (see Hamilton, 2003: 167). Hence, the basic formulation that is estimated is of the form in equation 6.2 below.[13] All factors are described in equation 6.1 above.

$$\begin{aligned}\ln VA_i = {} & a+\alpha(\ln F_i-\ln\overline{F})+\beta(\ln K_{Li}-\ln\overline{K}_L)+\gamma(\ln G_i-\ln\overline{G})+\vartheta(\ln F_i-\ln\overline{F})^2\\ & +\rho(\ln K_{Li}-\ln\overline{K}_L)^2+\sigma(\ln G_i-\ln\overline{G})^2+\delta(\ln F_i-\ln\overline{F})(\ln K_{Li}-\ln\overline{K}_L)\\ & +\varepsilon(\ln F_i-\ln\overline{F})(\ln G_i-\ln\overline{G})+\phi(\ln K_{Li}-\ln\overline{K}_L)(\ln G_i-\ln\overline{G})\\ & +\eta\,(\ln IV_i-I\overline{V})+\upsilon(\ln H_i-\ln\overline{H})+(Ndummy)+\mu_i \qquad (6.2)\end{aligned}$$

where VA_i represents value added for each district rather than the gross value of production. Ndummy represents the dummy for the Northern region. The other variables are denoted as in equation (6.1) and their mean values by $(-)$

The appropriateness of the translog framework vis-à-vis the Cobb-Douglas framework is checked by testing the restrictions on the production technology. Within the translog framework, homogeneous technology will make the sum of the coefficients of the squared terms and the cross-effects zero. Linear homogeneity will require that, in addition to the above condition, the sum of the linear terms equals one (Chambers, 1988). Cobb Douglas technology requires that each of the squared terms and cross-effects is zero. These restrictions are tested with an F-test, with the computed F-statistic given by

$$F_{m,n-k_u} = [(RSS_R - RSS_U)/m]/(RSS_U / n - k_U)$$

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 facilitate comparison of the results with those of earlier infrastructure studies, the overwhelming majority of which have utilised the Cobb-Douglas formulation, the results from that formulation are also reported. In this, the study considers the effect of public infrastructure on agricultural productivity, that is, agricultural productivity of labour (agricultural value added per worker). This choice follows from the derivation in Chapter 2 of the impact of public infrastructure on per capita growth of output.[14] Hence,

Agricultural value added per worker (V_L) =

$$\frac{\textit{Value of Agricultural Value Added (Ug. Shillings)}}{\textit{Persons engaged in crop farming}}$$

The conventional inputs, that is, agricultural land and fertilisers, and the different types of infrastructure are therefore also expressed on a per unit labour basis. However, as a starting point, the Cobb-Douglas production function is linear in the logarithms of variables (equation 6.3)

$$\ln VA_i = \lambda + \alpha \ln F_i + \beta \ln K_{L_i} + \varepsilon \ln L_i + \gamma \ln G_i + \upsilon \ln H_i + \eta \ln IV_i + NorthDummy + \mu_i \quad (6.3)$$

where

- VA_i as before, represents value added for each district
- F_i represents aggregate value of fertiliser used for crop production per district
- K_{L_i} represents total cultivable land in acres per district
- L_i is the number of persons engaged in crop farming per district
- G_i represents the composite public infrastructure variable or the different types of public infrastructure per district
- H_i represents human capital (mean number of school years completed by crop farmers per district)
- IV_i is the percentage of staple food crop area that was planted with improved varieties per district (average for the years 1992, 1994, 1996 and 1998).

$NorthDummy$ is the dummy for the Northern region.

As discussed in Chapter 5, it is preferable to estimate the above production function equation in intensive form with no *a priori* restrictions regarding returns to scale; hence it is re-arranged as below (equation 6.4). If the parameter '$(\beta+\alpha+\gamma+\varepsilon-1)$ ' is significantly different from zero, then the null hypothesis of constant returns to scale is rejected. If the assumption of constant returns to scale holds, then $(\beta+\alpha+\gamma+\varepsilon=1)$.

$$\ln\left(\frac{VA_i}{L_i}\right) = \lambda + \beta \ln\left(\frac{K_{Li}}{L_i}\right) + \alpha \ln\left(\frac{F_i}{L_i}\right) + \gamma \ln\left(\frac{G_i}{L_i}\right) + (\beta+\alpha+\gamma+\varepsilon-1)\ln L_i + \upsilon \ln(H_i) + \eta \ln(IV_i) + North\ Dummy + \mu_i \quad (6.4)$$

6.4 Regression Results

The estimation results for the Cobb Douglas formulation and the more flexible translog production function are presented in Tables 6.1, 6.2 and 6.3. Equations 1 to 5 present the results for various types of public infrastructure while equation 6 presents the results for the public infrastructure composite variable.

Focusing on the investigative variable, that is, public infrastructure, the results from both the functional formulations show that dry-weather roads, which are mainly feeder roads, are positively and significantly associated with agricultural value added and productivity,[15] highlighting the importance of farm-to-market roads. As discussed above, this seems to be very plausible given that these types of roads are almost exclusively the ones that link rural agricultural communities to commercial and socio-economic centres and are therefore important for delivery of farm inputs, marketing of agricultural produce and delivery of social and administrative services. The other public infrastructure types, that is, paved roads, electricity, public telephones and the public infrastructure composite variable, do not appear to have statistically significant associations with agricultural value added and labour productivity. The next subsections elaborate on the estimation results of the Cobb-Douglas production function and the translog production function.

6.4.1 Elaboration of the estimates of the Cobb-Douglas production function

The estimated results are shown in Table 6.1. The primary coefficient of interest may be interpreted as the elasticity of agricultural productivity (value added) to public infrastructure intensity. Specifically, the dependent variable measures Log value added per worker while the key independent variable measures the logarithm of the particular type of public infrastructure. There are six versions of equations. Equations 1 to 5 incorporate one type of infrastructure measure at a time, that is, dry-weather roads, all-weather roads, paved roads, electricity and telephones respectively, while equation 6 incorporates the public infrastructure composite variable. However, there are two versions of equation 1 (that is equations 1 and 1a). Equation 1 presents the regression results of the exact model as depicted in equation 6.4, which has no restrictions concerning assumptions about returns to scale. The coefficient of Log L is, however, statistically insignificant and is dropped from the model. Hence the results that are discussed are those for equations 1a to 6.

As noted above, among the public infrastructure variables only dry-weather roads have a positive and significant coefficient, with an elasticity of 0.123. All the other public infrastructure variables have statistically

Table 6.1
Dummy Variable Model Estimates of Cobb-Douglas Agricultural Production Function: Dependent Variable – Log Value Added per Worker

Variable	Eqn 1	Eqn 1a	Eqn 2	Eqn 3	Eqn 4	Eqn 5	Eqn 6
Constant	12.495*** (1.272)	12.14*** (0.879)	10.912*** (0.996)	12.123*** (1.316)	12.088*** (1.345)	10.024*** (1.297)	10.256*** (0.320)
Log Agric. Land / Worker	0.501*** (0.115)	0.520*** (0.101)	0.493*** (0.120)	0.421*** (0.110)	0.423*** (0.110)	0.463*** (0.113)	0.462*** (0.107)
Log Fertiliser / Worker	0.116*** (0.035)	0.111*** (0.032)	0.083** (0.033)	0.104*** (0.052)	0.103** (0.036)	0.074* (0.036)	0.103** (0.036)
Log Dry-weather/worker	**0.109** **(0.066)**	**0.123**** **(0.054)**					
Log All-weather/worker			**0.038** **(0.054)**				
Log Paved/worker				**0.157** **(0.107)**			
Log Electricity / worker					**0.154** **(0.110)**		
Log Telephone/worker						**-0.015** **(0.085)**	
Log Labour (crop farming)	-0.048 (0.122)						
Infrastructure composite							**0.065** **(0.047)**
North Dummy	-0.786*** (0.155)	-0.811*** (0.138)	-0.910*** (0.150)	-0.789*** (0.163)	-0.793*** (0.163)	-0.934*** (0.224)	-0.792*** (0.165)
Log Human Capital	0.195 (0.428)	0.217 (0.413)	0.372 (0.481)	0.321 (0.443)	0.324 (0.446)	0.513 (0.462)	0.290 (0.455)
Log Improved Varieties (% staple food crop area)	-0.018 (0.054)	-0.026 (0.049)	-0.039 (0.055)	-0.012 (0.056)	-0.014 (0.057)	-0.047 (0.055)	-0.022 (0.055)
Adj R-squared	0.8796	0.8859	0.8533	0.8667	0.8654	0.8491	0.8649
SSE(RSS)	0.385	0.389	0.500	0.455	0.459	0.515	0.461
Mean (VIF)	2.41	2.02	1.92	2.24	2.22	2.47	2.18
RESET (test) Prob >F	0.5794	0.6100	0.5650	0.4807	0.4939	0.5071	0.5265
Heteroskedasticity test Prob >chi2	0.9757	0.8787	0.8599	0.5463	0.5885	0.9200	0.6626
N	23	23	23	23	23	23	23

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

insignificant coefficients. The insignificance of paved roads and public telephones is not surprising and can be explained by the fact that they are virtually non-existent in rural areas where most of agricultural production takes place. These areas are mostly served by feeder roads, the majority of which are dry-weather roads. Similarly, electricity per worker has a positive but insignificant coefficient, which may simply reflect the fact that there is hardly any power available and/or directly utilised in the agricultural sector. However as previously discussed, the availability of electricity and its likely impact on agricultural output and productivity can be direct, as an intermediate input, or indirect. It may define whether agriculture is mechanised or not. Most of the agricultural sector is at subsistence level and not commercialised, and in the few cases where electricity is available it is used only for lighting. The insignificance of these types of infrastructure variables does not mean that they are not crucial in production and the modernisation of Ugandan agriculture; rather, their absence determines and limits the type of production technology utilised.

Of the remaining variables, two have a positive and significant coefficient in all the equations: Agricultural land per worker (estimates range from 0.421 to 0.520) and Fertiliser per worker (0.074 to 0.111).

It is worth noting that in the case of equation 1a, where we have a positive and statistically significant coefficient for the relevant type of public infrastructure (dry-weather-roads), the size of the coefficient for agricultural land per worker is relatively bigger, suggesting that land becomes more important when there is availability of transportation, which improves access to markets and agricultural inputs, and so on. This argument is explored further below, first in a Cobb-Douglas framework with land productivity as the independent variable, and second, with the more flexible translog production function since it enables us to assess their interaction. The relatively larger land coefficients in all equations are also suggestive of the still-existing traditional forms of agricultural production.

As shown in Table 6.2, the results of the empirical analysis of agricultural land productivity are consistent with the study's earlier findings. They confirm the importance of dry-weather roads as a significant determinant of agricultural productivity. As before, all the other public infrastructure variables have statistically insignificant coefficients. Of the control variables, one, the dummy variable representing the Northern

Table 6.2
Dummy Variable Model Estimates of Cobb-Douglas Agricultural Production Function: Dependent Variable – Log Value Added per Acre of Agricultural Land

Variable	Eqn 1	Eqn 1a	Eqn 2	Eqn 3	Eqn 4	Eqn 5
Constant	12.495*** (1.272)	12.144*** (0.879)	10.912*** (0.996)	12.123*** (1.316)	12.088*** (1.345)	10.024*** (1.297)
Log Labour/ agric land	0.227 (0.155)	0.246 (0.143)	0.386** (0.163)	0.317* (0.153)	0.320* (0.154)	0.478*** (0.154)
Log Fertiliser / agric land	0.116*** (0.035)	0.111*** (0.032)	0.083** (0.033)	0.104*** (0.036)	0.103** (0.036)	0.074* (0.036)
Log Dry-weather/Agric.land	**0.109** **(0.066)**	**0.123**** **(0.054)**				
Log All-weather/Agric.land			**0.038** **(0.054)**			
Log Paved /Agric land				**0.157** **(0.107)**		
Log Electricity / agric land					**0.154** **(0.110)**	
Log Telephone/worker						**-0.015** **(0.085)**
Log Agricultural land	-0.048 (0.122)					
North Dummy	-0.786*** (0.155)	-0.811*** (0.138)	-0.910*** (0.150)	-0.789*** (0.163)	-0.793*** (0.163)	-0.934*** (0.224)
Log Human Capital	0.195 (0.428)	0.217 (0.413)	0.372 (0.481)	0.321 (0.443)	0.324 (0.446)	0.513 (0.462)
Log Improved Varieties (% staple food crop area)	-0.018 (0.054)	-0.026 (0.049)	-0.039 (0.055)	-0.012 (0.057)	-0.014 (0.057)	-0.047 (0.055)
Adj R-squared SSE(RSS)	0.9208 0.385	0.9250 0.389	0.9036 0.500	0.9123 0.455	0.9115 0.459	0.9008 0.515
Mean (VIF)	2.96	2.41	2.28	2.65	2.65	2.89
RESET (test) Prob >F	0.5715	0.5881	0.2855	0.1535	0.1814	0.333
Heteroskedasticity test Prob >chi2	0.7399	0.8139	0.6467	0.4078	0.4517	0.6204
N	23	23	23	23	23	23

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

region, has a negative and significant coefficient in all the equations (estimates range from -0.786 to -0.934). This is what was expected given that this region has been affected by the ongoing war which started in 1986, negatively affecting agricultural productivity there.

Lastly, two variables, that is, human capital (with number of school years completed by crop farmers as a proxy) and research and extension (with percentage of staple food crop area that was planted with improved varieties as a proxy) are statistically insignificant. As also found by some other studies (for example, Antle, 1983 and Felloni et al., 2001) the human capital variable has insignificant coefficients in all equations.[16] The insignificance of these two variables needs to be analysed in conjunction. As noted in Antle (1983) education (human capital) and extension are two crucial components of the transmission of technical information to farmers; lack of one may nullify or at least compromise the importance of the other. He states:

> Agricultural research expands the set of technologies from which farmers may choose. However, the extent to which farmers are able to use new technologies to their advantage depends on the costs and benefits of learning and using them. (Antle, 1983: 611)

Farmers' ability to adopt and use new technologies also depends on their level of education and or whether there is reasonable extension work, which is not the case in Uganda. According to the Crop Survey 1999/2000 data, on average approximately 85 per cent of households engaged in crop farming did not receive any kind of advice from extension workers during 1992-98. Therefore, the insignificance of the improved varieties variable may be a reflection of their poor usage generally. According to the Crop Survey 1999/2000, about 95 per cent of households reported using local seeds.

To test the validity of the study's results, several post-regression tests were carried out, including checks on the assumption of constant error variance and multicollinearity (that is, the heteroskedasticity test and mean variance inflation factor – VIF). The results show that we can accept the null hypothesis of constant variance and no multicollinearity (see Tables 6.1 and 6.2).

6.4.2 Elaboration of the estimates of the Translog production function

As discussed previously, the translog production function allows us to account for direct and indirect effects, which makes it a very convenient functional form in the analysis of the relationship between public infrastructure, factor inputs and private output (in value added) and productivity. The model in equation 6.2 was estimated.

Five equations were estimated, each with one of the five public infrastructure measures: dry-weather roads, all-weather roads, public telephones, electricity and paved roads.

The results are shown in Table 6.3. The primary coefficients of interest, that is, public infrastructure, largely reflect the results of the earlier estimations, except that in this case dry-weather roads and all-weather roads both show a positive and significant association with value added. However, in these two cases it is only the indirect effect, that is, the interaction between agricultural land and either dry-weather roads or all-weather roads, that is positive and significant .This suggests that these forms of public infrastructure capital and private capital in the form of agricultural land are complementary inputs. The interaction term between agricultural land and dry-weather roads has a coefficient equal to 0.429 (equation 1). Similarly, agricultural land and all-weather roads return a positive and significant coefficient of 0.360 (equation 2).

From the theoretical discussion, the interaction term between public infrastructures especially roads and fertilisers, would be expected to be positive and significant since it is hypothesised that proximity to roads would be associated with greater fertiliser use. However, the relevant coefficient turns out to be insignificant in all cases. The reason for this may be that most of the fertilisers used are in the form of manure, which is organic and obtained locally.

Table 6.3 *Estimates of the Translog Production Function Model: Dependent Variable: Log Value Added*

Variable (in Logs)	Eqn 1	Eqn 2	Eqn 3	Eqn 4	Eqn 5
Constant	23.438***	23.410***	23.376***	23.507***	23.487***
	(0.051)	(0.066)	(0.069)	(0.085)	(0.1085)
Agric_Land	0.803**	0.753***	0.539***	0.525***	0.755***
	(0.112)	(0.128)	(0.109)	(0.118)	(0.214)
Fertilisers	0.115***	0.106***	0.184***	0.156***	0.221**
	(0.023)	(0.030)	(0.039)	(0.036)	(0.089)
Dry-weather road	0.106				
	(0.065)				
All-weather road		0.082			
		(0.075)			
Public Telephone			-0.236		
			(0.149)		
Electricity				-0.048	
				(0.056)	
Paved road					-0.247
					(0.239)
Agric.Land x Dry-weather road	**0.429***				
	(0.206)				
Fertilisers x Dry-weather road	0.008				
	(0.028)				
Agric.Land x All-weather road		**0.360***			
		(0.195)			
Fertilisers x All-weather road		-0.073			
		(0.055)			
Agric.Land x Public telephone			0.199		
			(0.284)		
Fertilisers x Public telephone			-0.118		
			(0.097)		
Agric.Land x Electricity				0.142	
				(0.129)	

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

Table 6.3 *(Continued)*

Variable (in Logs)	Eqn 1	Eqn 2	Eqn 3	Eqn 4	Eqn 5
Fertilisers x Electricity				0.043 (0.078)	
Agric.Land x Paved road					1.209 (0.964)
Fertilisers x Paved road					0.028 (0.278)
Agric-Land x Fertilisers	-0.119** (0.047)	-0.173** (0.075)	0.020 (0.095)	-0.111 (0.120)	-0.576 (0.360)
(Agric. Land)^2	0.584** (0.210)	0.348* (0.194)	-0.074 (0.153)	0.043 (0.188)	0.727 (0.665)
(Fertilisers)^2	0.011 (0.008)	0.025** (0.012)	0.006 (0.023)	-0.005 (0.032)	0.007 (0.064)
(Dry-weather road)^2	**-0.296**** **(0.117)**				
(All-weather road)^2		0.024 (0.092)			
(Public Telephones)^2			0.608 (0.348)		
(Electricity)^2				-0.051 (0.045)	
(Paved road)^2					-0.223 (0.456)
North Dummy	-1.160*** (0.188)	-1.516*** (0.343)	-0.985*** (0.262)	-0.822** (0.291)	-1.396*** (0.408)
Adj R-squared	0.9498	0.9267	0.9161	0.9017	0.8306
SSE(RSS)	0.2171	0.317	0.363	0.346	0.286
Mean Variance Inflation Factor (VIF)	5.29	5.76	8.56	10.45	20.94
RESET (test) Prob >F	0.1769	0.4444	0.74	0.7895	0.3381
Heteroskedasticity test Prob >chi2	0.1278	0.2613	0.7382	0.5393	0.2582
N	23	23	23	21	18

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

It also worth noting that the squared term for dry-weather roads is negative and significant (model 1, Table 6.3), thus exhibiting diminishing returns. Although there is underinvestment in almost all other types of road infrastructure in comparison with other East African countries, Uganda has a higher density of low-grade roads, particularly feeder roads, which are almost exclusively dry-weather roads (World Bank, 2001). What is required, therefore, is a focus on maintenance and upgrading of roads rather than construction of new low-grade roads. Hence, poverty studies that recommend giving priority to increasing the number of low-grade roads such as feeder roads (for example, Fan et al., 2004) may be misleading in the Ugandan context.

6.4.3 Comparison of the results with results from other studies

A direct comparison of results between different studies on the relationship between public infrastructure and agricultural output/productivity is not possible, not only because of differences in the measurement of infrastructure variables but also due to flaws in the methodologies used, especially in the earlier studies. As discussed previously, studies that econometrically analyse the relationship between public infrastructure and agricultural output and productivity in sub-Saharan African countries are scarce. Comparison with the findings of the few studies available from past and recent literature are summarised in Tables 6.4 (this study) and 6.5 (other studies). A number of conclusions can be drawn.

a. The more recent studies and this one find a positive, large-magnitude and significant effect of public infrastructure on agricultural output and productivity, particularly in regard to road or transportation infrastructure. Focusing on sub-Saharan Africa in particular, Abrar (2001) calculates an output elasticity of 0.56 for road density while this study shows an output (value added) elasticity of 0.429 and 0.360 for dry-weather road density and all-weather road density respectively.

b. While it is important to be cautious when using the results of earlier studies in any kind of analysis, due to their methodological flaws, the findings of some of the more recent studies, which apply sophisticated econometric techniques to minimise or eliminate the methodological problems that earlier studies had been criticised for, still show a positive, large-magnitude and significant effect (see examples in Table 6.5). One possible explanation for this is that some of the recent studies manage to capture both the direct and indirect effects.

Table 6.4
Estimated Parameters of the Relationship Between Public Infrastructure Capital and Agricultural Output and Productivity in Uganda

Study	Country and Sample	Type of Estimation	Public Infrastructure	
			Type/ measure	**Output Elasticity**
Present study (2006)	Uganda (Districts) (1999/2000)	Translog Production Function	Dry weather roads density	**0.429** (Total effect)
			All weather roads density	**0.360** (Total effect)
			Paved roads density	**Insignificant**
			Electricity	**Insignificant**
			Telephone	**Insignificant**
Present study (2006)	Uganda (Districts) (1999/2000)	Cobb Douglas Production Function	Dry weather roads density	**0.123**
		Agricultural Labour Productivity and Agricultural Land Productivity	All weather roads density	**Insignificant**
			Paved roads density	**Insignificant**
			Electricity	**Insignificant**
			Telephone	**Insignificant**

Table 6.5
Results from Studies of the Relationship between Infrastructure and Agricultural Output and Productivity

Study	Country and Sample	Type of Estimation	Public Infrastructure		
			Type/ measure	Output Elasticity	Cost Elasticity
Teruel and Kuroda (2005)	Philippine (regional) (1974 - 2000)	Translog Cost Function	Roads		**-0.7115**
			Irrigation		**-0.1253**
			Rural Electrification		**Not significant**
Mamatzakis (2003)	Greece (national) (1960 - 1995)	Translog Cost Function	**Core infrastrucuture** includes services derived from public capital stock in ports, railways, motor vehicles roads, electrical and communication facilities and irrigation canals		**-0.382**
Suleiman Abrar (2001)	Ethiopia Farm Households 1994	Normalised Quadratic Production Function	Road density	**0.560**	
Paul et al (2001)	U.S.A (48 states) (1960 - 1996)	Generalised Leontief - Quadratic Cost Function	Highway capital stock estimates (investments)		**-0.895**
Felloni et al., (2001)	Cross-country (83 countries) 1991	Model based on Cobb - Douglas Production Function	Road density	**0.235**	
			Electricity per capita	**Not significant**	
	China (30 provinces) 1991, 1993 and 1996	Model based on Cobb - Douglas Production Function	Road density	**0.480**	
			Electricity per capita	**Not significant**	

Table 6.5 *(Continued)*

Study	Country and Sample	Type of Estimation	Public Infrastructure		
			Type/ measure	Output Elasticity	Cost Elasticity
Yoshino and Nakahigashi (2000)	Thailand (national) (1971 - 1996)	Translog Production Function	Transport & communication Electricity & Water supply	**0.364** (total effect)	
	Japan (national) (1905 - 1940)	Translog Production Function	Transport & communication Public utility sector	**0.05** (total effect)	
Benziger V (1996)	China (counties) 1980	Log-linear	Road density	**0.158**	
Binswanger et al (1993)	India (1960/61 - 1981/82) 1971 - 1981	Production Function Panel data - fixed effects technique	Roads He also uses other infrastructure variables	**0.20**	
Antle (1984)	India 1438 farms 1970 -1971	Variable coefficient model based on Cobb Douglas	Transportation costs		**-0.059** Total effect
Antle (1983)	Cross- country Combined developed & less developed countries 43 countries (1965)	Cobb Douglas Production Function	Gross domestic product of each country's transportation and communication industries per square kilometer of land area	**0.213**	
	Cross-country Less developed countries (26 countries) 1965	Cobb Douglas Production Function	Gross domestic product of each country's transportation and communication industries per square kilometer of land area	**0.265**	

Notes:
1. Felloni et al. (2001) make several estimates with different explanatory and dependent variables. Here, the estimates have labour productivity as the dependent variable and one explanatory variable, road density per worker.
2. Some elasticities are evaluated at the mean while in others elasticity is just an addition of the direct and indirect effect coefficients.

6.5 Concluding Remarks

The findings in this chapter confirm that even after taking into account the robustness and generality of models used in estimation, there is a positive, large-magnitude and significant relationship between public infrastructure and agricultural output (value added) and productivity.

The results suggest that dry-weather roads (which are mainly feeder roads) and all-weather roads have a positive and significant association with agricultural output and productivity. The other public infrastructure types included in the study, that is, paved roads, electricity and public telephones, do not appear to have a statistically significant association with agricultural output or productivity. Given the nature of the agricultural sector in Uganda, these results are plausible. Dry-weather roads, and to a lesser extent all-weather roads, are almost exclusively the ones that can be considered to be important technological inputs in agricultural production as they link rural agricultural communities to commercial and socio-economic centres. Therefore, these roads, as indicators of transportation infrastructure, provide a positive and significant coefficient through the facilitation of better access to input and output markets as well as diffusion of technical knowledge, which may positively affect production through an improvement in productivity. The results also suggest that, in this particular case, it is the indirect effects of public infrastructure (dry-weather and all-weather roads) that are most important through complementarity with agricultural land.

As discussed earlier, an important implication of the study's results is that although infrastructure is a necessary condition for productivity and growth, it is not a sufficient condition. To increase output and productivity, public infrastructure and other complementary factors such as good agricultural land, access to fertilisers, and so on, are necessary.

However, the results also suggest that there are diminishing returns to investments in dry-weather roads. Despite the fact that Uganda has far less densities of other types of road infrastructure in comparison with other East African countries, it has a higher density of low-grade roads, particularly dry-weather roads. From a policy point of view, what is needed is a focus on maintenance and upgrading, say to all-weather roads, rather than new expansion of this particular type of road infrastructure. Therefore, poverty studies (for example, Fan et al., 2004) that have recommended that priority should be given to low-grade roads such as feeder roads, which are mainly dry-weather roads, rather than to murram (all-weather) or tarmac roads may be misleading in the Ugandan context.

The insignificance of paved roads, electricity and public telephones is possibly due to very low infrastructure stocks in the rural areas. Hence, they are not good measures of technological input into agriculture. The insignificance of these infrastructure types, however, does not mean that they are not important for the development and modernisation of the sector. Rather, it suggests that absence of investment or underinvestment in these types of infrastructure limits the type of production technology utilised in agricultural production.

Lastly, the analysis and findings of this chapter as well as Chapter 5 suggest that the relationship between public infrastructure capital and private sector output and productivity may not be constant across the sample. The next chapter investigates whether there are nonlinearities in the output/productivity effect of public infrastructure capital on private rates of return.

Notes

1. Fan et al. (2004) include the impact of roads on agricultural productivity in a simultaneous equation model, but the focus of their study is on the effects of different types of government expenditure on agricultural growth and rural poverty. They find that feeder roads have a significant and positive impact on agricultural production. They use distance to the nearest road as a proxy.
2. The figures in this chapter are computed from various statistical documents of the Uganda Bureau of Statistics.
3. Hence, agricultural output is affected by the amount and timing of rainfall year after year. However, the differences among districts are not significant and so this factor is not included in the regression analysis.
4. See, for example, Felloni et al. (2001).
5. Public infrastructure stock variables are for the year 1999, while the value added variables are for the year 2000/01.
6. Farmers' technology is defined as a method of productively combining useful knowledge and other resources.
7. In a similar analysis using cross-sectional data for 1991, 1992 and 1996 from Chinese provinces, they found electricity consumption in rural areas to be a positive and significant explanatory variable of labour productivity.

8. Antle (1984) includes irrigation and other capital inputs in addition to land. Here, these are not applicable because of the nature of agriculture in Uganda. They are negligible.
9. The functional forms applied and their justifications are discussed later in the chapter.
10. In addition, the variable deflated by population had an insignificant coefficient on estimation.
11. Some urban roads (owned and managed by urban governments with assistance from the central government) are also paved.
12. He tests the constant returns to scale assumption and finds he cannot reject it.
13. Labour was dropped from the estimated model because of its high correlation with the cultivable land variable, which was causing both variables to be insignificant on estimation.
14. This study's findings on the impact of public infrastructure capital on agricultural labour productivity led the author to also investigate its impact on agricultural land productivity (see sub-section 6.4.1).
15. All-weather roads also show a positive and significant relationship when the results of the translog production formulation are considered.
16. Those studies use adult literacy to represent human capital.

7 Non-Linearities in Returns to Public Infrastructure Capital: Implications for Public Investment

7.1 Introduction

The empirical results in Chapters 5 and 6 show a strong positive linkage between public infrastructure and private sector output and productivity. The chosen functional specification also indicates that the relationship may not be constant across the sample. This chapter argues that public infrastructure investments are 'lumpy' in nature, such that in countries or underdeveloped areas with infrastructure stocks below a certain minimum threshold, the concept of marginal productivity of capital may be rendered difficult to apply. It therefore tests the hypothesis that marginal increments in infrastructure stocks will not have a significant effect until a minimum critical mass or threshold level of infrastructure stocks has been attained. This is a departure from existing studies that similarly study threshold effects related to public infrastructure but focus on 'maximum threshold levels' or saturation points. These studies assume that all countries have the minimum critical mass and therefore attempt to establish the points at which the marginal effects are quite high as well as the maximum point at which marginal increases in stocks will have no significant positive effects (for example, Sanchez-Robles, 1998).

The minimum critical mass scenario which is the focus of the current study is most relevant to sub-Saharan Africa (SSA), including Uganda. Infrastructure has increasingly become the focus of the discourse on the abysmal growth performance and related abject poverty in SSA. According to World Bank (1994), public infrastructure capital represents if not the engine then the 'wheels' of economic activity. Hence, very low levels of infrastructure can stifle a country's growth performance. Small investments below the requisite critical mass may actually be wasteful if non-linearities exist in the relationship between infrastructure, output and productivity.

As discussed in Chapter 2, evidence from a number of empirical studies shows that the relationship between public infrastructure and economic output/growth can be non-linear. Aschauer (2000), using state-level data showed that the relationship between the level of public capital stock and output and employment growth is non-linear. This is also supported by other studies, for example, Barro (1990), Barro and Sala-i-Martin (1992), Canning and Bennathan (2000) and Cashin (1995). However, these studies focus on the existence of an output- and growth-maximising level of public capital stock relative to either private capital or a country's GDP. The implication of these studies is that the benefits of public capital are subject to diminishing returns for several reasons, for example due to costs of providing public capital or due to the fact that the services provided by the stock of public infrastructure capital may be subject to congestion. This study contributes to the literature by focusing on the notion of threshold effects from the point of view of a minimum critical mass as theoretically referred to by Nurkse (1953) rather than the concept of a 'saturation point'. Nurkse argues that

> Once a minimum structure of social overhead capital exists, any private firm can make use of it at small or zero additional cost not only to itself but to the community…. In a poor country an overhead capital structure may not initially have enough work to do to justify its existence and can then justify itself only by faith in the future. (Nurkse, 1953: 152)

A few studies, for example, Kelly (1997) and Röller and Waverman (2001) adopt a similar focus.

Kelly (1997) analysed the development of the Chinese economy between 805 AD and 1075 AD. His findings showed that below a critical density of transport linkages the economy was split into isolated local markets with limited specialisation and growth. However, after the attainment of a critical density, there was increased specialisation as a result of the fusion of the small local markets into a large economy-wide market, which resulted in 'Smithian growth' and progress.[1]

Röller and Waverman (2001), using a piece-wise linear regression model and data from 21 OECD countries, found that a critical mass exists for telecommunications infrastructure, leading to increasing returns to growth for those countries with levels approaching universal service (that is, a 40 per cent penetration rate).

The current research follows these two studies, but it differs in some aspects. First, it considers several types of physical public infrastructure, and second, it uses country-specific data. Third, since many of the issues that arise in relation to threshold externalities in a country context also pertain to the performance of individual units such as firms or enterprises, it uses micro-level data instead of macro cross-country data in the analysis.

In the rest of the chapter, the next section elaborates on the method and approach applied in threshold estimation and analysis and identifies the threshold level of public infrastructure capital stock (that is, the minimum critical mass). Section 7.3 analyses threshold effects and discusses regression results from spline regressions. It also uses results of separate regressions for observations above and below the threshold value to corroborate the spline regression results. Section 7.4 assesses the deviations of the actual stock levels of infrastructure per district from the threshold value and computes the infrastructure investments required to reach the critical minimum mass for each type of infrastructure. In section 7.5 the returns to investments after the threshold value has been reached are assessed. Benefit-cost ratios for different infrastructure investments for different sectors provide an indication of the extent of underinvestment. Concluding remarks are made in section 7.6.

7.2 Method and Approach to the Analysis of Threshold Effects

Two approaches are applied to assess whether there are nonlinearities in the relationship between public infrastructure and firm value added and to establish the threshold level (that is, the minimum critical mass).

a. Exploratory data analysis

The exploratory data analysis approach enables maximisation of the insight into the data, uncovering the underlying structure as well as guiding the development of a parsimonious model by helping inform the kind of function that would best fit the data. The appropriate function is later used in the empirical analysis to determine whether the output/productivity effects of public infrastructure are subject to a threshold. The true response function could be curvilinear, whereby all the parameters of the regressors are actually linear but with the dependent variable nonlinear vis-à-vis the regressors, or it could be a very complex non-linear function, one in which at least one of its parameters appears non-linearly (Ratkowsky, 1990). Use of regression graphics also helps to better explain some of the particularities in the study regarding patterns in the data that later guide the threshold effects estimations.[2]

b. Econometric modelling analysis

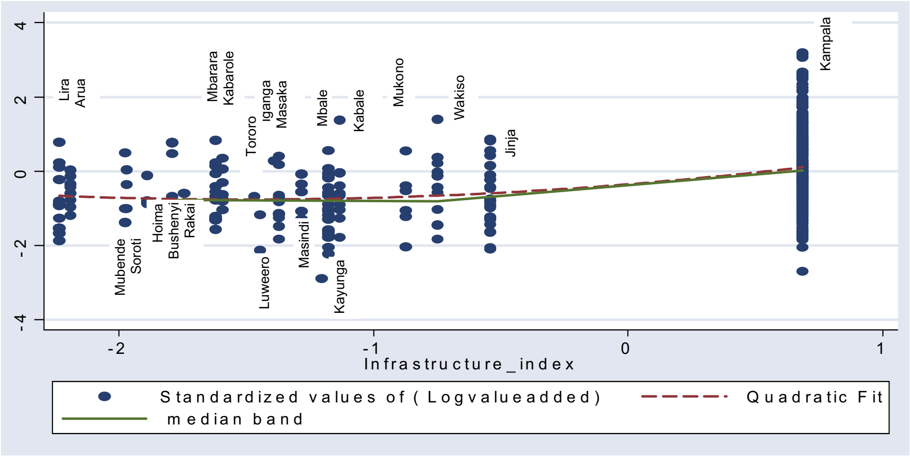
Econometric modelling techniques are applied to check the robustness of results from the exploratory data analysis approach. In order to identify the threshold value empirically, a robust specification with flexibility for different threshold values is applied using spline function theory. To confirm whether there are differences in regression structures, two different methods are applied: (i) A spline function approach, using an automatic stepwise regression method to identify the threshold value empirically and spline regression models to test the level of significance of the spline coefficients.[3] That is, the method makes it possible to test whether the change in the slope from the preceding interval is significant. (ii) Estimation of separate regressions in which each sample is divided into sub-samples based on whether firms are at/below the threshold value or above it, and testing for the significance of the investigative variable.

7.2.1 Exploratory data analysis — graphically identifying the threshold value

In this approach, usual assumptions about what kind of model the data follow are put aside and replaced by a more direct approach of allowing the data themselves to reveal the underlying structure and model. Therefore, regression graphics and various quantitative techniques are applied.

To assess linearity or otherwise, a linear fit and higher-order polynomial fits are superimposed on the data in the scatter-plots for the full sample and sub-samples of both the service and industrial firms. To identify/approximate the threshold value graphically, exploratory band regression together with a quadratic fit are applied in a visual inspection. (The finding here is later compared with the threshold value obtained empirically.) Exploratory band regression plots the dependent variable against the explanatory variable(s) and observes if there is a sharp change in the relation after a given value of G (infrastructure), that is, G* the threshold level of public infrastructure capital. First, the scatter-plot is divided into a series of vertical bands.

Figure 7.1
Scatter-plot of Service Firms with Linear Fit, Quadratic Fit and Median Bands Superimposed - Graphical Identification of Threshold Value



Note: 1. Infrastructure composite index for Masindi district is the threshold value
2. Firms are clustered by district

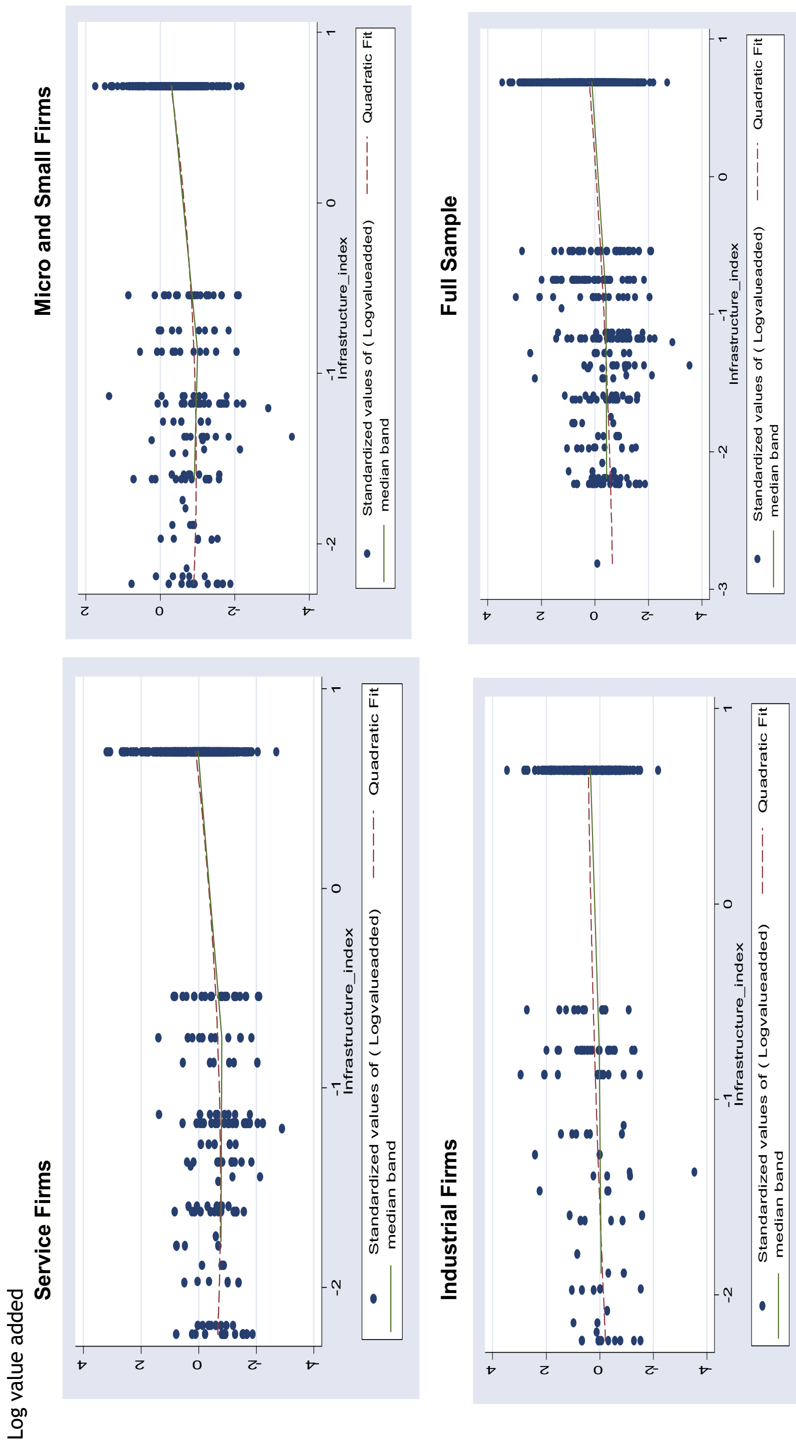
Central points, median values (X, Y) within each band, are then established and used to define a line or curve, making it possible to approximate the threshold value visually (see Figures 7.1 and 7.2).

From Figure 7.1, the threshold value of the composite public infrastructure variable is approximated at -1.20345, which is close to the public infrastructure composite variable of Masindi district. From Figure 7.2, visual inspection indicates the threshold value also falls at or close to -1.20345 for both the service sector sample and the full sample. This is empirically corroborated, as will be shown later in this chapter, even though the empirically identified value is not exactly the same for the service sector and full sample. However, for the industrial sector sample, it is not clear from the graphs where the threshold point lies. This is probably because these firms do not solely depend on public infrastructure provision. In the final analysis, the study uses use the threshold value identified within the service sector sample.

The next sub-section describes the identification of the threshold value empirically, which enables us to check the robustness of the graphically determined threshold value (section 7.22).

Figure 7.2

Scatter-plots of Different Samples of Firms with Linear Fit, Quadratic Fit and Median Bands Superimposed



Note: Firms are clustered by district

7.2.2 Empirical approach in assessing threshold value and threshold effects of public infrastructure capital

In the empirical strategy, the study creates a large number of potential spline knots (threshold values) and then uses an automatic stepwise regression method (a non-parametric method) to choose those values that are most statistically significant. This procedure is also used by Marsh and Cormier (2001). As detailed below, this method enables estimation of the location of spline knots (threshold values) so their location does not have to be assumed *a priori*, making it a robust procedure.

As discussed previously, the study's empirical approach is based on equation 2.4, which was presented in Chapter 2:

$$VA = a + bG + cG^2 - dG^3 > 0$$

However, polynomial regression in the form of equation 2.4, that is, regressing G, G^2, and G^3 performs poorly as a modelling approach because it generally suffers from perfect multicollinearity problems. Nevertheless, a polynomial regression as in equation 2.4 was run and significant multicollinearity was found, especially for the squared and cubic terms which turned out to be insignificant, although the linear term was significant.[4] This problem is solved by the use of spline models (in this case cubic spline functions) which are seen as extensions of, or restricted versions of, polynomial regressions rather than an alternative to them (Marsh and Cormier, 2001). Spline regression models are more flexible and less likely to generate perfect multicollinearity in higher dimensions. As argued in Chapter 2, another method that could be used is kernel regression; however, evidence provided by Welsh et al. (2002) suggests that spline methods are more efficient.

Based on theory and from the regression graphics, the empirical approach adopted applies models with parameters that vary across partitions of the sample data (that is, varying coefficient models). Hence, observations are analysed with the presumption that a process with changing structural parameters generates them. We now go on to discuss the formal models, which will be followed by the empirical results.

a. Piece-wise linear regression model

To make explicit the method and approach, we start by analysing the relationship within the simpler but more restrictive piece-wise linear regression model. This method establishes whether there are differences in regression structures within a given sample. In this restrictive form, it is assumed that the threshold value (the position of the knot) is known in advance. As discussed above, this assumption is relaxed in the final model that is applied in estimation, allowing an empirical identification of the threshold value (knot).[5]

As shown in Figures 7.1 and 7.2, the pattern of the response function could be estimated as a continuous piece-wise linear regression model. The assumptions are that the data can be partitioned into regimes, the parameters are constant within each regime and structural changes occur immediately and abruptly;[6] hence we can use dummy variables to model changes in the coefficients. This approach has been used to study, among others, 'sheepskin effects' and other non-linearities in returns to education[7] (see, for example, Arabsheibani and Manfor, 2001; Belman and Heywood, 1997; Hungerford and Solon, 1987).

In general this can be formally modelled as follows (see Gujarati, 2003; Formby et al., 1984; and Montgomery et al., 2001):

Taking equation 7.1, below, as our starting point,

$$Y_t = \beta_1 X_{t1} + \beta_2 X_{t2} + ...+ \beta_k X_{tk} + u_t, \quad \text{t} = 1\ldots \text{T}, \qquad (7.1)$$

where u_t obeys the assumption of the classical linear regression model.

If there are no differences in the coefficients in the different segments of the function, then the parameters $\beta_i \;\; i = 1,...,k$ are fixed for all T observations and best linear unbiased parameter estimates are obtained by applying least squares. In general, if one assumes that the regression structure is different for, say, observations $t = 1,...,t_0$ (the first segment) and $t = t_0 + 1,...,T$ (second segment) and that the structural change is confined to parameters $\beta_i, i = r + 1,...,k$ where $r \varepsilon \{0,...,(k-1)\}$ with $k = r + q$. Then the standard dummy variable approach can be applied to define a dichotomous variable

$$D_t = \begin{cases} 0 \;\; if \;\; t = 1,...,t_0, \\ 1 \;\; if \;\; t = t_0 + 1,...,T. \end{cases} \qquad (7.2)$$

Hence the general model is as follows:

$$Y_t = \sum_{k=1}^{k} \beta_k X_{tk} + \left(X_{t,r+1} \times D_t\right)\delta_{r+1} + \ldots + \left(X_{t,k} \times D_t\right)\delta_k + u_t, \qquad (7.3)$$
$$t = 1,\ldots T.$$

For the observations in the first segment,

$$\mathrm{E}(Y_t) = \sum_{k=1}^{k} \beta_k X_{tk}$$

and for observations in the second segment

$$\mathrm{E}(Y_t) = \sum_{k=1}^{r} \beta_k X_{tk} + \sum_{k=r+1}^{k} (\beta_k + \delta_k) X_{tk}$$

where δ_k represents the incremental change in the structural parameter associated with X_{tk} in the second sample segment. Best linear unbiased estimates of δ_k are obtained by applying least squares to equation (7.3), and a test of the hypothesis that no structural change occurred is carried out by testing the joint hypothesis $H_0 : \delta_{r+1} = \ldots\delta_k = 0$.

Turning to our specific case, and assuming that we have a single knot and it is known, a continuous piece-wise regression model can be fitted using dummy variables and then estimation and testing of the (differing) slopes of the two segments can be carried out. For simplicity, let us assume that in equation (7.4), below, besides public infrastructure, other factors that impact on the firm's value added are represented by the stochastic disturbance term.[8] Then,

$$\ln VA_i = a + \beta_1 \ln G_i + \beta_2 (\ln G_i - \ln G^*) D_i + u_i \qquad (7.4)$$

where

$\ln VA_i$ = is the natural logarithm of value added for firm i

$\ln G_i$ = is the natural log of the public infrastructure capital stock in the district in which the firm is located.

ln G* = is the natural logarithm of the threshold value of public infrastructure stock also known as a knot. To identify the knot empirically, equation 7.4 can be estimated for different values of the knot (threshold value) and tested for statistical significance (see table 7.1).

D = 1 if ln G_i > ln G*
= 0 if ln G_i <= ln G*

Assuming E (u_i) = 0, then

$$\mathrm{E}(\ln VA_i \mid D_i = 0, \ln G, \ln G^*) = \alpha + \beta_1 \ln G_i \tag{7.5}$$

This gives the mean Log value-added up to the threshold level of public infrastructure capital G* and

$$\mathrm{E}(\ln VA_i \mid D_i = 1, \ln G, \ln G^*) = \alpha - \beta_2 \ln G^* + (\beta_1 + \beta_2) \ln G_i \tag{7.6}$$

This gives the mean Log value added beyond the threshold level G*. β_1 gives the slope of the regression line in the first segment, and $\beta_1 + \beta_2$ gives the slope of the regression line in the second segment (see figure 7.3). A test of the threshold effect hypothesis can be conducted by noting the statistical significance of the estimated differential slope coefficient $\hat{\beta}_2$ in relation to $\hat{\beta}_1$. $\hat{\beta}_1$ would not be significantly different from zero while $\hat{\beta}_2$ would have to be positive and statistically significant.

However, a piece-wise linear regression model as illustrated in Figure 7.3 has some disadvantages.

As argued by Suits et al. (1978), although its function is continuous, its derivatives are not (at the kinks). Depending on the data-generating process, this could blur the resulting analysis, especially if a curvilinear relationship could be a better fit than linear approximations. To check for this, a spline function which replaces the linear approximations by a system of piece-wise polynomial approximations is applied in the initial estimations. The advantage of the spline function is that it allows the approximation of a curvilinear stochastic function without the necessity of pre-specifying the mathematical form. Therefore there is no need to restrict the estimate to a straight line, a polynomial of pre-specified degree, an exponential or any other particular form (Marsh and Cormier, 2001; Pindyck and Rubinfeld, 1998; and Suits et al., 1978).

Figure 7.3
Parameters of the Continuous Piece-wise Linear Regression Model

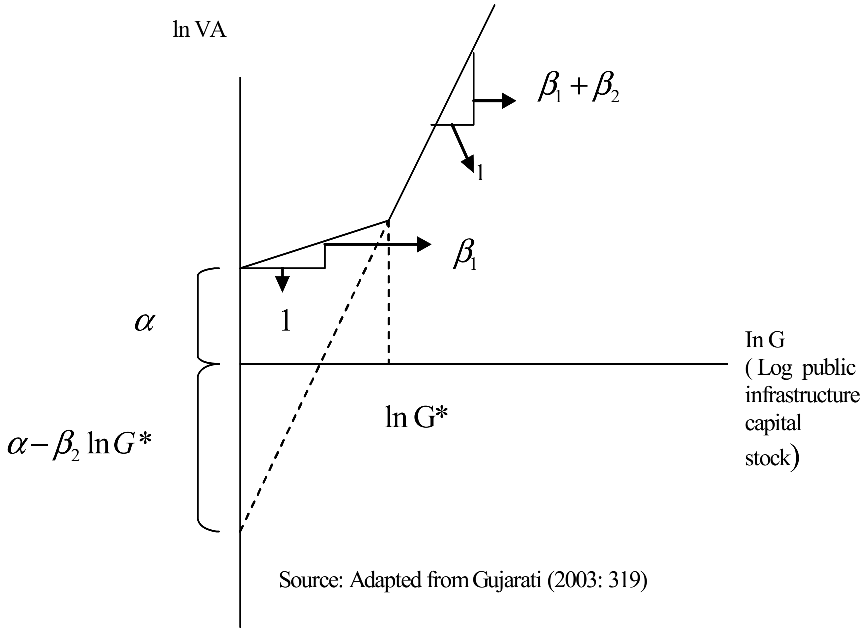
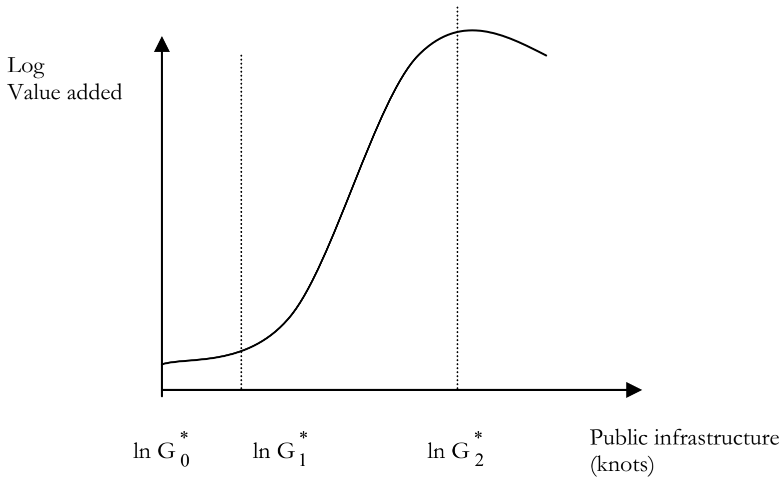


Figure 7.4
Piece-Wise Polynomial Regression – Cubic Spline



Source: Adapted from Suits et al, 1978

b. *Piece-wise polynomial regression model — spline regression model*

The spline function can be modelled in general terms by piece-wise polynomials of any degree, say order k. However, the cubic polynomial is found convenient for most purposes (Suits et al., 1978). In this case it is also consistent with the theoretical exposition in Chapter 2.

Taking a cubic spline $(k = 3)$, and assuming that function values and the first $k-1$ derivatives agree at the knots, then the spline is a continuous function with $k-1$ continuous derivatives.[9] Therefore a cubic spline with h knots, $\ln G_0^* < \ln G_1^* < ... < \ln G_h^*$, with continuous first and second derivatives, can be formulated. The number of knots is determined by chosen intervals which are usually taken to be equal. However this is not an essential part of the procedure, although equality is advised unless there is good reason not to have it (ibid.). The regression can then be fitted as below.

$$\ln VA = [a_1 + b_1(\ln G - \ln G_0^*) + c_1(\ln G - \ln G_0^*)^2 + d_1(\ln G - \ln G_0^*)^3]D_1 +$$
$$[a_2 + b_2(\ln G - \ln G_1^*) + c_2(\ln G - \ln G_1^*)^2 + d_2(\ln G - \ln G_1^*)^3 \;]D_2 +$$
$$[a_3 + b_3(\ln G - \ln G_2^*) + c_3(\ln G - \ln G_2^*)^2 + d_3(\ln G - \ln G_2^*)^3 \;]D_3 + \mu \qquad (7.7)$$

D_i is a dummy variable defined by the ith interval.

It was assumed above that function values and the first $k-1$ derivatives agree at the knots. In general, (7.7) is discontinuous at the knots, as are its derivatives. In the empirical implementation it is necessary to apply appropriate constraints to coefficients of the model, which makes the function continuous, as well as to guarantee continuity of the first and second derivatives (see details in Appendix F. Equation 7.8, below, is the last equation derived in the appendix).[10]

Having introduced the constraints and carried out the necessary manipulations and simplifications, the resulting expression is of the form in equation 7.8.[11]

$$\ln VA = a + b_1(\ln G - \ln G_0^*) + c_1(\ln G - \ln G_0^*)^2 + d_1(\ln G - \ln G_0^*)^3$$
$$+ (d_2 - d_1)(\ln G - \ln G_1^*)^3 D_1^* + (d_3 - d_2)(\ln G - \ln G_2^*)^3 D_2^* \qquad (7.8)$$

This formulation is easier to use in practice and can be generalised to a large number of knots and hence intervals. The dummy variables in this case, D_1^* *and* D_2^* can be defined as follows. $D_1^* = 1$ if and only if $\ln G > \ln G_i^*$, otherwise $D_1^* = 0$. Hence equation 7.8 is a multiple regression with five composite variables. However, the spline function can be fitted to k + 1 intervals[12] with knots at $\ln G_0, \ln G_1, \ln G_2, ..., \ln G_{k+1}$, and dummy variables $D_1^*, D_2^*, ..., D_k^*$. In this generalised form the equation becomes:

$$\ln VA = a + b_1(\ln G - \ln G_0^*) + c_1(\ln G - \ln G_0^*)^2 + d_1(\ln G - \ln G_0^*)^3 + \sum_{i=1}^{k}(d_{i+1} - d_i)(\ln G - \ln G_i^*)^3 D_i^* \quad (7.9)$$

This bivariate specification can be adapted to a multivariate analysis (Suits et al., 1978). Therefore, since firm value added is affected by other independent variables in addition to the investigative variable, they can be incorporated into the above formulation either additively or as spline functions depending on what is known or assumed about their relationship with the dependent variable. If the spline function (7.9) is represented by $\ln VA = S(G)$, then we can additively (Log-linearly) incorporate the other independent explanatory variables as identified in the firm production function in Chapter 5, represented as Z in equation 7.10 below.

$$\ln VA = S(G) + kZ \quad (7.10)$$

Alternatively, Z can be incorporated as a spline function T(Z) to obtain

$$\ln VA = S(G) + T(Z) \quad (7.11)$$

Since the other explanatory variables determining firm value added are assumed to have a log-linear relationship with firm value added, equation 7.10 is applied. In building the final model that is used in regression fitting, we follow Montgomery et al. (2001)'s procedure of backward elimination. In this model building strategy, we fit the highest order model appropriate, which in this case is assumed to be the cubic polynomial. Then terms are deleted one at a time, starting with the highest order, until the highest-order remaining term has a significant *t* statistic. We find that both the third- and second-order (quadratic model) polynomials return insignificant *t* statistics while the first-order polynomial (that is, the piece-wise linear regression model) returns significant *t* statistics. To a great extent this result reflects what we see in the scatter graphs. Hence, we use the model below (equation 7.12) in the final analysis.[13]

$$\ln VA_i = a + \beta_1 \ln G_i + \beta_2 (\ln G_i - \ln G^*)D_i + \beta_3 \ln K_i + \beta_4 \ln L_i + \beta_5 \ln(unemp_i) + \beta_6 (Fownership_i) + u_i \qquad (7.12)$$

where, as before,

$\ln VA_i$ = is the natural log of the firm's value added

$\ln G_i$ = is the natural log of the public infrastructure capital stock in the district in which the firm is located

$\ln G^*$ = is the natural logarithm of the threshold value of public infrastructure stock also known as a knot. To identify the knot empirically, all possible threshold values are used in estimation (see Table 7.1)

$\ln K_i$ = is the natural log of the firm's total assets

$\ln L_i$ = is the natural log of the number of people employed by the firm

$\ln(unemp_i)$ = is the natural log of the unemployment rate in the district, it captures capacity utilisation of the firm.

$(Fownership_i)$ = is the dummy variable representing whether or not a firm has some degree of foreign ownership.

Human capital is left out of equation 7.12 and all subsequent estimations because it was found to be insignificant in all prior estimations (see discussion in chapters 5 and 6).

On the basis of equation 7.12, it is possible to determine the threshold value (knot) empirically by successively fitting models with all possible values of G* until the *t* test for a particular slope coefficient is significant and the best fit. This was done with the STATA software package, which enables automatic backward elimination when a command that includes all of the possible predictor variables and a maximum P-value required to retain them is applied. The P-value criteria were set at 5 per cent level, ensuring that only predictors having coefficients that are significantly different from zero at the 5 per cent level or less are kept in the model.[14] After this automatic procedure, the result was cross-checked by including each possible threshold value singly in the model

Table 7.1

Results of the Empirical Determination of the Threshold Value (Knot)

District	Possible Public infrastructure capital threshold values	Coefficient of first segment	Estimated Differential slope coefficient
	ln G*	$\hat{\beta}_1$	$\hat{\beta}_2$
Lira	-2.235029	-	-
Arua	-2.189271	-0.946	1.355
Mubende	-1.97524	-0.272	0.738
Soroti	-1.967977	-0.269	0.737
Hoima	-1.887673	-0.271	0.769
Bushenyi	-1.791116	-0.111	0.610
Rakai	-1.744796	-0.121	0.632
Mbarara	-1.620306	-0.081	0.612
Kabarole	-1.592573	-0.059	0.589
Tororo	-1.466247	-0.012	0.558
Luwero	-1.444474	-0.005	0.553
Iganga	-1.39133	0.020	0.529
Masaka	-1.370844	0.029	0.521
MASINDI	**-1.283412**	0.043	**0.526****
Kayunga	-1.20345	0.057	0.525**
Mbale	-1.175943	0.066	0.518**
Kabale	-1.131595	0.085	0.498**
Mukono	-0.873078	0.157	0.393
Wakiso	-0.74759	0.179	0.360
Jinja	-0.539175	0.199	0.334
Kampala	0.685955	-	-

Notes: 1. P-value criteria set at 5%. 2. **Significant at 5% level.
3. The infrastructure composite variable for Masindi district is the threshold value.

and checking the significance of the corresponding slope coefficient. As shown in Table 7.1, the results are consistent with the automatic backward elimination procedure.

The results in Table 7.1 are also consistent with the threshold hypothesis. First, the slope of the regression line in the first segment β_1 is not significantly different from zero in all cases. Second, the estimated differential slope coefficient is significant at 5 per cent level when the threshold value (knot), that is, public infrastructure composite variable, is equivalent to -1.283412, which corresponds to the public infrastructure composite variable for Masindi district (see disaggregation into component parts in section 7.4).

As can be seen from this table, the values just below the threshold value (that is, for districts below Masindi) are insignificant when singly included in the model, further validating the threshold result.

In addition, it is important to point out here that Figure 7.1 could give the impression that Kampala district may be unduly influencing the threshold value result. This is unlikely to be the case for two reasons.

First, there are several other districts (Kayunga, Mbale, Kabale, Mukono, Wakiso and Jinja) between the Masindi district index (the threshold value) and Kampala. Actually, Masindi district is a far-off district in the western part of the country.

Second, the same procedures were carried out after all firms in Kampala were dropped, that is, Kampala was dropped from the sample, and there was no change in the conclusions. In other words, the automatic step-wise regression backward elimination method produced the same threshold value even without Kampala. Further, the threshold value having been identified, the regression with the 'spline dummy' that identifies the threshold point (knot) was run again without Kampala, and the spline dummy returned a positive and significant result. The results are given on page 209, in Model 4, Table 7.2 (Continued)-Full sample. In addition, separate regressions were run for firms below and above the threshold, again excluding Kampala. The results (which are not included in the tables) were similar to the earlier conclusions. This gave confidence that the result is robust.

7.3 Threshold Effects: Results from Spline Regressions Model and From Separate Regressions

The results in Table 7.1 are used as a basis for the subsequent analysis in which a 'spline dummy' is included in the regressions with the identified threshold value as the reference infrastructure stock index level. Empirical results obtained from the spline regression model show that public infrastructure is associated with firm value added only when it exceeds a certain threshold. This is also consistent with results from separate regressions for firms below and above the threshold value. The results are shown in Table 7.2 (dependent variable – Log value added) and Table 7.3 (dependent variable – Log value added per worker). The Chow test further validates the existence of a significant structural difference between the samples. In both tables, Models 1 contain results for the spline regression model for the various sub-samples (sectors) and the full sample while Models 2 and 3 contain results for the separate regressions for firms below and above the threshold level respectively. The results in all cases are consistent with the public infrastructure capital threshold hypothesis.

For the service firms sample as well as the full sample, the coefficient for the spline variable is positive and significant at 5 per cent level while the slope of the first segment of the regression line (that is, β_1) is no different from zero in all cases. For the industrial firms sample, the spline variable is only significant at p.values of 0.11 and 0.18 with Log value added and Log value added per worker as dependent variables respectively. However, the separate regressions for firms below and above the threshold are consistent with the earlier results; that is, for firms above the threshold value, the coefficient for the infrastructure composite variable is positive and significant at 1 per cent level while the opposite is the case for firms below the threshold.

The results from the two different econometric regression analysis methods confirm the threshold effect hypothesis and provide evidence to support a 'critical mass' phenomenon. The results show that only eight districts (19.5 per cent of the districts in the sample) are above the threshold level while the majority are far below it. As was shown by the derivations in Chapter 5, the significance of the coefficient of Log L implies increasing returns. The results in Table 7.3 show that the coefficient of Log L is positive and significant for firms above the threshold. The implication of this is that there is a significant influence of public infrastructure on the viability and success of firms as long as critical mass is achieved. This also suggests that convergence in public infrastructure between districts would stimulate growth and possibly positively benefit poor areas and the poor.

Table 7.2
Spline Regression Model Results and Estimates from Separate Regressions for Firms Above and Below the Threshold Value: Dependent Variable: Log Value Added

	Service Firms		
Variable	Model 1 **Spline Regression Model**	Model 2 **below**	Model 3 **above**
Constant	5.118*** (0.484)	7.057*** (0.783)	5.451*** (0.606)
Log L	0.505*** (0.043)	0.859*** (0.125)	0.452*** (0.046)
Log K	0.400*** (0.021)	0.205*** (0.051)	0.433*** (0.023)
Infrastructure composite index (Log G)	**0.043 (0.211)**	**0.387 (0.255)**	**0.595*** (0.209)**
Log (unemployment)	-0.343 (0.324)	-0.586 (0.452)	-0.260 (0.458)
Spline	**0.526**** (0.252)		
Foreign Ownership	0.571*** (0.089)	0.273 (0.507)	0.563*** (0.091)
R-squared	0.7298	0.5794	0.735
Adj R-squared	0.7272	0.5588	0.7325
SSE (RSS)	554.414	75.031	463.535
Mean Variance Inflation Factor (VIF)	13.85	1.22	4.62
Heteroskedasticity test Chi2(1)	0.91	0.42	0.26
Prob > chi2	0.3400	0.515	0.6069
N	639	108	531

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

Table 7.2 *(Continued) – Industrial Firms*

	Industrial Firms			
	Model 1	Model 2	Model 3	Model 3a
Variable	**Spline Regression Model**	**below**	**above**	**above**
C	4.62*** (0.664)	3.872*** (1.172)	5.573*** (1.007)	4.000*** (0.350)
Log L	0.525*** (0.063)	0.419*** (0.151)	0.537*** (0.071)	0.528*** (0.071)
Log K	0.508*** (0.037)	0.597*** (0.107)	0.500*** (0.040)	0.499*** (0.040)
Infrastructure composite index (Log G)	**0.287** **(0.273)**	**0.312** **(0.386)**	**0.885***** **(0.339)**	**0.339***** **(0.084)**
Log (unemployment)	-1.120** (0.465)	-1.102* (0.605)	-1.316* (0.791)	
Spline	**0.509** (0.321)			
Foreign Ownership	0.250** (0.106)	0.628 (0.383)	0.225** (0.112)	0.236** (0.112)
R-squared	0.7998	0.8235	0.7872	0.7849
Adj R-squared	0.7958	0.8019	0.7830	0.7815
SSE (RSS)	215.44	29.341	184.835	186.856
Mean Variance Inflation Factor (VIF)	13.41	1.88	7.86	1.77
Heteroskedasticity test Chi2(1)	1.64	3.76	0.54	0.47
Prob > chi2	0.2009	0.0526	0.4644	0.4916
N	306	47	259	259

Notes:
1. ***Significant at 1% level **Significant at 5% level * Significant at 10% level
2. [a,b] Robust Standard Errors

Table 7.2 *(Continued) – Full Sample*

Variable	Full Sample			
	Model 1[a]	Model 2[b]	Model 3	Model 4[a]
	Spline	**below**	**above**	**Spline (excluding Kampala)**
C	4.903*** (0.413)	6.386*** (0.795)	5.157*** (0.480)	5.689*** (0.518)
Log L	0.517*** (0.035)	0.770*** (0.097)	0.476*** (0.037)	0.649*** (0.070)
Log K	0.419*** (0.021)	0.275*** (0.060)	0.444*** (0.019)	0.332*** (0.042)
Infrastructure composite index (Log G)	**0.046 (0.162)**	**0.269 (0.210)**	**0.524*** (0.167)**	**0.078 (0.162)**
Log (unemployment)	-0.404 (0.260)	-0.696* (0.372)	-0.193 (0.369)	-0.652* (0.338)
Spline	**0.532*** (0.181)**			**0.978* (0.511)**
Foreign Ownership	0.437*** (0.066)	0.326 (0.273)	0.435*** (0.070)	0.340*** (0.128)
R-squared	0.760	0.696	0.7579	0.748
Adj R-squared			0.7564	
SSE (RSS)			672.411	
Mean Variance Inflation Factor (VIF)	12.93	1.38	5.27	3.17
Heteroskedasticity test Chi2(1)			1.32	
Prob > chi2			0.2508	
N	962	157	805	335

Notes:
1. ***Significant at 1% level **Significant at 5% level * Significant at 10% level
2. [a,b] Robust Standard Errors

Table 7.3
Spline Regression Model Results and Estimates from Separate Regressions for firms Above and Below the Threshold Value: Dependent Variable: Log Value Added per worker

	Service Firms		
Variable	Model 1 **Spline Regression Model**	Model 2 **below**	Model 3 **above**
Constant	5.111***	7.330***	6.538***
	(0.839)	(1.101)	(0.953)
Log (K/L)	0.400***	0.206***	0.432***
	(0.021)	(0.051)	(0.023)
Log (G/L)	**0.019**	**0.270**	**0.541*** **
(aggregate measure)	**(0.205)**	(0.239)	(0.189)
Log L	-0.076	0.328	0.427**
	(0.210)	(0.268)	(0.189)
Log (unemployment)	-0.334	-0.539	-0.480
	0.337	(452)	(0.527)
Spline	**0.544***		
	(0.278)		
Foreign Ownership	0.571***	0.323	0.564***
	(0.089)	(0.508)	(0.091)
R-squared	0.4900	0.1958	0.5021
Adj R-squared	0.4851	0.1564	0.4974
SSE (RSS)	554.442	75.781	463.41
Mean Variance Inflation Factor (VIF)	26.84	3.19	14.92
Heteroskedasticity test Chi2(1)	1.43	0.21	0.39
Prob > chi2	0.2319	0.6477	0.5347
N	639	108	531

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

***Table 7.3** (Continued) – Industrial Firms*

	Industrial Firms				
Variable	Model 1 **Spline regression Model**	Model 2 **below**	Model 2 **Robust std. err**	Model 3 **above**	Model 3a **above**
Constant	5.125***	4.426***	4.426**	7.096***	4.403***
	(1.133)	(1.579)	(2.009)	(1.620)	(0.360)
Log (K/L)	0.507***	0.596***	0.596***	0.499***	0.499***
	(0.037)	(0.106)	(0.111)	(0.040)	(0.040)
Log (G/L)	**0.265**	**0.293**	**0.293**	**0.768****	**0.256*****
(aggregate measure)	**(0.267)**	**(0.350)**	**(0.347)**	**(0.307)**	**(0.065)**
Log L	0.297	0.307	0.307	0.804**	0.282***
	(0.269)	(0.362)	(0.335)	(0.318)	(0.086)
Log (unemployment)	-1.167**	-1.130*	-1.130**	-1.586*	
	0.487	(0.610)	(0.455)	(0.931)	
Spline	**0.479**				
	(0.356)				
Foreign Ownership	0.253**	0.619	0.619	0.224**	0.236**
	(0.105)	(0.385)	(0.374)	(0.112)	(0.112)
R-squared	0.4981	0.4899	0.4899	0.4761	0.4700
Adj R-squared	0.4881	0.4277		0.4657	0.4617
SSE (RSS)	215.534	29.306		185.249	187.377
Mean Variance Inflation Factor (VIF)	31.09	7.40	7.4	29.73	2.27
Heteroskedasticity test					
Chi2(1)	3.82	9.17		1.89	2.17
Prob > chi2	0.051	0.0025		0.1697	0.1408
N	306	47	47	259	259

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

Table 7.3 *(Continued) – Full Sample*

Variable	Full Sample Model 1 Spline Regression Model	Model 1 Robust std. err	Model 2 below	Model 3 above
Constant	4.957***	4.957***	6.620***	6.01***
	(0.638)	(0.697)	(0.852)	(0.747)
Log (K/L)	0.419***	0.419***	0.275***	0.443***
	(0.018)	(0.021)	(0.045)	(0.019)
Log (G/L)	**0.036**	**0.036**	**0.195**	**0.453*** **
(aggregate measure)	**(0.155)**	**(0.160)**	**(0.191)**	**(0.148)**
Log L	-0.028	-0.028	0.236	0.374**
	(0.158)	(0.163)	(0.208)	(0.151)
Log (unemployment)	-0.406	-0.406	-0.682*	-0.330
	0.266	(0.273)	(0.356)	(0.420)
Spline	**0.534** **	**0.534*** **		
	(0.212)	**(0.204)**		
Foreign Ownership	0.438***	0.438***	0.341	0.436***
	(0.068)	(0.066)	(0.299)	(0.070)
R-squared	0.4808	0.4808	0.2560	0.4843
Adj R-squared	0.4775		0.2314	0.4811
SSE (RSS)	798.568		114.609	672.788
Mean Variance Inflation Factor (VIF)	27.47	27.47	4.59	17.86
Heteroskedasticity test				
Chi2(1)	4.59		2.52	1.21
Prob > chi2	0.0322		0.1124	0.2717
N	962	962	157	805

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

In addition, the results suggest that marginal improvements in public infrastructure for most of the districts might not generate any significant effect on the value added of firms and may require significant increases to at least the threshold level before any effects can be realised.

7.4 Divergence between the Threshold and Levels of Public Infrastructure in Different Districts

Having determined the public infrastructure threshold level, it is then possible to estimate the needed increase in physical public infrastructure to bring stock levels to at least the threshold level, and to estimate the necessary investment expenditure. It is worth noting that necessary investment here refers to the amount needed to bring stock levels to the threshold level and not to any socially optimal measure of infrastructure investment. Hence, 'need' as used in this chapter is distinguished from 'demand', which is closely related to affordability and perceived benefits. It is therefore possible that there could be districts which could initially have hardly any demand for particular infrastructure services or infrastructure investments. These would mainly be rural districts, where the majority of the people have low incomes and little appreciation of the kinds of benefits that could be derived from access to these services/investments. Nevertheless, in view of the acute lack of public services in Uganda generally, and given that the country's population is mainly rural based and that one of the most important sectors of the economy is agriculture, it can be argued that these areas need these services/investments even more than other areas (mainly urban). As demonstrated in the threshold quantitative analysis, this could be a major bottleneck to growth, and by implication to poverty alleviation efforts. (See Chapter 2 for a discussion of the underlying mechanisms leading to the developmental effects.)

7.4.1 Disaggregation of the threshold composite infrastructure variable

To facilitate further analysis, it is imperative to disaggregate the public infrastructure composite variable into its component parts. Using the weights (score coefficients) from the principal components analysis in Chapter 5, it is possible to derive the different infrastructure types. Hence, (Infra_index) = 0.25955*(Log Paved roads) + 0.25278*(Log (Weather roads)) + 0.25334*(Log (Power)) + 0.25942*(Log (Telephone)). (7.13)

Taking the threshold value, that is the public infrastructure composite variable for Masindi district, the different components are derived as from the equation below.

-1.28341 = 0.25955*(Log Paved roads) + 0.25278*(Log (Weather roads)) + 0.25334*(Log (Power)) + 0.25943*(Log (Telephone)).

The critical minimum stocks (threshold values) of the different types of public infrastructure capital in physical values at/below which the infrastructure composite variable is not associated with firms' value added are shown in the last column of Table 7.4. The threshold value for paved roads is 0.0074947 kilometres per square kilometre, while for all-weather roads it is 0.0379307 kilometres per square kilometre.

The threshold value for electricity is approximately 5.1 per cent of the households in a district having electricity connections. The threshold value for public telephones, which is the distance from the centre of the village or community to the telephone, is approximately 15.9 kilometres.

Table 7.4
Threshold Value: Disaggregated Into Individual Infrastructure Values

Infrastructure type	Weight (Score coefficient)	Infrastructure Standardized Value (Logs)	Components of the composite Infrastructure Value (Logs)	Physical Infrastructure Value Unstandardized (Not Logs)
	(a)	(b)	(a)*(b)	
Paved roads (Kms/sq.km)	0.25955	-1.3713114	-0.355923874	0.0074947
All Weather roads (Kms/sq.km)	0.25278	-0.9773698	-0.247059548	0.0379307
(% of Households with electricity)	0.25334	-1.4164553	-0.358844786	5.1
Mean distance to the nearest public telephone in district (Kms)	0.25943	-1.2395648	-0.321580296	15.9202
Total			**-1.283409**	

Note:
Standardised values are transformed to unstandardised values before taking antilogarithms to get the physical infrastructure values in the last column.

7.4.2 Implications for investment

By comparing infrastructure stocks in each district to the threshold infrastructure stock level and computing the difference, we derive the minimum new investments required. For districts with stocks above the threshold level, no additional investments are considered.

For example, in Nakasongola district, which currently has approximately 0.00036 kilometres of paved roads per square kilometre (0.4 metres per km^2), at least 12.6 kilometres of paved road would have to be constructed to reach the threshold level shown in Table 7.4 before any productivity effects can be realised (see computations for other districts in Appendix G - Table G2). This can be interpreted in the same way as Kelly (1997)'s analysis of the development of the Chinese economy which was discussed earlier. This kind of investment could provide the critical density required to link up local isolated markets, and those markets to the rest of the economy and export markets, increasing specialisation and leading to a fusion of the small local markets into a large economy-wide market. This would promote 'Smithian growth', to use the term coined by Kelly. At the same time, the roads could facilitate delivery of social and administrative services to the district.

In order to approximate the kind of returns that would be expected, we calculate rates of return on the basis of the regression estimates. Unit costs of the different infrastructure investments (for example, cost per kilometre of each type of road for the year 1999/2000 or a future year) are derived on the basis of World Bank data or Government of Uganda project information (see Table 7.5 below).

a. Electricity

As discussed in Chapter 3, the prospects for investment in the power sub-sector mainly lie in hydropower, whose potential is estimated at 2,000 MW along the River Nile. Exploitation to-date is at 300 MW, mainly in Jinja, and 17 MW at Kasese (Ministry of Energy and Mineral Development, 2004). However, with an abundance of very high-radiation solar resources, there is also potential for solar photovoltaic systems.[15] The unit costs (which take into account associated network costs) for the various electricity sources as indicated in Table 7.5 are taken from the country's electrification programme. The programme aims to connect 495, 000 households to the power grid over a 10-year period, of which 370,000 households would be rural and 125,000 urban (see Appendix B for the electrification targets to be achieved by 2010).

Table 7.5
Unit Costs and the Required Infrastructure Investment

Infrastructure Type	Unit cost ($)	Unit	Physical Infrastructure investments required	Required Investment Amount ($)	Percent of GDP 1999/2000
Electricity			New Dam construnction	$ 500 million	**9.55**
Solar PV systems Mini-Grids Main Grid extension	$ 400 - 800 $ 2,000 - 3,000 $ 1,000 - 2,000	Per connected household	93,236 households connected	$ 139.9 million	**2.67**
Telephone					
Public Payphones 1993 2005	 $ 3280 $ 1000	Per public phone access unit	926 public telephones (one installed in each sub-county)	$ 0.926 million	**0.02**
Roads					
Paved roads 2-lane road 1-lane road	 $410,000 $79,442	 Per kilometre Per kilometre	738.5 kilometres	$ 302.8 million	**5.78**
All Weather roads 2-lane road 1-lane road	 $102,500 $19,860.5	 Per kilometre Per kilometre	2931.75 kilometres	$ 300.5 million	**5.74**
			Total	**$ 1.244 billion**	**23.76**

Sources:
1. Ministry of Works, Transport and Communications et al. (1994).
2. Uganda Communications Commission (2005).
3.Ministry of Energy and Mineral Development, Uganda (2004).
4. Fay and Yepes (2003).

The cost per household connected varies, depending on the source, as highlighted in Table 7.5. Since the greatest potential for expansion is with the main grid,[16] this study uses the average unit costs of the main grid for the threshold computation, which is US$ 1500 per connected household. From the threshold analysis, more than 5.1 per cent of the households within a district should have electricity if any association between power availability and private sector output/productivity is to be realised. The number of households that would need to be electrified country-wide in order to bring the numbers per district to the threshold would be 93,236 (Table G.2, appendix G).[17]

Hence, required investment would be equivalent to US$ 1500 x 93,236 = US$ 139.854 million. This would be in addition to the cost of power generation, which requires construction of a new dam. A new dam costing US$ 500 million is planned (Ministry of Energy and Mineral Development, Uganda, 2004). Hence, total cost, excluding required maintenance, would be US$ 639.9 million, equivalent to approximately 12.2 per cent of GDP.[18] Divided over a five year period, this would be equivalent to about 2.4 per cent of GDP per year. If we include costs of approximately 0.63 per cent of GDP for maintenance as recommended in Fay and Yepes (2003), the annual cost would come to approximately 3.1 per cent of GDP. As noted in Chapter 3, these kinds of expenditures are now expected to be met by the private sector through public-private partnerships; however, significant difficulties are curtailing progress in this direction so far.

b. Road infrastructure

The study estimates the required increase in the number of kilometres of paved roads and all-weather roads on the basis of the threshold analysis results. For paved roads, the required investment to the threshold level would be at least 738.5 kilometres, and for all-weather roads it would be 2,931.75 kilometres. To calculate the required investment, we need information on the unit cost of each type of road, that is, cost per kilometre. This is normally estimated in several ways.

We could apply the present cost of building an additional kilometre of road, but unfortunately this information is not available. As discussed earlier, all current road project investments have been geared to reconstruction, rehabilitation and maintenance, with no new construction.

Alternatively, we could estimate the average cost from past investments by regressing the length of roads against investment in roads, using time series data. Needless to say, this requires long-term time series data, which are not readily available, especially in African countries including Uganda.

Another approach sometimes applied is taking the total length of roads and dividing it with total investment in roads made over time, say 30 years.

This study follows Fay and Yepes (2003) in using best practice prices as derived from World Bank road project costs. The unit cost of constructing a kilometre of a new two-lane paved road is US$ 410,000.[19] For a one-lane paved road, we derive the unit cost from World Bank reports on the average road work cost per kilometre, which comes to US$ 79,442 for 2002. (See World Bank, 2002). We assume that the unit cost for all-weather roads is one-quarter that for paved roads, that is, US$ 102,500 per km for a two-lane road and US$ 19,860.5 per km for a one-lane road. This is on the basis of the differential costs of the different types of World Bank-funded road projects across different countries.

For two-lane roads, the required investment would be as follows:[20]

Paved roads:
US$ 410,000 x 738.5 = US$ 302,785,000 = US$ 302.8 million

All -weather roads:
US$ 102,500 x 2931.75 = US$ 300,504,375 = US$ 300.5 million

Total expenditure would be equivalent to approximately US$ 603.3 million, approximately 11.5 per cent of GDP or 2.3 per cent annually over a five-year period (excluding maintenance). This is significantly higher than the development expenditure on roads and works in 2003/04, which amounted to 1.6 per cent of GDP while including expenditures not necessarily directly linked to reconstruction, rehabilitation or periodic maintenance of roads. This, therefore, raises major challenges as to the creation of fiscal space for the additional infrastructure investments.[21]

c. Telephone infrastructure

The 1994 *Master Plan Study for the Telecommunications Network* recommended expansion of basic telecommunication services such that there would be a public call office in all counties (162 locations) in the country. This meant establishing public call offices in 'all county centres' by 2010, which would bring access to within 20 kilometres for everyone.[22]

The unit cost (which takes into account associated network costs) was US$ 3280 per public pay phone in 1993 (see Ministry of Works, Transport and Communications et al., 1994). However, technological advances and investment made since then have reduced it to US$ 1000 (see Uganda Communications Commission, 2005).

From the threshold analysis, the distance from the centre of the village or community to the nearest public telephone should be within 15.9 kilometres if any association between public telephones and private sector output/productivity is to be realised. This study utilises the current recommendation on the review of the telecommunications sector, which proposes increasing the number of pay phones so that there is at least one in each sub-county. Since installing a public pay phone in each county would bring access to within 20 kilometres for all households, and installing one in each sub-county would bring the distance to 3-5 kilometres, this would also be within the threshold.

There are 926 sub-counties, implying that at least 926 public telephones would have to be installed. Hence, required investment would be US$ 1000 X 926 = US$ 926,000, approximately 0.02 per cent of GDP. The current plan is to have public-private partnerships in these investment projects, with the government subsidising investments made in sub-counties where they would not be viable for private investors. Here, we assume that all the investment is done by the government.

Alternatively, it can be argued that given the growing importance and role of mobile phones in Uganda, public investment might better concentrate on facilitating that communications infrastructure rather than public pay phones. However the private cost of mobile phones makes it a less attractive proposition especially for the majority of rural dwellers. Since the nature of technology required for mobile phones allows for private sector provision and sufficient competition between providers, the role of public investment could be in the provision of electricity which is a major impediment for private sector investments in rural areas.

7.5 Marginal Effects and Elasticities of Infrastructure Investments

The investments presented above would only bring infrastructure stocks in all the districts included in this analysis to the threshold level. As illustrated in the earlier estimates in Chapter 5, significant returns to the investment would be expected thereafter, with acceleration in the growth of output/productivity or value added. Investments that bring infrastructure stocks to the threshold level would hardly be associated with value added, but any additional investments should have an effect. The value added elasticities for different types of infrastructure capital were calculated on the basis of the results in Tables 5.3, 5.8, 5.9 and 6.3. They are displayed in Table 7.6, which shows that in almost all cases, different infrastructure types have significant positive elasticities vis-à-vis the value added for the different sectors of the economy. The only exception is the agricultural sector in regard to electricity, paved roads and public telephones (see Chapter 6).

Table 7.6 *Value Added Elasticities with Respect to Different Types of Infrastructure Capital*

	Electricity	Public Telephone	Roads		Public infrastructure composite variable
			Paved	All Weather	
Sector					
Services	0.517*** (0.058)	0.347*** (0.062)	0.215*** (0.033)	0.366*** (0.060)	0.446*** (0.066)
Industry	0.401*** (0.086)	0.266*** (0.066)	0.176*** (0.039)	0.238*** (0.067)	0.346*** (0.086)
Agriculture	-	-	-	0.360*** (0.195)	-
Total GDP	0.477*** (0.049)	0.341*** (0.042)	0.214*** (0.024)	0.343*** (0.042)	0.442*** (0.053)

Notes:
1. ***Significant at 1% level **Significant at 5% level * Significant at 10% level
2. Standard errors in parentheses.
3. Coefficients used in the computation of total GDP value added elasticities are for the full sample.
4. a dash (-) means the coefficient was insignificant.

Source: Calculated by author from results in Tables 5.3, 5.8, 5.9 and 6.3.

Despite these positive elasticities, the policy-relevant question arises as to whether they would also translate to positive returns from the point of view of cost-effectiveness, that is, whether the benefits of an intended investment justify its cost. This is examined by calculating the benefit-cost ratio for each marginal investment made after the threshold level. Computing benefit-cost ratios also provides an indication of whether there is underinvestment in public infrastructure capital.[23] .

In this computation, the study focuses on one type of infrastructure, that is, road investments, since they comprise the biggest percentage of public infrastructure capital expenditure in most low-income countries (Fay and Yepes, 2003).

7.5.1 Benefit-cost ratios for road infrastructure investments

On the basis of results from the estimated equations in Chapters 5 and 6 and the computed value added elasticities, it is possible to derive marginal returns to expenditure on the different types of physical infrastructure in terms of output/productivity or value added. In the case of road investments, this is done as follows:[24]

a. Calculation of benefits

i. We calculate the marginal returns to value added per unit of physical unit (for example, increase in value added per kilometre of road constructed).

ii. To calculate the benefit to total GDP, services GDP or industry GDP of an additional kilometre of a two-lane paved road for a one-year period, the following formula is applied:

$$\alpha \beta \frac{Y}{L} \tag{8.4}$$

where

α refers to the weight of the specific type of road infrastructure in the infrastructure composite variable (see Table 7.4)

β refers to the value added elasticity with respect to public infrastructure composite variable (see Table 7.6)

Y refers to either total GDP, services GDP or industry GDP

L refers to total length of roads by type.

For example, we compute what every kilometre of paved road constructed in 1999/2000 would contribute to total GDP. Given that a 1 per cent increase in paved road density will translate to a 1 per cent increase in the number of kilometres of paved road, we can calculate the value added benefit of one additional kilometre of paved road as follows:

$$0.25955\ x\ 0.442\ x\ \frac{Ug.\,Shs\ 7,921,208,000,000}{2{,}260\ kilometres} = Ug.\,Shs\ 402,092,785.44$$

In computing the total present-day value over the lifespan of the road, the following assumptions are made:[25]:

First, for paved roads the beneficial effect is assumed to begin in the third year after the investment is made, and for all-weather roads in the second year. The effect is assumed to last for the life of the road, assumed to be 20 years for paved roads and 10 years for all-weather roads.

Second, the annual average interest rate on the 364-day Government of Uganda Treasury bill is used as the discount rate.[26] This was 11.4 per cent in 1999/2000, which is close to the discount rate of 12 per cent used by Adler (1987) in his study of highways in developing countries. It is assumed that the discount rate is constant over time.

In the final analysis, the total present-day value of the benefits (returns in total GDP) from one kilometre of paved road (discount rate 11.4 per cent and 20-year lifespan) amounts to UShs 2517.92 million. A similar computation for all-weather roads (discount rate 11.4 per cent and 10-year lifespan) amounts to UShs 455.44 million (see Table 7.7).

b. Calculation of cost

i. The unit costs of constructing one kilometre of different types of road are shown in Table 7.5. For example, the unit cost of constructing one kilometre of a two-lane paved road is US$ 410,000, which is equivalent to UShs 620,248,000. However these are best practice prices derived from World Bank road project costs (Fay and Yepes, 2003) and may be significantly lower than those in many African countries.27 Pritchett (1996) argues that high unit cost prices in developing countries are partly due to government inefficiencies and may be a reflection of corruption and problematic procurement procedures, among other factors. In the final analysis, therefore, we conduct a sensitivity analysis using African average unit cost prices for the year 2000 derived from the World Bank's Road Costs Knowledge System, as shown in Table 7.7.

ii. For maintenance and service costs, two assumptions are made. First, following Fay and Yepes (2003), maintenance and service costs per km per year are assumed to be 2 per cent of initial construction costs. Second, costs take effect in the same year as when the benefits begin to take effect.

In the final analysis, the total present-day maintenance and service costs for one kilometre of two-lane paved road (discount rate 11.4 per cent and 20-year lifespan) amounts to UShs 77.5 million using best practice prices. A similar computation for all-weather roads (discount rate 11.4 per cent and 10-year lifespan) amounts to UShs 16.12 million.

7.5.2 Comparison of costs and benefits

In order to compare the benefits and costs of the road investment, the results can be expressed as marginal benefit-cost ratios. Returns to investment in physical infrastructure (say paved roads) are measured as shillings of additional value added per one additional shilling spent on paved roads.

Table 7.7 shows that on the basis of best practice unit cost prices, for every shilling invested in paved roads, UShs 3.61 would be added to total GDP. Hence, returns to investment in road infrastructure are quite high. Because of this, conclusions about justification of the investment are not particularly sensitive to changes in cost. Using African average unit cost prices, which are more than double best practice prices; the returns are still quite high, with the cost-benefit ratio at 1:1.56.

Similar calculations and conclusions can be drawn for all-weather roads. As discussed previously, apart from showing that these investments are well justified, these results also imply that there is gross under-investment in these types of road infrastructure.[28]

7.6 Concluding Remarks

This chapter explored whether there are non-linearities associated with public infrastructure capital vis-à-vis private sector output performance. The basic reasoning is that if threshold externalities exist, marginal investment may have minimal beneficial effects on output or productivity.

Table 7.7

Benefit-Cost Ratios for Different Types of Road Infrastructure Capital

	Paved roads 2-Lane		All-weather Roads 2-Lane	
Benefits	Ug Shs Millions (i = 0.114, N = 20)		Ug Shs Millions (i = 0.114, N = 20)	
Returns in total GDP	2514.17		455.44	
Returns in Services GDP	1026.68		186.13	
Returns in Industrial GDP	365.78		66.5	
Returns in Agricultural GDP	-		205.4	
Costs	African Average unit cost prices, (i= 0.114, N=20)	Best practice unit cost prices (i = 0.114, N=20)	African Average unit cost prices (i=0.114, N =10)	Best practice unit cost prices (i=0.114, N=10)
	Shs. Millions	Shs. Millions	Shs. Millions	Shs. Millions
Unit cost of construction	1432.8	620.25	358.2	155.1
Present-day value of maintenance costs	179.4	77.5	37.43	16.12
Total costs	1612.2	697.75	395.63	171.22
Benefit - Cost ratios				
Returns in total GDP	1.56	3.60	1.15	2.66
Returns in Services GDP	0.64	1.47	0.47	1.09
Returns in Industrial GDP	0.23	0.52	0.17	0.39
Returns in Agricultural GDP	-	-	0.52	1.20

Notes:
1. a dash (-) indicates that the coefficients were not statistically significant at the 10% level.
2. i is the discount rate.
3. N is the lifespan of the specific type of road.
4. Returns are calculated on the basis of 1999/2000 data.

Source: Calculated by author on the basis of results in Chapter 5 and Tables 7.5 and 7.6.

Chapters 5 and 6 showed that public infrastructure has a complementary effect on private investment as well as a positive productivity effect on other private inputs. However, insufficient provision in some areas and the indivisibility of many types of public infrastructure may result in these effects being insignificant and the area's or country's economy getting stuck in a low-output growth trap.

The threshold effects estimation, in which we used spline regression models and separate regressions for firms below and above the threshold, yielded results that are consistent with a threshold hypothesis. There are only eight districts (about 19.5 per cent of the 41 in the sample) above the threshold. Hence, all other districts have too-low levels of public infrastructure capital for it to have any significant output or productivity effects.

Comparison of benefits and costs of road investments after the threshold level has been attained shows that the benefits are significantly higher than costs, which implies underinvestment in physical infrastructure. Therefore, there is justification for large-scale public investment in infrastructure to bring stock levels above the minimum threshold level. The analysis shows that the required investment would amount to at least 24 per cent of GDP. Even if the investment were made over a five-year period, it would amount to about 4.8 per cent of GDP per year. This compares well with the 1994 *World Development Report* estimate that developing countries spent on average 4 per cent of GDP on investments in infrastructure, although this figure probably includes rehabilitation, upgrading and maintenance. Fay and Yepes (2003) estimate that sub-Saharan countries would on average require annual investment of 5.5 per cent of GDP on infrastructure (investment and maintenance) for the 2005-10 period. This is also close to the estimate reached by this study, given that Fay and Yepes include rail, water and sanitation, which were excluded from this study.

As noted in Chapter 3, Uganda currently spends about 2 per cent of GDP on infrastructure. Hence, the required new investments are substantial and raise major challenges as to the creation of fiscal space and therefore for fiscal policy.

The next chapter discusses the policy implications of making such large infrastructure investments for a sub-Saharan country like Uganda. The chapter also summarises the main conclusions and policy contributions of the thesis and provides some ideas for further research.

Notes

1. The term 'Smithian growth' refers to Adam Smith's economic theories and is applied to growth that comes as a result of specialisation and trade.
2. This approach is explained in Cook and Weisberg (1994), Hamilton (1992) and Murkherjee et al. (1998).
3. The spline function is the kind of estimate produced by a spline regression in which the slope varies for different ranges of the regressors. This study does not pre-specify the mathematical form of the function. However, visual graphics (scatter plots) aid the form of functions that are tested empirically.
4. These results are not presented in the chapter.
5. Here, one has to apply switching regression models, systematically varying parameter models, or random coefficient models like the Hildreth-Houck Random coefficient model or the Swamy random coefficient model (see Fomby et al., 1984).
6. These assumptions are relaxed later.
7. 'The sheepskin effects are the returns specific to educational credentials rather than to accumulated years of education. The term follows from the tradition of presenting diplomas on parchments usually made from the skin of a sheep. Such parchments date from the second century BC in Asia Minor where they replaced papyrus' (Belman and Heywood, 1997: 623).
8. This assumption is relaxed in the final model used in estimation. That is, other independent variables are introduced.
9. It is advisable to fit a model that has all terms significant, and to use discipline knowledge and regression graphics rather than an arbitrary rule as an additional guide in model formulation.
10. Buse and Lim (1977) show that spline functions are a special case of restricted least squares.
11. See derivations in Appendix F.
12. However, one has to consider that more intervals mean more variables in the regression equation and hence loss of degrees of freedom.
13. It does not make any difference to the results whether we include (In G) in the equation or not.
14. See details in Hamilton (2003) and Marsh and Cormier (2001).
15. Other possible energy sources include biomass and geothermal resources.
16. Solar photovoltaic systems and mini-grids are regarded as complementary (Ministry of Energy and Mineral Development, 2004).

17. However, it should be noted that it is not the number of households per se, but the amount of electricity available in a district that is critical.
18. In all cases, GDP used is for the fiscal year 1999/2000.
19. In the benefit-cost ratio analysis carried out later in this chapter, sensitivity analysis is done using African average unit cost prices.
20. It should be noted that, in some cases, for example in rural agricultural areas, a one-lane road would suffice.
21. Fiscal space is defined as 'the availability of budgetary room that allows a government to provide resources for a desired purpose without any prejudice to the sustainability of a government's financial position' (Heller, 2005a: 3).
22. The target date was later changed to 2002 due to the introduction of public-private partnerships. The access target was also changed to at least one pay phone per sub-county with at least 5000 people. This would reduce the distance to a public telephone to 3-5 kilometres for the average household (Ministry of Finance, Planning and Economic Development, 2001).
23. Some of the literature (for example, Berndt and Hansson, 1992) attempts to determine the optimal amount of public capital by calculating the amount of infrastructure for which social marginal benefits just equal marginal costs. By this criterion, the optimal amount of public capital is then compared with the actual stock before conclusions are reached about underinvestment (or otherwise) in public capital.
24. See note 25.
25. See Adler (1987) and Fan and Chang-Kang (2005), who carried out economic appraisals of transport projects in developing countries, for the basis of the assumptions.
26. That is, the interest rate on government securities.
27. Unit construction costs in Uganda are likely to be higher than best practice prices, as shown by a recent study on maintenance and rehabilitation costs in Uganda compared with countries in the same region (see Policy Research Corporation & Royal Haskoning, 2004).
28. The infrastructure benefits could be much higher if one included the demand of final consumers.

8 Concluding Remarks

8.1 Introduction

This research arose from a development policy dilemma faced by many highly indebted low-income countries, which are confronted on one hand by the commitment to implement IMF/World Bank-type economic reforms and on the other by the need to deal effectively with absorptive capacity constraints such as lack of sufficient critical physical infrastructure. From a macroeconomic perspective, there is continual pressure for reduction in public expenditure, premised on the crowding-out hypothesis of public expenditure vis-à-vis the private sector that is enshrined in the models on which economic reform measures are based. However, political considerations prevent reductions in recurrent expenditure, meaning that productive and especially infrastructure sectors bear a larger burden of expenditure adjustments. This results in underinvestment in public infrastructure capital.

This study argues that, depending on the level and state of public infrastructure capital, investments in infrastructure capital can be a major factor in initiating and facilitating economic growth in developing countries. This is achieved, first, through the role of infrastructure capital as an intermediate input, and second, because it is a major factor in the generation of positive vertical externalities and increasing returns to scale, and through these, affects the process of economic structural change. While productivity growth in developed countries is driven by technological innovation, changing the structure of production towards activities with higher levels of productivity can still be the major channel through which developing countries escape from low-growth development traps. This makes public infrastructure capital an important catalyst in the development process. Underinvestment or otherwise in public infrastructure capital can, therefore, help explain differences in economic development between countries, regions, districts, and so on.[1] In the Ugandan case, poor and inadequate public infrastructure was mainly a result of poor maintenance and political instability/wars prior to the mid-1980s. However, continued underinvestment in the 1980s to date can largely be attributed to economic models underlying economic policy design. The model that guides the IMF and World Bank macroeconomic stabilisation and structural adjustment programmes (as illustrated by Khan et al.,1990) tends to lead neoclassical fiscal policy and growth analysis of public spending to focus on either public consumption goods or transfer payments. This largely overlooks public spending that is productivity-enhancing as well as its crowding-in effects on private investment, with serious implications for long-run growth.

In addition, there are controversies in the empirical literature as to the productivity effects of public infrastructure capital. There are two extremes, one that suggests that there are high rates of return to infrastructure investment and another that suggests that the impact is essentially zero or negative. One explanation for these conflicting results is that there were flaws in the approaches and methods used in the studies that biased the results one way or the other. However, more recent studies that use modern econometric techniques have not produced conclusive results either, particularly in regard to the magnitude of impact, even though there is growing consensus as to the positive productivity effects of infrastructure. Nonetheless, any evidence that casts doubt on the productivity effects of public investment in infrastructure capital challenges arguments for increased investment in response to expenditure reductions brought on by adjustment programmes.

This study, therefore, empirically tested the hypotheses that the impact of infrastructure development on output/productivity is more significant in an economy where there are bottlenecks caused by underdeveloped infrastructure, that it crowds-in private investment, and that its productivity effects may be subject to a threshold, especially in the context of poor sub-Saharan countries like Uganda. It addressed the empirical ambiguity over links between public investment in infrastructure capital and growth, and argued that, in addition to the econometric problems highlighted previously, ambiguities could be due to the macroscopic/cross-country nature of most of these studies, which are characterised by a high level of aggregation, ignore the heterogeneity of public capital and use wrong proxies of public infrastructure capital such as public expenditures (see section 8.7 below). The study suggested more focus on micro-economic approaches that allow direct estimation and analysis of the impact on particular production processes and facilitate identification of some of the underlying transmission mechanisms.

The earlier chapters having dealt with the above issues in detail, this chapter sums up the study findings, draws theoretical and policy implications for public investment programmes in Uganda, particularly in regard to the three core types of physical infrastructure, roads, electricity and telephony, and suggests directions for further research.

The rest of the chapter is organised as follows. Section 8.2 summarises what economic theories predict about the relationship between public infrastructure capital and output and productivity. Section 8.3 presents the results of the analysis of the state of public infrastructure in Uganda and summarises the indicators of underinvestment in public infrastructure. Section 8.4 recapitulates the roles of the private and public sectors in Uganda in infrastructure provision and provides policy implications. Sections 8.5 and 8.6 summarise the empirical results of the analysis of the link between infrastructure and output/productivity, and the implications for Uganda and other developing countries. Lastly, section 8.7 discusses methodological and policy issues and makes suggestions for further research.

8.2 Economic Theories and the Role of Public Infrastructure Capital

The review of economic theories highlighted the existence of differences in the way that development, neoclassical and endogenous growth theories view the role of public infrastructure in the growth process. However, they all contribute to understanding of its role. As the distinction between them is more to do with aggregate returns to capital, the duration of effect and the implications for long-run growth, they need not be mutually exclusive. From the neoclassical perspective, the extension of the investment concept to include investment in human capital, research and development, and public infrastructure, improves the measurement of inputs and allows technological progress to be measured accurately, while from the point of view of endogenous growth, a broader concept of capital means constant returns may be possible and realistic (Stiroh, 2001).

Although the study did not set out to test the validity of these theories, the results satisfy the conditions necessary for endogenous growth, that is, increasing returns and complementarity between public infrastructure capital and private capital for paved roads, all-weather roads and telephones. While it is not possible to make explicit conclusions about long-term growth, which would require series data covering a long period, the results suggest that infrastructure investment may serve as a means of stimulating long-term growth. A limitation of endogenous growth models is that they consider factor accumulation and total factor productivity growth but ignore the possibility that the production process may involve the inefficient use of factors of production. For developing countries in particular, public infrastructure may affect output growth by facilitating a more efficient use of factors.

In addition, the study findings point to the relevance of earlier arguments in classical development theory regarding the role of infrastructure in the growth process and successfully bring development economics back into economic growth analysis. In particular, the evidence is consistent with the presence of the threshold effects concerning a critical minimum mass of public infrastructure capital (see section 8.6 below).

8.3 State of Public Infrastructure Capital and Trends in Public and Private Fixed Capital Formation

Despite the productivity-enhancing effects of infrastructure, the study shows continued underinvestment not only in Uganda but also in other sub-Saharan African countries. When investments can be shown to have higher social marginal benefits in comparison with marginal costs, standard economic reasoning would imply that this would be evidence of underinvestment. Within the strict limits of the study, we find that the marginal benefits of investment in different types of physical infrastructure are significantly higher than marginal costs. Paved roads, for example, have cost-benefit ratios that range from 1:3.61 to 1: 1.56 depending on whether one uses best practice unit cost prices or African average unit cost prices, respectively.

In addition, Uganda's public infrastructure capital stocks compare poorly with those in other low-income sub-Saharan African countries. The stocks of some infrastructure types are less than half of the average for sub-Saharan African countries even with the exclusion of South Africa. Uganda's electricity-generating capacity in 1999 was 0.008 kW per capita, compared with 0.04 kW per capita for sub-Saharan African countries excluding South Africa. Per capita stocks have declined over time, with the 1999 level of stocks of some major types of infrastructure lower than they were in the 1970s. Apparently there have been no significant increases in infrastructure provision in per capita or per square kilometre terms for some time. Consequently, Uganda's stocks have even fallen far behind those of its neighbouring East African countries, Kenya and Tanzania. For example, the density of paved roads (kms/1000 persons) was 0.13 in 1999, compared with 0.445 kms for Kenya in 1991. The average for low-income countries was 1.06 kms in the year 2000.

One important explanation for the low stocks of public infrastructure capital is reductions in public investment brought on by adjustment programmes. The analysis shows a correlation between fiscal adjustment and decline in public investment in infrastructure capital and the consequent decline in productive private investment. Despite significant increases in foreign aid, there has been a persistent decline in public investment as a percentage of GDP in Uganda since the onset of economic reforms. Public investment fell from about 8.6 per cent in 1987/88 to 3.6 per cent in 2004/05, which could be negatively impacting on private productive capital. Although there has been some modest growth in total private investment, it is largely driven by construction of private buildings (mostly residential) while more productive investments in machinery and equipment have seen a downward trend.

Results from some studies have shown that public infrastructure capital is not productive in Africa, but this is inconceivable given that the stocks of such capital are below optimal levels in many low-income countries like Uganda. This study argues that the evidence provided by some of the literature is a likely result of poor proxies for public capital stocks.

8.4 Public Infrastructure Capital and Output and Productivity Performance

Contrary to the findings of some literature on sub-Saharan African countries, this study's findings suggest that there is a strong linkage between public infrastructure capital and private sector output and productivity performance. The empirical evidence presented suggests that public infrastructure has both direct and indirect effects on firm output/productivity, with the direct effect being more dominant. The signs and significance levels of the coefficients of the investigative variable are supportive of the crowding-in hypothesis and a positive association between public infrastructure capital and firm value added. They are also consistent with the necessary conditions for endogenous growth, that is, increasing returns and complementarity between public infrastructure capital and private capital, which indicates the presence of positive production externalities.

The findings also suggest that there are differences in the impact of different types of public infrastructure capital on different sectors, but no difference in regard to firm size. Without considering further effects on the general economic system (that is, general equilibrium effects), output elasticity appears to be stronger for service firms than for industrial firms, which is at odds with the findings of many other studies. The study argues that in relative terms, less capital-intensive service firms are more likely to be incapable of providing their own infrastructure and are more dependent on inadequate public provision and hence benefit more from improved public provision. More capital-intensive industrial firms benefit relatively less from public infrastructure since they invest in complementary capital and so are less captive to inadequate public service. However, because of scale economies in comparison with pure public provision, they incur higher unit costs when they provide their own services or blend public and own provision. This has an effect on their expansion plans (investments).

In general the study corroborates the findings of perception studies, with the effect of electricity supply on value added of firms appearing to be greater than that of other types of physical infrastructure for both service and industrial firms, reflecting the gross underinvestment in electricity infrastructure. The study estimates indicate that a 1 per cent increase in the public infrastructure composite variable increases firm value added of the service and industrial sectors by 0.442 and 0.346 per cent respectively. This has important policy implications from both economic growth and fiscal policy viewpoints. Taking the service sector, which accounts for 40 per cent of GDP in Uganda, a 0.442 per cent increase in the value added would imply an increase of 0.18 per cent of GDP. At the going Value Added Tax of 18 per cent, this would mean additional tax revenue of approximately 0.03 per cent of GDP. Similarly, a 0.346 per cent increase in the value added of the industrial sector, which accounts for 19 per cent of GDP in Uganda, would imply an increase of 0.07 per cent of GDP. This would mean additional tax revenue of approximately 0.01 per cent of GDP. Given that the revenue to GDP ratio has increased by only 2 per cent over the last 10 years in Uganda, these are very significant revenue increases. Therefore, continued underinvestment will not only compromise economic growth but may even hamper fiscal stability in the long run.

For the agricultural sector, the results show that only dry-weather roads (which are mainly feeder roads) and all-weather roads have a positive and significant association with agricultural output and productivity. The other public infrastructure types included in the study, that is, paved roads, electricity and public telephones, do not appear to have a statistically significant association with agricultural output or productivity. Given the nature of the agricultural sector in Uganda today, these results are plausible. Dry-weather roads, and to a lesser extent all-weather roads, are almost exclusively the ones that can be considered to be important technological inputs in agricultural production as they link rural agricultural communities to commercial and socio-economic centres. These roads, therefore, as indicators of transportation infrastructure, provide a positive and significant coefficient through the facilitating of better access to input and output markets as well as diffusion of technical knowledge. The results also suggest that, in this particular case, it is the indirect effects of public infrastructure (dry-weather and all-weather roads) that are most important through complementarity with agricultural land. It is worth noting that the insignificance of paved roads, electricity and public telephones does not mean that they are not important for the development and modernisation of the sector. Rather, it suggests that absence of investment or underinvestment in these types of infrastructure limits the type of production technology utilised in the sector.

It is also important to note that the results suggest diminishing returns to new investments in dry-weather roads. Despite the fact that Uganda has far less densities of other types of road infrastructure in comparison with other East African countries, it has a higher density of low-grade roads, particularly dry-weather roads. Therefore, poverty studies (for example, Fan et al., 2004) that have recommended that priority be given to constructing new low-grade roads such as feeder roads, which are mainly dry-weather roads may be misleading in the Ugandan context. From a policy point of view, what is needed is a focus on maintenance and upgrading of roads rather than construction of new low-grade roads.

The results of the empirical analysis point to the possibility that the relationship between public infrastructure capital and output/productivity and growth could be subject to a threshold, particularly in the context of a minimum critical mass, that is, under-capacity rather than over-capacity levels of infrastructure capital stocks.

8.5 Threshold Effects: What Implications?

The study explored whether there are non-linearities associated with public infrastructure capital vis-à-vis private sector output and productivity performance. The findings are consistent with the hypothesis that marginal increments in infrastructure stocks will not have a significant effect in the majority of districts in Uganda until a minimum critical mass or threshold level of infrastructure stocks has been attained. Using spline regressions and separate regressions for firms below and above the threshold, the threshold effects estimation showed that only eight districts (about 19.5 per cent of all 41 in the sample) are above the threshold, with all other districts having too-low levels of public infrastructure capital for it to have any significant output or productivity effects.

Comparison of total present-day values for the benefits and costs of different physical infrastructure categories after the threshold level has been attained shows that the benefits are significantly higher than the costs. This implies a need for a large increase in public investment in infrastructure in order to raise the level of stocks to the required level. The investment needed to bring districts to at least the minimum critical mass amounts to about 24 per cent of GDP (excluding costs of maintenance). Even if the investment were made over a five-year period, it would amount to about 4.8 per cent of GDP per year, which compares well with Fay and Yepes (2003)'s estimate of 5.5 per cent of GDP (investment and maintenance) required annually on average by sub-Saharan African countries for the 2005-2010 period. Nevertheless, given that Uganda's expenditure on infrastructure currently amounts to approximately 2 per cent of GDP, the required amount is substantial and raises major challenges regarding the creation of fiscal space for the additional investment. Apparently total expenditure on infrastructure will have to be over 7 per cent of GDP annually, given that most of the current 2 per cent of GDP is spent on rehabilitation and maintenance. The question that arises therefore is what the economic policy implications would be with this level of expenditure.

There are a number of macroeconomic and microeconomic policy challenges that have raised concern and need attention and consideration (Bevan, 2005; Heller, 2005b; Heller and Gupta, 2002). As discussed in Chapter 2, depending on the nature of financing, there is a possibility of financial crowding-out of other sectors, Dutch disease effects and absorptive capacity constraints. Here they are discussed in the context of availability/exploitation of fiscal space for additional expenditure on infrastructure investments.

8.5.1 Public investment, the 'big push', Dutch disease and availability/exploitation of fiscal space

As discussed previously, for countries like Uganda, which have overcome major macroeconomic distortions mainly through strict public expenditure controls, significant expansion of government expenditures can only get support if it can boost growth and/or possibly have potential to bring in future revenue. In this context, fiscal space refers to making resources available for justifiable government spending. In Uganda's particular circumstances, additional public infrastructure investments could be financed in six possible ways.

a. Expenditure rationalisation

Rationalisation involves re-allocating resources from less-productive or unproductive expenditures to public investments in infrastructure. Although there may be some scope for expenditure savings in this regard, they may be difficult to implement and politically costly. In Uganda, many of the possible cutbacks were made at the start of the 1987 economic reforms. Nevertheless, from a strictly efficiency point of view there is some scope, but it is unlikely to be substantial enough to meet a reasonable part of the required level of resources. In addition, the returns from different expenditures would have to be compared with this study's infrastructure investment estimates and returns before such a policy decision could be made. This would require other studies similar to this one, covering other productive sectors. However, as illustrated in the expenditure composition analysis in Chapter 3, productive sectors are currently receiving a very small share of government expenditure.

b. Government taxes and domestic borrowing

Given Uganda's low revenue share in GDP (12.5 per cent in 2004/5), it could be argued that increasing this share could be a possible option. However, despite the implementation of tax reforms, the revenue-GDP ratio has increased by only 2 per cent since 1994/95, highlighting the difficulty in raising domestic revenues. This is not unique to Uganda; it has been the case in many African countries because of the political economy challenges of significantly increasing tax burdens from one period to another (see Heller, 2005a). In addition, and as argued in Chapter 3, the availability of financial capital for others may be affected (that is, financial crowding-out may occur). However, it can be argued that financial crowding-out may apply to any form of government expenditure, as long as the expenditure is financed by taxation or borrowing rather than revenue from services generated. Chapter 5 and section 8.4 of this chapter argue that infrastructure investment would generate significant revenue, even though only some time after the initial investment had been made.

c. Private sector provision

Public-private partnerships are deemed to be one way of encouraging the private sector to finance infrastructure investments. As argued in Chapter 3 and section 8.6 below, though suitable for some types of infrastructure, they are unlikely to satisfy the necessary requirements, at least in the medium term, because of the risks associated with long-term investments in Africa by private investors. There are also contingent risks that need to be taken into account, for example, bankruptcy of the private investors (Bevan, 2005).

d. Aid (grants or concessional loans)

External borrowing, while a possibility, is inappropriate for a number of reasons. First, Uganda is among the Heavily Indebted Poor Countries, which are currently receiving debt relief due to difficulties in repaying loans. In obtaining commercial loans, the main consideration becomes whether the return on the expenditure justifies the cost of borrowing, and if the spending would enhance fiscal revenues to enable loan repayment. However, other more justifiable options are still available to Uganda. The most tenable option, at least in the medium term, is grant aid and/or concessional loans. This is especially so given the current global consensus to substantially increase aid to low-income countries to enable them to achieve the millennium development goals which were agreed at the United Nations. As argued previously, the economic policy challenges in this regard are possible Dutch disease effects and absorptive capacity constraints.

First, there is concern that substantial increases in external financial inflows could be problematic because of limited domestic absorption capacity in many low-income countries, which may result in the inefficient use of resources (Heller and Gupta, 2002). Absorptive capacity constraints can have various aspects, for example, lack of skilled manpower to deliver services. Grant aid could be used to remove existing bottlenecks such as poor physical infrastructure, which could also help remove capacity constraints in other sectors.[2] Because of the many different constraints and inefficiencies in different sectors in developing countries, what needs to be critically assessed on an individual country basis is the right sequencing of public investments to deal effectively with absorptive capacity bottlenecks. Aid spent on roads, for example, may open up remote agricultural areas, leading to increased agricultural supply, which may also increase the capacity of the economy to absorb agricultural inputs (Bevan, 2005).

Second, there is concern that substantial scaling-up of aid would translate into appreciation of the exchange rate, leading to loss of the competitiveness of the export sector; that is, the Dutch disease phenomenon.[3] The standard theoretical argument is that large aid inflows would increase demand for both tradables and non-tradables. While the increase in demand for tradables can be met by an increase in imports, the increase in demand for non-tradables may not be met by an increase in supply, due to domestic production bottlenecks. This would result in an increase in the prices of non-tradables relative to those of tradables, and thus an appreciation of the real exchange rate, with detrimental effects on the competitiveness of a country's export sector.

Apparently, concerns based on the standard Dutch disease argument may be exaggerated, as its focus is on demand-side effects of the aid inflow. When both demand- and supply-side effects are considered, it is difficult to predict the outcomes *a priori* since there may be several counteracting effects. Some empirical studies (for example, Van Wijnbergen, 1986a, on six sub-Saharan African countries; White and Wignaraja, 1992, on Sri Lanka; and Younger, 1992, on Ghana) show that increases in foreign aid can result in an appreciation of the real exchange rate, while evidence from other studies, (for example, Nyoni, 1998, on Tanzania) suggest the opposite, that is, a real depreciation.[4] Bevan (2005) and Adam and Bevan (2006) identify a number of factors that determine whether an aid inflow results in real exchange rate appreciation and/or has a negative impact on export performance, with long-term growth consequences.

First, when aid is used to raise the productivity of non-tradable goods, it may help offset the appreciation of the real exchange rate. The increase in the supply of non-tradable goods may equal or surpass the increase in demand. Hence, there may not be a real exchange rate appreciation or, if it happens, it may only be in the short run.

Second, aid may facilitate a rise in productivity of the export sector. While this would be expected to lead to an increase in real appreciation, it also means an increase in profitability and the net outcome vis-à-vis the incentive to export would depend on the trade-off between the two effects. For example, removing transportation bottlenecks and enhancing the productivity of the traded goods sector would improve export sector competitiveness.

Third, aid may be used to remove bottlenecks and facilitate the reduction of unutilised capacity, thereby enabling an economy to work closer to its existing productive potential.

In conclusion, it is clear that there can be counteracting effects when there is a substantial increase in aid inflows. The outcomes are complex because they depend on how the foreign exchange inflow is managed and the comparative impact of the aid on supply and demand. In addition, net outcomes may evolve over time, that is inter-temporal net outcomes may differ. In terms of infrastructure investment spending, there would be a trade-off between Dutch disease effects and long-term benefits associated with spending on physical infrastructure such as roads. As discussed earlier, an important consideration is the danger of stifling export growth over a long period of time. From this viewpoint, it is important to consider investing in physical infrastructure because its supply pay-off is faster than that of the social sectors that are the focus of current aid programmes (Bevan, 2005).

Therefore, critical consideration should be given to whether the scaling-up of aid would result in sufficient returns in terms of sustained growth in comparison with the negative effects. Studies like Adam and

Bevan (2006) provide simulation-based evidence that supply-side responses to the aid-financed public expenditure are the key to evolution of the aggregate economy.[5] The current study provides evidence from Uganda which shows that public infrastructure investments would not only have a direct positive and large effect on private sector output/productivity, but would also augment the productivity of private factors. There are potentially large medium-/long-term gains from aid-funded efficient public infrastructure investments, which could be sufficient to offset short-run Dutch disease effects.

Thus, exploitation of fiscal space to make infrastructure investments is justifiable.

8.6 Public vs Private Provision

The significant magnitude of the impact of infrastructure capital and the associated positive production externalities that this study has found suggest a need for greater government involvement in provision. This is re-inforced by other factors such as 'lumpy' investment requirements and non-excludability in consumption or high exclusion costs.

However, in line with current economic orthodoxy, the tendency is to allow greater involvement of the private sector in provision. Due to the lack of confidence in African economies, there is doubt as to whether private investors would be interested in large long-term investments there, at least in the short to medium term. The main factors that explain this reluctance are higher political and economic risks, lack of counterpart agents, greater investment needs and the consumers' lower payment capacities (Schwartz et al., 2004).

In addition, the private sector in public-private partnerships may not be by itself a source of funds for new infrastructure investments. Taking the example of independent power producers, the terms of power purchase agreements between private investors and government are quite stringent and are meant to provide a hedge against the perceived risks associated with long-term projects in Africa. In many cases, government guarantees are required by private investors before they raise the necessary finance. This makes governments indirectly responsible for raising the necessary funds on the basis of the guarantee. The abortive Bujagali energy project agreement between the Government of Uganda and EAS Power, which was discussed in Chapter 3 of this study, was a clear example of this.

Nonetheless, depending on the macroeconomic environment, properly formulated incentives and possibility of sovereign or multilateral support, success in attracting private sector participation may vary between countries and there may be room for private investors in operational aspects as well as in making new investments. It should be borne in mind, though, that a purely commercial approach may not address development objectives: private investors would not be interested in less viable and unviable rural areas of the country although they may have the greatest need and be areas where infrastructure investments could potentially play an important role in stimulating development.

Although government involvement may not be necessary in all aspects of infrastructure provision, additional analytical research needs to be done to come up with institutional frameworks that provide the appropriate mix between public provision, dependency on the market mechanism, and/or public-private mechanisms in the context of sub-Saharan African countries like Uganda.

8.7 Methodological and Policy Implications and Suggestions for Further Research

The framework that was adopted in this study enabled analysis of the impact of public infrastructure capital on private sector output and productivity at the micro level and by sector. The advantage of this was that it allowed a more direct linkage and analysis of how public infrastructure impacts on particular production processes. The study's approach also allowed flexibility in functional specifications, which enabled analysis of complementarity and substitutability between production inputs, testing of the crowding-in/crowding-out hypothesis and assessment of direct and indirect effects of public infrastructure capital.

To take into account the possibility that output/productivity effects of public infrastructure may be subject to a threshold, econometric modelling techniques based on spline function theory were used to empirically test whether there are threshold effects in infrastructure provision. In contrast to most studies, the focus was not on the optimal level or 'saturation point' but on the critical minimum mass of infrastructure required to have productivity effects. This is more relevant to developing countries like Uganda, which have underdeveloped infrastructure. However, the study only captured supply-side effects. A complete analysis would require use of a Computable General Equilibrium model to assess not only the supply-side effects but also economy-wide effects including demand-side effects. The results of the quantitative analysis for different sectors conducted in this study can be used for further research as an input into economy-wide general equilibrium model simulation studies that try to examine the economy-wide implications of making infrastructure investments but use 'guess estimates' for output/value added elasticities with respect to public infrastructure capital. Within this framework, it would be possible capture the trade-offs of investing in infrastructure as compared with other areas such as education and health, given that governments face financial and absorptive capacity constraints. This kind of analysis would also help assess the extent to which better infrastructure services would impact on other areas that are of concern, such as those highlighted in the millennium development goals, for example, educational achievements and health indicators. Such analysis would assist governments to choose better when faced with difficult policy options.

Notes

1. However, public infrastructure capital is only a necessary, not sufficient, factor in the development process.
2. Constraints associated with the infrastructure investments themselves may be alleviated through involvement of both domestic and foreign private sector actors in implementation. Nevertheless, infrastructure investments coming as a result of the scaling-up of expenditure may still be associated with inefficiencies, which should be minimised as much as possible.
3. 'The Dutch disease phenomenon basically describes a situation where an inflow of foreign exchange in any form (export earnings, private capital flows or foreign aid) creates upward pressure on the real exchange rate of the recipient country by stimulating more rapid domestic inflation. A large inflow of foreign aid may therefore result in exports losing competitiveness, counteracting other efforts to increase exports' (Hjertholm et al., 2000: 361).
4. Nyoni's main argument is that the effect on the real exchange rate depends on a country's monetary and fiscal policies and what aid is used for.
5. Adam and Bevan's study applies a recursive dynamic real computable general equilibrium model of a small open economy with the principal features of a low-income aid-dependent country like Uganda. In fact, the underlying social accounting matrix is loosely based on data from Uganda. This is used to simulate the effect of a year-on-year increase in net aid flows. The study concludes that 'the macroeconomic impact of aid depends closely on the

underlying microeconomics of the associated public expenditures it finances' (Adam and Bevan, 2006: 289).

Appendices

Appendix A:
Selected Empirical Results from Other Studies

Table A Selected Empirical Results from Studies of Infrastructure Productivity

Study	Aggregation Level	Data; Infrastructure measure	Method; Specification	Elasticities & Marginal Factor Productivity (MFP)
Aschauer (1989a)	National	Time series (1949 – 85) Public Capital	Production Function (Cobb-Douglas; log level)	Output: 0.39
Aschauer (1989b)	G-7 countries	Panel data (1966 – 85) Public Capital	Production Function (Cobb-Douglas; delta log)	Output: 0.34 – 0.73
Pinnoi (1994)	48 states	Panel data (1970 – 86) Public Capital	Production Function (Translog; level)	Output: -0.11 – 0.08
Dalamagas (1995)	National (Greece)	Time series manufacturing (1950 – 92) Total public investment	Behavioural Approach (Cost: Translog)	Cost: -2.35
Shah (1992)	National (Mexico)	Panel,26 sectors, 1970–87 manufacturing Transport, communications and Electricity	Behavioural Approach (Cost: Translog)	Output: 0.05

***Table A** (Continued)*

Study	Aggregation Level	Data Infrastructure Measure	Method; specification	Elasticities & Marginal Factor Productivity (MFP)
Morrison & Schwartz (1992	48 states (USA)	Panel 1970–87 manufacturing Motorways & water & sewers	Behavioral Approach (Cost: generalized leontief	Cost: (0.07; -0.17)
Lynde and Richmond (1993)	U.S.A	Time series 1958 – 89 (Non-financial corporate sector) Total public capital stock excl. dwellings	Behavioral Approach (Profit: translog)	Output: 0.20
Clarida (1993)	U.S.A., France, Germany, U.K	Public capital stock; other variable is MFP.	VAR approach	MFP and public capital are cointegrated, but direction of causality is unclear.
Sturm et al. (1995)	Netherlands	1853 – 13 Public capital stock; other variables are private capital stock, private sector GDP, private labour	VAR approach	Infrastructure Granger causes output
Otto & Voss (1996)	Australia,	1959:III –92:II Public capital stock; other variables are private capital stock, private sector GDP, number of working hours	VAR approach	No relationship between public capital and labour or output. Private capital affects public capital positively

***Table A** (Continued)*

Study	Aggregation Level	Data Infrastructure Measure	Method; Specification	Elasticities & Marginal Factor Productivity (MFP)
Barro (1989)	72 non-OPEC countries	1960 – 85 Public Investment	Cross country growth regressions	Significant effect
Barro (1991)	76 countries	1960 – 85 Public Investment	Cross country growth regressions	No effect
Easterly & Rebelo (1993a)	About 100 countries. (incldg developing countries)	1970 – 88 Public investment or transport and communication spending	Cross country growth regressions	First variable not significant, second variable is significant
Mas et al (1995b)	50 Spanish regions	1955 – 91 1955 –67 1967-79 1979 – 91 Public capital	Cross states growth regressions	MFP of public capital. 0.0043 0.0094 0.009 Insignificant respectively.

Source: Sturm et al. (1995), Hakfoort (1996) and World Bank (1994)

Appendix B:
Electrification Targets to Be Achieved by 2010

Year	2000	2005	2010
Urban Areas			
Population (millions)	3.4	4.8	6
Households (millions)	0.8	1.1	1.3
Electrified Households	170,000	220,000	295,000
Urban Electrification Rate (%)	**21**	**20**	**23**
Rural Areas			
Population (millions)	18.6	20.2	22
Households (millions)	3.8	4.1	4.5
Electrified Households	80,000	164,000	450,000
Rural Electrification Rate (%)	**2.1**	**4.0**	**10.0**
Total			
Population (millions)	22	25	28
Households (millions)	4.6	5.2	5.8
Electrified Households	250,000	384,000	745,000
Total Electrification Rate	**5.4**	**7.4**	**12.8**

Source: 'Rural Electrification Strategy and Plan, 2001', in Ministry of Energy and Mineral Development (2004: 11–34).

Appendix C:
Method of Firm-Level Data Collection and Editing

The method of data collection comprised questionnaires sent by post as well as face-to-face interviews and was carried out by the Uganda Bureau of Statistics. The survey started in June 2002 and lasted for a period of 16 months. The financial year 2000/01 was the reference period. In regard to the 'postal' method, questionnaires were issued to respondents by enumerators and respondents were asked to fill them in and return them within two to three weeks. The face-to-face interviews were utilised for the small unit establishments, which did not keep records of their economic activities.

Data editing was done in stages, with the first editing being done by the enumerators in the field. The supervisors then edited the questionnaires submitted by the enumerators. If an error was detected, the supervisor and the enumerator would go back to the relevant establishment to rectify the problem. The editors also allocated codes to the different activities in the establishments. These were International Standard Industrial Classification (ISIC) codes of all economic activities. For identification, each establishment was given two unique identification codes, the Uganda Business Inquiry serial number, (UBI code), and the Census of Business Establishment serial number, (COBE code). These two were useful in identifying/tracing different establishment questionnaires in case a physical reference to the questionnaire was needed. All districts in Uganda were assigned different codes, which enabled the tracing of firm locations within the country and facilitated the kind of analysis undertaken in this study (see Chapter 4).

In the final stage of editing, inconsistencies in figures, wrong activity codes or any other errors were detected by a computer programme which had in-built error checks. Any wrong entries were rejected. This was followed by an elaborate process of correction, including revisiting the relevant establishment where necessary.

Appendix D: Descriptive Statistics

Table D.1 Descriptive Statistics – Full Sample

Full Sample	Obs.	Mean	Median	Minimum	Maximum	Standard Deviation
Private output						
Gross output (Ug. Shs'000)	962	2411450	281438	945	113000000	8656416
Log (Gross output)	962	12.72	12.55	6.85	18.54	1.9
Value Added (Ug Shs'000)	962	1111915	123053	202.68	90500000	4928512
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
capital (K) - (net total assets) (Shs'000)	962	2798761	123301	41.35	914000000	31100000
Log (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

Table D.2 Descriptive Statistics – Industrial Sector

Industry sector	Obs.	Mean	Median	Minimum	Maximum	Standard Deviation
Private output						
Gross output (Thousand shillings)	306	4688611	608100	4941	113000000	12700000
Log (Gross output)	306	13.6	13.3	8.51	18.54	1.89
Value Added (Thousand shillings)	306	1733391	195839	203	90500000	6522102
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
capital (K) - (net total assets) (Shs'000)	306	5792056	321590	970	914000000	53400000
Log (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

Table D.3 Descriptive Statistics – Services Sector

Services sector	Obs.	Mean	Median	Minimum	Maximum	Standard Deviation
Private output						
Gross output (Thousand shillings)	639	1341066	198373	945	74600000	5657184
Log (Gross output)	639	12.286	12.2	6.85	18.13	1.75
Value Added (Thousand shillings)	639	826074	101992	668	54600000	3995916
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
Capital (K) - (net total assets) (Shs'000)	639	1399513	64681	41	172000000	9172449
Log (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

Table D.4 Descriptive Statistics – Agricultural Sector

Agriculture sector **Unit of Analysis - District**	Obs.	Mean	Median	Minimum	Maximum	Standard Deviation
Private output						
Agricultural labour productivity (shillings)	23	97431	93926	36137	162417	32893
Log (Agricultural Labour productivity)	23	11.423	11.450	10.495	11.998	0.386
Value Added (million shillings)	23	16000	13300	3410	32000	8390
Log (Value Added)	23	23.339	23.308	21.949	24.190	0.601
Value Added per worker(shillings)	23	83329	80175	27695	149009	32787
Log (Value Added per worker)	23	11.241	11.292	10.229	11.912	0.462
Private inputs						
Labour - number of people engaged in crop farming as main activity	23	197006	200356	58348	334571	79791
Log (Labour)	23	12.097	12.208	10.974	12.721	0.468
Agricultural Cultivable Land (Acres)	23	345349	324115	59839	862099	175005
Log (Agricultural cultivable land)	23	12.623	12.689	10.999	13.667	0.553
Aggregate value of fertilizers (million shillings)	23	283	67	0.747	1730	486
Log(Aggregate value of fertilizers)	23	17.899	18.013	13.523	21.272	2.139
Infrastructure measures						
Dry weather roads(in km. Per sq.km.area)	23	0.044	0.038	0.013	0.090	0.024
Log (Dry weather roads)	23	-3.262	-3.264	-4.373	-2.411	0.580
All weather roads(in km. Per sq.km.area)	23	0.033	0.026	0.005	0.081	0.019
Log (All weather roads)	23	-3.620	-3.660	-5.230	-2.517	0.691
Paved roads (in km. Per sq.km.area)	23	0.009	0.008	0.000	0.029	0.008
Log (Paved roads+1)	23	0.009	0.008	0.000	0.029	0.008
Electricity (ratio of households with electricity per district)	23	0.036	0.032	0.000	0.142	0.039
Log (Electricity+1)	23	0.035	0.031	0.000	0.133	0.036
Telephone - Mean distance to the nearest public phone per district - inverted	23	0.055	0.055	0.013	0.092	0.022
Log(Telephone)	23	-2.999	-2.905	-4.327	-2.389	0.511
Other variables						
Human capital (mean number of school years completed)	23	2.672	2.688	1.905	3.314	0.326
Log (Human Capital)	23	0.975	0.989	0.644	1.198	0.126
Improved varieties - % staple food crop area with improved varieties	23	4.622	3.770	0.080	16.550	4.349
Log (improved varieties+1)	23	1.442	1.562	0.077	2.865	0.791

Appendix E:
Principal Components and Factor Analyses

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 analyses 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.[1] Information of K variables, $Z_1, Z_2, Z_3, ..., Z_k$ can be re-expressed 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 shown below, correlation between our infrastructure variables is quite high. The correlation matrix of our standardised values shows a high correlation between the variables (see Table E.1).

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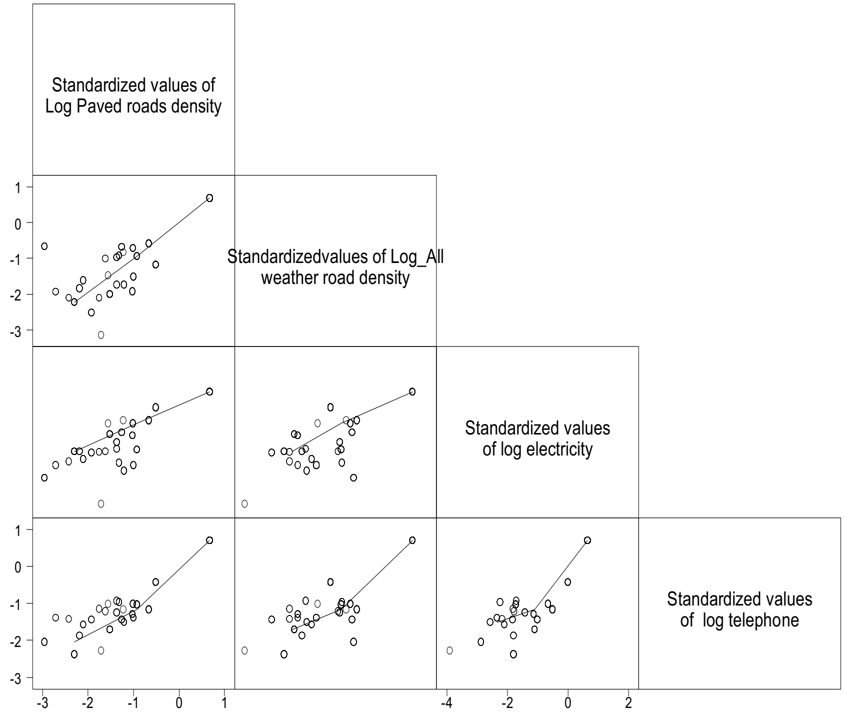
[1] This section borrows substantially from Hamilton (1992).

Table E.1 Correlation Matrix of 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	1

Figure E.1, a scatterplot matrix with exploratory band regression curves, confirms these relations graphically.

Figure E.1 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 E.2** 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

	Factor Loadings	
Variable	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 E.2 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), and so on. The sum of the eigenvalues equals the number of variables, that is, $\lambda_1 + \lambda_2 + \ldots\ldots + \lambda_k$ where k is the number of variables. This is so since standardised variables have variances of 1; hence the number of variables also equals the total variance of all variables.

The proportions as shown in Table E.2 are therefore computed as fractions of the total variance. That is, for the jth component, we have $\frac{\lambda_j}{K}$. The first component, for example, explains over 95 per cent of the total variance, that is,.

$$\frac{3.80598}{4} = 0.9515.$$

The four components explain 100 per cent of the combined variance of the original four variables. Since the first component explains over 95 per cent 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.

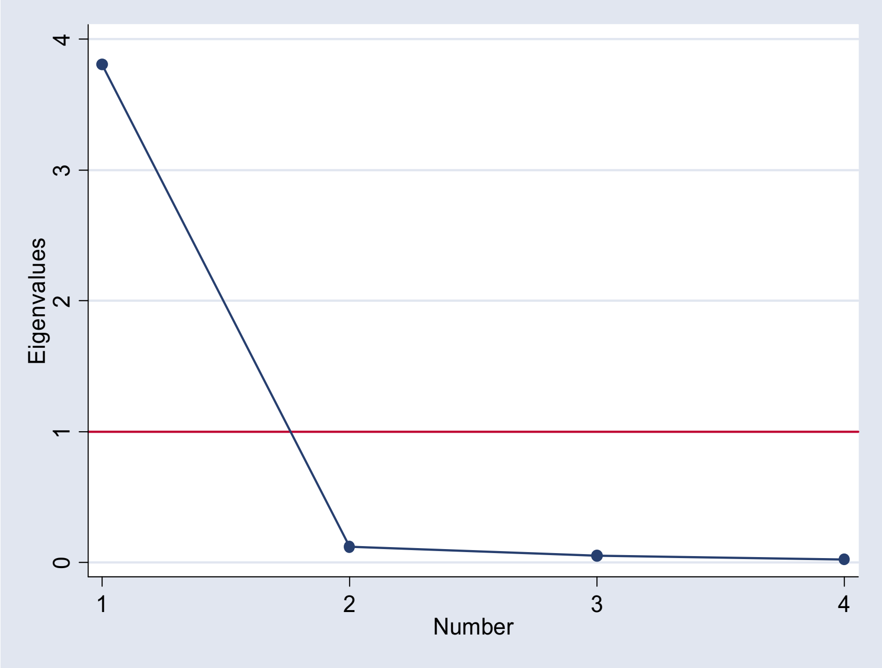
Factor loadings are standardised coefficients in the regression of variables on components (or factors). Each observed variable could be expressed as a linear function of K uncorrelated principal components:

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

Here l_{k1} is the loading of variable Z_k on standardised 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 per cent of the variance of paved roads, 7.4 per cent of the variance of weather roads, 7 per cent of the variance of power (electricity) and 2.5 per cent of the variance of telephones are not explained by the first component.

The eigenvalues provide a criterion with which we judge the components to keep. A common rule of thumb is to disregard principal components with eigenvalues of less than 1. This is so since each standardised variable has a variance of 1, a component with an eigenvalue of less than one accounts 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 numbers. 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 E.2 below. In the figure, 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 in our case since we retain one component.

Figure E.2 *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 (that is, 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 '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' 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

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

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 E.3, below, shows the derived factor score coefficients for our infrastructure composite index.

Table E.3 *Factor Score Coefficients*

(based on unrotated factors)	
	Scoring Coefficients
Variable	1
Paved roads	0.25955
Weather roads	0.25278
Power	0.25334
Telephone	0.25942

Appendix F:
Constraints to Coefficients of Spline Regression Model

From Chapter 7, we have the following equation (7.7):

$$\ln VA = [a_1 + b_1(\ln G - \ln G_0^*) + c_1(\ln G - \ln G_0^*)^2 + d_1(\ln G - \ln G_0^*)^3]D_1 +$$
$$[a_2 + b_2(\ln G - \ln G_1^*) + c_2(\ln G - \ln G_1^*)^2 + d_2(\ln G - \ln G_1^*)^3]D_2 +$$
$$[a_3 + b_3(\ln G - \ln G_2^*) + c_3(\ln G - \ln G_2^*)^2 + d_3(\ln G - \ln G_2^*)^3 \ ]D_3 + \mu \qquad (7.7)$$

D_i is a dummy variable defined by the i^{th} interval

To guarantee that the function in equation (7.7) and its first and second derivatives are continuous, it is necessary to apply appropriate constraints to the coefficients as follows: (see Suit *et al.*, 1978).

For equation 7.7, above, the following constraints are necessary:

$$a_2 = a_1 + b_1(\ln G_1 - \ln G_0^*) + c_1(\ln G_1 - \ln G_0^*)^2 + d_1(\ln G_1 - \ln G_0^*)^3$$

$$b_2 = b_1 + 2c_1(\ln G_1 - \ln G_0^*)^2 + 3d_2(\ln G_1 - \ln G_0^*)^2$$

$$c_2 = c_1 + 3d_1(\ln G_1 - \ln G_0^*)$$

$$a_3 = a_2 + b_2(\ln G_2 - \ln G_1^*) + c_2(\ln G_2 - \ln G_1^*)^2 + d_2(\ln G_2 - \ln G_1^*)^3$$

$$b_3 = b_2 + 2c_2(\ln G2 - \ln G_1^*)^2 + 3d_2(\ln G2 - \ln G_1^*)^2$$

$$c_3 = c_2 + 3d_2(\ln G_2 - \ln G_1^*) \qquad (7.7a)$$

i. Essentially, the constraints on the a_i equate the values of the left and right branches of the function at the knots

ii. The constraints on b_i equate the slopes of the right and left branches at the knots

iii. And the constraints of the c_i equate the slopes of the right and left branches at the knots for the second derivatives.

Assuming equal intervals, then:

$$(\ln G_1 - \ln G_0^*) = (\ln G_2 - \ln G_1^*) \ = (\ln G_3 - \ln G_2^*) = w$$

Substituting w into 7.7a and the result into (7.7) and collecting terms with the same coefficient gives:

$$\ln VA = a_1 + b_1(\ln G - \ln G_0^*) + c_1\{ (\ln G - \ln G_0^*)^2 + d_1(\ln G - \ln G_0^*)^3]D_1 + (w + \ln G - \ln G_1)^2 D_2 + (2w + \ln G - \ln G_2)^2 D_3 \}$$
$$+ d_1\{(\ln G - \ln G_0)^3 D_1 + \left[w^3 + 3w(\ln G - \ln G_1)^2 + 3w(\ln G - \ln G_1)^3\right] D_2 + \left[7w^3 + 9w^2(\ln G - \ln G_2) + 3w(\ln G - \ln G_2)^2\right] D_3\}$$
$$+ d_2\{(\ln G - \ln G_1)^3 D_2 + \left[w^3 + w^2(\ln G - \ln G_2) + 3w(\ln G - \ln G_2)^2\right] D_3\}$$
$$+ d_3(\ln G - \ln G_2)^3 D_3 \qquad (7.7b)$$

In equation 7.7b, when the data are transformed to get the required five composite variables, then the multiple regression directly yields the required coefficient values of a_1, b_1, c_1, d_1, d_2, *and* d_3 with the remaining coefficients of equation 7.7 obtained by substitution into equation 7.7a.

However, equation 7.7b can be further simplified to enable straight estimation in an econometric software package like STATA as well as to enable generalisation to a larger number of intervals. If we define a new set of variables, that is;

$D_i^* = 1$, if and only if $\ln G \geq \ln G_i^*$, otherwise, $D_i^* = 0$

Meaning that D_1^* has value 0 until $\ln G$ reaches $\ln G_1^*$ and is thereafter equal to 1. D_2^* has value 0 until $\ln G$ reaches $\ln G_2^*$ and is thereafter equal to 1. Then it is possible to show that equation 7.7b is equivalent to:

$$\ln VA = a + b_1(\ln G - \ln G_0^*) + c_1(\ln G - \ln G_0^*)^2 + d_1(\ln G - \ln G_0^*)^3 + (d_2 - d_1)(\ln G - \ln G_1^*)^3 D_1^* + (d_3 - d_2)(\ln G - \ln G_2^*)^3 D_2^* \qquad (7.8)$$

Equation 7.8 is equivalent to equation 7.7b with five composite variables. The regression of equation 7.8 can easily be carried out in STATA software. The mkspline command makes the calculation relatively easy. The goodness of fit, significance tests, and so on, can be obtained as in any other multiple regression estimation.

Appendix G:
Thresholds and Required Investments

Table G.1 *Districts with Firms Above and Below the Threshold*

Public infrastructure composite variable (Threshold Value)	Districts with Firms below or at Threshold value	District with Firms above Threshold value
-1.283412	Nakasongola	Kayunga
	Arua	Kabale
	Lira	Mbale
	Kyenjojo	Mpigi
	Kamuli	Mukono
	Soroti	Wakiso
	Mubende	Jinja
	Hoima	Kampala
	Rakai	
	Bushenyi	
	Mbarara	
	Kabarole	
	Luweero	
	Tororo	
	Iganga	
	Masaka	
	Masindi	

Table G.2 *Required Public Infrastructure Investments*

	Divergence from Threshold				
District	Paved roads Kms/sq.km	Paved roads No. of Kms	Weather roads Kms/sq.km	Weather roads No. of Kms	Electricity No. of HouseholdsH without
NAKASONGOLA	0.004	12.636	0.035	115.46	1,221
ARUA	0.007	56.614	0.000	0.00	6,353
LIRA	0.006	41.436	0.030	192.36	2,622
KAMULI	0.007	24.403	0.029	104.33	3,762
SOROTI	0.006	25.947	0.024	103.13	1,628
MUBENDE	0.005	31.721	0.032	195.77	2,425
HOIMA	0.006	22.561	0.023	86.06	1,338
RAKAI	0.004	17.095	0.029	118.44	1,620
BUSHENYI	0.000	0.000	0.023	89.59	4,790
MBARARA	0.002	20.186	0.027	270.09	0
KABAROLE	0.002	25.747	0.024	290.02	6,050
LUWERO	0.003	17.408	0.001	7.56	1,479
TORORO	0.000	0.000	0.023	42.09	1,408
IGANGA	0.000	0.000	0.000	0.00	5,189
MASAKA	0.000	0.000	0.026	92.82	0
MASINDI	0.000	0.082	0.000	0.42	18
KABALE	0.000	0.000	0.000	0.00	0
MBALE	0.000	0.000	0.000	0.00	2,569
MPIGI	0.000	0.000	0.002	8.01	0
MUKONO	0.000	0.000	0.000	0.00	0
JINJA	0.000	0.000	0.009	5.87	0
KAMPALA	0.000	0.000	0.000	0.00	0
Kalangala	0.007	3.510	0.038	17.76	296
Kiboga	0.007	30.318	0.029	117.81	1,846
Sembabule	0.007	17.376	0.031	71.43	1,493
Bugiri	0.002	3.484	0.032	49.64	973
Busia	0.000	0.000	0.011	7.75	2,234
Kapchorwa	0.007	12.979	0.029	50.19	1,465
Katakwi	0.007	36.839	0.008	38.53	1,873
Kumi	0.000	0.000	0.000	0.00	3,221
Pallisa	0.007	14.430	0.000	0.00	3,265
Adjumani	0.007	22.716	0.016	49.09	0
Apac	0.000	1.956	0.000	0.00	6,816
Kotido	0.007	99.267	0.020	270.72	4,550
Moroto	0.007	107.559	0.017	237.39	4,322
Moyo	0.007	13.496	0.016	28.46	851
Nebbi	0.007	21.247	0.025	71.01	5,344
Kibale	0.007	31.820	0.037	156.10	2,468
Kisoro	0.007	5.256	0.000	0.00	1,958
Ntugamo	0.000	0.000	0.021	43.87	3,201
Rukungiri	0.007	20.401	0.000	0.00	4,587
Total	**0.161**	**738.490**	**0.666**	**2931.750**	**93,236**

Table G.2 *(Continued)*

	Cost per Kilometre		Cost per	Required investment to reach threshold		
District	Paved roads (US $)	Weather roads (US $)	Household (US $)	Paved roads (US $)	Weather roads (US $)	Electricity (US $)
NAKASONGOLA	410,000	102,500	1,500	5,180,724	11,834,867	1,831,608
ARUA	410,000	102,500	1,500	23,211,565	0	9,529,251
LIRA	410,000	102,500	1,500	16,988,960	19,716,539	3,932,405
KAMULI	410,000	102,500	1,500	10,005,186	10,694,265	5,643,639
SOROTI	410,000	102,500	1,500	10,638,436	10,570,838	2,441,448
MUBENDE	410,000	102,500	1,500	13,005,803	20,066,260	3,637,121
HOIMA	410,000	102,500	1,500	9,250,145	8,821,342	2,007,201
RAKAI	410,000	102,500	1,500	7,009,049	12,139,774	2,429,652
BUSHENYI	410,000	102,500	1,500	0	9,182,848	7,185,064
MBARARA	410,000	102,500	1,500	8,276,289	27,683,792	0
KABAROLE	410,000	102,500	1,500	10,556,219	29,726,653	9,074,805
LUWERO	410,000	102,500	1,500	7,137,415	775,136	2,219,010
TORORO	410,000	102,500	1,500	0	4,314,374	2,112,652
IGANGA	410,000	102,500	1,500	0	0	7,783,506
MASAKA	410,000	102,500	1,500	0	9,513,861	0
MASINDI	410,000	102,500	1,500	33,493	42,559	27,224
KABALE	410,000	102,500	1,500	0	0	0
MBALE	410,000	102,500	1,500	0	0	3,854,053
MPIGI	410,000	102,500	1,500	0	820,846	0
MUKONO	410,000	102,500	1,500	0	0	0
JINJA	410,000	102,500	1,500	0	601,200	0
KAMPALA	410,000	102,500	1,500	0	0	0
Kalangala	410,000	102,500	1,500	1,439,005	1,820,702	444,618
Kiboga	410,000	102,500	1,500	12,430,507	12,075,019	2,768,735
Sembabule	410,000	102,500	1,500	7,124,042	7,321,220	2,239,538
Bugiri	410,000	102,500	1,500	1,428,310	5,088,290	1,459,114
Busia	410,000	102,500	1,500	0	794,124	3,350,394
Kapchorwa	410,000	102,500	1,500	5,321,215	5,144,331	2,197,386
Katakwi	410,000	102,500	1,500	15,103,867	3,949,814	2,809,998
Kumi	410,000	102,500	1,500	0	0	4,832,029
Pallisa	410,000	102,500	1,500	5,916,421	0	4,897,812
Adjumani	410,000	102,500	1,500	9,313,431	5,031,229	0
Apac	410,000	102,500	1,500	802,151	0	10,223,917
Kotido	410,000	102,500	1,500	40,699,286	27,748,424	6,825,101
Moroto	410,000	102,500	1,500	44,099,369	24,332,447	6,483,194
Moyo	410,000	102,500	1,500	5,533,240	2,917,643	1,276,647
Nebbi	410,000	102,500	1,500	8,711,157	7,278,498	8,016,053
Kibale	410,000	102,500	1,500	13,046,302	16,000,493	3,701,339
Kisoro	410,000	102,500	1,500	2,154,974	0	2,937,724
Ntugamo	410,000	102,500	1,500	0	4,496,986	4,801,776
Rukungiri	410,000	102,500	1,500	8,364,235	0	6,880,334
Total				**302780794**	**300504373**	**139854346**

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