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# Infrastructure and Economic Development in Sub-Saharan Africa

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## Abstract

An adequate supply of infrastructure services has long been viewed by both academics and policy makers as a key ingredient for economic development. Sub-Saharan Africa ranks consistently at the bottom of all developing regions in terms of infrastructure performance, and an increasing number of observers point to deficient infrastructure as a major obstacle for growth and poverty reduction across the region. This paper offers an empirical assessment of the impact of infrastructure development on growth and inequality, with a focus on Sub-Saharan Africa. The paper uses a comparative cross-regional perspective to place Africa's experience in the international context. Drawing from an updated data set of infrastructure quantity and quality indicators covering more than 100 countries and spanning the years 1960-2005, the paper estimates empirical growth and inequality equations including a standard set of control variables augmented by infrastructure quantity and quality measures, and controlling for the potential endogeneity of the latter. The estimates illustrate the potential contribution of infrastructure development to growth and equity across Africa.

This paper—a product of the Growth and the Macroeconomics Team, Development Research Group—is part of a larger effort in the department to understand the determinants of growth in Africa. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at lserven@worldbank.org.

# Infrastructure and Economic Development in Sub-Saharan Africa

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## 1. Introduction

Decades of economic stagnation and declining living standards have turned Sub-Saharan Africa into the world's poorest region. In spite of an incipient recovery since the end of the 1990s, with per capita income growth rates outpacing those of rich countries for the first time in many years, leading observers in the development and policy community are advocating a 'big push' to help the region escape poverty and regain the lost ground vis-à-vis the rest of the developing world (e.g., Sachs *et* al 2004, Collier 2006). These calls for action propose a variety of remedial policy agendas, but virtually all of them list infrastructure development among the top priorities.

An adequate supply of infrastructure services has long been viewed as a key ingredient for economic development, both in the academic literature (starting with the work of Aschauer 1989) as well as in the policy debate (e.g., World Bank 1994). Over the last two decades, academic research has devoted considerable effort to theoretical and empirical analyses of the contribution of infrastructure development to growth and productivity. More recently, increasing attention has been paid also to the impact of infrastructure on poverty and inequality (Estache, Foster and Wodon 2002, World Bank 2003, 2006). While the empirical literature on these two topics is far from unanimous, on the whole a consensus has emerged that, under the right conditions, infrastructure development can play a major role in promoting growth and equity – and, through both channels, helping reduce poverty.

In most dimensions of infrastructure performance, Sub-Saharan Africa ranks at the bottom of all developing regions, so the strategic emphasis on infrastructure is hardly surprising. And the literature suggests that some intrinsic features of Africa's economies may enhance the potential role of infrastructure for the region's economic development – in particular, the large number of Africa's landlocked countries, home to a major proportion (about 40 percent) of the region's overall population, and the remoteness of most of the region's economies from global market centers. These geographic disadvantages result in high transport costs that hamper intra and inter-regional trade, as variously shown by Limao and Venables (2001), Elbadawi, Mengistae and Zeufack (2006), and Behar and Manners (2008). Reduced openness to trade is the main factor behind the robust empirical finding that – other things equal – landlocked countries tend to grow more slowly than the rest. However, these geographic disadvantages do not pose an insurmountable obstacle to development -- they can be offset with good transport and communications facilities.[1] Africa's problem is that poor infrastructure adds to its geographic disadvantage.

Aside from external trade, there are many concrete indications that deficient infrastructure hampers Africa's development in other ways. Reinikka and Svensson (1999) use data from Uganda's industrial enterprise survey to test the impact of poor infrastructure – as reflected by an inadequate supply of electricity – on firm-level investment, and find that unreliable electricity is a significant investment deterrent. Diao and Yanoma (2003) show that growth in the agricultural sector is constrained by high marketing costs, which largely reflect poor transport (as well as other infrastructure) facilities. Estache and Vagliasindi (2007) argue that an insufficient power generation capacity limits growth in Ghana. Lumbila (2005) finds that deficient infrastructure may hinder the growth impact of FDI in Africa.

This paper offers an empirical assessment of the impact of infrastructure development on growth and inequality, with a focus on Sub-Saharan Africa. The paper uses a comparative cross-regional perspective to place Africa's experience in the international context. Drawing from an updated data set of infrastructure indicators covering 100 countries and spanning the years 1960-2005, we estimate empirical growth and inequality equations including a standard set of control variables augmented with infrastructure development indicators. The empirical approach extends previous literature in several dimensions: it encompasses different core infrastructure sectors, considers both the quantity and quality of infrastructure, and accounts for their potential endogeneity. We use the empirical estimates to illustrate the contribution of infrastructure development to growth and equity across Africa.

The paper follows recent empirical studies of the contribution of infrastructure to the level and growth of aggregate output and productivity (Sánchez-Robles 1998; Canning 1999; Demetriades and Mamuneas 2000; Röller and Waverman 2001; Esfahani

[1] In other words, geography is only part of the story. Limao and Venables (2001) conclude that poor infrastructure is responsible for a good portion of Africa's record-high transport costs and its abnormally low intra-regional trade.

and Ramirez 2003; Calderón and Servén 2003, 2008). It also adds to a still incipient, but rapidly expanding literature on the distributive impact of infrastructure provision and reform (Estache, Foster and Wodon 2002; Calderón and Chong 2004).

The rest of the paper is organized as follows. In Section 2 we offer a brief review of recent literature concerned with the effects of infrastructure development on growth and distribution, with a focus on Sub-Saharan Africa. Section 3 discusses the empirical strategy and the econometric issues that arise when attempting to identify the impact of infrastructure on growth and income distribution. It presents the empirical results and reports illustrative exercises highlighting their implications for Africa. Finally, section 4 offers concluding comments.

## 2. Infrastructure and economic development

There is abundant theoretical work on the contribution of infrastructure to output, productivity and welfare. Much of it is closely related to a literature concerned with the macroeconomic role of productive public expenditure. Arrow and Kurz (1970 were the first to provide a formal analysis of the effects of public capital on output and welfare under alternative financing schemes. In their framework, public capital enters as an input in the economy's aggregate production function, in the context of a Ramsey model with long-run growth exogenously determined. The endogenous growth version of this basic setup was developed first by Barro (1990), who assumed that the government's contribution to current production is driven by its flow of productive expenditure, and later extended by Futagami, Morita and Shibata (1993) to include both public and private capital stock accumulation.

This analytical literature has grown enormously in the last fifteen years, exploring a multitude of variants of the basic model, such as alternative tax structures, considering simultaneously public capital and productive current spending flows, adding public capital services in the utility function, or allowing for public infrastructure congestion.[2]

In turn, empirical research on the impact of infrastructure took off relatively recently, following the seminal work of Aschauer (1989), but it has boomed over the last

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[2] See for example Turnovsky (1997), Glomm and Ravikumar (1997), Baier and Glomm (2001), and Ghosh and Roy (2004).

two decades – literally hundreds of papers have been devoted to assess the effects of infrastructure on growth, productivity, poverty, and other development outcomes, using a variety of data and empirical methodologies. Calderón and Servén (2008) offer a partial account of the literature on the growth and inequality effects of infrastructure; more comprehensive surveys include Estache (2006), Romp and de Haan (2007) and Straub (2007).

The bulk of the empirical literature on the effects of infrastructure has focused on its long-run contribution to the level or growth rate of aggregate income or productivity. The starting point was Aschauer's (1989) finding that the stock of public infrastructure capital is a significant determinant of aggregate TFP in the U.S. However, his estimate (based on time series data) of the marginal product of infrastructure capital -- as much as 100% per year -- was implausibly high.

The massive ensuing literature on the output impact of infrastructure has employed a variety of data, empirical methods and infrastructure measures. The most popular approaches include the estimation of an aggregate production function (or its dual, the cost function) and empirical growth regressions. Infrastructure is variously measured in terms of physical stocks, spending flows, or capital stocks constructed accumulating the latter.

A majority of this literature finds a positive long-run effect of infrastructure on output, productivity, or their growth rate. More specifically, this is the case with almost all of the studies using physical indicators of infrastructure stocks, but results are more mixed among the growth studies using measures of public capital stocks or infrastructure spending flows (Straub 2007).

Another strand of recent literature has examined the effects of infrastructure on income inequality. The rationale is that infrastructure provision may have a disproportionate effect on the income and welfare of the poor by raising the value of the assets they hold (such as land or human capital), or by lowering the transaction costs (e.g., transport and logistic costs) they incur to access the markets for their inputs and outputs. These effects may occur through a variety of mechanisms documented in the empirical literature; see for example Estache, Foster and Wodon, (2002), Estache (2003), and Calderón and Servén (2008). Of course, for infrastructure development to reduce income inequality, the key ingredient is that it must help expand access by the poor, as argued for example by Estache et al. (2000).[3]

A related strand of the empirical literature focuses on the poverty effects of specific infrastructure projects using matching techniques that combine samples of beneficiaries with samples drawn from regular household surveys.[4] On the whole, the evidence shows that public investment in infrastructure —specifically, in the rehabilitation of rural roads— improves local community and market development. For example, rehabilitation of rural roads raises male agricultural wages and aggregate crop indices in poor villages of Bangladesh (Khandker et al. 2006). Likewise, in Vietnam the result is an increase in the availability of food, the completion rates of primary school and the wages of agricultural workers (Mu and van de Walle, 2007). In the same vein, other studies find that access to new and improved roads in rural areas enhances opportunities in non-agricultural activities in Peru (Escobal and Ponce, 2002) and in non-farm activities among women in Georgia (Lokshin and Yemtsov, 2005).[5]

Few empirical studies have tackled directly the inequality impact of infrastructure at the macroeconomic level. Among them are those of López (2004) and Calderón and Servén (2008), both of which use cross-country panel data. López uses telephone density to proxy for infrastructure, while Calderón and Servén employ synthetic indices of infrastructure quantity and quality. In both cases, the finding is that, other things equal, infrastructure development is associated with reduced income inequality. Combined with the finding that infrastructure also appears to raise growth, the implication is that, in the right conditions, infrastructure development can be a powerful tool for poverty reduction.

[3] We should also note that there may be two-way causality in this relationship, that is, income inequality may prevent the access of poorer people to infrastructure services. For example, Estache, Manacorda and Valletti (2002) show that income inequality adversely affects access to internet, while Alesina, Baqir and Easterly (1999) argue that more unequal societies devote less effort to the provision of public goods, including infrastructure.

[4] This line of research compares the beneficiaries of the infrastructure project under analysis and a control group, using propensity score matching methods to eliminate the bias arising from time-invariant unobservable community characteristics that might affect the project's outcome.

[5] Note that in the Peruvian case, income expansion generated by the rehabilitation of rural roads is faster than consumption expansion in areas articulated product and factor markets through motorized roads. The excess income is saved since beneficiaries perceived improvements in rural roads as transitory given the record of road maintenance in the area (Escobal and Ponce, 2002).

## 2.1 Infrastructure and development in Africa

A strand of recent papers has focused on the development impact of infrastructure in Africa. Ndulu (2006) offers an overview of the big issues, and Ayogu (2007) surveys the empirical literature. Most of the latter deals with the growth and productivity effects of infrastructure development. For example, Estache, Speciale and Veredas (2005) present pooled OLS growth regressions based on an augmented Solow model including a variety of infrastructure indicators, one at a time. Their main conclusion is that roads, power and telecommunications infrastructure – but not water and sanitation -- contribute significantly to long-run growth in Africa. Other studies follow a production function approach. Ayogu (1999) applies it to regional panel data from Nigeria, finding a strong association between infrastructure and output. Kamara (2006) uses data from African countries to calculate various dynamic panel estimates of the effects of infrastructure in an aggregate production function augmented with indicators of the quality of macroeconomic policy. Boopen (2006) likewise presents panel estimates of the output contribution of transport infrastructure using similar data.

South Africa (along with Nigeria) has attracted special attention in this literature, partly reflecting the significantly better quality of its data relative to that of other countries in the region. Perkins, Fedderke and Luiz (2005) use a detailed database on infrastructure investment and capital stocks, spanning as long as a hundred years, to test for the existence of a long-run relation between different infrastructure measures and GDP. Their results suggest a bi-directional relation in most cases. Kularatne (2005) explores the effects of infrastructure investment (as well as social spending on health and education) on GDP. He also finds bi-directional effects, although the impact of infrastructure investment appears to occur indirectly through private investment. Dinkelman (2008) finds a significant impact of household electrification on employment in South Africa's rural labor markets.

## 2.2 Caveats

Much of the literature reviewed above is subject to some major caveats. There are three main concerns: identification, measurement and heterogeneity. We discuss them next, focusing on the case when the relation of interest is that between infrastructure and output or its growth rate – although similar concerns apply to the relation of infrastructure with other development outcomes.

Consider first the issue of measurement. Infrastructure is a multi-dimensional concept, comprising services that range from transport to clean water. Yet many studies take a single indicator (most often telephone density) to proxy for "infrastructure". Omitting other indicators of infrastructure where they are relevant – e.g., in growth empirics – is likely to lead to invalid inferences owing to omitted variable biases. No less problematic is the measurement of infrastructure through spending flows – typically public investment, or its accumulation via perpetual inventory into public capital -- used by much of the literature. Public investment and public capital are likely to be poor proxies for infrastructure accumulation if the private sector plays a significant role in infrastructure provision, as is increasingly the case in many countries. Moreover, even if all infrastructure were owned by the public sector, the link between observed public capital expenditure and the accumulation of infrastructure assets or the provision of infrastructure services may be weak, owing to inefficiencies in public procurement and outright corruption (Pritchett 2000). In fact, these factors are likely behind the generally mixed results obtained by empirical studies using these kinds of infrastructure measures.[6]

In turn, the issue of identification is perhaps the most problematic one. Infrastructure and output (or income) are subject to two-way causality. Richer or faster-growing countries may systematically devote more resources to infrastructure, and empirical assessments of the impact of infrastructure that fail to take this into account are likely to be subject to an upward simultaneity bias. There is no easy solution to this problem. In theory, a full structural model would be able to account for two-way causation. In practice, its empirical implementation poses stringent data requirements. The closest the literature has come to such a model is perhaps in the use of stripped-down versions of Barro's (1990) framework (e.g., Canning and Pedroni 2004). An alternative is to use some kind of instrumental variable approach, ideally featuring outside instruments

[6] Straub (2007) offers a meta-analysis of the output or growth contribution of infrastructure. Less than half of the empirical studies using expenditure-based infrastructure measures find significant positive effects. In contrast, over three-fourths of the studies using physical indicators find a significant positive contribution of infrastructure.

for infrastructure. For example, Calderón and Servén (2003, 2008) employ demographic variables as instruments -- alone or in combination with internal instruments -- in a generalized method of moments (GMM) panel framework. Roller and Waverman (2001) follow a similar approach.

Note also that in a time-series context the issue of simultaneity is arguably more problematic for those studies using investment flows to measure infrastructure services than for those using physical asset stocks. Decision lags and time-to-build suggest that physical assets are likely to be predetermined variables relative to output or productivity, and this may help address identification issues. However, time series data also pose the problem of spurious correlation, which if untreated will result in upward-biased estimates of infrastructure effects on output, particularly in the production-function approach mentioned earlier. Output (or productivity) and infrastructure stocks typically display stochastic trends, and failing to account for them can lead to the spurious finding of a positive and significant association between both variables where in reality there is none. Indeed, this upward bias was largely responsible for Aschauer's early findings of a very large impact of infrastructure on output using time series data. In a panel context, recent theoretical research shows that spurious regression is much less of an issue provided the cross-section dimension of the data is sufficiently large (Philips and Moon 1999). As for pure time-series models, recent studies often seek to avoid this problem by following cointegration methods to estimate a long-run relation between infrastructure, aggregate output or productivity, and other production inputs. This, however, is typically done in a single-equation context, and therefore it is subject to the same identification problems just discussed, unless the researcher can somehow establish the existence of a single long-run relation among these variables that can be interpreted as 'the output equation'.

Finally, heterogeneity is a pervasive problem too. The contribution of infrastructure, as summarized by the standard measures described earlier, to output or its growth rate may well vary across countries and time periods, for various reasons. Physical infrastructure stocks, for example, are rarely homogeneous in terms of quality or productivity, which should be reflected in their output or growth impact; yet few empirical studies using physical stock data control for the quality of stocks – which is admittedly hard to do due to the scarcity of infrastructure quality data.[7] In this sense spending flows are again especially problematic, as their contribution to the supply of infrastructure assets or services can vary greatly across countries and over time depending on a host of factors ranging from geographic to institutional ones.

Aside from these considerations, technological or other factors may make the impact of otherwise homogeneous infrastructure assets or services differ across locations or time periods. Few empirical studies allow for such heterogeneity, and when they do they typically restrict heterogeneity to tractable forms, with country (or state, province etc) specific effects as the most popular option. Conceptually, heterogeneity could be parameterized by relating it to observable variables – e.g., institutional or governance variables intermediating the translation of spending into assets. In theory, very general forms of parameter heterogeneity – e.g., across countries -- can be easily accommodated empirically, but in practice this demands time-series sample sizes that are often unavailable, as is the case for a number of African countries. A few recent studies (e.g., Bogetic and Fedderke 2006) employ a pooled mean-group approach that allows for unrestricted short-run heterogeneity in the impact of infrastructure, while imposing long-run homogeneity of its effects across countries or industries.

## 3. Empirical assessment

We turn to the empirical assessment of the contribution of infrastructure to growth and equity. Our empirical strategy involves estimation of simple equations relating growth and inequality to a set of standard controls, augmented by measures of the quantity and quality of infrastructure. For this purpose, we construct a large macroeconomic panel data set spanning the period 1960-2005 and comprising a total of 136 countries (see Table A1 for the detailed list of countries, and Table A2 for the list of variables and data sources). To avoid potential distortions introduced by very small

[7] Neglecting quality may lead to seriously misleading inferences. Hulten (1996) finds that differences in the effective use of infrastructure resources explain one-quarter of the growth differential between Africa and East Asia, and more than 40 percent of the growth differential between low- and high-growth countries. Among the few studies that attempt to control for infrastructure quality, Esfahani and Ramirez (2003) report significant growth effects of infrastructure in a large panel data set in which the contribution of infrastructure is affected by institutional factors. Calderón and Servén (2008) find significant growth effects of a synthetic indicator of infrastructure quality in an empirical framework including both quantity and quality effects.

economies, in which infrastructure poses some special issues – owing for example to indivisibilities -- we limit our coverage to countries with total population over one million. Also, to remove cyclical factors and focus on longer-term effects, we work with non-overlapping 5-year averages. Data is not available for all countries in all time periods, and hence the panel is unbalanced. To keep a meaningful time-series dimension, we restrict our regression sample to countries with at least three consecutive 5-year observations.

### 3.1 Methodological issues

Our methodological approach allows us to address some of the problems commonly encountered in empirical evaluations of the development impact of infrastructure. The first one is measurement. In contrast with the abundant literature that measures infrastructure in terms of an investment flow or stock ("public capital") or a single physical asset (such as telephone density), we consider different types of core infrastructure assets. Second, our estimation procedure deals with potential endogeneity and/or reverse causality running from growth and inequality to infrastructure development. Third, we also take account of heterogeneity along various dimensions. On the one hand, our estimations control not only for the quantity of infrastructure, but also for its quality. On the other hand, we allow for some degree of heterogeneity in the relationship between infrastructure and growth, by including unobservable country-specific effects in our empirical specification. We also perform some robustness experiments letting the coefficients of the empirical equation vary with selected country characteristics.

#### 3.1.1 Measuring the quantity and quality of infrastructure

While infrastructure is a multi-dimensional concept, empirical studies typically take a single-sector approach. For instance, Easterly (2001) and Loayza, Fajnzylber and Calderón (2005) use indicators of telephone density to appraise the effects of infrastructure on growth. One reason behind the single-sector approach is the difficulty of properly capturing the multiple dimensions of infrastructure in a simple way. Another reason is the high correlation often found among indicators of different types of infrastructure assets. For example, in our sample the correlation between standard measures of telephone density and power generation capacity (measured respectively by a country's total number of telephone lines, and its total power generation capacity, in both cases relative to the number of workers) exceeds 0.90, which makes it hard to disentangle in a regression framework the separate roles of the two types of assets.

To overcome this problem, while still keeping account of the multi-dimensionality of infrastructure, we use principal component analysis to build synthetic indices summarizing information on the quantity of different types of infrastructure assets as well as the quality of services in different infrastructure sectors.[8] These synthetic indices combine information on three core infrastructure sectors -- telecommunications, power, and roads -- and help address the problem of high collinearity among their individual indicators.[9] We denote the synthetic quantity and quality indices that result from this procedure **IK** and **IQ**, respectively. The indices can be expressed as linear combinations of the underlying sector-specific indicators, and hence their use in a regression context is equivalent to imposing linear restrictions on the coefficients of the individual infrastructure indicators. These restrictions can be tested using standard Wald tests, as we shall do below.

Proceeding in this manner, we define the synthetic infrastructure quantity index $\mathbf{IK}_1$ as the first principal component of three variables: total telephone lines (fixed and mobile) per 1000 workers ($Z_1/L$), electric power generating capacity expressed in MW per 1000 workers ($Z_2/L$), and the length of the road network in km. per sq. km. of arable land ($Z_3/A$). Each of these variables is expressed in logs and standardized by subtracting its mean and dividing by its standard deviation. All three infrastructure stocks enter the first principal component with roughly similar weights:

$$IK_1 = 0.603 * \ln\left(\frac{Z_1}{L}\right) + 0.613 * \ln\left(\frac{Z_2}{L}\right) + 0.510 * \ln\left(\frac{Z_3}{A}\right)$$

[8] Alesina and Perotti (1996) used principal component analysis to create a measure of political instability, while Sanchez-Robles (1998) employed it to build an aggregate index of infrastructure stocks.
[9] We should caution that the sector-specific indicators of infrastructure quantity and quality employed below, while standard in the literature, are subject to caveats regarding their homogeneity and international comparability. For example, the quality and condition of a 'paved road' can vary substantially across countries – even within the same country. More homogeneous measures of infrastructure performance would be clearly preferable, but unfortunately they do not exist, at least with any significant coverage across countries and time periods.

The index accounts for almost 80 percent of the overall variance of the three underlying indicators and, as Table 1 shows, it is also highly correlated with each one of them.

As a robustness check, we compute an alternative index of infrastructure quantity, **IK**$_2$, which uses main telephone lines instead of the combined main lines and mobile phones employed in the first index; this is in accordance with much of the empirical literature, which uses main lines to measure telephone density. However, the correlation between the two synthetic quantity indices is over 0.99 (see Table 2); this is unsurprising given the similarly high correlation between the two indicators of telephone density underlying the respective synthetic indicators.

Measuring infrastructure quality is less straightforward. The country and/or time-series coverage of some of the objective quality indicators that should be most informative (such as the frequency of power outages or phone faults) is severely limited. In turn, some subjective indicators of perceived infrastructure quality offer broad cross-country coverage, but lack a time-series dimension (see Calderón and Servén 2008). We opt for using the available objective indicators that allow broadest sample coverage. Specifically, we construct a synthetic index of infrastructure quality **IQ**, defined as the first principal component of three indictors of quality of service in telecommunications, electricity and roads, respectively. The indicators are: waiting time (in years) for the installation of main telephone lines ($Q_1$), the percentage of transmission and distribution losses in the production of electricity ($Q_2$) and the share of paved roads in total roads ($Q_3$). The first of these three variables is admittedly not a direct indicator of the quality of telecommunications networks, but is robustly positively correlated with the conceptually preferable measure (the number of telephone faults per 100 main lines) whose availability is severely limited in our sample; see Calderón and Servén (2008). All three variables are rescaled to lie between zero and one in such a way that higher values indicate better quality of infrastructure services.

Using the weights obtained from the principal components procedure, the synthetic index of infrastructure quality can be expressed as:

$$IQ = 0.608 * Q_1 + 0.559 * Q_2 + 0.564 * Q_3$$

The index captures approximately 60 percent of the total variation of the three underlying indicators, and shows a high correlation with each of them, as reported in Table 1.

Like with the quantity index, as a robustness check we compute an alternative index of infrastructure quality, $\mathbf{IQ}_2$. We do so by dropping from the list of variables the indicator of waiting time (in years) for the installation of main telephone lines ($Q_1$) – which is related to quality of service only indirectly. As shown in Table 1, the remaining two variables carry approximately equal weights in the synthetic index that result from this procedure. Moreover, the correlation between the two synthetic quality indices (shown in Table 2) exceeds 0.93.

Table 2 also shows that the indicators of quantity and quality of infrastructure share a good deal of common information —i.e., the full-sample correlation between **IK** and **IQ** ranges from 0.63 to 0.73, depending on the specific indices considered. Closer inspection reveals that the same applies to individual infrastructure sectors: the respective stocks and their quality measures are also positively correlated —i.e. 0.59 for telecommunication, 0.46 for electricity, and 0.54 for roads.

The synthetic indices can be used to provide a summary perspective on Africa's infrastructure performance vis-à-vis other world regions and developing country groups. This is done in Figure 1. The choice of comparator groups in the figure deserves some comment. Given the preponderance of low-income countries across Africa, the best comparator region is probably South Asia, which is likewise dominated by low-income economies. For the same reason, we use as another comparator the group of non-African low-income economies. For illustration, the figure also shows the infrastructure performance of the East Asian tigers (which could be appropriate comparators for Africa's upper middle income economies), along with that of industrial countries. The top panel of the figure offers a comparative perspective on infrastructure quantity, using the synthetic quantity index $\mathbf{IK}_1$, while the bottom panel refers to quality as measured by $\mathbf{IQ}_1$ (the alternative indices $\mathbf{IK}_2$ and $\mathbf{IQ}_2$ give a very similar picture). In both cases, the graphs depict the situation in the early 1990s as well as that in the early 2000s.[10] The performance of each region is measured relative to the overall sample mean (equal to zero by construction).

[10] The qualitative conclusions are be unchanged if we instead compare the early 1980s with the most recent period. The country samples are smaller, however.

The figure conveys three messages. First, Sub-Saharan Africa consistently lags behind the comparator regions, in terms of both quantity and quality of infrastructure. Second, over the last fifteen years progress in Africa has been slower than in other developing regions, and as a result Africa has fallen further behind in both dimensions. Third, in the case of infrastructure quality, the region's performance has worsened also in absolute terms, not just relative to that of other regions.

Of course, these cross-regional comparisons conceal a great deal of heterogeneity within Africa in terms of infrastructure performance. A closer look at the country-specific data reveals a sharp contrast between the performance of some low-income economies (such as Niger or Togo), which lag well behind the rest of low-income developing countries, and that of the region's richer economies (South Africa, Botswana, Mauritius), which are roughly on par with countries of similar income levels in other developing regions. The appendix documents these differences across sub-regions of Africa, and offers extensive details on various dimensions of infrastructure performance, including that of universality of access to infrastructure services– an area in which Africa also lags significantly behind other regions.

### 3.1.2 Econometric methodology[11]

Our empirical strategy is based on estimation of simple equations relating growth and inequality to a set of standard controls, augmented by the synthetic measures of the quantity and quality of infrastructure, in a panel data setting. This poses some well-known problems: (a) the presence of unobserved country-specific effects and common time effects, and (b) potential endogeneity of the regressors. To address these issues, we employ the generalized method of moments (GMM) developed by Arellano and Bond (1991) and Arellano and Bover (1995) for dynamic panel data models. Specifically, we deal with common factors through the inclusion of period-specific dummies, and unobserved country effects are handled by differencing. To control for endogeneity we rely on instrumental variables.

This approach permits relaxing the assumption of strong exogeneity of the explanatory variables by allowing them to be correlated with current and previous

[11] This section draws from Calderón and Servén (2008).

realizations of the time-varying error term. In this context, we use a mixture of internal instruments in the spirit of Arellano and Bond (1991) -- that is, suitable lags of the explanatory variables – along with external instruments for our variables of interest, infrastructure quantity and quality, The reason for this two-track approach is double. First, infrastructure might not be weakly exogenous – e.g., anticipated future productivity shocks might encourage infrastructure investment today. This would make lags of the infrastructure indicators —both quality and quantity – invalid as instruments. Second, our infrastructure indicators might contain measurement error, particularly in the case of infrastructure quality, as discussed earlier. To address these problems, we employ demographic variables as outside instruments. Specifically, we use current and lagged values of urban population and population density of each country as instruments for the quantity and quality of infrastructure. The role of these and other demographic variables as determinants of infrastructure demand has been stressed by a number of studies; see e.g. Canning (1999). Further, while demographic factors drive the demand for infrastructure (in terms of both quantity and quality), there is no reason to expect them to exhibit any systematic relation with measurement errors in the latter.

Of course, for the demographic variables to provide valid instruments, they must also not belong in the growth regression —*i.e.*, they must satisfy the exclusion restrictions. In light of existing literature, we see this requirement as fairly uncontroversial. Although some analytical arguments can be found in the literature for a role of population density as a determinant of long-run growth, the potential growth effect that they highlight is mediated by other variables already included in our empirical specifications. For example, Herbst (2000) argues that Africa's land abundance may have helped reduce inter-country conflict by lowering population density, thus contributing to forge stronger national institutions and thereby facilitating economic development in the longer term. We view this as an argument (additional to others made in the literature) for a growth role of institutional quality, which we include in our regressions as a standard control. On a different tack, from a very long run perspective, it has also been argued that low population density may retard technological innovation and thereby economic development (Klasen and Nestmann.2006). While some indirect effect of this kind may well be possible, the literature on innovation and technological upgrading points instead to factors such as education and competition as the more direct drivers of innovation. To account for the latter, in our empirical growth specifications we include measures of openness and human capital among the standard controls.[12]

We rely on the system GMM estimator (Arellano and Bover 1995), which combines the equation of interest expressed in first differences – using lagged levels of the regressors as internal instruments – and in levels – using lagged differences as instruments. Consistency of the GMM estimator depends on the validity of the internal and external instruments, which can be checked through two specification tests (Arellano and Bond, 1991; Arellano and Bover, 1995): (i) Tests of over-identifying restrictions (Hansen and difference-Sargan tests) that evaluate the validity of the full set of instruments, as well as selected subsets, by testing the null hypothesis that they are uncorrelated with the estimated residuals. Failure to reject the null hypothesis gives support to the model. (ii) Tests of serial correlation of the residuals – specifically, of the null hypothesis that the residual of the regression in differences shows no second-order serial correlation (first-order serial correlation of the differenced error term is expected even if the original error term (in levels) is uncorrelated, unless the latter follows a random walk). Second-order serial correlation of the differenced residual would indicate that the original error term is itself serially correlated. This would render the proposed internal instruments invalid (and would call for higher-order lags to be used as instruments). Again, failure to reject the null lends support to the model.

The standard errors of the efficient two-step GMM estimator are significantly downward biased in small samples. The bias arises from the fact that the approximation to the asymptotic standard errors does not take into account the extra small-sample variation due to the use of estimated parameters in constructing the efficient weighting matrix. Windmeijer (2005) proposes a correction that accounts for this fact. The correction term vanishes with increasing sample size and provides a more accurate

[12] The exclusion restrictions underlying our choice of external instruments also accord with existing empirical growth literature. For example, neither the rural/urban population composition nor population density appear among the "candidate" regressors in Levine and Renelt (1992), or in the broader set of potential explanatory factors examined by Fernández et al (2001). Further, in the mammoth list of 147 regressors in Durlauf at el (2005) that summarizes the specifications used by several hundred empirical growth papers, no study is listed using the urban/rural composition of population as a growth determinant, while population density appears as a regressor in only one study (which finds its effect insignificant anyway).

approximation in finite samples when all moment conditions are linear. Thus, in our estimations we use Windmeijer's correction, as implemented in STATA by Roodman (2006). [13]

### 3.2 Growth, infrastructure stocks and the quality of infrastructure services

As a preliminary step, the top half of Table 2 shows that the aggregate indices of infrastructure quantity and quality are strongly and positively associated with long-run growth. Specifically, we find a positive correlation (0.34) between average annual growth in real GDP per capita over 1960-2005 and the average of each of the two synthetic indices of infrastructure quantity over the same period. We find an even stronger positive correlation between average growth per capita and the synthetic indices of aggregate quality of infrastructure services (0.42 for $\mathbf{IQ}_1$ and 0.35 for $\mathbf{IQ}_2$). Across infrastructure sectors (not shown in the table), growth is positively correlated with telecommunication stocks (0.24 for total phone lines, and 0.21 for main phone lines), electricity generating capacity (0.15) and the length of the road network (0.22). In addition, growth is positively associated with the quality of telecommunications (0.23), quality of electricity supply (0.14) and road quality (0.23).

Table 3 reports the GMM estimates of the parameters of the growth regression augmented by the synthetic indices of infrastructure performance. As already noted, the two alternative indices of infrastructure quantity, as well as those of quality, are very highly correlated, and hence to save space we only report results using $\mathbf{IK_1}$ and $\mathbf{IQ_1}$. The set of standard control variables included in the regressions comprises measures of human capital (secondary enrollment, from Barro and Lee 2001), financial depth (from

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[13] The number of instruments is also a potential concern. The GMM estimators described in the text are designed for panels with a small time dimension T. The number of available internal instruments grows with the square of T (Windmeijer 2005; Roodman 2007). Using too many instruments in finite samples causes several problems in GMM-system estimators. First, a large set of instruments tends to over-fit the endogenous variables, thus failing to remove their endogenous component and yielding biased coefficient estimates. Second, the estimated variance matrix of the moments may not be accurately estimated, especially in finite samples. Usually, the number of elements in the estimated matrix is quadratic in the number of instruments —which, as noted, is itself quadratic in T. Even for modest sizes of T this tends to reduce the power of the Hansen/Sargan tests for joint validity of the instruments (as well as the difference-Sargan tests for subsets of instruments), thus leading to Type I errors —that is, accepting the null of validity of instruments when it is not true. Following Roodman (2007), we tested the robustness of the estimates and the specification tests to reductions in the instrument count. Overall, the results were supportive of the empirical model. These experiments are not reported here to save space, but are available form the authors.

Beck, Demirguc-Kunt and Levine 2000), trade openness, institutional quality, lack of price stability, government burden and terms of trade shocks – in addition to the lagged level of output per worker, to capture conditional convergence. The standard errors reflect Windmeijer's (2005) small-sample correction.

Column 1 of Table 3 reports parameter estimates including only the synthetic quantity indicator $\mathbf{IK}_1$in the regression, and thus neglecting infrastructure quality. Among the standard controls, the estimates show evidence of conditional convergence in real output per capita. They also suggest that human capital accumulation and lower inflation significantly encourage economic growth. The coefficients of the remaining controls carry the expected signs, but none is statistically significant.

In turn, the infrastructure quantity index carries a positive and significant coefficient, suggesting that infrastructure contributes to economic growth. Further, the specification tests shown at the bottom of the table (Hansen and difference-Sargan tests, as well as the second-order serial correlation test) show little evidence against the validity of the moment conditions underlying the empirical specification.

Column 2 adds to the regression the synthetic indicator of infrastructure quality. It also carries a positive and strongly significant coefficient. The estimated coefficient of the quantity indicator declines somewhat in size, but remains positive and significant as well. Thus, both infrastructure quantity and quality contribute to growth. On the whole, there is a gain in precision, and in addition to the significant regressors in column 1, two other standard control variables – government burden and terms of trade shocks – now carry significant coefficients, whose signs are in accordance with expectations. The specification tests continue to lend support to the model specification.

Column 3 reports the result of adding to the specification the squared values of the infrastructure quantity and quality indices, thus allowing for a quadratic effect of infrastructure development on growth. This provides a simple test for non-constant returns to infrastructure development. However, the estimates offer little evidence of nonlinearities, neither individually nor jointly – a Wald test of the joint significance of the two quadratic terms in column 3 yields a p-value of 0.98 -- while the linear effects of infrastructure quantity and quality remain virtually unchanged and strongly significant.

The coefficients of the standard controls also show little change, as do the specification tests.

One potential concern with the estimates in columns 1-3 is that they implicitly assume that the effect of infrastructure development on growth is homogeneous across countries. If in reality the effect is heterogeneous, the estimates would be inconsistent. More specifically, a number of recent papers (e.g., Sachs et al 2004, Collier 2006) have argued that infrastructure development is likely to have a bigger growth impact in African countries. In column 4 we test this view by interacting the aggregate indices of infrastructure quantity and quality with a dummy for Sub-Saharan African countries, and adding them to the regression. The estimates of these Africa-specific effects, over and above the average effects, are positive – in line with the literature mentioned above – but very imprecise. Indeed, a Wald test cannot reject the null hypothesis that they are jointly insignificant (the p-value equals 0.40).

We performed other tests of heterogeneity by interacting the infrastructure indicators with a dummy for landlocked countries (which are numerous in Africa) and, alternatively, doing the same only with the road density and quality measures. These tests failed to yield significant evidence that the growth impact of infrastructure development is different for landlocked countries.[14]

As a robustness check, we repeated all the estimations in Table 3 replacing the synthetic indices $IK_1$ and $IQ_1$ with the alternative indices $IK_2$ and $IQ_2$. The results (not shown to save space) were virtually unchanged, which is unsurprising in view of the high correlation between the two sets of indices.

The final robustness check concerns the use of synthetic infrastructure indices in the regressions, rather than the underlying sector-specific variables. As noted earlier, this is equivalent to a regression imposing linear restrictions on the parameters of the latter, forcing them to enter in the empirical equation in the proportions dictated by the principal components. Specifically, use of the synthetic quantity index amounts to imposing two linear restrictions on the three underlying sector-wise quantity measures, while use of the quality index likewise amounts to placing two restrictions on the three underlying sector-wise quality measures. These restrictions can be tested through standard Wald tests.

[14] These results are not reported here but they are available from the authors.

Taking this approach with the specification including (linear) effects of both quantity and quality of infrastructure, reported in column 2, yields a p-value of .57 when all four restrictions are jointly tested.[15] This implies that the use of the synthetic indices of infrastructure quantity and quality does not due undue violence to the data and hence lends support to our approach.

We can employ these results to give an idea of the economic significance of the effects of infrastructure development on growth. Using the estimates in the second column of Table 3, we calculate the contribution of infrastructure development —as proxied by the aggregate indices of infrastructure quantity and quality, $\mathbf{IK}_1$ and $\mathbf{IQ}_1$ — to growth over the last 15 years of the sample. That is, for each country in the sample we compare the average values of $\mathbf{IK}_1$ and $\mathbf{IQ}_1$ over 2001-5 with those observed in 1991-5, and multiply the observed change by the corresponding regression coefficient. This calculation is illustrative rather than conclusive, because -- among other simplifying assumptions – it is based on the implicit hypothesis that changes in infrastructure development do not lead to changes in any of the other growth determinants.

The calculation shows that, on average, growth in the world sample increased by 1.6 percent in 2001-5 relative to 1991-5 due to infrastructure development (see Figure 2). This total comprises 1.1 percent due to accumulation of infrastructure stocks, and 0.5 percent due to improved infrastructure quality. The largest contribution of infrastructure development to growth was achieved in South Asia, where it reached 2.7 percent per annum. Of this total, enlarged stocks increased growth by 1.6 percent per year, and enhanced infrastructure quality raised growth rates by 1.1 percent per year in 2001-5 relative to 1991-5. Finally, infrastructure development made, on average, a smaller contribution to growth in Sub-Saharan Africa than in other regions – just 0.7 percent per annum. While the expansion in infrastructure stocks raised the growth rate by 1.2 percent per annum, the deterioration of the quality of infrastructure services in the region contributed to reduce the growth rate by 0.5 percent per annum.

[15] We can also test the restrictions imposed on the quantity and quality indicators separately (two restrictions in each case). This yields p-values of 0.27 in the case of quantity, and 0.80 for quality, likewise failing to reject either set of restrictions.

### 3.3 Infrastructure and income distribution

We turn to the regressions exploring the empirical relationship between infrastructure development and income inequality. Our dependent variable is the Gini coefficient, for which the main source is the database constructed by Deininger and Squire (1996) complemented by the WIDER-UNU database on income inequality and poverty. The selection of explanatory variables follows the existing empirical literature on the determinants of income inequality (Li, Squire and Zou, 1998; Milanovic, 2000; Lundberg and Squire, 2003). Among the regressors we include the (log) level of GDP per capita and its square, to allow for nonlinear effects in the spirit of the conventional Kuznets curve.[16] In addition, we continue to include our education proxy, the measure of financial depth, macroeconomic instability (proxied by the CPI inflation rate), and trade openness. As before, infrastructure quantity and quality are measured by the synthetic indices $\mathbf{IK_1}$ and $\mathbf{IQ_1}$ derived from principal components analysis described earlier.

As a preliminary step, Table 2 shows that across countries the Gini coefficient of income inequality is strongly negatively correlated with the synthetic indices of infrastructure quantity and quality: their correlations with inequality range from -.47 to -.56.[17] The literature on the linkages between infrastructure and income distribution argues that infrastructure development can reduce inequality if it enhances the access of the poor to telecommunication services, electricity, roads and railways, safe water and sanitation.[18] The first column in the bottom half of Table 2 confirms this view: across countries,[19] the percentage of population with access to the services of each of these infrastructure sectors is negatively associated with the degree of income inequality, as measured by the Gini coefficient of income distribution. For our purposes, one key question is to what extent the synthetic indices of infrastructure quantity and quality

[16] The same specification is used by Milanovic (2000) and Gradstein, Milanovic and Ying (2001).

[17] This negative association also holds across individual infrastructure sectors. The Gini coefficient is negatively correlated with the quantity of infrastructure in telecommunications (-0.44), power (-0.47), and roads (-0.53). Regarding the quality of infrastructure services, the Gini coefficient is also negatively related to quality in telecommunications (-0.34), power (-0.37) and transportation (-0.62).

[18] The appendix offers a cross-regional comparative perspective on standard indicators of access to electricity, roads, water and sanitation.

[19] Unfortunately, there is too little time-series data on access to infrastructure to examine the correlation in the time dimension. Instead, we use cross-section data for the period 2001-5.

capture trends in access.[20] To assess this issue, we correlate the access figures with the synthetic indices of infrastructure quantity and quality. The bottom half of Table 2 shows that access to the various infrastructure services is positively and very significantly associated with the synthetic indices of infrastructure quantity and quality. The only exception is the correlation between electricity access and infrastructure quality, which is positive but not significant. On the whole, therefore, these facts suggest that the empirical results below regarding the income distribution impact of infrastructure development (as measured by the synthetic quantity and quality indices) do capture the distributional effects of changes in access to infrastructure services.

Estimation results from the inequality regressions are presented in Table 4. Sample size is somewhat smaller than in the previous table because of the more limited availability of income distribution data. As before, column 1 reports estimations excluding infrastructure quality. Among the standard controls, we note first that the sign pattern of the level and square of output per capita conforms to the 'Kuznets curve' hypothesis – i.e., the linear term is positive and the quadratic term is negative. Second, education is negatively associated with income inequality. Finally, trade openness – as proxied by the ratio of exports and imports to GDP – tends to make the distribution of income more unequal, as found by Barro (2000).

The infrastructure quantity index $\mathbf{IK}_1$ has a significant negative effect on inequality in column 1. This is consistent with the view that infrastructure development enhances the ability of poor individuals and/or residents of backward areas to access additional productive opportunities. The diagnostic tests (Hansen and difference-Sargan tests of joint validity of instruments, and the second-order serial correlation test) lend support to the specification of the model and the choice of instruments.

Column 2 adds the infrastructure quality indicator $\mathbf{IQ}_1$. Its coefficient is negative and significant, while that of the quantity indicator declines roughly by half but remains negative and significantly different from zero. Among the other regressors, the quadratic

[20] We should note that access is not distributed evenly across the population. Households in the upper percentiles of the income distribution typically enjoy much better access than poorer households do (World Bank 2006), and Africa is no exception to this rule (Diallo and Wodon 2004; Estache 2005). Nevertheless, expanding service coverage is typically associated with improved access by the poor.

income term becomes insignificant. The rest of the coefficients do not show major changes, nor do the specification tests.

As with the growth regressions, in column 3 of Table 4 we allow for nonlinear effects of infrastructure development on inequality. As the table shows, there is very little evidence of non-linearities in the effects of infrastructure quantity or quality. A Wald test cannot reject the null hypothesis that they are jointly zero (p-value = 0.21). In turn, column 4 looks for a differential effect of infrastructure quantity and/or quality on inequality in Africa vis-à-vis other regions. As in the case of income growth, we fail to find much evidence of any such difference, and a Wald test fails to reject the null that Sub-Saharan Africa behaves just like the rest of the sample in this regard (p-value = 24).

All these empirical exercises make use of the synthetic indices $\mathbf{IK}_1$ and $\mathbf{IQ}_1$. As a robustness check, we repeated the estimations using the alternative indices $\mathbf{IK}_2$ and $\mathbf{IQ}_2$. The results (not shown to save space) were virtually unchanged, except for a modest indication of a negative quadratic effect of infrastructure quantity $\mathbf{IK}_2$ on inequality, which fell just short of statistical significance.

Finally, we can follow the same procedure as with the growth regressions to assess the validity of the parameter restrictions implicitly imposed by the use of the synthetic indicators of quantity and quality rather than the individual sectors' indicators. A Wald test of these restrictions, as implicitly embedded in column 2 of Table 4, yields a p-value of 0.30, thus lending support to the use of the principal components.[21]

To illustrate the economic significance of the empirical results, we focus again on the regression results in the second column of table 4. Consider first the contribution of infrastructure development to changes in income inequality over the last 15 years. As before, we compare the levels of infrastructure development over 2001-5 with those over1991-5 for the average country in Sub-Saharan Africa, as well as for that of other regions across the world. Using the coefficient estimates, Figure 3 shows that average inequality –as proxied by the Gini coefficient– in the world declined by 3 basis points in 2001-5 relative to 1991-5 due to infrastructure development (2 basis points due to accumulation of infrastructure stocks and 1 basis point due to improved infrastructure

[21] Again, we can also test separately the restrictions imposed on the quantity and quality indicators. This procedure yields p-values of 0.33 in the case of quantity and 0.20 for quality, thus failing to reject either set of restrictions.

quality). Like in the case of growth, the largest contribution of infrastructure development to inequality reduction was achieved by South Asia (6 basis points) where enlarged stocks yielded a reduction in the Gini coefficient by 4 basis points and enhanced infrastructure quality added another 2 basis points. Infrastructure development in Sub-Saharan Africa made –on average– a comparatively smaller contribution to inequality reduction –approximately 2 basis points. While larger infrastructure stocks reduced the Gini coefficient by 3 basis points, the worsening quality of infrastructure services in the region raised the Gini coefficient by 1 basis point

### 3.4 Counterfactual exercises

We can also use our econometric estimates to illustrate the growth consequences of alternative infrastructure development scenarios. To do this, we calculate the growth increase that each country in Sub-Saharan Africa would experience in two counterfactual scenarios of infrastructure development. The first one involves catching up with countries in other regions. The second scenario is one of 'keeping up' with them.

Because our regression sample includes African countries of different per capita income levels-- 30 low-income countries and 3 upper-middle income countries[22] – we use different benchmarks for each of these two income groups. For the low-income countries in Sub-Saharan Africa, we use as benchmark the average of 12 low-income countries from other regions for which we have data. For the upper-middle income African countries in our sample (Botswana, Gabon and South Africa), we use the average of 23 countries from other regions in the same income category. The details of the two scenarios are as follows.

*Scenario A*: in 2001-2005, we raise the level of infrastructure development of each Sub-Saharan African country so as to reduce in half its infrastructure gap relative to the average country in other regions in the relevant per-capita income group. To give a more concrete idea of the benchmarks considered, the low-income countries outside Africa closest to the average level of infrastructure development are Pakistan (quantity) and India (quality). In turn, the average for upper-middle income countries is given by Chile (quantity) and Hungary (quality).

[22] The regression sample does not include any lower-middle income Sub-Saharan African countries.

*Scenario B*: over the period 1991-1995 to 2001-2005, we make infrastructure development in Sub-Saharan African countries grow at the same average pace observed in the group of countries of comparable per-capita income in other regions – thus leaving Africa's (relative) infrastructure gap unchanged at its 1991-95 level. Among low-income countries, Indonesia comes closest to the average infrastructure growth (in terms of both quantity and quality) outside Africa. Among upper-middle-income economies, the rough benchmark is Brazil in infrastructure quantity and Malaysia in infrastructure quality.

It is important to stress that these counterfactual scenarios involve no presumption about the desirability, on welfare grounds, of the assumed infrastructure expansion. More fundamentally, these exercises focus only on the growth benefits of catching up, and ignore the costs that it might involve – for example, in terms of public resources that could be diverted from other uses in order to support enhanced infrastructure development. As we shall see below, such costs are quite significant, and hence these illustrative exercises have to be viewed with caution.

To save space, we report the results of each scenario organizing Africa's low-income countries (LICs) by geographic subregion: West Africa (ECOWAS), East Africa (EAC), Southern Africa (SADC), and a residual group that we label Central Africa.[23] On the other hand, we group together the three upper-middle-income countries (UMCs) in the sample (Botswana, Gabon and South Africa).

Consider the first scenario of reducing in half the gap between Africa's levels of infrastructure development and the average in the comparable income category. Figure 4 shows that Central African LICs would gain, on average, 2.2 percentage points of growth—roughly equally attributable to the increased infrastructure quantity and the improved quality of infrastructure services (1.16 and 1.06 percent, respectively). Low-income countries in East and West Africa also would raise their growth by 1.6 percentage points, and those in South Africa by just over 1 percent—with most of the increase coming from the larger infrastructure stocks in all three cases. Finally the growth

[23] The country composition of these sub-regions is as follows: West Africa (ECOWAS) comprises Benin, Burkina Faso, Cote d'Ivoire, Gabon, Gambia, Ghana, Niger, Nigeria, Senegal, and Togo, East Africa (EAC) comprises Burundi, Kenya, Somalia, Tanzania, and Uganda; Southern Africa (SADC) includes Angola, Botswana, Mauritius, Mozambique, Namibia, South Africa, Swaziland, Zambia and Zimbabwe; and Central Africa consists of Cameroon, Central African Republic, Congo, Dem. Rep., Congo, Rep., Ethiopia and Sudan.

increase for upper-middle income countries in Sub-Saharan Africa would also reach around 1.6 percent per annum, but the bulk of the increase would be due to improvements in the quality of infrastructure services.

The second scenario assumes catch-up with the rate of change, rather than the level, of infrastructure development – in each African country, infrastructure growth (in quality and quantity) would have proceeded at the same pace as in the average country in the comparable income group outside Africa. In other words, Africa's level of infrastructure development is assumed to keep up (rather than catch up) with that of the relevant benchmark group. The bottom half of Figure 4 shows that in this scenario West Africa LICs reap the biggest gain: their growth would rise by 1.7 percent per annum (of which most would come from faster growth in infrastructure quality, 1.3 percent). At the other end, growth increases in East Africa LICs and Central Africa LICs are just below 1 percent per annum (and quality improvements would account for two-thirds of this total). Finally, the growth rate of upper-middle income African countries would rise by 1.2 percent, and the increase would be fully attributable to higher quality of infrastructure services.

We can use these counterfactual scenarios to illustrate also the equity potential of infrastructure development. This is shown in Figure 5. The top half of the figure shows that the biggest redistributive payoffs under the first scenario (catch-up) are attained by Central Africa LICs, with a reduction in the Gini coefficient by 4.7 basis points, of which over half (0.026) is attributable to enlarged infrastructure stocks. At the other end, the equity gain among South Africa LICs would be much more modest -- a decline in the Gini coefficient by 0.026, again mostly attributable to faster accumulation of infrastructure assets (0.017). In turn, East- and West Africa LICs, as well as upper-middle-income African countries, would achieve a decline in the Gini coefficient of just over 0.03. In low-income countries this would be mainly due to the expanded quantity of infrastructure, while in middle-income countries most of the effect would be due to the improved quality of infrastructure services.

Finally, the bottom half of Figure 5 shows the change in the Gini coefficient that would have occurred if infrastructure development in each African country had kept up with the average outside Africa. In this case, West Africa LICs and South Africa LICs reap the largest reductions in income inequality, with declines in the Gini coefficient of 0.034 and 0.031, respectively. For the latter group, the inequality decline is almost equally attributable to larger infrastructure stocks and higher quality, while for the former it is mainly due to the improved quality of infrastructure services. In turn, the upper-middle-income countries of Sub-Saharan Africa under this scenario experience a decrease in the Gini coefficient of 0.023, due in full to the improved quality of infrastructure services.

So far we have focused on the benefits of infrastructure development – but what about the costs? The faster pace of infrastructure development assumed in the counterfactual scenarios must surely involve extra costs too. Higher investment would be needed to acquire the additional infrastructure assets, and higher current expenditures would likewise be necessary to operate and maintain them. Assessing the magnitude of these extra expenditures is not an easy task, owing to the very limited availability of data on investment and, especially, O&M costs of infrastructure, as well as their unavoidable heterogeneity across countries. However, an illustration of the required investment can be provided using the unit capital costs reported by Yepes et al (2008) to compute a rough estimate of the additional investment needs that would be posed by infrastructure expansion.

For brevity, we focus on the first counterfactual scenario described above. It is important to stress that the lack of suitable data forces us to restrict our attention to the costs of acquiring additional infrastructure assets (roads, power generation capacity, telephone lines), ignoring the costs of maintaining them, as well as the costs of upgrading their quality as assumed in the counterfactual simulation.

Figure 6 reports the results of these calculations, expressed as percentage of GDP.[24] The figure shows that the infrastructure investment effort implicit in the catch-up scenario is quite considerable – as much as 15 percent of GDP in the low-income countries of East and Central Africa. The effort is more modest, but still substantial, among Southern Africa's low-income countries, as well as upper middle-income economies, where it ranges between 7 and 8 percent of GDP. Although international data

[24] Since the simulation assumes that Africa possesses larger infrastructure assets in 2001-2005, to take account of time-to-build the costs are expressed as percentage of average GDP over 1996-2000, assuming it takes five years for the assets to become available.

on infrastructure investment are quite scarce, the available information suggests that these numbers exceed by a wide margin those observed across the developing world, perhaps with the exception of some rapidly-growing East Asian countries.[25]

Furthermore, given the fairly limited involvement of the private sector in infrastructure across the region (with South Africa as the main exception) one can conjecture that the bulk of this additional spending would correspond to the public sector, for which it would pose a heavy burden indeed. In fact, in a number of countries in Sub-Saharan Africa total government revenue is well below 20 percent of GDP. This means that in those countries a fast-pace infrastructure catch-up would be financially infeasible, and this even ignoring its associated O&M costs. Instead, the acceleration of infrastructure development would have to be spread over a number of years. Most importantly, its benefits would have to be compared with those of other pressing demands on scarce government resources, a task beyond the scope of this paper.

## 4. Concluding remarks

Poor infrastructure is commonly viewed as one of the key obstacles to economic development in Sub-Saharan Africa. In this paper we have provided an empirical evaluation of the potential contribution of improved infrastructure to growth and equity in the region. Our assessment is based on the estimation of infrastructure-augmented growth and income inequality regressions using a large data set comprising 100 countries over the period 1960-2005. The empirical approach encompasses different core infrastructure sectors, considers both the quantity and quality of infrastructure services, and employs instrumental variable techniques to account for the potential endogeneity of infrastructure and non-infrastructure determinants of growth and inequality.

We find robust evidence that infrastructure development – as measured by an increased volume of infrastructure stocks and an improved quality of infrastructure services – has a positive impact on long-run growth and a negative impact on income inequality. The evidence also suggests that these impacts are not different in Sub-Saharan Africa vis-à-vis other regions. A variety of specification tests and robustness checks lend support to our empirical experiments. Since most African countries are lagging in terms

[25] See Calderón, Odawara and Servén (2008).

of infrastructure quantity, quality, and universality of access, the tentative conclusion is that infrastructure development offers a double potential to speed up poverty reduction in Sub-Saharan Africa: it is associated with both higher growth and lower inequality.

Illustrative exercises show that our results are significant not only statistically, but also economically. Simple decompositions of observed growth and inequality changes suggest that over the last fifteen years infrastructure development made a contribution to growth and equity in virtually all world regions. Outside Africa, such contribution was particularly large in East and South Asia, and smallest in Western Europe, where infrastructure was already highly developed by the early 1990s. Infrastructure also helped in Sub-Saharan Africa, but to a much more modest extent than in Asia, and the primary reason seems to be the region's lack of progress on the quality of infrastructure services over the sample period. Finally, counterfactual simulations also illustrate the substantial gains in terms of growth and equity that most Sub-Saharan African countries could reap if their levels of infrastructure development were to catch up, or even just keep up, with those of comparator country groups.

Speeding up infrastructure development also entails costs, however. Illustrative calculations show that just cutting in half the infrastructure quantity gap between African countries and those of comparable income levels in other regions could require as much as 15 percent of GDP in additional investment, plus potentially large (but hard to quantify) amounts in additional O&M expenditures – with most of the burden likely falling on the public sector. Barring a massive increase in aid flows, the sheer magnitude of these figures likely places a fast infrastructure catch-up beyond the financial reach of most African countries. Even a more gradual approach to infrastructure catch-up would pose considerable demands on fiscal resources over several years, competing with other pressing expenditure needs – such as education and health. In the end, the relative priority of infrastructure is likely to vary greatly across the region, depending on a host of country-specific factors – including their current infrastructure performance, which shows considerable cross-country variation.

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## Table 1

## Synthetic infrastructure indices: correlation with underlying measures

*Panel correlations over the period 1960-2005 (5-year non-overlapping observations)*

### 1.1 Synthetic quantity index

| | Synthetic Quantity Index | |
|---|---|---|
| Indicator | [IK1] | [IK2] |
| Total telephone lines (main lines and mobile phones) | 0.935 | .. |
| *(per 100 workers)* | (0.000) | |
| Main telephone lines | .. | 0.943 |
| *(per 100 workers)* | | (0.000) |
| Electricity generating capacity | 0.950 | 0.956 |
| *(in MW per 1000 workers)* | (0.000) | (0.000) |
| Total road length | 0.644 | 0.644 |
| *(in km. per sq. km. of arable land)* | (0.000) | (0.000) |

### 1.2 Synthetic quality index

| | Synthetic Quality Index | |
|---|---|---|
| Indicator | [IQ] | [IQ2] |
| Quality of telecommunication services | 0.813 | .. |
| *(based on waiting time for main line installation)* | (0.000) | |
| Quality of electricity | 0.746 | 0.839 |
| *(based on technical losses of transmission and distrib.)* | (0.000) | (0.000) |
| Quality of roads | 0.754 | 0.810 |
| *(Share of paved in total roads)* | (0.000) | (0.000) |

Note: The numbers in parenthesis under the correlation coefficients are the corresponding p-values. The first synthetic index of infrastructure quantity [IK1] is given by the formula: IK1 = 0.603*K1 + 0.613*K2 + 0.51 * K3, where K1, K2, and K3 denote the logs of (standardized) physical measures of infrastructure in telecommunications (main lines and mobile phones), electricity (electricity generating capacity), and roads (total road length). The measures of telecommunications and electricity are normalized by working population of the country, while roads are normalized by the area of arable land. The second synthetic index of infrastructure quantity [IK2] is obtained as follows: IK2 = 0.606*K1A + 0.614*K2 + 0.506 * K3. The synthetic index IK2 uses the number of main phone lines per 100 workers (K1A) instead of the total number of phone lines (K1). The first synthetic index of infrastructure quality [IQ1] is obtained as follows: IQ1 = 0.608*Q1 + 0.559*Q2 + 0.564 * Q3, where Q1, Q2 and Q3 are (standardized) physical measures of quality in telecommunications (waiting time in years for the installation of main telephone lines), power (the percentage of transmission and distribution losses in the production of electricity) and roads (the share of paved roads in total roads). The second synthetic index of infrastructure quality [IQ2] omits Q1 from the set of underlying indicators, and is given by IQ2 = 0.7*Q2 +0.71* Q3.

**Table 2**
**Infrastructure and Economic Development: Correlation Analysis**

| Variables | Economic Growth | Gini Coefficient | Synthetic Infrastructure Index: Infrastructure Quantity [IK1] | Infrastructure Quantity [IK2] | Infrastructure Quality [IQ1] | Infrastructure Quality [IQ2] |
|---|---|---|---|---|---|---|
| Infrastructure Quantity (IK1) | 0.3397 | -0.4667 | 1.0000 | | | |
| (*synthetic index*) | (0.000) | (0.000) | | | | |
| Infrastructure Quantity (IK2) | 0.3384 | -0.4649 | 0.9962 | 1.0000 | | |
| (*synthetic index*) | (0.000) | (0.000) | (0.000) | | | |
| Infrastructure Quality (IQ) | 0.4213 | -0.5613 | 0.7287 | 0.7269 | 1.0000 | |
| (*synthetic index*) | (0.000) | (0.000) | (0.000) | (0.000) | | |
| Infrastructure Quality (IQ2) | 0.348 | -0.5681 | 0.6286 | 0.6361 | 0.9328 | 1.0000 |
| (*synthetic index*) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | |

| Variables | Economic Growth | Gini Coefficient | Synthetic Infrastructure Index: Infrastructure Quantity [IK1] | Infrastructure Quantity [IK2] | Infrastructure Quality [IQ1] | Infrastructure Quality [IQ2] |
|---|---|---|---|---|---|---|
| Access to Sanitation | 0.3553 | -0.3763 | 0.8299 | 0.8275 | 0.6418 | 0.6046 |
| *(% population with access to sanitation)* | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Access to Safe Water | 0.4370 | -0.3023 | 0.7442 | 0.7423 | 0.6152 | 0.5317 |
| *(% population with access to safe water)* | (0.000) | (0.003) | (0.000) | (0.000) | (0.000) | (0.000) |
| Access to Rural Roads | 0.4732 | -0.4929 | 0.7992 | 0.7957 | 0.6496 | 0.5867 |
| *(% population with access to rural roads)* | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Access to Electricity | 0.3494 | -0.3651 | 0.6929 | 0.7122 | 0.2078 | 0.1219 |
| *(% households with access to electricity)* | (0.022) | (0.047) | (0.000) | (0.000) | (0.330) | (0.915) |

*Note: The numbers in parenthesis below the correlation coefficients represent their corresponding p-values.*
*Correlations between growth, infrastructure quantity and infrastructure quality are computed over country averages in the period 1990-2005*
*Access information is generally not available prior to 2000; hence the correlations of access measures with the other variables refer to averages over 2000-2005.*

## Table 3
## Infrastructure and Economic Growth

*Dependent Variable: Growth in GDP per capita (annual average, percent)*
*Sample: 97 countries, 1960-2005 (non-overlapping 5-year period observations)*
*GMM-IV System Estimation*

| Variable | [1] | [2] | [3] | [4] |
|---|---|---|---|---|
| *Infrastructure Development (synthetic indexes):* | | | | |
| Infrastructure Quantity (IK1) 1/ | 2.6641 ** | 2.1927 ** | 2.0260 * | 1.0609 |
| | (1.105) | (0.981) | (1.328) | (1.403) |
| IK1 squared | .. | .. | -0.0403 | .. |
| | | | (0.247) | |
| IK1 * Sub-Saharan Africa | .. | .. | .. | 0.2897 |
| | | | | (1.450) |
| Quality of Infrastructure Services (IQ1) 2/ | .. | 1.9581 ** | 1.9373 ** | 1.5233 * |
| | | (0.549) | (0.598) | (0.800) |
| IQ1 squared | .. | .. | -0.0265 | .. |
| | | | (0.298) | |
| IQ1 * Sub-Saharan Africa | .. | .. | .. | 1.3582 |
| | | | | (1.281) |
| *Control Variables* | | | | |
| Initial Output per capita / per worker | -4.3056 ** | -6.2404 ** | -5.9773 ** | -5.2489 ** |
| *(in logs)* | (1.099) | (1.285) | (1.815) | (1.635) |
| Education | 1.9914 * | 2.7857 ** | 2.8253 ** | 2.9420 ** |
| *(secondary enrollment, in logs)* | (1.095) | (1.160) | (1.175) | (1.376) |
| Financial Development | 0.4856 | -0.0147 | -0.0231 | -0.0489 |
| *(private domestic credit as % of GDP, logs)* | (0.605) | (0.492) | (0.508) | (0.640) |
| Trade Openness | 1.2705 | 1.0965 | 1.1278 | 0.9347 |
| *(trade volume as % of GDP, logs)* | (1.053) | (1.410) | (1.380) | (1.363) |
| Lack of Price Stability | -0.0990 ** | -0.0510 * | -0.0511 * | -0.0618 ** |
| *(inflation rate)* | (0.036) | (0.033) | (0.033) | (0.031) |
| Government Burden | -1.3229 | -1.9217 * | -2.0330 * | -1.2706 |
| *(Government consumption as % GDP, logs)* | (1.274) | (1.281) | (1.297) | (1.363) |
| Institutional Quality | 0.4748 | -0.3029 | -0.2769 | 0.2056 |
| *(ICRG Political risk index, logs)* | (2.418) | (1.735) | (1.632) | (2.408) |
| Terms of Trade Shocks | 0.0197 | 0.0944 * | 0.0991 * | 0.0768 |
| *(first differences of log terms of trade)* | (0.066) | (0.051) | (0.053) | (0.055) |
| Observations | 582 | 582 | 582 | 582 |
| Specification Tests (p-values) | | | | |
| (a) A-B test for 2nd-order serial correlation | (0.360) | (0.482) | (0.484) | (0.481) |
| (b) Hansen test of overidentifying restrictions | (0.241) | (0.275) | (0.211) | (0.190) |
| (c) Difference-Sargan tests | | | | |
| All instruments for levels equation | (0.166) | (0.340) | (0.290) | (0.197) |

*Numbers in parentheses are robust standard errors. Our regression analysis includes an intercept and period-specific dummy variables.*
** (**) denotes statistical significance at the 10 (5) percent level. Standard errors are computed using the small-sample correction by Windmeijer (2005)*
*1/ See the notes to Table 1 for the definition of the synthetic indices of infrastructure quantity and quality.*

## Table 4
## Infrastructure and Income Inequality

*Dependent Variable: Gini Coefficient (end-of-period, in logs)*
*Sample: 87 countries, 1960-2005 (non-overlapping 5-year period observations)*
*Estimation: GMM-IV System Estimation*

| **Variable** | **[1]** | **[2]** | **[3]** | **[4]** |
|---|---|---|---|---|
| *Infrastructure Development (synthetic indexes):* | | | | |
| Infrastructure Quantity (IK1) 1/ | -0.0828 ** | -0.0485 * | -0.0489 * | -0.0537 |
| | (0.034) | (0.026) | (0.029) | (0.045) |
| IK1 squared | .. | .. | -0.0120 | .. |
| | | | (0.010) | |
| IK1 * Sub-Saharan Africa | .. | .. | .. | 0.1815 |
| | | | | (0.112) |
| Quality of Infrastructure Services (IQ1) 2/ | .. | -0.0387 ** | -0.0274 | -0.0312 |
| | | (0.017) | (0.019) | (0.026) |
| IQ1 squared | .. | .. | 0.0086 | .. |
| | | | (0.006) | |
| IQ1 * Sub-Saharan Africa | .. | .. | .. | -0.0349 |
| | | | | (0.080) |
| *Control Variables* | | | | |
| Income per capita | 0.4305 ** | 0.2731 * | 0.1571 | -0.0123 |
| *(Real output per capita, in logs)* | (0.162) | (0.160) | (0.245) | (0.240) |
| Income per capita squared | -0.0213 ** | -0.0112 | -0.0049 | 0.0058 |
| | (0.009) | (0.009) | (0.014) | (0.014) |
| Education | -0.0031 ** | -0.0032 ** | -0.0029 ** | -0.0034 ** |
| *(secondary enrollment)* | (0.001) | (0.001) | (0.001) | (0.001) |
| Financial Development | -0.0178 | -0.0079 | 0.0043 | -0.0115 |
| *(private domestic credit as % of GDP, logs)* | (0.016) | (0.017) | (0.022) | (0.025) |
| Lack of Price Stability | -0.0116 | -0.0103 | -0.0058 | -0.0106 |
| *(inflation rate)* | (0.016) | (0.015) | (0.018) | (0.016) |
| Trade Openness | 0.0365 * | 0.0431 * | 0.0552 * | 0.0485 |
| *(exports and imports as % of GDP, logs)* | (0.021) | (0.027) | (0.030) | (0.035) |
| Observations | 476 | 476 | 476 | 476 |
| Specification Tests (p-values) | | | | |
| (a) A-B test for 2nd-order serial correlation | (0.314) | (0.347) | (0.320) | (0.551) |
| (b) Hansen test of overidentifying restrictions | (0.821) | (0.681) | (0.758) | (0.602) |
| (c) Difference-Sargan tests | | | | |
| All instruments for levels equation | (0.423) | (0.669) | (0.396) | (0.521) |

*Numbers in parenthesis are robust standard errors. Our regression analysis includes an intercept and period-specific dummy variables.*
** (**) denotes statistical significance at the 10 (5) percent level. Standard errors are computed using the small-sample correction by Windmeijer (2005*
*1/ See the notes to Table 1 for the definition of the synthetic indices of infrastructure quantity and quality.*

**Table A.1**
**List of Countries**

**Industrial countries (23)**
Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland

**Latin America and the Caribbean (22)**
Argentina, Bahamas, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay, Venezuela

**East Asia and the Pacific (12)**
China, Hong Kong, Indonesia, Republic of Korea, Malaysia, Mongolia, Papua New Guinea, Philippines, Singapore, Taiwan, Thailand, Vietnam

**Eastern Europe and Central Asia (18)**
Belarus, Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Kazakhstan, Kyrgyz Republic, Latvia, Lithuania, Poland, Romania, Russian Federation, Slovak Rep., Slovenia, Turkey, Ukraine, Yugoslavia (Serbia)

**Middle East and North Africa (20)**
Algeria, Bahrain, Cyprus, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Malta, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, United Arab Emirates, Yemen

**South Asia (5)**
Bangladesh, India, Nepal, Pakistan, Sri Lanka

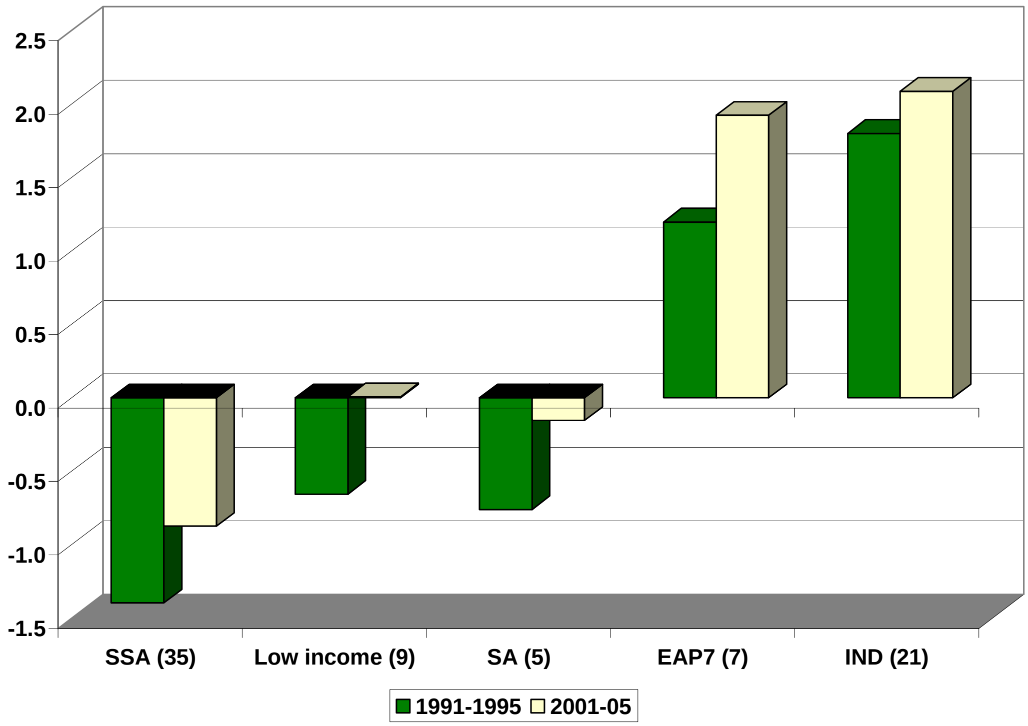
**Sub-Saharan Africa (36)**
Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Congo, Dem. Rep., Congo, Rep., Cote d'Ivoire, Ethiopia, Gabon, The Gambia, Ghana, Guinea, Guinea Bissau, Kenya, Lesotho, Madagascar, Malawi, Mali, Mauritania, Mauritius, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Sudan, Tanzania, Togo, Uganda, Zambia, Zimbabwe

**Table A.2**
**Definitions and Sources of Variables Used in Regression Analysis**

| Variable | Definition and Construction | Source |
|---|---|---|
| Gini Coefficient | Gini Coefficient of Income Inequality (0-100), end of period, and expressed in logs | Authors' construction using Deininger and Squire (1996), Milanovic (2000) and World Bank's World Development Indicators (WDI). |
| Real Income per capita | Ratio of real GDP (in US$ at 2000 prices) to total population, beginning of period, and expressed in logs. | Authors' construction using Summers, Heston and Aten (2006) |
| Economic Growth | Log difference of real GDP per capita. | Authors' construction using Summers, Heston and Aten (2006) |
| Education | Ratio of total secondary enrollment, regardless of age, to the population of the age group that officially corresponds to that level of education. | Easterly and Sewadeh (2002) and The World Bank's WDI |
| Financial Development | Domestic credit to the private sector as a percentage of GDP, in logs | Beck, Demirguc-Kunt and Levine (2001) and The World Bank's WDI |
| Trade Openness | Exports and imports as a percentage of GDP, in logs. All magnitudes expressed in US dollars at 2000 prices. | Easterly and Sewadeh (2002) and The World Bank (2003). |
| Lack of price stability | CPI inflation rate, in logs. It is computed as log((1+*dp*)*100), where *dp* is the inflation rate. This transformation smooths the original variable and gives less weight to hyperinflation episodes. | Author's calculations using data from IFS and the publications of the Central Bank. The method of calculations is based on Beck, Demiguc-Kunt and |
| Government Burden | General Government Consumption Expenditure as percentage of GDP, average of period, and expressed in logs. | The World Bank's World Development Indicators and IMF's Government Financial Statistics |
| Institutional Quality | ICRG Political Risk Index (in logs). The index includes the following categories: Government Stability, Socio-Economic Conditions, Investment Profile, Internal Conflict, External Conflict, Corruption, Military in Politics, Religion Tensions, Rule of Law, Ethnic Tensions, Democratic Accountability, Bureaucratic Quality | International Country Risk Guide |
| Terms of Trade | Net barter terms of trade index (2000=100) | The World Bank, World Development Indicators CD-ROM |
| Terms of Trade Changes | Log differences of the terms of trade index | Authors' construction using WDI |
| Size of the modern sector | Share of non-agricultural activities in total value added (in percentages) | The World Bank, World Development Indicators CD-ROM |
| Telecommunications Infrastructure Stock | (a) Main telephone lines per 1000 workers (in logs). (b) Main telephone lines and mobile phones per 1000 workers (in logs). | Authors' construction using Canning (1999) and International Telecommunication Union's World Telecommunication Report |
| Quality of Telecommunication Services | Waiting time for main telephone line installation. The variable was rescaled such that it takes values between 0 and 1, with higher numbers implying higher quality of telecommunication services. | International Telecommunication Union's World Telecommunication Report and the World Bank's World Development Indicators |
| Infrastructure Stock of the Electricity Sector | Electricity Generating Capacity (in MW per 1000 workers). The variable was expressed in logs. | Authors' construction using Canning (1999), United Nation's Energy Statistical Yearbook, and national sources where available. |
| Quality of Electricity Services | Electric Power Transmission and Distribution Losses (as percentage of electricity output). The variable was rescaled such that it takes values between 0 and 1, with higher numbers implying higher quality of telecommunication services. | The World Bank's World Development Indicators and national sources where available. |
| Road Network | (a) Length of total road network, and (b) Length of paved road network. Both variables are measured in kilometers per sq. km. of surface area of the country, and then expressed in logs | International Road Federation's World Road Statistics, the World Bank's World Development Indicators, and national sources where available. |
| Quality of the Road Network | Share of paved roads in the overal road network. This variables takes values between 0 and 1, with higher numbers implying higher quality of the road network. | International Road Federation's World Road Statistics, the World Bank's World Development Indicators, and national sources where available. |
| Synthetic Index of Infrastructure Quantity | First principal component of the three different dimensions of infrastructure considered in our analysis: telecommunications, electricity and roads. IK1 comprises information on main lines, EGC, and total roads; IK2 on main lines, EGC and paved roads. On the other hand, IK3 uses main lines and mobile phones, EGC and total roads, while IK4 uses main lines and mobile phones, EGC and paved roads | Author's calculations. |
| Synthetic Index of Infrastructure Quality | First principal component of the three different dimensions of infrastructure quality considered in our analysis: telecommunications, electricity and roads. The synthetic index considered transformations of waiting time for main line installation, electricity transmission and distribution losses, and share of paved roads. | Author's calculations. |
| Period-specific Shifts | Time dummy variables. | Authors' construction. |

**Figure 1**

**A. Synthetic index of infrastructure quantity**
(medians by country group)




**B. Synthetic index of infrastructure quality**
(medians by country group)

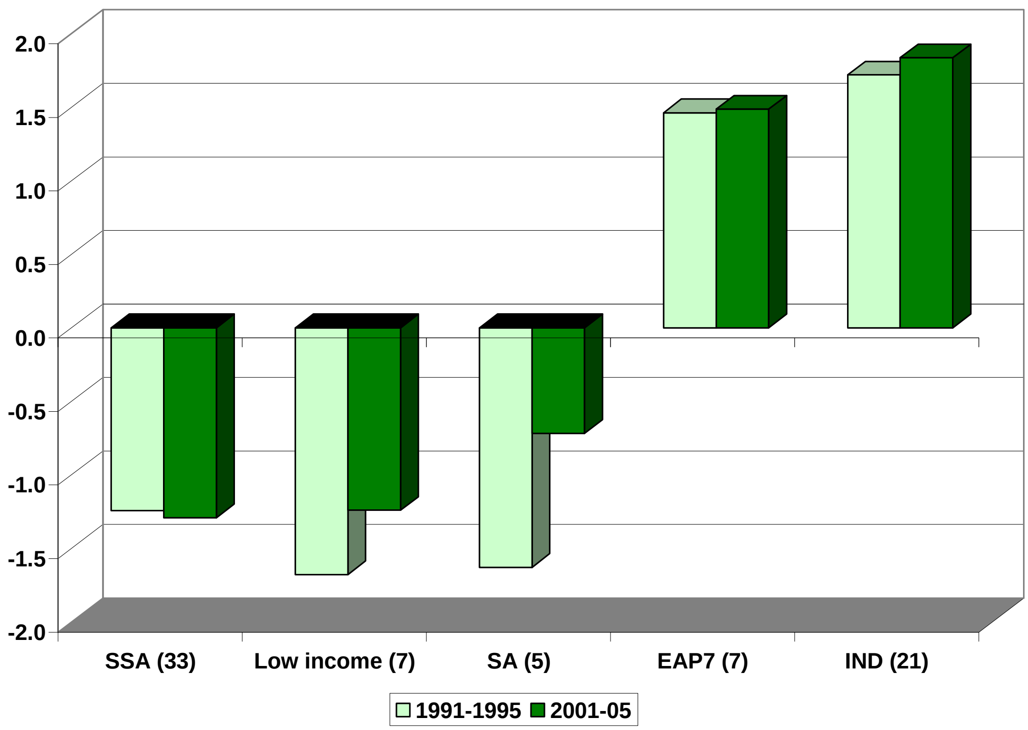


**Figure 2**
**Growth changes across regions due to infrastructure development**
(Change in average per capita growth, 2001-5 vs.1991-5)

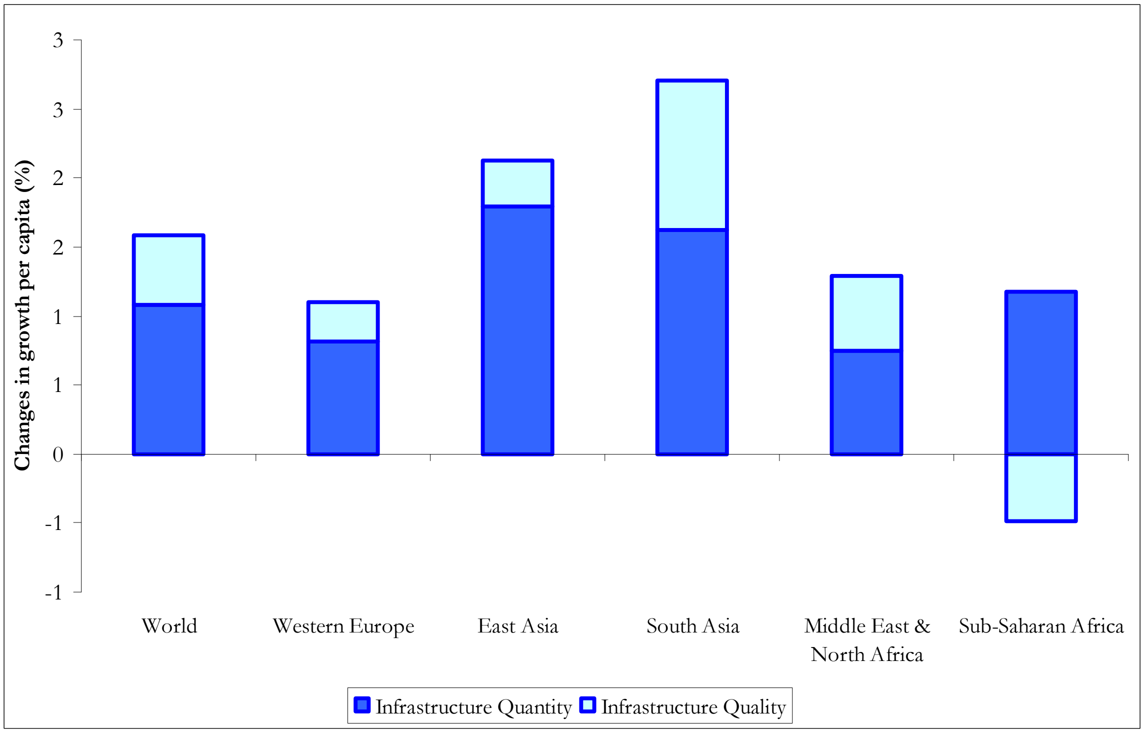



**Figure 3**
**Changes in inequality across regions due to infrastructure development**
Change in Gini coefficient of income distribution, 2001-5 vs.1991-5

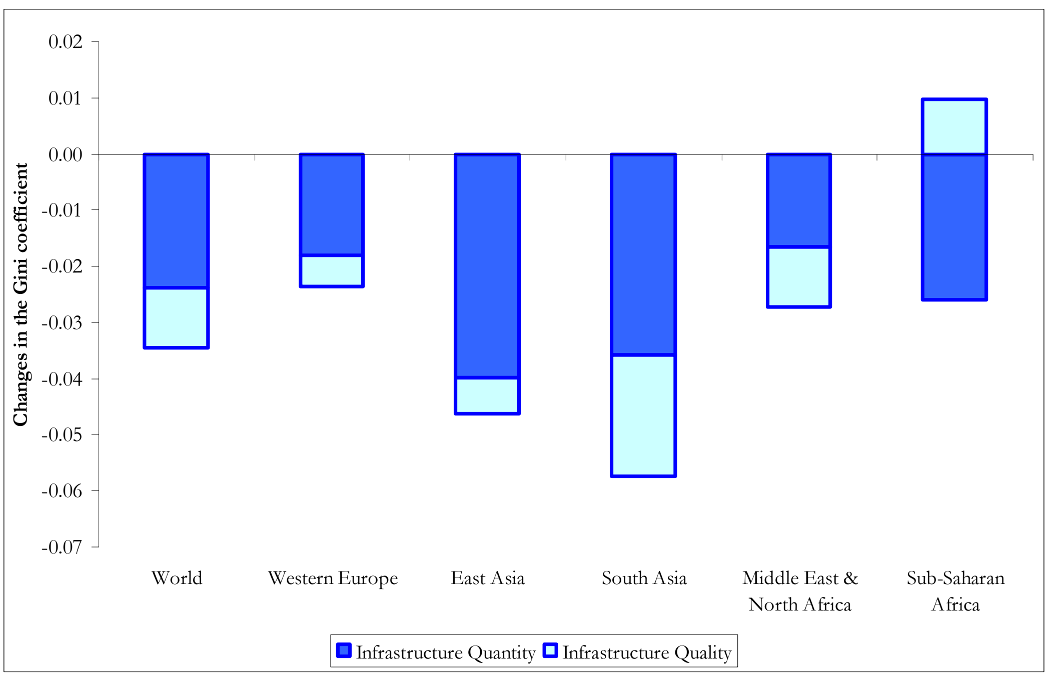
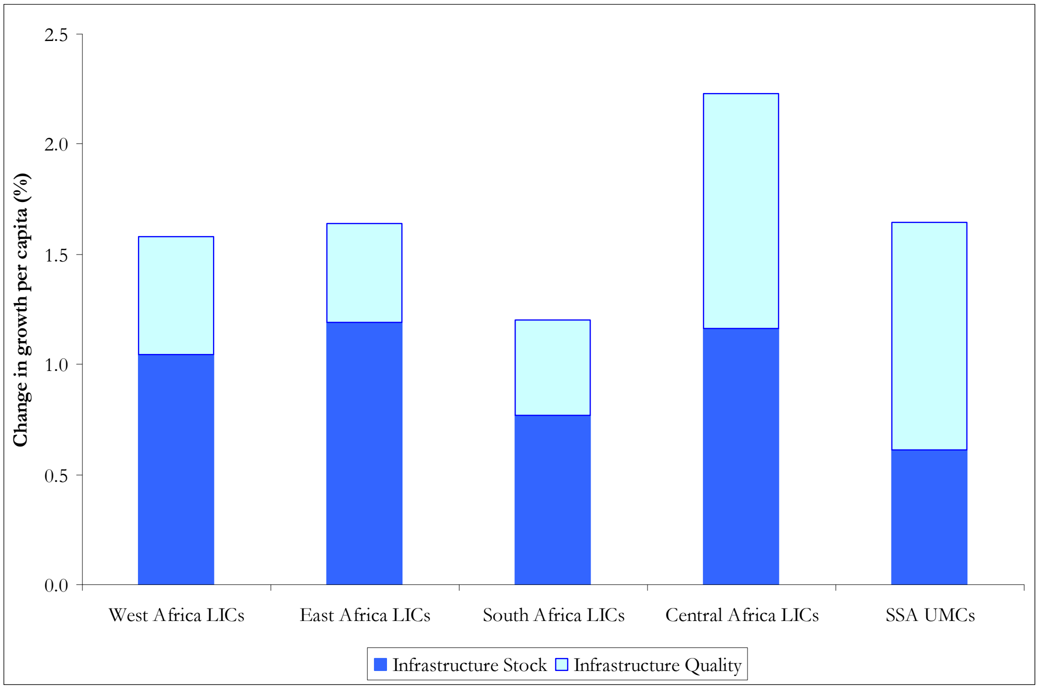


**Figure 4**

**Growth change under alternative infrastructure development scenarios**

A. Catching up: halving the infrastructure level gap with other regions




B. Keeping up: matching the rate of infrastructure growth of other regions

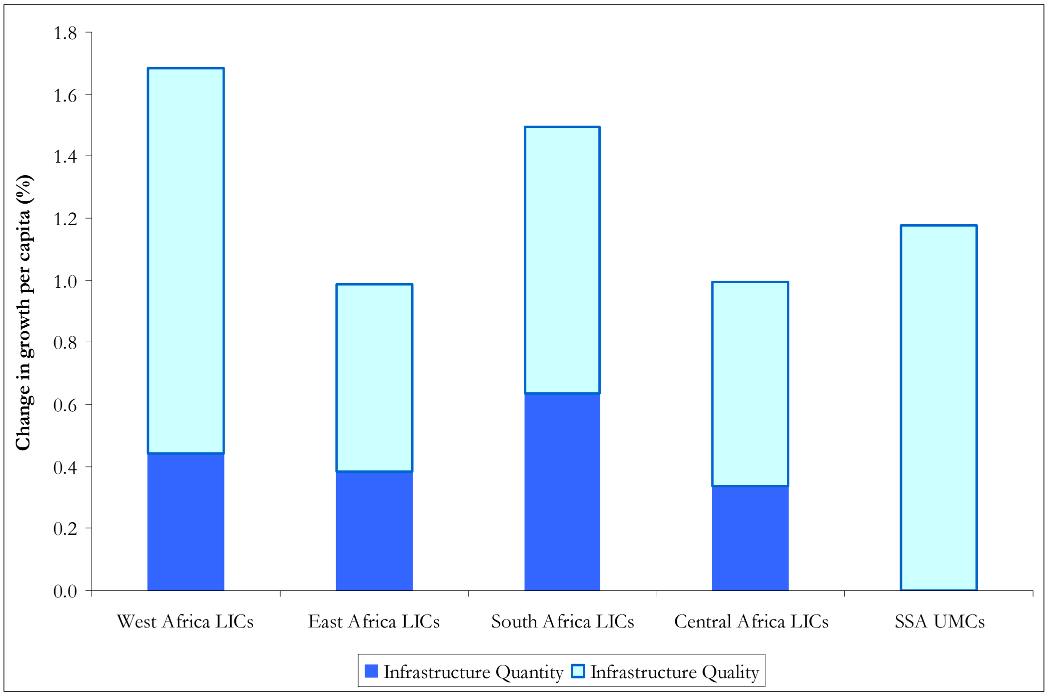
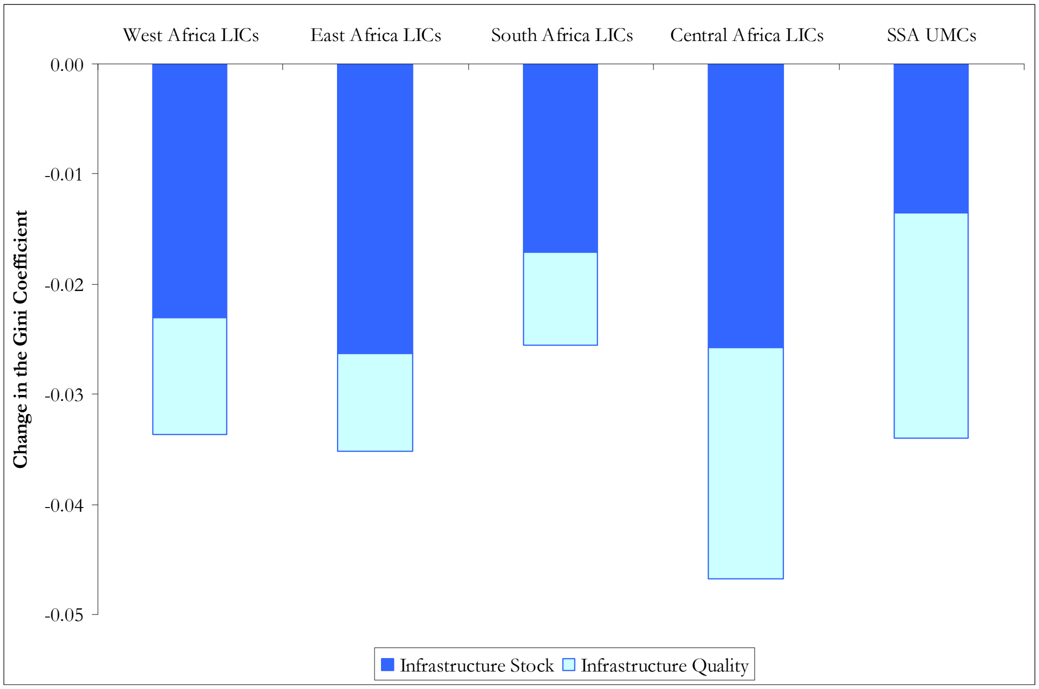


**Figure 5**
**Inequality change under alternative infrastructure development scenarios**

A. Catching up: halving the infrastructure level gap with other regions




B. Keeping up: matching the rate of infrastructure growth of other regions

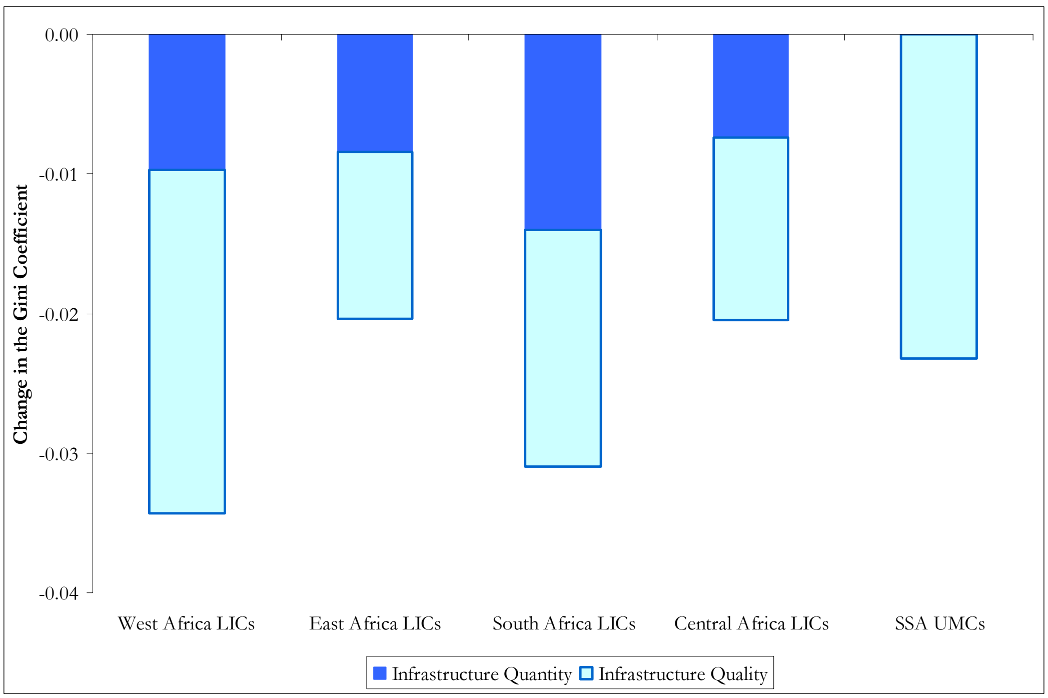
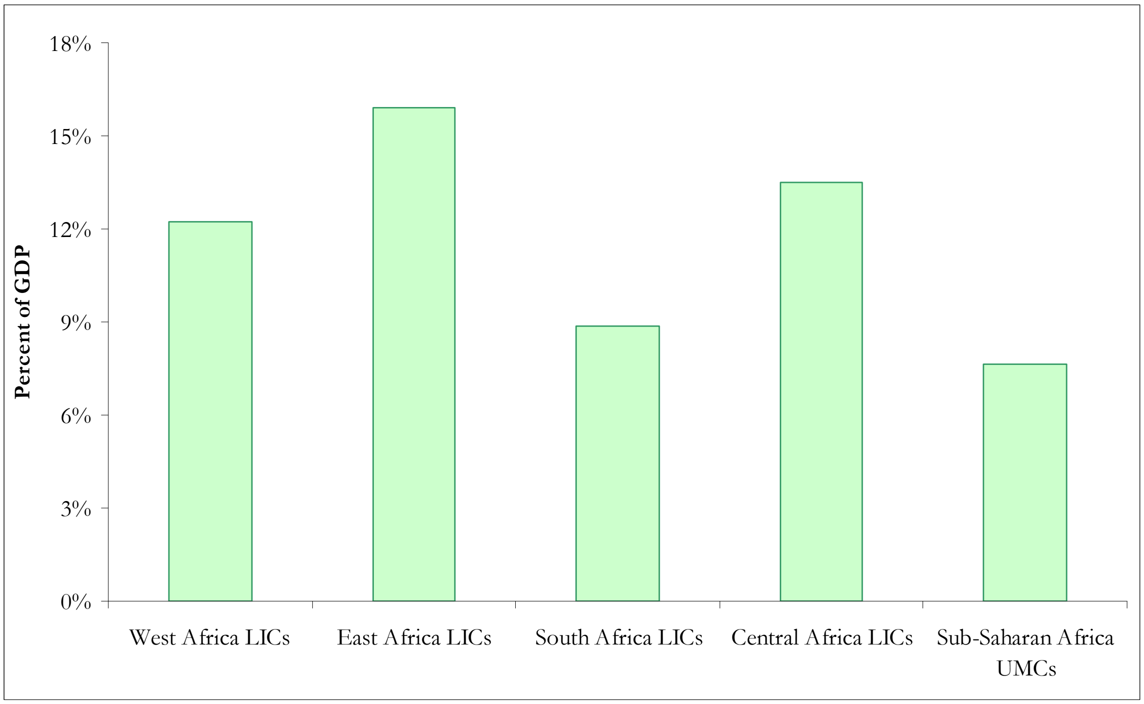


**Figure 6**
**Cost of infrastructure catch-up**

Investment required for halving the infrastructure quantity gap with other regions



## Appendix

### Trends in infrastructure in Sub-Saharan Africa over the last quarter century

This appendix offers an overview of trends in infrastructure performance in Sub-Saharan Africa since 1980. We focus on core infrastructure – roads, electricity, telecommunications – which is most directly relevant for growth. However, we shall also make reference to water and sanitation, which are widely perceived as critical from the point of view of poverty reduction.

To avoid potential distortions introduced by very small economies, in which infrastructure poses some special issues – owing for example to indivisibilities -- we limit our coverage to countries with total population over one million. This leaves us with up to 42 Sub-Saharan countries with available infrastructure data. To keep information manageable, we organize them into four subregions: West Africa (ECOWAS), East Africa (EAC), Southern Africa (SADC) and a residual group that we shall label Central Africa.[26] It is important to keep in mind, however, that each of these groups is still quite heterogeneous, comprising countries of different sizes and income levels. Most notably, the SADC group includes very small economies, such as Swaziland and Lesotho, along with big South Africa, which by itself represents 40 percent of the entire region's GDP. Likewise, the group combines upper-middle income South Africa and Botswana with low-income Malawi and Madagascar. Hence the summary statistics reported below for this group have to be interpreted with caution.

Throughout we use a comparative perspective, placing Africa against the background of other world regions. Given the preponderance of low-income countries across Africa, the best comparator region is probably South Asia (likewise dominated by low-income economies). For the same reason, we also use the group of non-African low-income economies as another comparator. For illustration, we also look at the infrastructure performance of the East Asian tigers (which could be appropriate comparators for Africa's upper middle income economies), along with that of industrial countries.

Finally, since our focus here is on infrastructure performance rather than its determinants, we do not attempt to develop a full benchmarking exercise to "explain" such divergences on the basis of endogenous and exogenous economic variables – e.g., demographic characteristics and per capita income levels.[27]

Figure A.1 offers a comparative perspective on telephone density. We use total phones per worker, rather than fixed lines, due to the increasing importance of mobile phones. Figure A.1a compares the median values in Sub-Saharan Africa and the other

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[26] The country composition of these subregions is as follows: West Africa (ECOWAS) comprises Benin, Burkina Faso, Cote d'Ivoire, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, and Tog;, East Africa (EAC) comprises Burundi, Kenya, Rwanda, Somalia, Tanzania, and Uganda; Southern Africa (SADC) includes Angola, Botswana, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, South Africa, Swaziland, Zambia and Zimbabwe; and Central Africa consists of Cameroon, Central African Republic, Chad, Congo, Dem. Rep., Congo, Rep., Eritrea, Ethiopia and Sudan.

[27] Such exercises are performed by Yepes, Pierce and Foster (2008) for Sub-Saharan Africa, Bogetic and Fedderke (2006) for South Africa, and Calderón and Servén (2004a) for Latin America.

country groups just listed. Figure A.1b in turn offers a perspective on the performance of the different groups of countries in Sub-Saharan Africa defined earlier.

It is apparent from Figure A.1a that telephone density in Sub-Saharan Africa lags far behind industrial countries and the high-performing economies of East Asia. Since 1980, Africa has fallen behind the group of (non-African) low-income countries and South Asia too in that respect. Figure A.1b shows that there is a lot of heterogeneity across country groups, with phone line density in SADC more than three times as high as in Central Africa in 2004. Over the last quarter century, West Africa has almost caught up with SADC. Inspection of country-level data (not shown to save space) reveals a stark contrast between the richer African countries (South Africa, Mauritius, Botswana), all close to or beyond the 1,000-line mark, and Ethiopia, Niger and Burundi, still far below the 100-line mark.

Figure A.2 turns to power generation capacity. There is clear evidence that since 1980 Africa has fallen far behind South Asia and low-income economies, not to mention the richer countries. Since 1980, power generation capacity per worker has remained virtually unchanged in Sub-Saharan Africa, while it has more than tripled in low-income countries and South Asia. Figure A.2b shows that the only subregion in Africa to witness a significant change in power generation capacity per worker has been SADC, where in fact the indicator shows a decline. This conceals a substantial expansion of generation capacity per worker in South Africa (the leading country in Africa) and Mauritius, along with major declines in Zambia and Namibia.

Figure A.3 shows the trends in transport networks, as measured by total road length relative to arable land surface. In this dimension too there has been little change in Sub-Saharan Africa over the last 25 years, while by this measure road networks have expanded considerably in the other regions shown. Southern Africa is the only subregion showing some progress on this front; in all other African country groups road density has, if anything, declined.

So far we have focused on the quantity of infrastructure. But the quality of infrastructure assets and services is also quite important. However, information on quality is much more limited. There are two kinds of information on the quality of infrastructure: official statistical data on quantitative quality indicators, and survey-based information on the perceptions – often qualitative -- of experts or end-users regarding the performance of infrastructure services.

In the case of telecommunications, data on the indicator that a priori should be most informative – the frequency of phone faults – is so sparse as to make the indicator useless to capture broad trends. Instead we opt for showing data on waiting times for installation of main lines, which show a significantly positive correlation with the phone faults indicator over the reduced sample for which the latter is available (Calderón and Servén 2008). Even these data offer limited coverage, however – only 22 countries in Sub-Saharan Africa possess the requisite information. With this caveat, Figure A.4a shows that waiting times have declined sharply outside Africa, and have dropped all the way to zero in industrial countries and East Asia. In Africa, however, the decline has been very modest, and in 2000-2004 the median waiting time of the countries for which information is available was still around three months. Figure A.4b reveals contrasting trends across Africa: wait times halved in East Africa, but doubled in Central Africa. SADC also experienced a sharp improvement, and wait times in South Africa, Madagascar and Mauritius fell close to zero. Across the region, some countries saw major progress (notably Mauritius and Tanzania), while others experienced major setbacks (especially Sudan).

The percentage of power transmission and distribution losses relative to total output offers a rough measure of the efficiency of the power sector – although it combines technical losses, reflective of the quality of the power grid, with pilferage (i.e., power theft). The available information (which again offers limited coverage) reveals little progress in Africa over the last 25 years. Power losses actually rose in Africa as well as low-income countries, in contrast with the improvement observed in other regions (Figure A.5a). Within Africa, only SADC showed some progress on this front (Figure A.5b). Only three countries (Zaire, Zambia, South Africa) show losses of 6 percent of less of total output, comparable to those of rich countries. In Congo, Togo and Nigeria, the figure exceeded 30 percent in 2004.

The main quality indicator widely available for transport is the percentage of paved roads in the total road network. Figure A.6a shows that, in spite of modest progress over the last 25 years, Africa lags far behind other world regions along this dimension. Figure A.6b shows that paved roads are a small fraction of the total in virtually all subregions of Africa, with Southern Africa placing first and East Africa last.

Given the paucity of statistical information on infrastructure quality, we turn to survey-based information. One source of such information is provided by the surveys of experts compiled for the World Competitiveness Report. Rather than quality alone, they tend to combine perceptions on both the quality of infrastructure services and their availability. Coverage of these data is also incomplete, and in particular their time series dimension is very limited. Hence we show data only for the latest year available (2006).

Figure A.7 summarizes perceptions regarding the *overall* quality of infrastructure. Higher bars denote higher quality, within a range from 1 to 7. Sub-Saharan Africa ranks last of all regions shown (Figure A.7a). Differences across subregions of Africa are relatively modest. East Africa is perceived as having the best infrastructure, while the worst is that of Central Africa (Figure A.7b).

Figures A.8 to A.10 respectively depict quality perceptions regarding telephones, power and roads. In all three cases Sub-Saharan Africa, along with the group of low-income countries, lags behind all other regions shown. Central Africa is perceived as having the worst quality in transport and telecommunications, while for power East Africa places last. In turn, SADC ranks at the top in terms of the perceived quality of roads and power. For telephones, the leader instead is ECOWAS, although the differences across subregions appear fairly modest.

A second source of information on infrastructure quality perceptions is provided by the World Bank's firm-level surveys (formerly known as Investment Climate Surveys), which at present cover some 70,000 firms in over 100 developing countries. For most countries, only one survey is available at present. The graphs below depict the regional medians of country averages of the firm-specific responses.

Figure A.11 reports the delays experienced by firms in acquiring a telephone connection. The median delay among the African countries with data is over 20 days, somewhat above that of South Asian countries, and three times as high as those reported in low-income economies and East Asia (Figure A.11a). Delays are particularly high in Central Africa (Fig. A.11b).

Figures A.12 and A.13 refer to power outages – their frequency and their cost in terms of lost sales. Outages are less frequent (or have shorter duration) in Africa than in South Asia, although in both regions they are much more frequent than in East Asia's high performing economies. However, the cost in terms of sales lost is similar in Africa and South Asia – about 2 percent of total sales. Within Africa, the number of days without power is especially high in Central Africa, while the cost is highest in East Africa – equivalent to a whopping 5 percent of sales.

Up to this point we have been concerned with the overall quantity and quality of infrastructure. But from the point of view of equality of opportunity and poverty reduction, another important dimension is the universality of access to infrastructure services – i.e., the extent to which existing infrastructure assets yield services to the broad population rather than just a few. One way to measure this phenomenon is through access rates. Below we offer a comparative perspective on standard indicators of access to electricity, roads, water and sanitation. Coverage of information on access rates is limited, especially in the time series dimension (except for water and sanitation indicators), and therefore we confine ourselves to the cross-country dimension.

Figure A.14 reports the percentage of the population with access to electricity. The indicator is available only for developing countries.[28] Sub-Saharan Africa shows very low access rates – the regional median in 2005 was below 20 percent, less than half the level of South Asia and non-Africa low-income countries, not to mention the near 100 percent access rate of East Asia. Across subregions, only West Africa shows a median access rate above 20 percent. Among individual countries, only two African countries (Mauritius and South Africa) report access rates above 50 percent, while five countries (Zaire, Mozambique, Burkina Fasso, Malawi and Uganda) report access rates below 10 percent.

A widely-used indicator of access to transport is given by the percentage of the rural population living within a short distance (2 km) of an all-season passable road.[29] Figure A.15a shows that Sub-Saharan Africa trails South Asia and other low-income economies along this dimension. Central Africa is the lowest-performing subregion, with access to transport just above 20 percent. Only a dozen countries in Africa show access rates above 50 percent (the South Asian norm). Botswana and Mauritius are the regional leaders, with access rates in excess of 70 percent.

Figures A.16 and A.17 report access to safe water and sanitation, respectively. Africa trails the low-income country group in both dimensions, although in the case of sanitation access it is almost on par with South Asia. Mauritius is the regional leader in both dimensions, with access rates at or close to 100 percent.

We should note that access is not distributed evenly across the population. Households in the upper percentiles of the income distribution typically enjoy much better access than poorer households do (World Bank 2006), and Africa is no exception to this rule (Diallo and Wodon 2004; Estache 2005). Nevertheless, expanding service coverage is typically associated with improved access by the poor. More broadly, across countries higher overall access rates are robustly associated with lower income

[28] We use the access indicator reported by the IEA in the World Energy Outlook, which has broader coverage that an alternative indicator of household access developed by the World Bank that covers only IDA borrowing countries. However, the two indicators show a very high (.89) cross-country correlation.
[29] See Desmarchelier (2005).

inequality. Indeed, the correlation coefficient[30] between access rates and the Gini index of income inequality is -.20 in the case of electricity, -.40 for roads, -.33 for sanitation and -.30 for water, significantly different from zero in all cases except for power, where the number of available observations (just 30) is too small to allow conclusive inferences. In turn, access rates are strongly associated with the quantity of infrastructure available. For example, the cross-country correlation between rates of access to electricity and power generation capacity per worker is .55, while that between rural road access and the total length of the road network is .47. Both are significantly different from zero at any reasonable confidence level.

[30] These are rank correlations, robust to outlying observations.

**Figure A.1a Total Telephone Lines, by Group
(lines per 1,000 workers)**

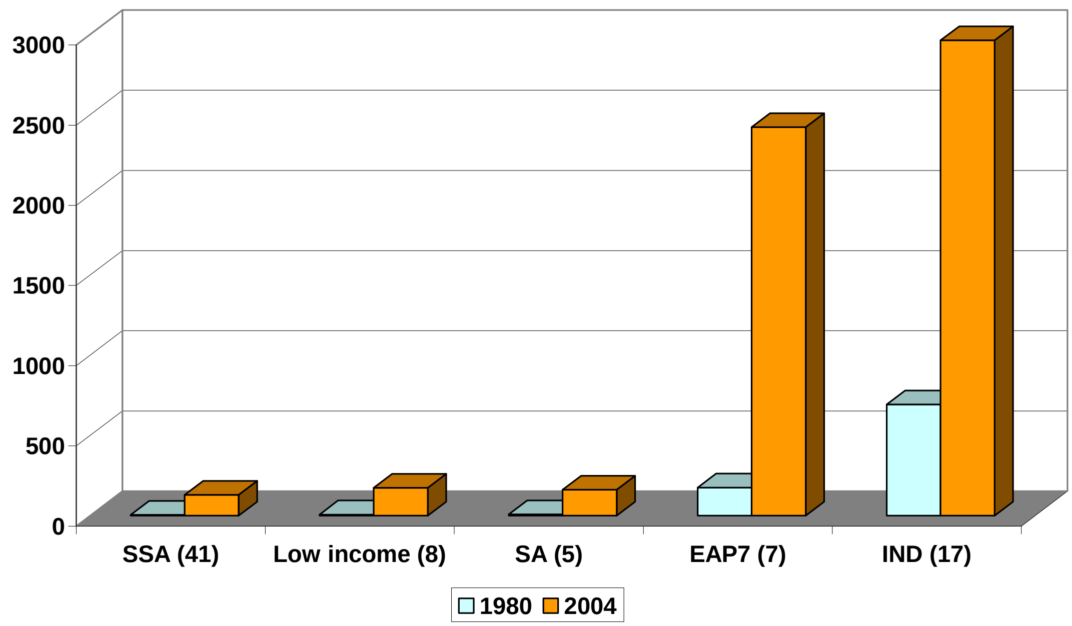



**Figure A.1b Total Telephone Lines, Medians by Sub-Region of Africa
(lines per 1,000 workers)**

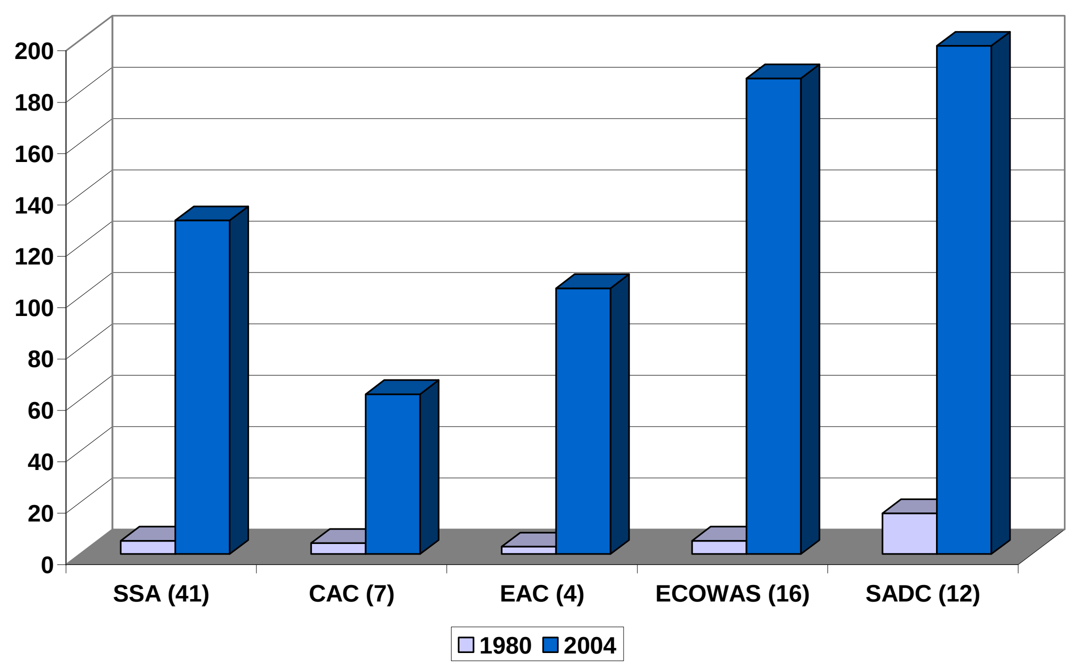


**Figure A.2a Electricity Generating Capacity, Medians by Group (megawatts per 1,000 workers)**

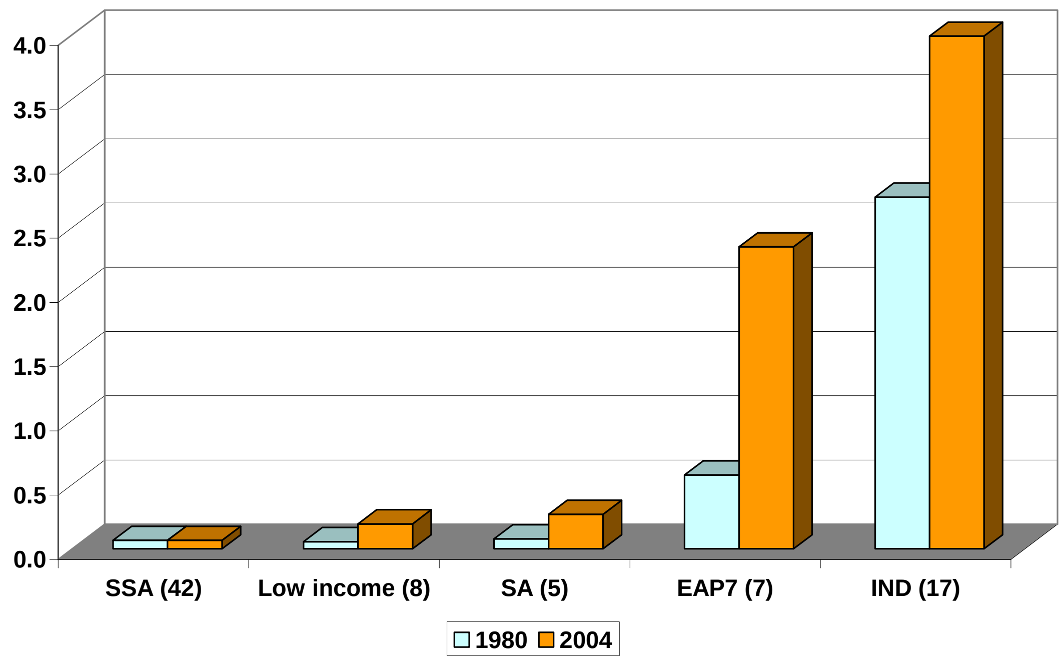



**Figure A.2b Electricity Generating Capacity, Medians by Sub-Region of Africa (megawatts per 1,000 workers)**

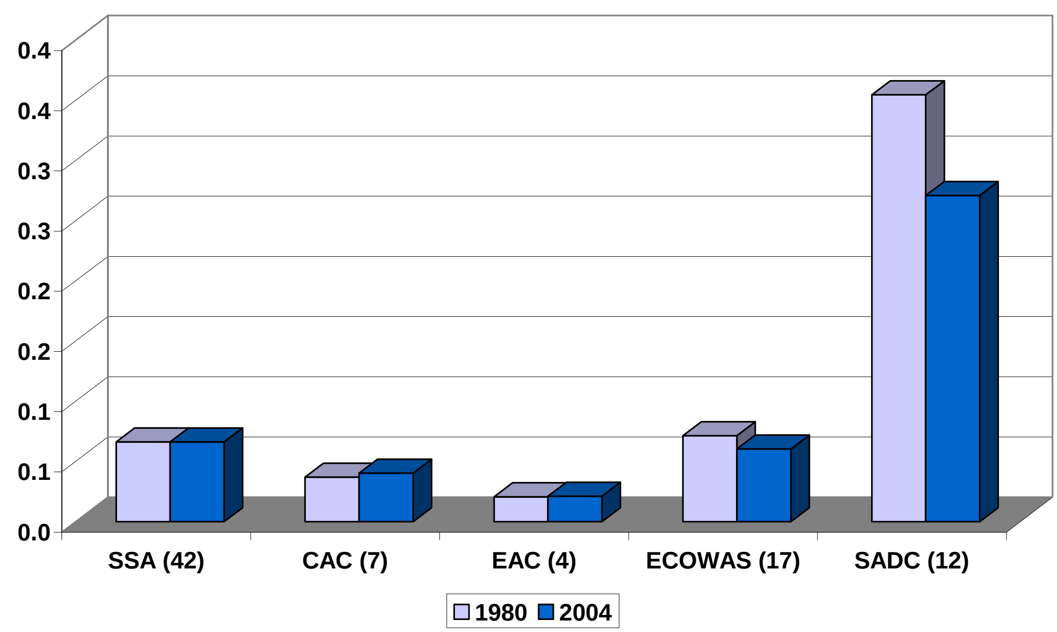


**Figure A.3a Total Road Length, Medians by Group**
**(km per 1,000 Ha of arable land)**

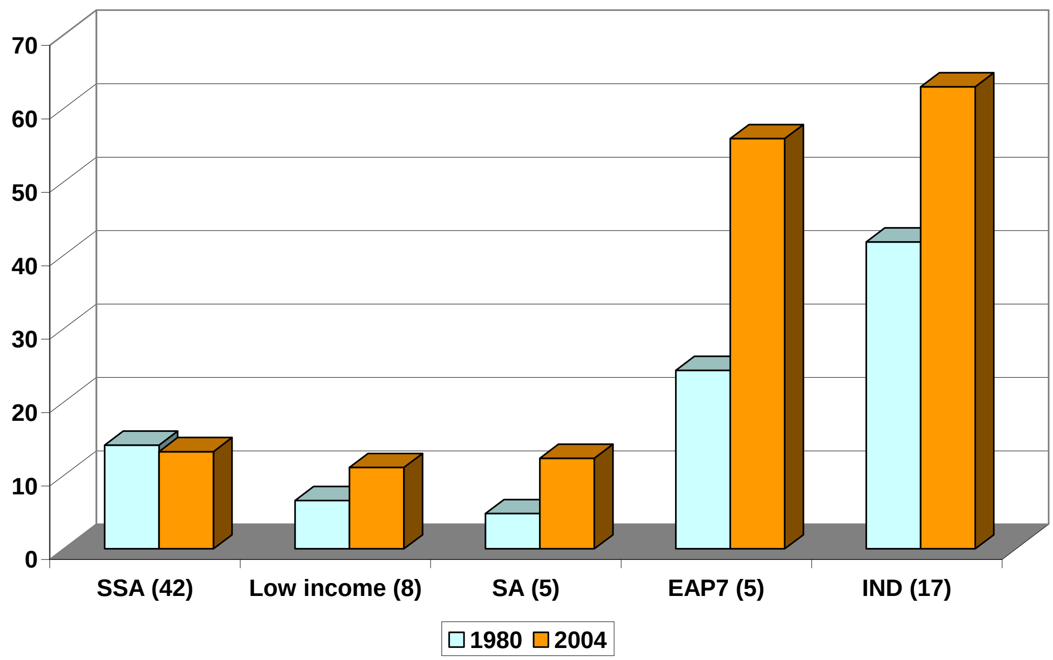



**Figure A.3b Total Road Length, Medians by Sub-Region of Africa**
**(km per 1,000 Ha of arable land)**

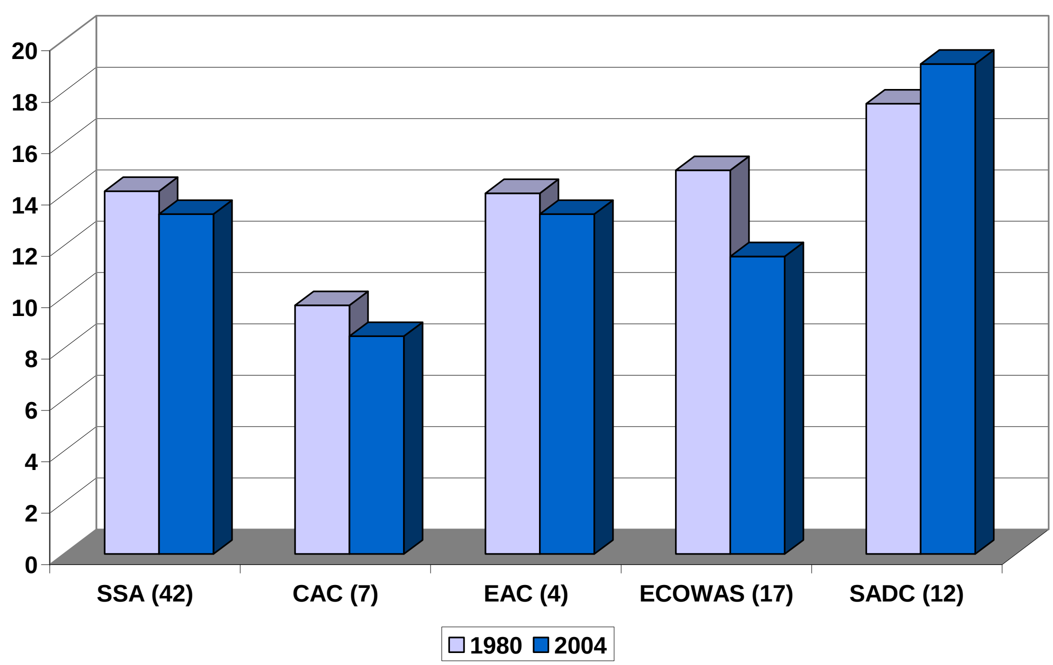


**Figure A.4a Telephone Mainlines, Waiting Time, Medians by Group (years)**

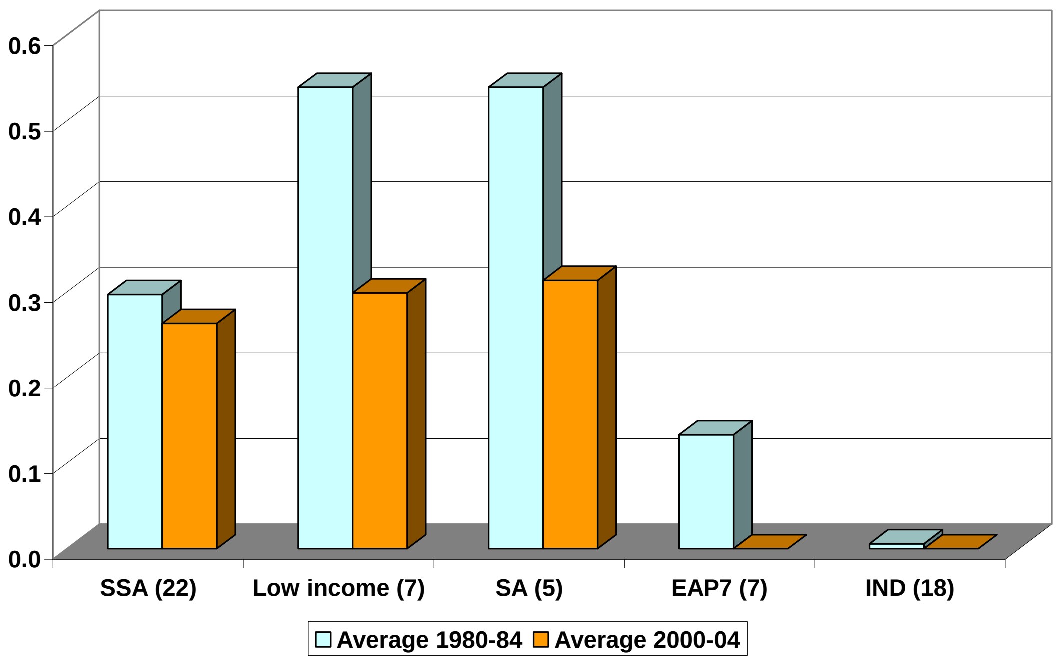



**Figure A.4b Telephone Mainlines, Waiting Time, Medians by Sub-Region of Africa (years)**

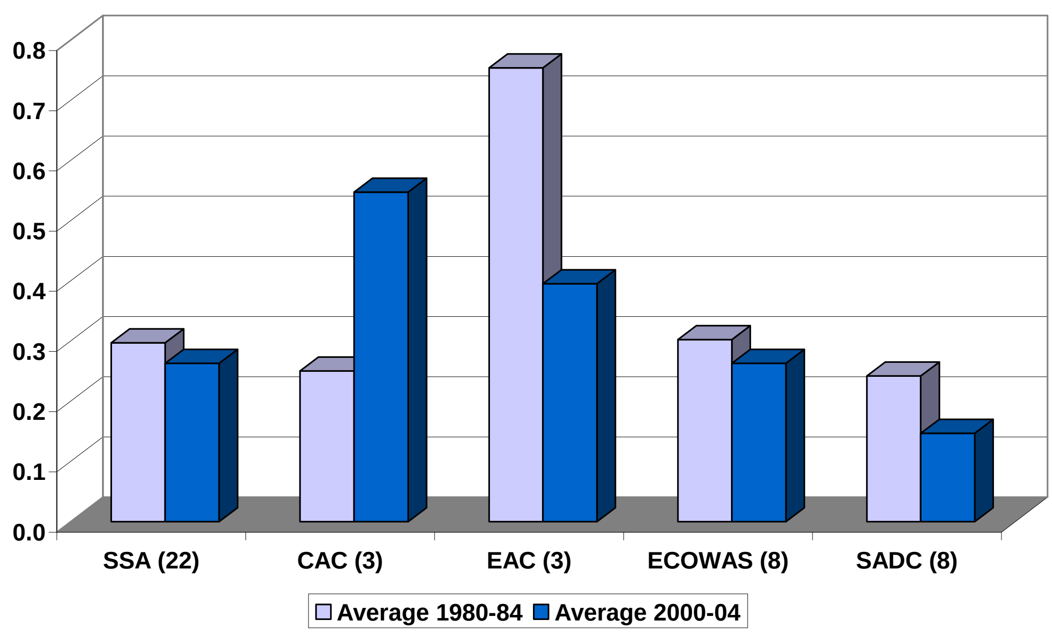


**Figure A.5a Power Losses, Medians by Group (percentage of power output)**

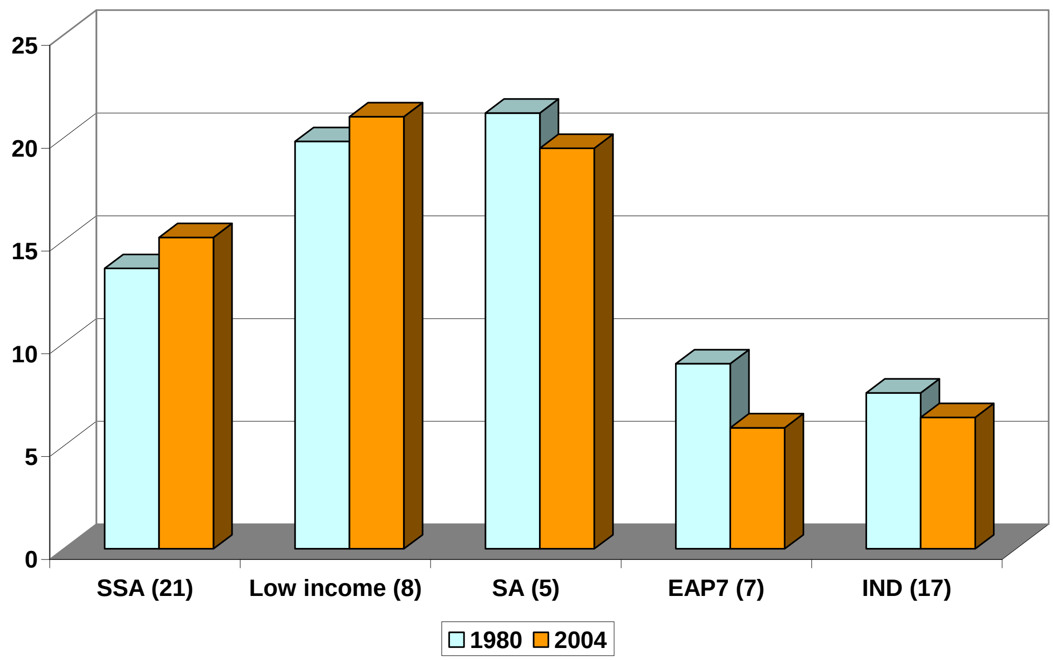



**Figure A.5b Power Losses, Medians by Sub-Region of Africa (percentage of power output)**

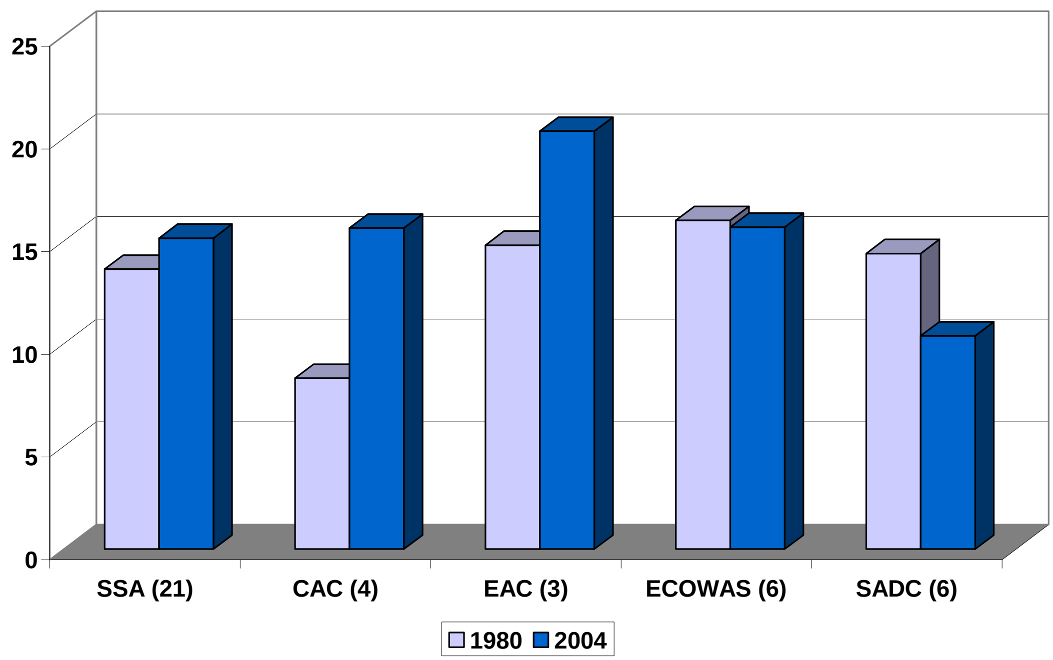


**Figure A.6a Paved Road Length, Medians by Group
(percentage of total road length)**

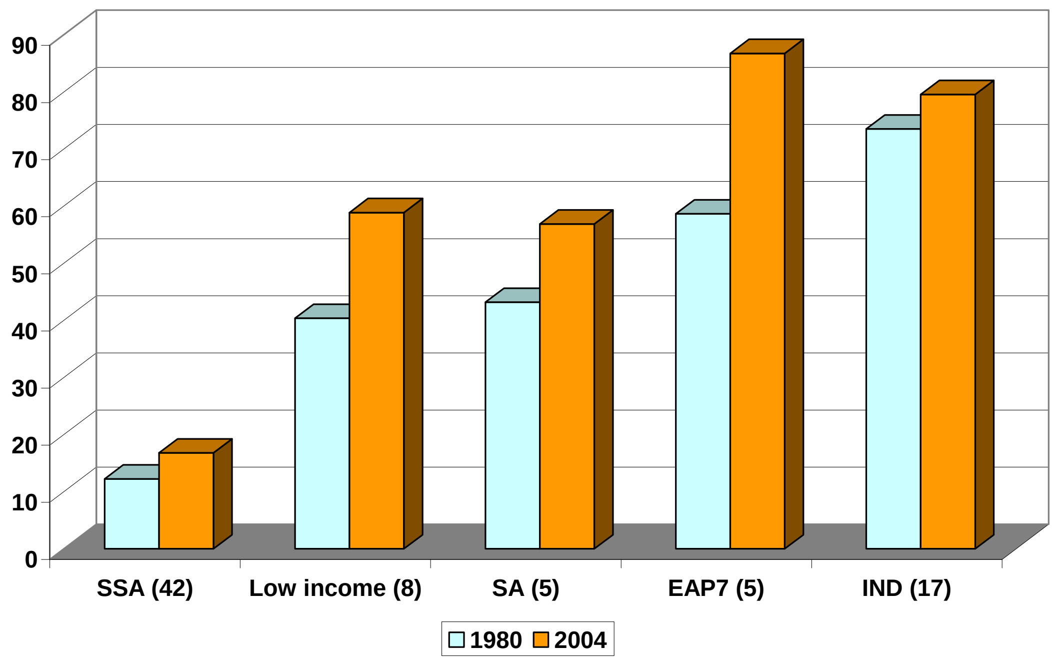



**Figure A.6b Paved Road Length, Medians by Sub-Region of Africa
(percentage of total road length)**

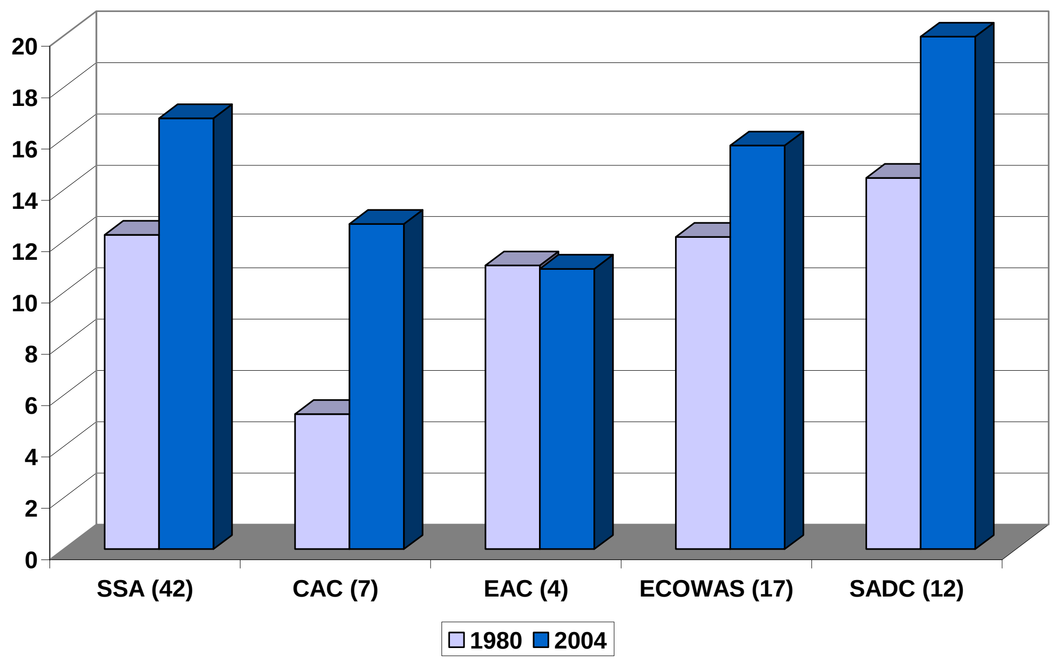
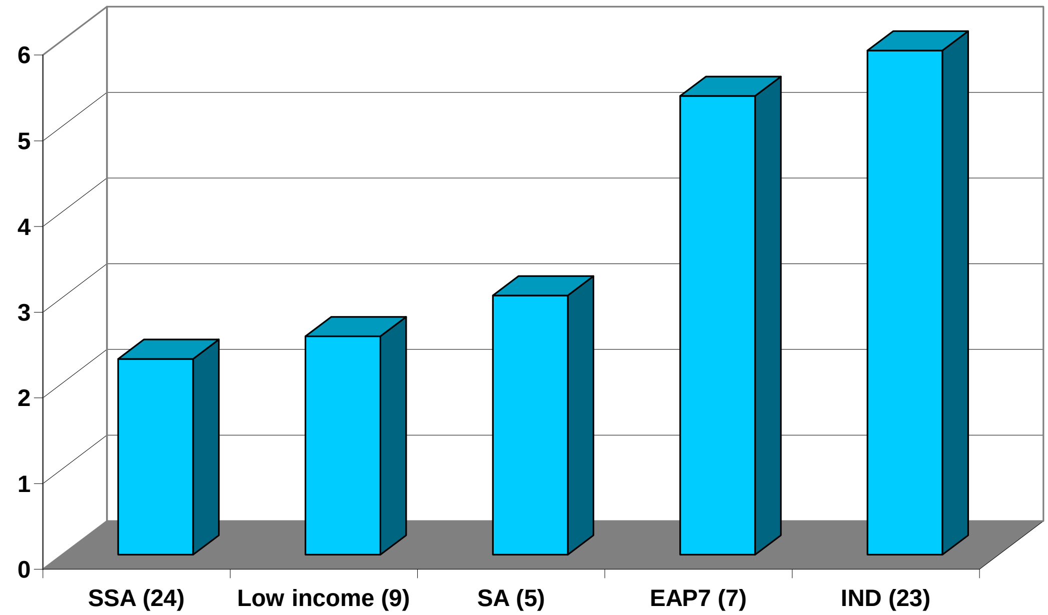
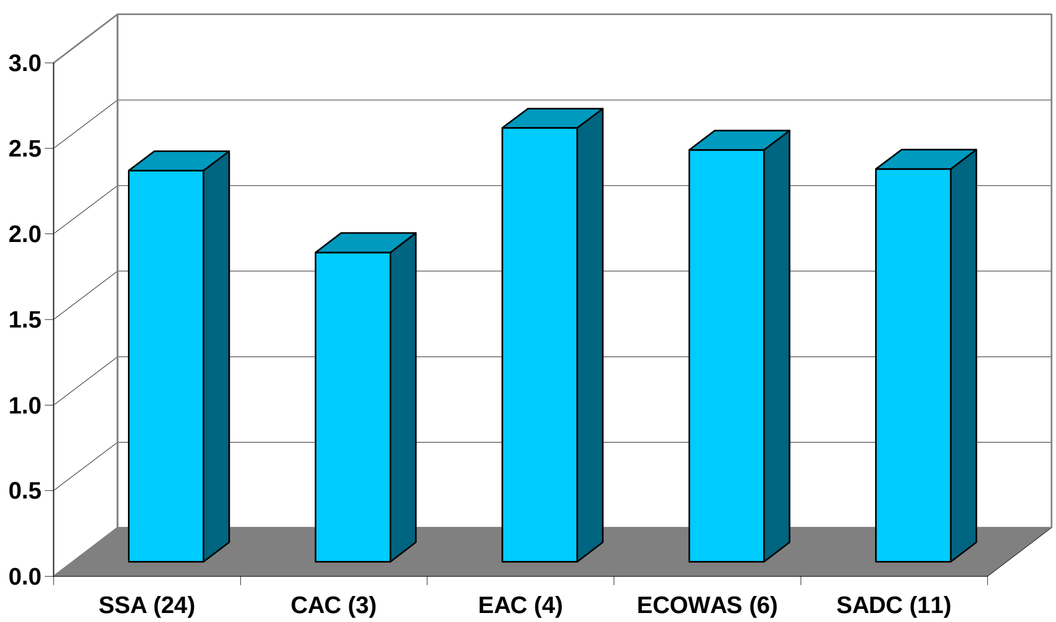


**Figure A.7a Overall Infrastructure Quality, Medians by Group (2006)**



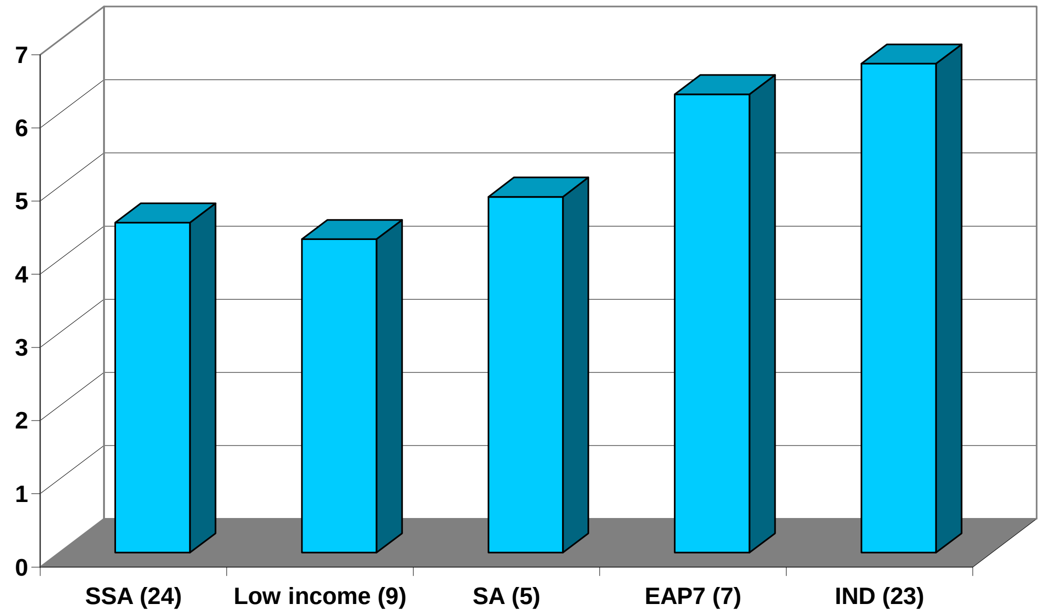

Question: The quality of the infrastructure is among the best in the world (1=strongly disagree; 7 =strongly agree).
Source: Global Competitiveness Report 2006.

**Figure A.7b Overall Infrastructure Quality, Medians by Sub-Region of Africa (2006)**



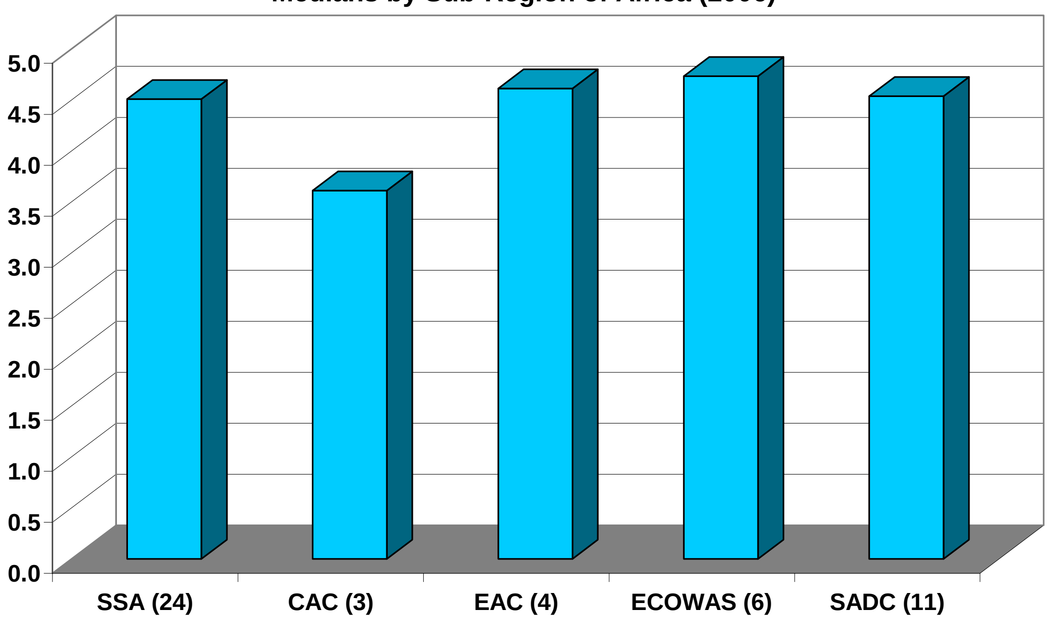

Question: The quality of the infrastructure is among the best in the world (1=strongly disagree; 7 =strongly agree).
Source: Global Competitiveness Report 2006.

**Figure A.8a Reliability of Telephones, Medians by Group (2006)**



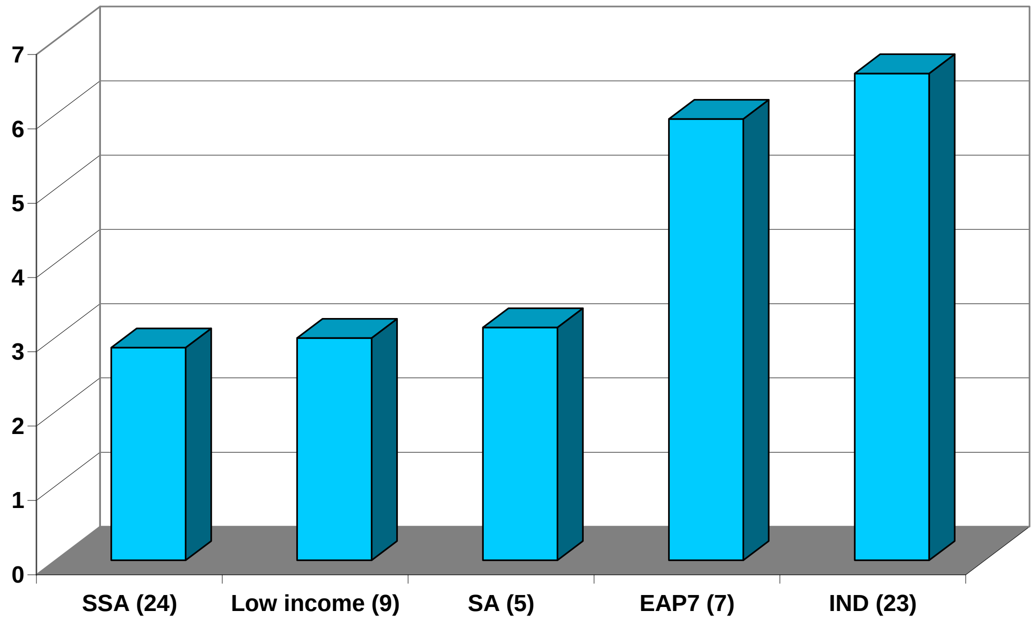

Question: Telephone lines have ample capacity and are highly reliable (1=strongly disagree; 7 =strongly agree).
Source: Global Competitiveness Report 2006.

**Figure A.8b Reliability of Telephones, Medians by Sub-Region of Africa (2006)**



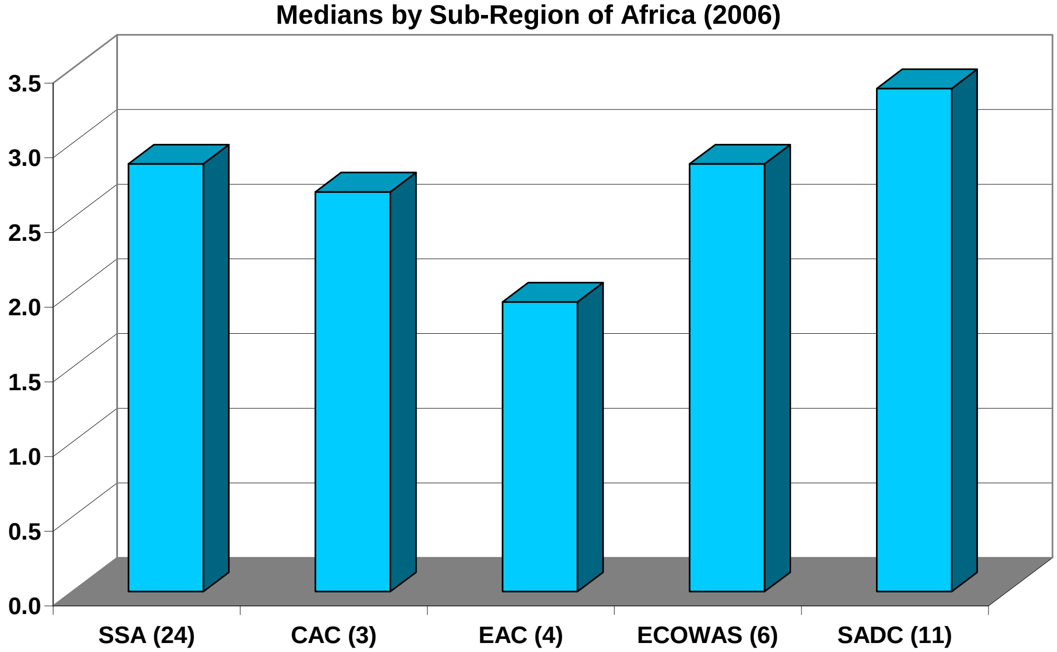

Question: Telephone lines have ample capacity and are highly reliable (1=strongly disagree; 7 =strongly agree).
Source: Global Competitiveness Report 2006.

**Figure A.9a Quality of Power Supply, Medians by Group (2006)**



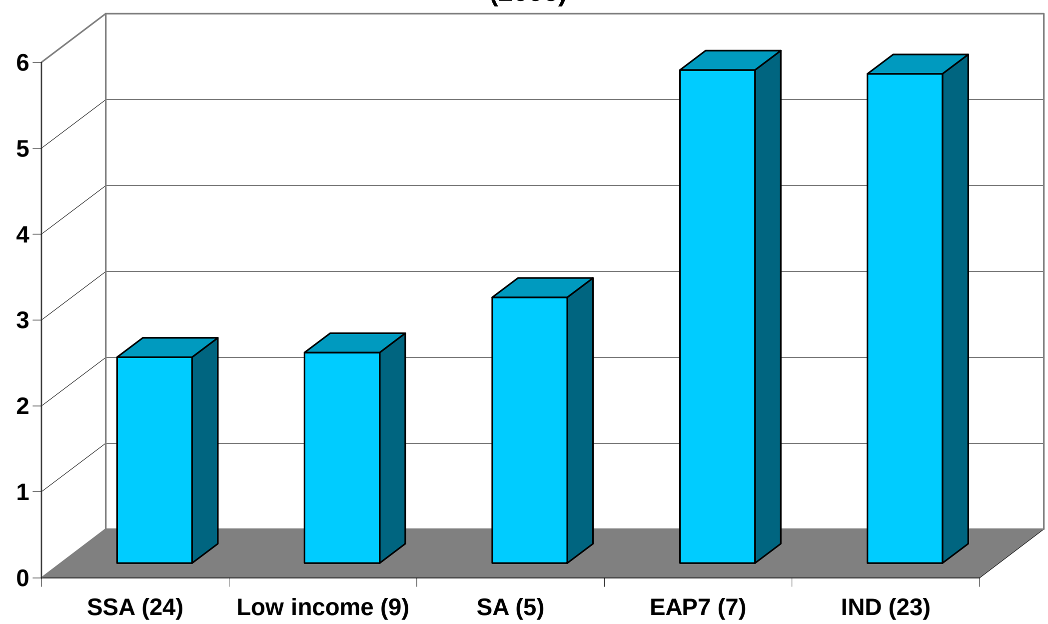

Question: Your country has sufficient power generation capacity (1=strongly disagree; 7 =strongly agree).
Source: Global Competitiveness Report 2006.

**Figure A.9b Quality of Power Supply, Medians by Sub-Region of Africa (2006)**



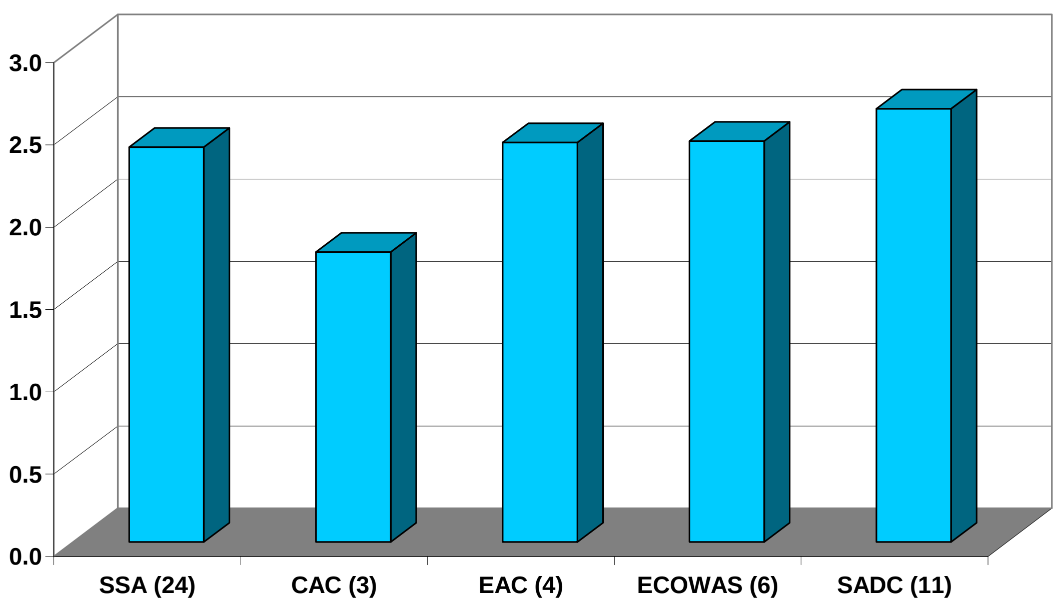

Question: Your country has sufficient power generation capacity (1=strongly disagree; 7 =strongly agree).
Source: Global Competitiveness Report 2006.

**Figure A.10a Road Infrastructure Quality, Medians by Group (2006)**



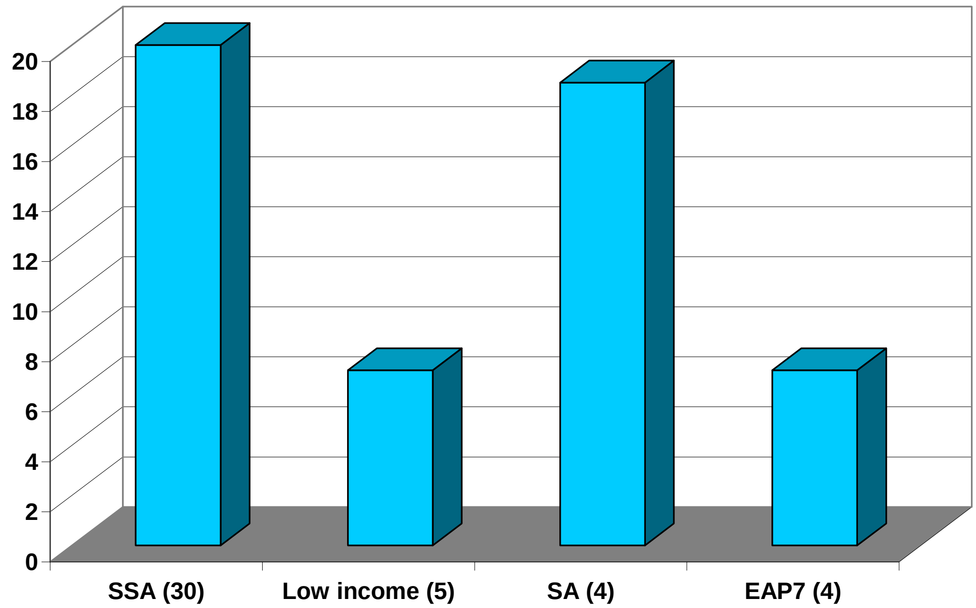

Question: Roads are extensive and well maintained (1=strongly disagree; 7 =strongly agree).
Source: Global Competitiveness Report 2006.

**Figure A.10b Road Infrastructure Quality, Medians by Sub-Region of Africa (2006)**



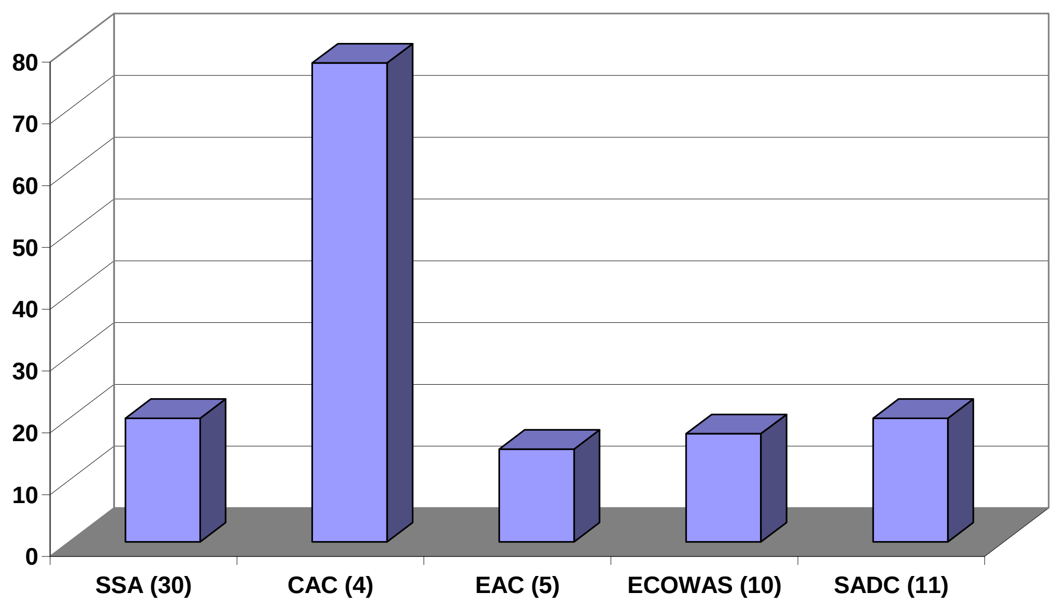

Question: Roads are extensive and well maintained (1=strongly disagree; 7 =strongly agree).
Source: Global Competitiveness Report 2006.

**Figure A.11a Actual Delay to Obtain Telephone Connection, Medians by Group (No. of days, latest years)**



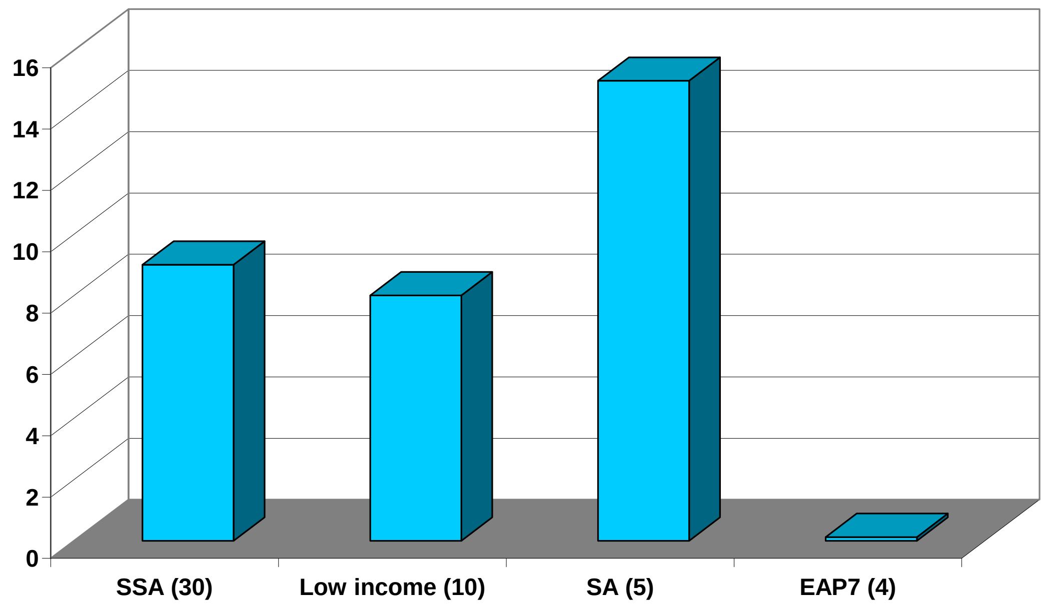

Source: ICA, The World Bank.

**Figure A.11b Actual Delay to Obtain Telephone Connection, Medians by Sub-Region of Africa (No. of days, latest years)**



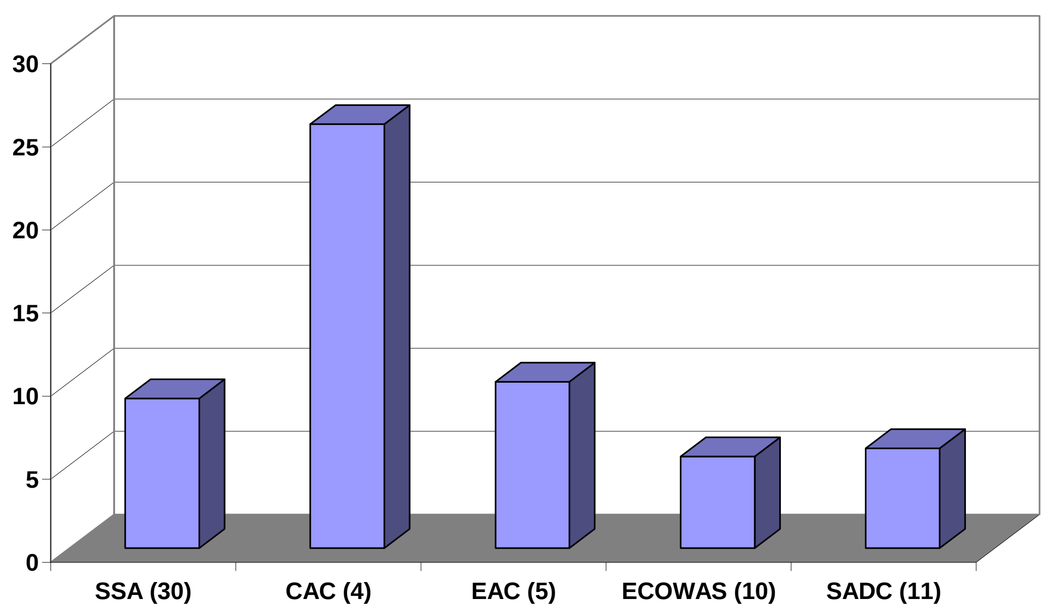

Source: ICA, The World Bank.

**Figure A.12a Power Outages, Medians by Group**
**(No. of days, latest years)**



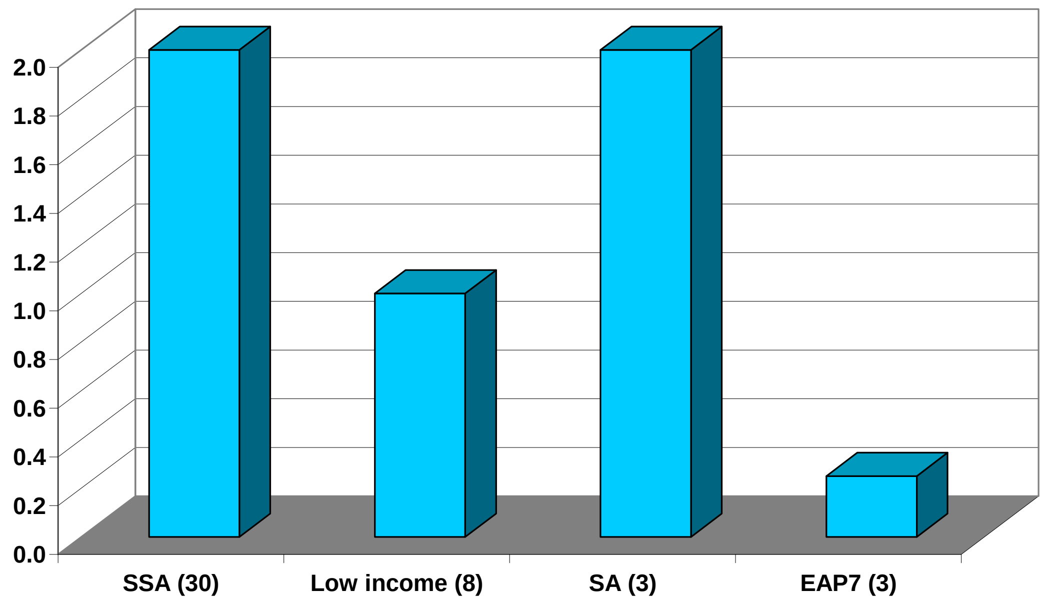

Source: ICA, The World Bank.

**Figure A.12b Power Outages, Medians by Sub-Region of Africa**
**(No. of days, latest years)**



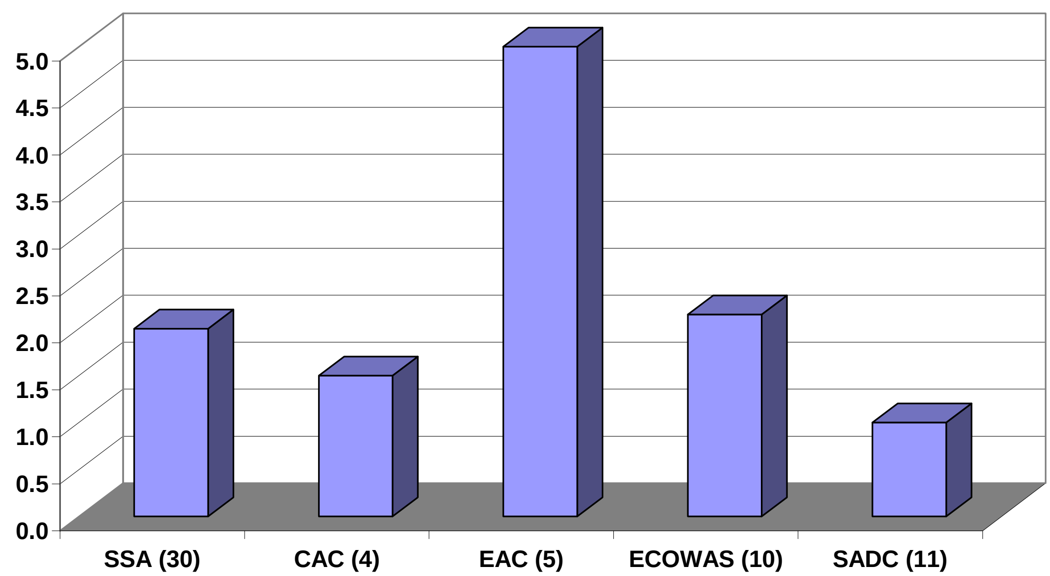

Source: ICA, The World Bank.

**Figure A.13a Sales Lost due to Power Outages, Medians by Group (percentage of total sales, latest years)**



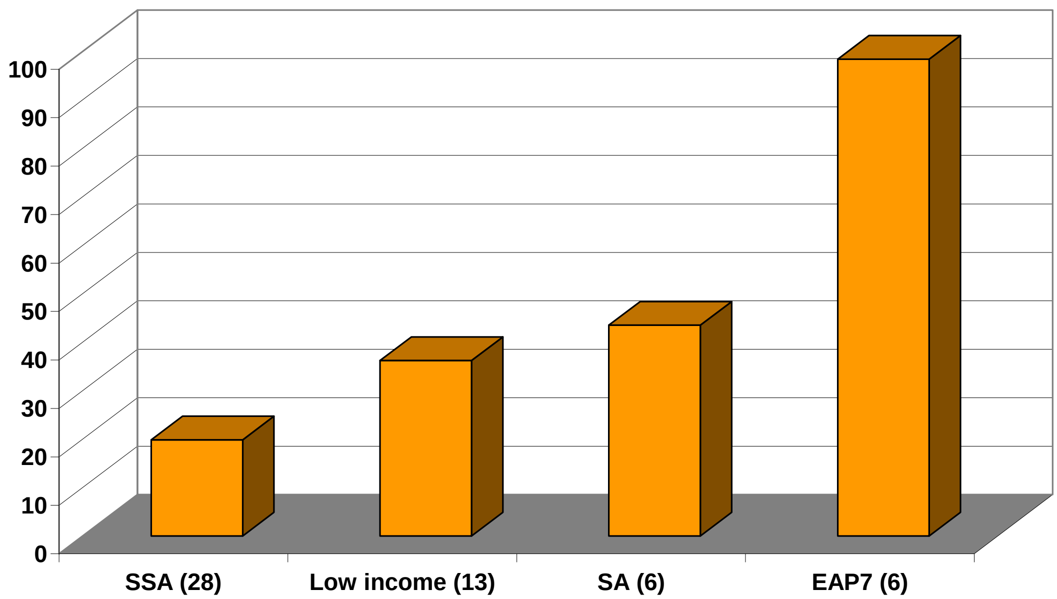

Source: ICA, The World Bank.

**Figure A.13b Sales Lost due to Power Outages, Medians by Sub-Region of Africa (percentage of total sales, latest years)**



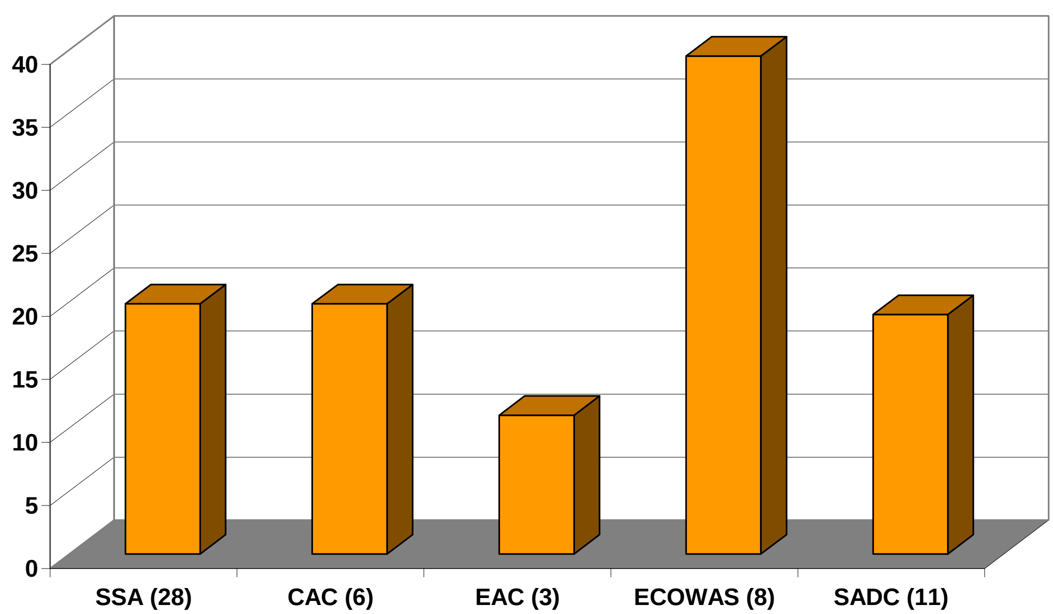

Source: ICA, The World Bank.

**Figure A.14a Access to Electricity by Group**
**(percentage of the population, 2006)**



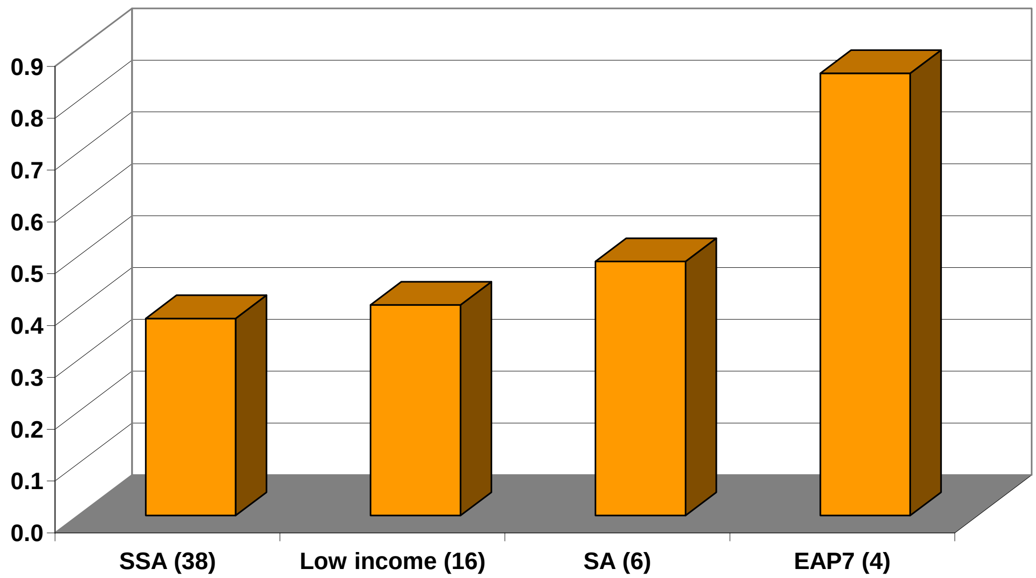

Source: World Energy Outlook 2006

**Figure A.14b Access to Electricity by Sub-Region of Africa**
**(percentage of the population, 2006)**



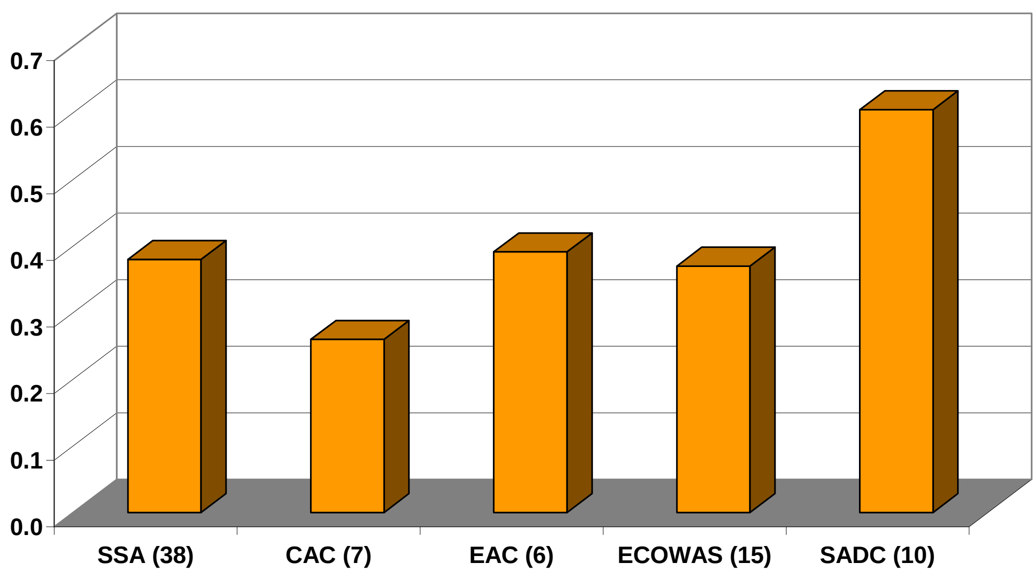

Source: World Energy Outlook 2006

**Figure A.15a Access to Transport by Group**
**(percentage of population who live within 2 km of all-season road)**
**(latest years)**



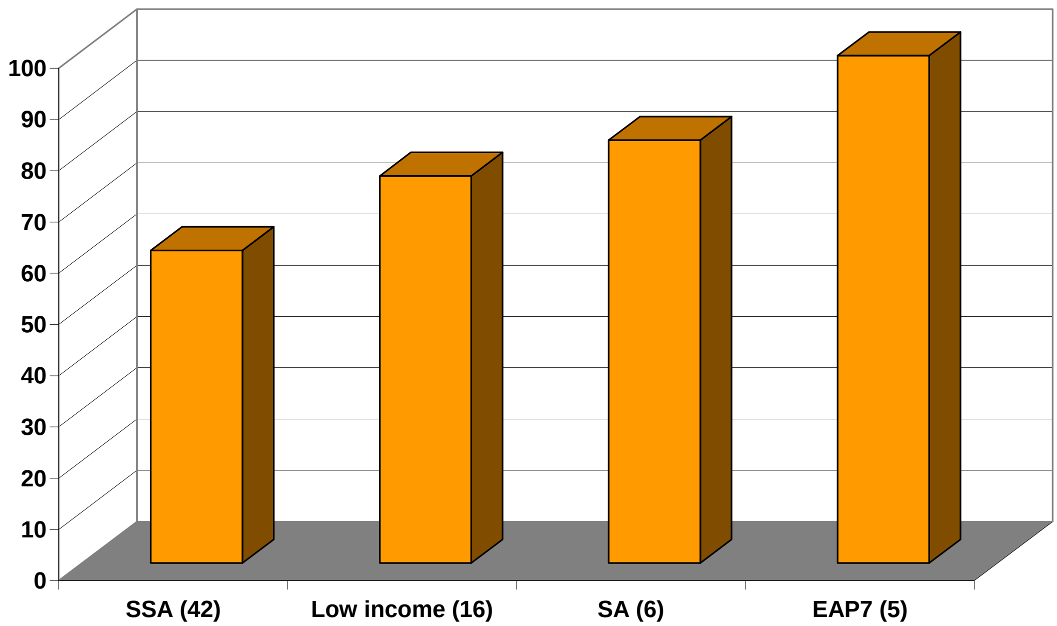

Source: Roberts, et al. (2006) "Rural Access Index: A Key to Development Indicator", The World Bank.

**Figure A.15b Access to Transport by Sub-Region of Africa**
**(percentage of population who live within 2km of all-season road)**
**(latest years)**



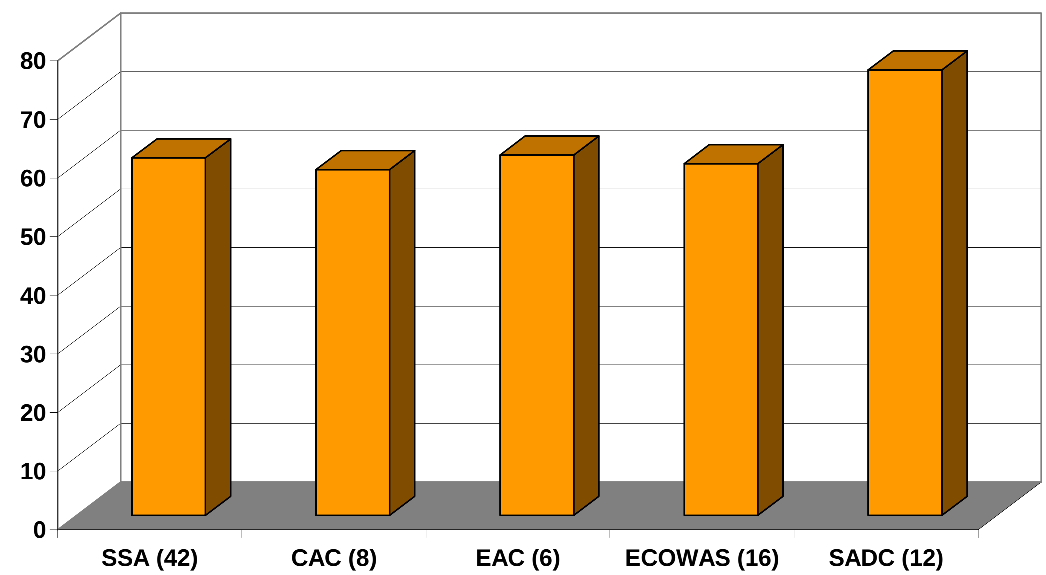

Source: Roberts, et al. (2006) "Rural Access Index: A Key to Development Indicator", The World Bank.

**Figure A.16a Access to Improved Water Source by Group (percentage of the population, 2004)**



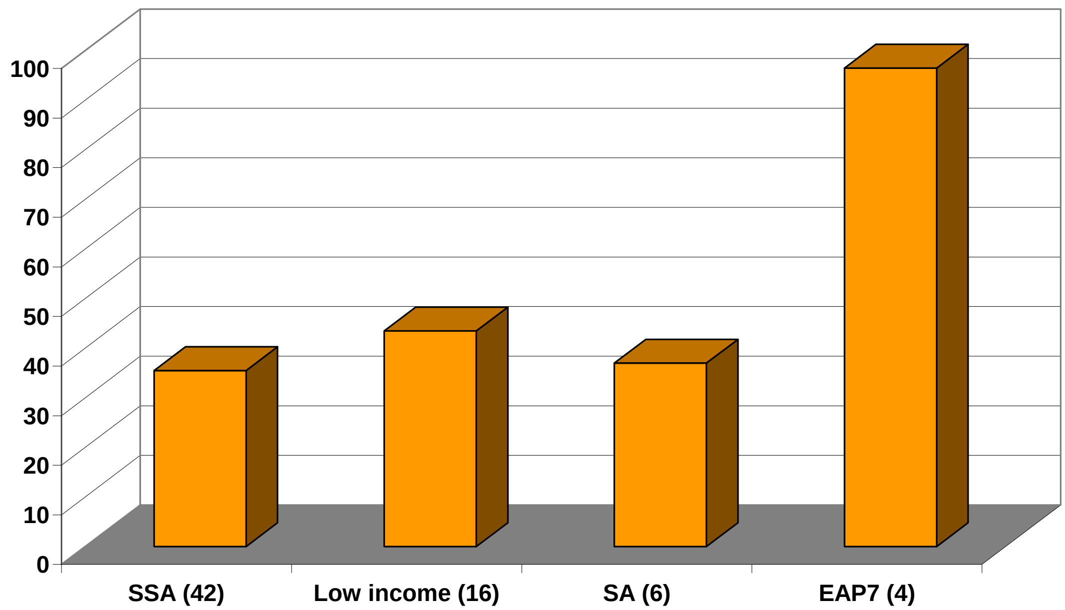

Source: WDI, The World Bank.

**Figure A.16b Access to Improved Water Source by Sub-Region of Africa (percentage of the population, 2004)**



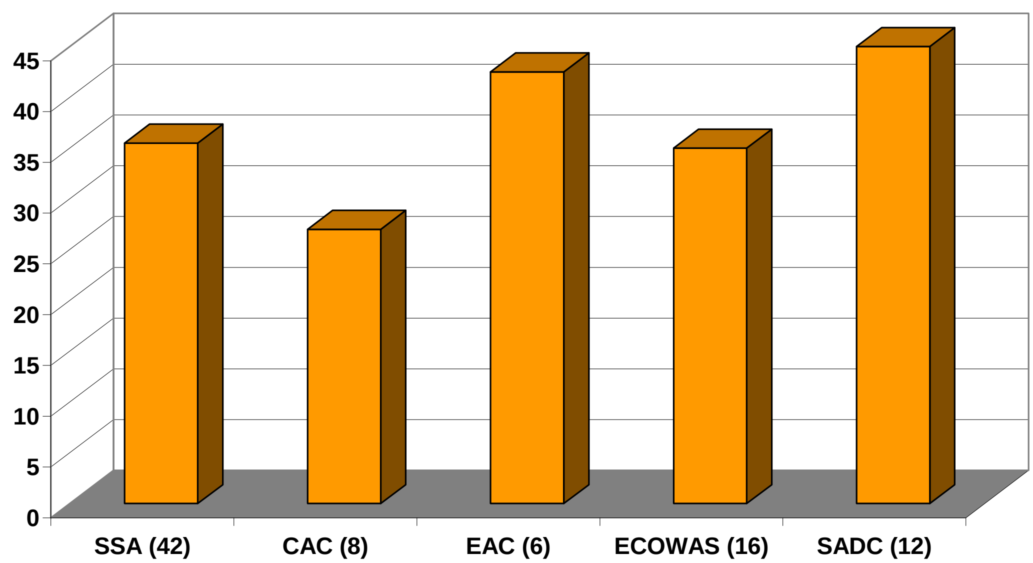

Source: WDI, The World Bank.

**Figure A.17a Access to Improved Sanitation Facilities by Group (percentage of the population, 2004)**




Source: WDI, The World Bank.

**Figure A.17b Access to Improved Sanitation Facilities by Sub-Region of SSA (percentage of the population, 2004)**




Source: WDI, The World Bank.