Nonlinearities in the Impact of Public-Private Infrastructure Investments the Long-Run Economic Growth: Evidence from African Countries

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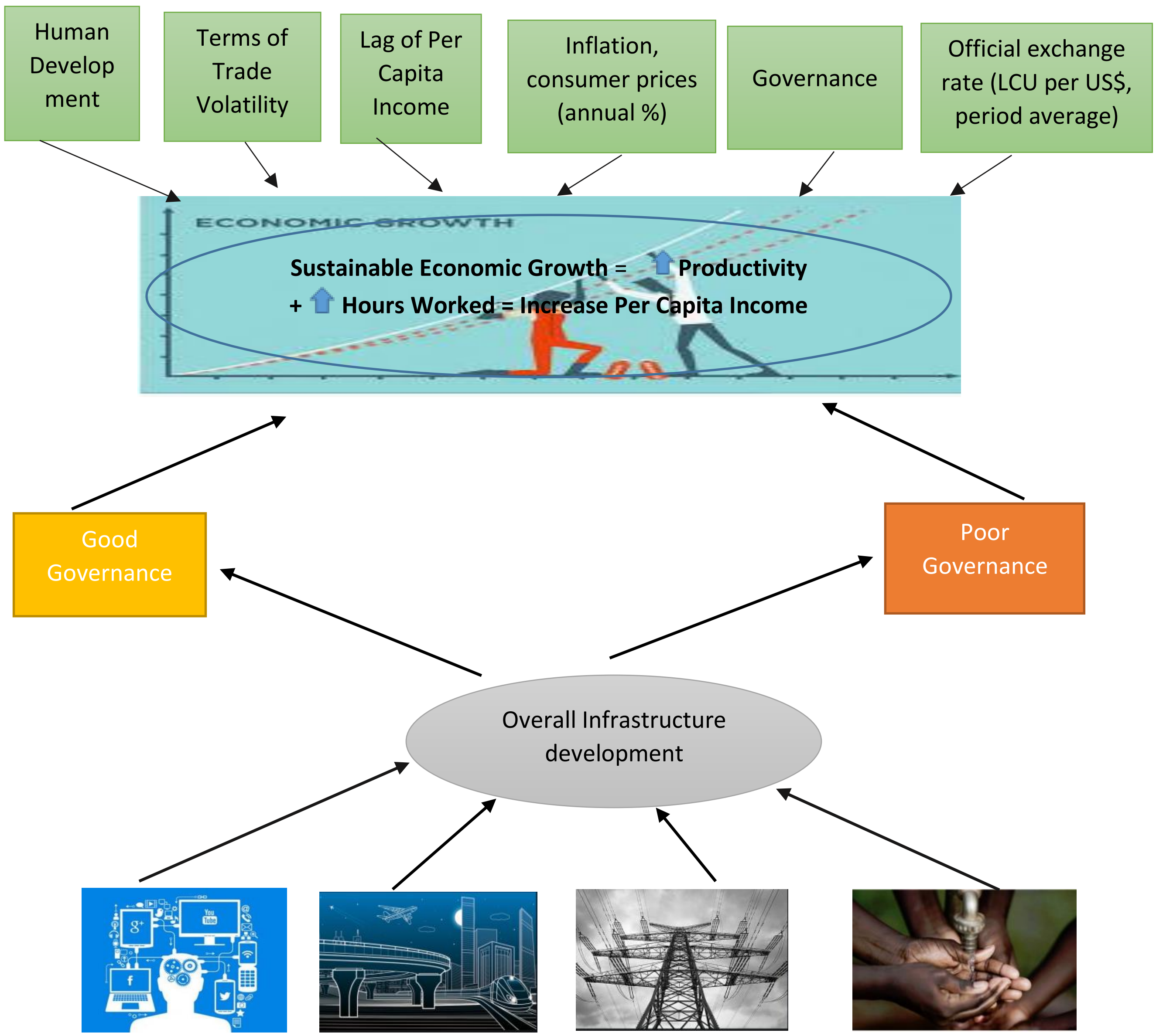
The basic objective of this study is to investigate the relationship between public and private infrastructure investments and the per capita income growth rate of African countries. Specifically, this study employs a threshold and quantile regression analysis to investigate nonlinearities in the relationship between infrastructure development and the economic growth rate of African countries. The study also analyzes the differential impacts of the various measures of infrastructure development and contributes to the existing literature by incorporating a more inclusive set of infrastructure indices and the possible nonlinearities that may exist between the infrastructure/economic growth rate nexus. We find governance thresholds in the impact of the overall, transport infrastructure, electricity, and ICT infrastructure indices on growth but not for access to improved water sources and sanitation facilities. From the quantile regression analysis, we find that the impact of the indices impacts each quantile of growth differently and that the growth impact of infrastructure may be magnified by good governance.

Key Words: Infrastructure, Economic Growth, Threshold, Quantile, Governance, African Economies

JEL Classification: H4, H54, O18, O55, R42

Graphical Abstract



1. INTRODUCTION

Numerous anecdotal evidence suggests that the African continent is among the world's most deficient regions in terms of infrastructure capacity. Transport, energy, sanitation, water, and telecommunication infrastructure investments have long been identified as the major bottlenecks for commerce and regional economic integration in Africa. More specifically, inadequate energy infrastructure investment continues to be Africa's largest impediment, exposing more than 30 countries to frequent power outages, restricting access to electricity to a third of Africa's population, reducing its productivity by as much as 40%, and curtailing its annual economic growth by about 2% (PIDA, 2014). Only 30% of African countries have access to electricity relative to 70-90% of other developing countries (Department of Infrastructure and Energy, Program for Infrastructure Development in Africa, 2018) In its Annual Development Effectiveness Review, the African Development Bank (AfDB) placed investment in reliable energy (infrastructure) among the "Top 5" priorities for accelerating the economic growth and development of the African content (AfDB, 2016). Consequently, a serious empirical study of the impact of infrastructure on the economic growth of the African continent is timely and relevant.

The most critical question is whether encouraging African policymakers to invest in more infrastructure will lead to a more sustainable economic growth rate and an increase in their citizen's wellbeing. The debate on this question is unsettled. While some studies find a positive infrastructure impact, others have found a negative or insignificant impact. Bhattasali and Thomas (2016) argue that infrastructure development can possibly have a positive impact on economic growth only if the focus is on the "quality and impact, not on quantity and the volume of investment." The controversial debates on the impact of public infrastructure investments on economic growth in the context of developed countries have been well documented. Early studies by Aschauer (1989), Munnell (1990, 1992), and Easterly and Rebelo (1993) find a significant and positive impact of infrastructure investment on economic growth. Apart from the debate on quality versus quantity of infrastructure investments and their differential impact on growth, there is a possibility that the mixed findings are due to the assumption of a linear relationship, thus, solely relying on the use of linear models. However, there is a possibility that the relationship may be nonlinear (Egert et al., 2009). De (2009) indicates that the level and quality of infrastructure in the Asian region is dependent on good governance, thus, providing further evidence of how crucial infrastructure is for the level and quality of infrastructure development. Other studies have also linked economic growth and development to good governance. These findings provide credence that the relationship between infrastructure development and economic growth may be linked to the quality of governance.

This study employs a more comprehensive panel data series for a cross-section of 50 African countries over the period 2003 to 2018 and employs a threshold and quantile regression in an effort to disentangle the controversy whether public infrastructure investment crowds, or promotes the economic growth of the African continent through the channels of job creation, the formation of capacities for domestic and regional economic integration, and enhancing the efficiency of the private investments rather than impeding the economic growth of African states (Fowler and Fayissa, 2007). Specifically, through the threshold and quantile regressions, we investigate whether the impact of infrastructure development on growth is different in good governance regimes as against bad governance regimes. Through the quantile regression analysis, we are also able to investigate whether the impact of infrastructure on growth depends on the level of economic growth of the economies in question. We, thus, contribute to the existing literature by considering the existence of nonlinearities in the infrastructure/growth nexus via the channels of governance and levels of economic growth for the overall infrastructure development, which we proxy with the African Infrastructure Development Index (AIDI), information and communications technology (ICT) infrastructure development, transport infrastructure development, electricity infrastructure development, and access to improved water and sanitation facilities. Preliminary results show that investment in infrastructure has a positive, but varying impact on the economic growth of African countries depending on their level of economic growth and their governance quality.

The rest of the paper is organized as follows. Section 2 presents a review of selected related literature. Section 3 presents an overview of our empirical methodologies and data employed. In section 4, we discuss our findings. Section 5 provides a summary of the conclusions and draws some policy recommendations based on the findings of the study.

2. REVIEW OF SELECTED LITERATURE

Economic policy analysts assert that there are five channels through which infrastructure may impact economic growth including: as a direct input into the production process serving as a factor of production, as a complement to other inputs into the production process, as a stimulant to factor accumulation by providing facilities for human development, through increased expenditure during construction and maintenance operations, and as a tool to guide industrial policy (Wolassa, 2012). While a significant number of empirical studies have found a positive causal impact of infrastructure on economic growth, however, the results are mixed for those using public capital stock, or infrastructure spending as their proxy (Konongo and Ojah, 2016).

In the context of the African continent, not many studies have investigated the relationship between infrastructure and growth. The majority of the existing literature is done on a country to country basis, with a significant number focused on South Africa due to data availability (See, Reinikka and Svensson, 1999; Fedderke et al., 2006; Wolassa, 2012). Furthermore, due to data availability, the existing panel analysis of the infrastructure/growth nexus for the continent of Africa tends to employ a single proxy for infrastructure (e.g. telephone mainlines), thus, disregarding the multidimensional measures of infrastructure and the possible heterogeneity of their impacts on remittances and economic growth (Konongo and Ojah, 2016). Only a few more recent studies have used a broader measure of infrastructure and sample of countries (See Estache et al., 2006, Calderón and Servén, 2010; Ndulu, 2011). Most of these studies have pointed to the low infrastructure development on the continent as a bane to economic growth because poor infrastructure reduces the trade competitiveness of the countries in the regions, increases the cost of doing business, and ultimately negatively impacts growth.

In a study of 19 African countries, Wolde-Rufael (2005) argues that there is a long-run relationship between energy use and economic growth. Wolde-Rufael (2006) also finds a long-run relationship between electricity consumption and economic growth. To verify the claims of African economic policymakers who attribute the anemic economic growth in Africa to the inadequacy of infrastructure investments, the Calderon and Serven (2010) study demonstrates the potential contribution of infrastructure to economic growth and equity across Africa. They confirm the positive role of infrastructure in the economic development of sub-Saharan African countries and the eradication of inequality in the region. Drawing on the existing literature of the various links through which infrastructure affects economic growth, Ndulu (2011) argues in favor of a big push in promoting infrastructure, not only to break the yoke of underdevelopment but also to be on the path of sustained growth. He further argues that infrastructure investment facilitates equitable growth by improving basic services to the poor (access to electricity, clean water, and roads to connect rural to urban areas). In a study of 45 sub-Saharan African countries for the 2000-2011 period, Kodongo and Ojah (2016) find that the main positive impact of infrastructure on growth is dependent mainly on infrastructure spending and increments in the access to infrastructure. Further, they find that infrastructure development is much more important for low-income African countries. This finding points to the issue of nonlinearities on the dependent variable side. Calderon (2009) using a panel of 39 African countries and three infrastructure indices (telecommunications, electricity, and roads) created from principal component analysis (PCA) and dynamic panel models find that infrastructure stocks and service quality boost economic growth. Most of the previous studies of the infrastructure/growth nexus in Africa have been based on a single infrastructure measure including telephone mainlines, or road networks, or electricity generation, and sanitation facilities amongst others. This practice has been mostly due to limited data availability, and/or the concern of the collinearity amongst infrastructure asset types.

Calderon (2009) is the first study on the infrastructure/growth nexus for Africa that employs PCA to get indices that circumvent the collinearity between the multidimensional infrastructure sectors including telecommunications, electricity, and roads. Using an econometric technique suitable for dynamic panel data models and likely endogenous regressors, the authors find that infrastructure stocks and service quality boost economic growth. Recently, using more complete infrastructure data from the African Development Bank (African Infrastructure Development Index (AIDI)) for 45 sub-Saharan African countries from 2000-2011, Konongo and Ojah (2016) conclude that spending on infrastructure and improvements in access to infrastructure positively impact the economic growth of the area. The index has nine indicators that cover four key components including transportation, electricity, water and sanitation, and communications technologies (ICT). This is the first study on the African growth/infrastructure nexus that fully accounts for the multidimensional nature of infrastructure. In a study of 100 countries for the period spanning 1960 to 2005, Konongo and Ojah (2016) found that infrastructure development may contribute to economic growth. Comparatively, however, they find that on average infrastructure development has a smaller contribution to growth in sub-Saharan Africa than other regions of the world.

The impact of infrastructure on the African growth experience is not straightforward, however. For example, in a study of sub-Saharan African countries, Andrianaivo and Kpodar (2011) find that the economic impact of mobile phone use is stronger when paired with credit to the private sector. Wamboye et al. (2015) argue that financial deepening serves as the conduit through which mobile phone use can impact growth through inducing of labor productivity. Similarly, Kumar (2012), shows that fixed phone lines development has a direct negative impact on the economic growth of African countries. He, however, finds that the impact becomes positive when paired with financial development.

The only study that has directly considered nonlinearities in the infrastructure/growth nexus in the case of African countries is that of Albiman and Sulong (2016), which investigate non-linearities in the impact of infrastructure on growth using a threshold analysis. However, their analysis is only based on ICT, leaving out other measures of infrastructure development. They find that mobile phones and the internet have a direct impact on growth, however, from their threshold analysis, they find that overall mass penetration of ICT slows economic growth. In particular, the penetration of mobile phones and the internet slows down economic growth after a threshold of 4.5 percent for both mobile phones and the internet is reached, and 5 percent for fixed telephone mainlines.

From the above literature review, it is clear that only one of the previous studies on the infrastructure/ growth nexus for Africa has analyzed the possible nonlinear relationship between infrastructure quality and access (together termed infrastructure development) and economic growth. Our study fills this gap by analyzing two avenues of a possible nonlinear relationship between economic growth and infrastructure development. Specifically, we seek to investigate whether the infrastructure development impact on growth depends on the quality of governance. Second, acknowledging that the impact of infrastructure development may depend on the level of economic growth, we also employ a quantile regression analysis to investigate the possible heterogeneity in the impact of infrastructure development based level of economic/income growth spectrum and the various measures of the infrastructure dimensions.

3. Empirical Methodology

3.1 Empirical Models

Under the assumption of linearity, most previous studies (especially on advanced economies) have invariably applied several estimation techniques to test the relationship between infrastructure development and economic growth. For example, in a study of 45 sub-Saharan African countries, Albiman and Sulong (2016) find that mobile phones and the internet were the main economic growth drivers in the long-run. However, in recent years, some studies have pointed out the possibility of nonlinearities in the infrastructure/growth nexus. For example, Henckel and McKibbin (2017) argue that the economic benefits from investments in transport infrastructure may be nonlinear due to network externalities indicating decreasing benefits to additional highway construction in economies with an already existing efficient transport network. This finding indicates that there can exist a threshold of transport infrastructure network beyond which its impact on the economy diminishes. Similarly, Röller and Waverman (2001) in a study of 100 countries found that the impact of telecommunications 21 OECD countries is substantially higher for countries with their penetration approaching universal coverage.

In our study, we argue that the nonlinear relationship between the infrastructure development and economic growth may arise from two possible sources: (i) quality of governance (good governance vs. bad governance), or (ii) the level of economic growth. This distinction is important because factors that are relevant at the lower end of the economic growth distribution may not be as important at the higher end of the income growth distribution, or the effectiveness of infrastructure may be conditional on the governance quality.

In order to analyze the possible existence of nonlinearity in the relationship between infrastructure development and economic growth, we use the threshold regression technique. Subsequently, we also analyze the difference in the impact of infrastructure development at different levels of GDP growth using a newly developed unconditional fixed-effects quantile estimation technique using panel data (henceforth, known as UQR model).

We first use the fixed-effects panel threshold model postulated by Hansen (1999) to analyze the possible nonlinear relationship between the African economic growth experience and infrastructure development by specifying a baseline-panel regression model presented in Equation (1) below.

$$y_{it} = \alpha_i + \delta q_{it} + \beta_i X_{it} + \varepsilon_{it}, \tag{1}$$

where y_{it} denotes the growth rate experienced in country i at time period t $(1 \leq i \leq N)$ and $(1 \leq t \leq T)$, respectively. α_i and ε_{it} denote country-specific fixed-effects and random errors, respectively. q_{it} denotes the infrastructure development proxy for country i at time period t and X_{it} is a k-dimensional vector of time-varying control variables commonly used as economic growth determinants in previous literature. To operationalize Equation (1), we conjecture a case of one threshold by transforming Equation 1 to obtain Equation 2 below.

$$y_{it} = \alpha_i + \delta_1 q_{it} I(q_{it} < \gamma) + \delta_2 q_{it} I(q_{it} \geq \gamma) + \beta_i X_{it} + \varepsilon_{it}, \tag{2}$$

where γ is the threshold that demarcates the two regimes (regime 1 and regime 2), $I(.)$ is the indicator function that identifies the two regimes, and δ_1 and δ_2 are the slopes of the threshold variable in region 1 and region 2, respectively. y_{it}, α_i, q_{it}, X_{it}, and ε_{it} are as described above. We then test the validity of the threshold model in comparison with its linear counterpart using the following F-statistic:

$$F_1 = \frac{(S_0 - S_1)}{\hat{\sigma}^2} \tag{3}$$

where S_0 is the residual sum of squared errors of a linear model, S_1 is the residual sum of squared errors of the panel threshold estimate model, and $\hat{\sigma}^2$ is the residual variance of the panel threshold estimation. Following Hansen's (1999) recommendation for obtaining asymptotically valid p-values, we also bootstrap our estimate. The null hypothesis of the non-identification of γ (no threshold effect → linear relation) and its accompanying alternate hypothesis of the existence of at least one threshold given as follows:

$$H_0: \delta_1 = \delta_2 \qquad\qquad H_a: \delta_1 \neq \delta_2$$

Note that under the null hypothesis of no threshold effect, the model specified in Equation (2) reduces to the linear model specification given in Equation (1). In some cases, it is technically possible that more than one threshold exists. If one were to estimate a two-threshold system, the model presented in Equation (2) can be rewritten without loss of generality as follows:

$$y_{it} = \alpha_i + \delta_1 q_{it} I(q_{it} < \gamma_1) + \delta_2 q_{it} I(\gamma_1 \leq q_{it} < \gamma_2) + \delta_3 q_{it} I(q_{it} \geq \gamma_2) + \beta_i X_{it} + \varepsilon_{it} \qquad (4)$$

In this case, our threshold estimates, $\{\gamma_1, \gamma_2 \in \mathbb{R} | \gamma_1 < \gamma_2\}$, divide our analysis into three distinct regimes that produce regime-dependent coefficients δ_1, δ_2, and δ_3, respectively. Similar to the F-test for a single threshold model, we can analyze the significance of the second threshold by estimating another F-statistic as given below:

$$F_2 = \frac{\{S_1(\hat{\gamma}_1) - S_2^r(\hat{\gamma}_2^r)\}}{\hat{\sigma}^2} \qquad (5)$$

where $S_1(\hat{\gamma}_1)$ denotes the residual sum of squared errors from stage one threshold estimation and $S_2^r(\hat{\gamma}_2^r)$ and $\hat{\sigma}^2$ are the residual sum of squared errors and the residual variance from the second threshold estimation, respectively. Given that the threshold effect is sequential, rejecting the null hypothesis for one level of threshold (say, the single threshold) implies automatically testing for the existence of the next threshold (the second threshold). In our analysis, we will test up to three thresholds using the STATA command XTHREG developed by Wang (2015).

The impact of infrastructure at different levels of the income growth distribution should be of interest to policymakers as well. The question we seek to answer here is if infrastructure development is impactful at the lower end of the GDP growth, or more effective at the higher end of the GDP growth of countries. The answer to the question obviously begs the use of quantile regression estimation.

Unlike the traditional ordinary least-squares regression analysis which provides estimates for the conditional mean of explanatory variables, quantile regression provides analysts the ability to estimate models for a full range of conditional quantile functions as introduced by Koenker and Basset (1978). Quantile regression has three major advantages over the traditional models. First, the estimated coefficients are not sensitive to the dependent variables' outliers because a quantile regression provides estimates on the median rather than mean estimates. Second, quantile regression provides a description of the entire conditional distribution of the dependent variable. Lastly, the quantile regression also provides more statistically efficient estimates of the error term, which is non-normal.

Specifically, we employ an unconditional quantile regression (UQR) based on the work of Firpo et al. (2009) and has been normalized into a STATA via the XTRIFREG estimation function developed by Borgen (2016). Unlike previous quantile regression estimation methods that are conditional quantiles (Koenker, 2004; Harding and Lamarche, 2009), our model is based on unconditional quantile estimates, which allows us to further divide the growth structure and the composition effects into the contribution of each covariate. On the whole, this methodology is unique in its capability to separate the overall components of the decomposition into the contribution of a single variable, or a group of variables. It will allow us to draw inferences on our covariates, especially our infrastructure measures which remain invariant across the entire distribution of GDP growth.

The estimation methodology involves the regression of the re-centered influence function (RIF) of the dependent variable (the per capita income growth rate on all regressors X) which makes the estimation of the contribution of each regressor for the components of the income growth decomposition. To estimate our unconditional quantile regressions, we have to first derive the RIF of our dependent variable (the per capita income growth rate). The RIF for the τ^{th} quantile is specified as follows:

$$RIF(y;\ q_\tau, F_y) = q_\tau + \frac{\tau - I\{y \leq q_\tau\}}{f_y(q_\tau)} \tag{6}$$

where q_τ is the sample quantile estimated by kernel approach, F_Y denotes the cumulative distribution function, $f_Y(q_\tau)$ and $I(Y \leq q_\tau)$ denotes the marginal density of our dependent variable (Y) at the point q_τ and an indicator function reflecting whether the outcome value is below q_τ, respectively. We can infer that the RIF allows for a linear approximation of a nonlinear function and the RIF quantile regression may be implemented using linear regression of the new transformed dependent variable on the explanatory variables X_i. In our particular case, we have 47 countries for which the RIF regressions for the per capita income growth can be estimated using Equation 7 given below:

$$E[RIF(Y_{it}; q_\tau|X_{it})] = X_{i,t}\beta_{\tau,i} \tag{7}$$

where $\beta_{\tau,i}$ denotes the approximation of the marginal effects of our explanatory variables on the per capita income growth rate quantile q_τ for countries i, 1,.., 47. Basically, the model fits a regression model of the RIF of the quantile marginal distribution of the dependent variable (per capita income growth rate) on the explanatory variables. Here, the RIF regressions can be interpreted as unconditional quantile regressions, where the dependent variable is replaced with the transformed (re-centered) influence function of the quantile in question.

3.2 Empirical Analysis & Data

Our sample consists of 47 African countries (see, Appendix 1) between 2007 and 2017. The decision to use this set of countries was solely dictated by data availability and the need for a balanced panel for the period of our study. The final sample has 417 country-year observations.

The dependent variable is the per capita GDP growth rate (*PCIGR*). The main variables of interest are our proxies for infrastructure development. We follow previous literature to select the most often used explanatory variables in the growth literature (e.g., Barro, 2003; Ndoricimpa, 2017).

The control variables in our regressions include the one-period lag of the log of per capita income (L*PCI*), broad money as a percent of GDP (*MONEY*), semi-log of the inflation rate (*INFLA*) which proxies macroeconomic stability, and square-root of the terms of trade (*TOTSTD*) which controls for the global product market competitiveness, the log of mean years of schooling (*MYSCH*) which controls for human capital formation, and the log of governance index (*GINDEX*) which captures the quality of good governance.

We follow Ibarra and Trupkin (2016) and use the semi-log transformation of the inflation rate following equation (8) to transform our inflation rate into a symmetric distribution.

$$\pi = \begin{cases} \pi_{it} - 1, if\ \pi_{it} \leq 1 \\ ln(\pi_{it}), if\ \pi_{it} > 1 \end{cases} \tag{8}$$

where π_{it} denotes the inflation rate for country i at time period t. Thus, the semi-log transformation of the data for the inflation rate follows the inflation augmentation process, i.e. when the inflation rate is at most unity, or less, we reduce it by one, and when the inflation rate exceeds unity, we take its natural logarithm.

3.2 Data

For this study, we employ data covering the period of 2007 to 2017. Our infrastructure indices are from AfDB's 2018 African Infrastructure Development Index (AIDI). We employ the overall index (OII), along with its sub-categories of electricity index (ELI), transport index (TPI), information and communication technologies index (ICT), and water supply and sanitation index

(WSS) in other to investigate the overall impact of infrastructure development and also the heterogeneity in the impact of different the different infrastructure dimensions. The indices capture access and to some extent the quality of the particular dimension of infrastructure. For example, for the transport composite index (TPI) captures both road networks and paved roads. While the total road network captures access per capita, the total paved roads capture per km of exploitable land area capture quality. The electricity index (ELI) captures total electricity production and imported in millions of kilowatt-hours produced per hour and per inhabitant. The ICT composite index (ICT) includes phone subscriptions per capita (including fixed lines and mobile subscriptions), the number of internet user's per capita, fixed broadband subscribers per capita and international internet bandwidth. Lastly, the water and sanitation composite index (WSS) includes the percentage of the population with access to an improved water source and improved sanitation facilities. The AIDI is the normalized composite index calculated using the four sub-indices. The AIDI and the other composite infrastructure sub-indices made up of more than one indicator are computed as a weighted average of the indicators which makes up each sub-index.

Our dependent variable is the growth rate of the real GDP per capita (PCI). This and all of our other control variables are from the World Bank's World Development Index dataset, except for the governance indicator (GINDEX) which is constructed from governance data from the World Bank's World Governance Index and from the Center for Systematic Peace (CSP). The GINDEX is a composite index computed from the subcomponents of voice accountability, political stability, government effectiveness, regulatory quality, rule of law, corruption control, and Polity2 a proxy for democracy from the CSP. In creating our GINDEX, first, each index is standardized to values between 0 and 100 [(xi-min)/(max-min)]. Then, the indices are summed to form one governance index (GINDEX).

4. Empirical Results

4.1 Single Threshold Analysis

Table 1 below describes the variables, presents summary statistics, and variable sources.

Table 1 Variable Description, Summary Statistics, and Variable Sources.

Variable	Description	Mean	SD	Min	Max
PCIL	GDP per capita - one lag	2,524.38	3,293.23	219.96	20,512.94
PCIG	GDP capita rate growth rate (%)	1.98	7.38	-62.38	121.78
OII	Infrastructure Index	21.35	17.77	1.96	85.66
TPI	Transport Composite Index	10.03	11.81	0.38	58.70
ELI	Electricity Composite Index	9.75	18.35	0.01	100.00
ICT	ICT Composite Index	6.48	9.64	0.01	66.08
WSS	WSS Composite Index	50.10	20.59	12.35	99.01
GINDEX	Governance Index	381.76	118.20	134.42	666.94
MYSCH	Mean Years of Schooling	4.93	2.04	1.30	10.20
TOTV	Terms of trade variability	0.01	0.11	-0.54	0.33
INFLA	Inflation	6.61	8.83	-29.69	60.70
XRATE	Exchange Rate	623.51	1,241.58	0.94	9,088.32
MONEY	Broad money (% of GDP)	40.40	35.56	6.48	289.36

Notes: The annual data for 47 African countries span over the 2007-2017 period. The first per capita income period lag is for 2006. All data are from the World Development Indicators apart from MYSCH (Human Development Indicators), the POLITY2 (Center for Systematic Peace), and the other governance indicators from the World Governance Index.

To avoid selecting the number of thresholds for this model arbitrarily, we first proceed with the test for the existence of a single threshold. Our null hypothesis, $H_0: \delta_1 = \delta_2$ indicates the absence of a threshold and our alternate hypothesis, $H_a: \delta_1 \neq \delta_2$ indicates the presence of a single threshold. Upon rejecting the null, we then proceed and test for three thresholds and work our way up, or down to arrive at the appropriate number of thresholds. We use 1,000 bootstrap replications to estimate and test for the existence of a single threshold effect. Tables 2 and 3 report the findings of the threshold analysis. In Table 2, we find that only a single threshold in the relationship between infrastructure development and economic growth occurs when the governance indicator (GINDEX) is 5.316, with a 95% confidence interval between 5.30 and 5.32. The threshold remains the same for transportation, electric, and water and sanitation infrastructure. However, for electricity and water and sanitation infrastructure, the confidence band changes to 5.29-5.32 and 5.30-5.32, respectively. In the case of ICT, the threshold is slightly lower at 5.30, with a confidence band of 5.27 to 5.30 of the GINDEX.

Table 2 Estimation of models with unitary thresholds.

Variable	Description	Threshold	95% CI	
			Lower	Upper
OII	Overall Infrastructure Composite Index	5.30	5.30	5.32
TPI	Transport Infrastructure Composite Index	5.32	5.30	5.32
ELI	Electricity Infrastructure Composite Index	5.32	5.29	5.32
ICT	ICT Infrastructure Composite Index	5.30	5.27	5.30
WSS	Water and Sanitation Composite Index	5.32	5.30	5.32

Note: Threshold Estimator (Confidence level $= 95\%$), with 1000 bootstrap estimates

The results of the tests of significance for the single threshold are reported in Table 3. The calculated F-statistic of greater than the critical value of 37.28 ($\text{p-value} < 10\%$), 52.31 ($\text{p-value} < 5\%$), 34.07 ($\text{p-value} < 10\%$), and 40.56 ($\text{p-value} < 5\%$), for overall infrastructure, transport, electric and ICT infrastructure index models, respectively, suggesting the existence of one, or more thresholds in the relationship between the proxies for infrastructure and per capita income growth based on the GINDEX, thereby rejecting the null of linearity in favor of non-linearity. However, for the WSS index, the p-value is greater than 10%, thus, failing to reject the null of linearity.

Table 3 Test for the unitary threshold models

Variable	Variable Name	RSS	MSE	Fstat	Prob	Crit10	Crit5	Crit1
OII	Overall Infrastructure Composite Index	17,900	35.47	37.28	0.06	28.30	39.23	71.66
TPI	Transport Infrastructure Composite Index	17,600	34.69	52.31	0.03	29.71	38.36	114.14
ELI	Electricity Infrastructure Composite Index	18,200	35.99	34.07	0.07	25.97	42.09	95.94
ICT	ICT Infrastructure Composite Index	17,700	34.98	40.56	0.01	22.17	26.74	37.40
WSS	Water and Sanitation Composite Index	17,800	35.17	24.37	0.15	29.03	33.75	119.86

Note: Threshold Estimator (Confidence level= 95%), with 1000 bootstrap estimates

4.2 Multiple Threshold Analysis

Next, we proceed to estimate double and triple threshold models to assess whether higher-order thresholds exist in defining the relationship between infrastructure development and the per capita income growth via the GINDEX. Once again, we employ the bootstrap method to approximate the test statistic. Similar to the single threshold analysis, the single threshold for the multiple threshold analysis is significant at less than 10% level for the overall, transport, electric and ICT infrastructure development proxies, with the exception of the WSS index. The double and triple threshold test statistics are, however, statistically insignificant with p-values of greater than 10% for all of our infrastructure development proxies. Thus, we can empirically validate the existence of only a single governance threshold in the relationship between infrastructure development proxies and the per capita income growth for all of the infrastructure development proxies, with the exception of the proxy for water and sanitation.

4.3 The Growth Threshold Model

We now re-estimate four models with a single threshold for the infrastructure proxies that exhibit a governance threshold in their impact on economic growth and present the results in Table 4. By setting our models this way, we split our sample into two regimes based on the threshold variable $GINDEX_{it}$ and its value γ. That is, the first regime includes countries where the governance indicators are below the threshold ($\leq \gamma$) and the second regime includes countries where the governance indicator is above the threshold ($> \gamma$).

To implement Equation (4) for our empirical estimation framework, we specify Equation (9) as follows:

$$
\begin{aligned}
PCIG_{it} = \alpha_{it} + \delta_1 \log(INFRA_{fit}).I(GINDEX \leq \gamma) \\
+\ \delta_2 \log(INFRA_{fit}).I(GINDEX_{it} > \gamma) + \beta_1 \log\left(PCI_{i,t-1}\right) \\
+ \beta_2 \log(MYSCH_{it}) + \beta_3 \log(XRATE_{it}) + + \beta_4 \log(TOTSD_{it}) + \beta_5 log\pi_{it} \\
+ \beta_6 \log(GINDEX_{it}) + \beta_7 \log(MONEY_{it}) + \varepsilon_{it}
\end{aligned} \tag{9}
$$

Table 4 presents the results for the four models we estimated for our threshold analysis. Model 1 presents the results in which the composite index of all the indicators of infrastructure is used. Here, we observe that the control variables including broad money (% of GDP), inflation, mean years of schooling and governance are statistically significant as is the lag of per capita income. The lag of per capita income has a statistically significant negative impact on current per capita income growth, indicative of the existence of convergence (the catch-up effect). In the case of broad money as a percent of GDP (used as a proxy for financial development), we find that a one percent increase results in a 4.79% decrease in GDP growth.

We find that a percentage increase in inflation is associated with a 0.23% increase in GDP. This finding is also interesting since we would normally expect increased inflation to be associated with decreased economic growth, however, our results may be pointing out to the fact that after taking out the monetary effect of inflation, other sources of inflation may have a positive impact on growth. We also find that good governance and education lead to improved economic growth. Specifically, we find that a 1% increase in mean years of schooling and governance index leads to a 0.1349 and 0.1348 percent respectively in economic growth for the period under considerations. These findings are very similar in the other models barring a few changes in the level of significance and the magnitude of the impacts discussed above.[1]

[1] As argued by some, economic growth may not occur without an appropriate level of money supply, credit, and sound financial conditions (Siyasanga and Hlalefang, 2017).

Table 4 Full Single Threshold Panel Regression Estimates.

		Model 1		Model 2		Model 3		Model 4	
		Overall Composite Index		Transport Composite Index		Electricity Composite Index		ICT Composite Index	
Variable	Description	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
Control Variables									
log(PCIL)	Log of one period lag GDP per capita	-0.4215	0.0351 ***	-0.4044	0.0342 ***	-0.4070	0.0349 ***	-0.4737	0.0353 ***
log(money)	Log of Broad money (% of GDP)	-0.0479	0.0127 ***	-0.0392	0.0126 ***	-0.0432	0.0128 ***	-0.0537	0.0131 ***
TOTSTD	Square root of Net barter terms of trade index (2000 = 100)	0.0070	0.0318	0.0029	0.0313	0.0005	0.0319	0.0028	0.0314
πlog	Semi-log transformation of inflation rate	0.0023	0.0011 **	0.0023	0.0011 **	0.0022	0.1070 **	0.0018	0.0011 *
log(MYSCH)	Log of Mean years of schooling	0.1349	0.0529 ***	0.1970	0.0448 ***	0.1915	0.0461 ***	0.0636	0.0565
log(XRATE)	Log of exchange rate (Local currency to US dollar)	0.0076	0.0177	0.0192	0.0164	0.0207	0.0165	0.0119	0.0176
log(GINDEX)	Log of Governance Index	0.1348	0.0596 **	0.1202	0.0586 **	0.1610	0.0590 ***	0.2063	0.0554 ***
log Infrastucture									
	<= GINDEX Threshold	0.0169	0.0240	-0.0205	0.0251	-0.0274	1.0850 **	-0.0277	0.0066 ***
	> GINDEX Threshold	0.0537	0.0233 **	0.0357	0.0239	0.0076	0.9350	0.0121	0.0030 ***
sigma_u		45.15		43.93		45.23		55.13	
sigma_e		6.25		6.18		6.29		6.20	
rho		0.98		0.98		0.98		0.99	
F-stats		24.75		26.55		23.80		26.12	
P > F		0.00		0.00		0.00		0.00	

Notes: The standard errors are bootstrapped (1,000 reps). Our estimates cover 11 years of annual data for 47 African countries for which complete data are available. The number of stars is in the order of decreasing statistical significance: *** = 1%, ** = 5%, and * = 10%.

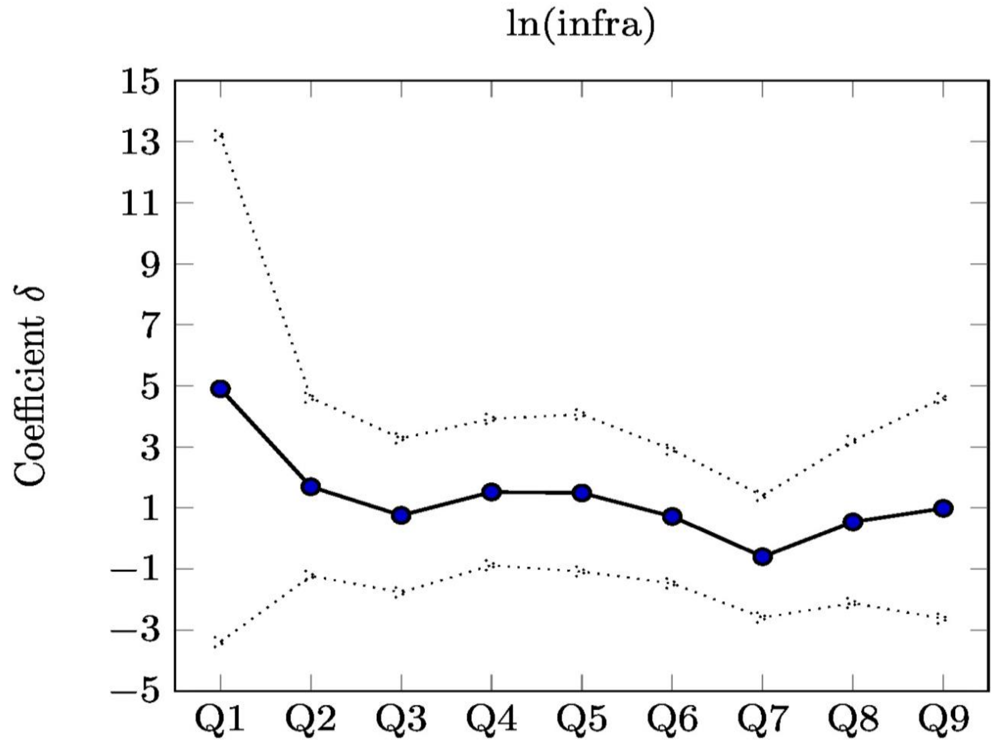
Turning to our infrastructure proxies, we observe that the impact of infrastructure on economic growth is dependent on the type of infrastructure under consideration (see, Models 1-4 in Table 4). First, we find that a 1% increase in the composite index of the infrastructure indicators has a significantly different impact in poor governance countries as opposed to in good governance countries. Specifically, we find that a 1% increase in the composite index of infrastructure may lead to a 0.0537% increase in economic growth. For the transport index, we find insignificant impacts for both below and above the governance threshold. However, the impact is positive for good governance countries and negative for poor governance countries. With regard to the electricity index, we observe a significantly negative impact of electricity generation on growth in low governance countries. Specifically, we find that a 1% increase in electricity generation is associated with a 0.0274% decrease in economic growth in low governance countries. For ICT we observe that while it significantly leads to improved economic conditions in high governance countries, it significantly negatively impact the economic growth of countries with bad governance.

While this finding may be interesting, it is not necessarily surprising because the findings from previous literature on the ICT/growth nexus has been ambiguous. As opined by Sassiand Goaied (2013), the previous studies that have found a negative impact can be due to rapid accumulation of ICT by developing countries leading to the elimination of unskilled workers and excluding the poor from due to their lack of qualified skills and as such increase poverty and deterring growth. These findings may shed some explanation for our results. In that countries with good governance may be able to implement policies that ensure the full utilization of ICT they acquire, whereas, for low governance economies, it may prove to be a futile exercise and displays low skilled workers and even further lead to improper use of funds on ICT that may be important for garnering higher economic growth for such countries.

4.4 Unconditional Quantile Regression Results

Similar to our exclusive infrastructure impact threshold analysis on economic growth, we estimate a quantile regression using the composite index of infrastructure. We then proceed to estimate separate models that employ each of the subcategories of infrastructure development including the WSS index which we couldn't use in the threshold analysis due to the lack of a governance threshold in the relationship between the index and economic growth. For our quantile regression, we apply 1,000 bootstrap replications in the derivation of our estimates and standard errors. Since our focus in this study is to investigate the impact of the overall and individual measures infrastructure, we only present the results of the impact of infrastructure on economic growth in Figures 1 and 2.

Figure 1: Quantile Regression for Overall Infrastructure Index Impact on Growth

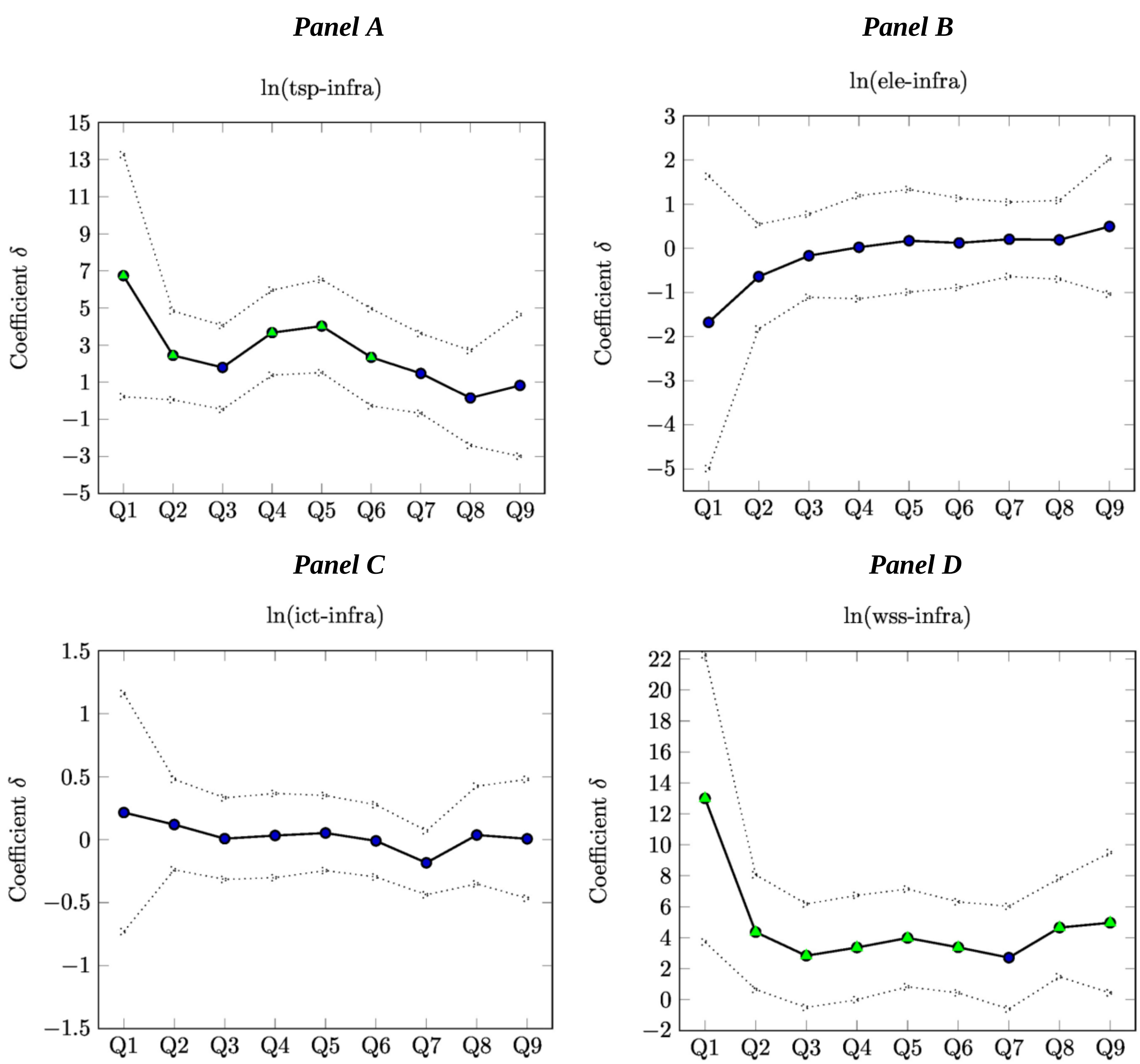


Note: The solid line denotes the estimated coefficients, and the dotted lines represent the upper and lower confidences bands.

From Figure 1 above, we observe that the overall infrastructure development positively impacts economic growth in all quantiles of growth. We, however, find that the impact is larger for lower levels of growth than higher levels of growth. This observation indicates that, on the average, a dollar invested in overall infrastructure may have a larger marginal return at the lower end the economic growth than at the upper end of the income spectrum.

Turning to the sub-categories of the infrastructure indicators and their impact on growth by quantile, we observe that the impact is larger at lower levels of growth than at the higher levels of the economic growth quantiles for the transport indicator. From Panel B, we observe a positive impact of electricity infrastructure on all levels of growth with the most impact at the higher levels of economic growth, however, the impact is minuscule, perhaps, indicting the widely documented gross inefficiencies and unreliability's in the African electricity generation sector.

Figure 2: Quantile Regression Results for the Infrastructure Indicators' Impact on Economic Growth

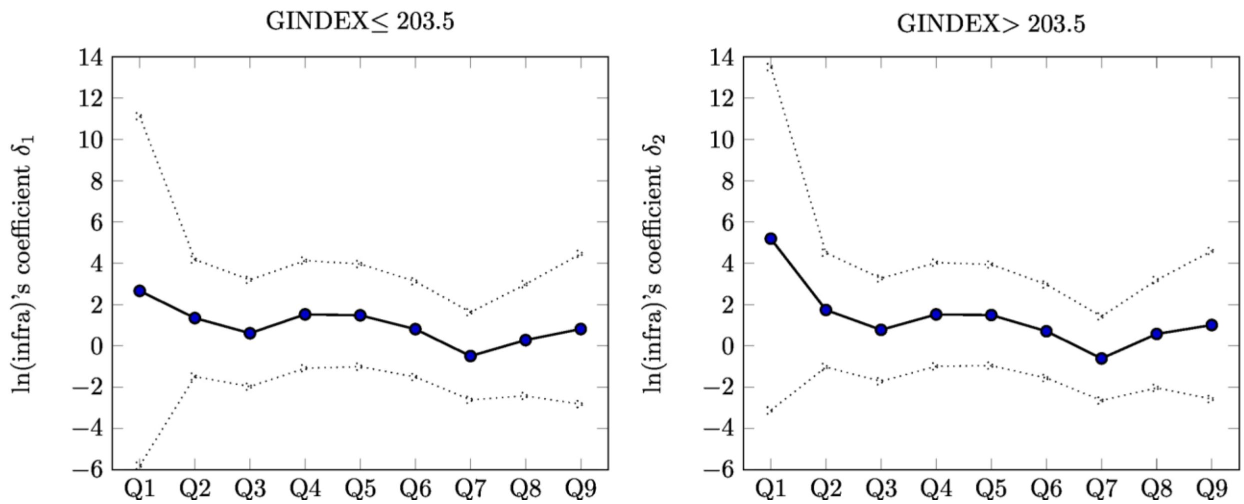


Note: The solid lines denote the estimated coefficients, and the dotted lines represent the upper and lower confidences bands.

From Panel C, we observe that the impact of the ICT infrastructure is largely flat. Similar to the findings for electricity, the impact is minuscule. Juxtaposing this finding to that of the threshold analysis, it implies that governments may implement effective governance institutions and policies that provide an environment for maximum growth gains from the ICT infrastructure. Panel D presents the estimation results for the quantile regression of the impact of access to improved water sources and sanitation facilities (WSS). The graph indicates that the impact of WSS is significantly larger at the lower end of the income distribution than at the upper end of the income distribution spectrum. Comparing the magnitudes of the impact of each infrastructure sub-sector, we find that the impact of an increase in the WSS index is relatively larger than that of the other three infrastructure indices. Thus, access to improved water sources and good sanitation facilities is important for the development agenda of low-income African countries.

Turning our attention to the case where the quantile regressions are estimated for the two governance regimes, we find that good governance plays a critical role in its impact on infrastructure at different quantiles of the income distribution. Figure 3 presents two graphs for the quantile impact of OII on growth for countries below and above the governance indicator threshold. From Figure 3, we observe that the impact of OII is relatively higher for countries with good governance at each growth quantile than for poor governance countries. Further, for the good governance countries, we observe a more pronounced growth return from the OII for low growth quantiles than higher growth quantiles.

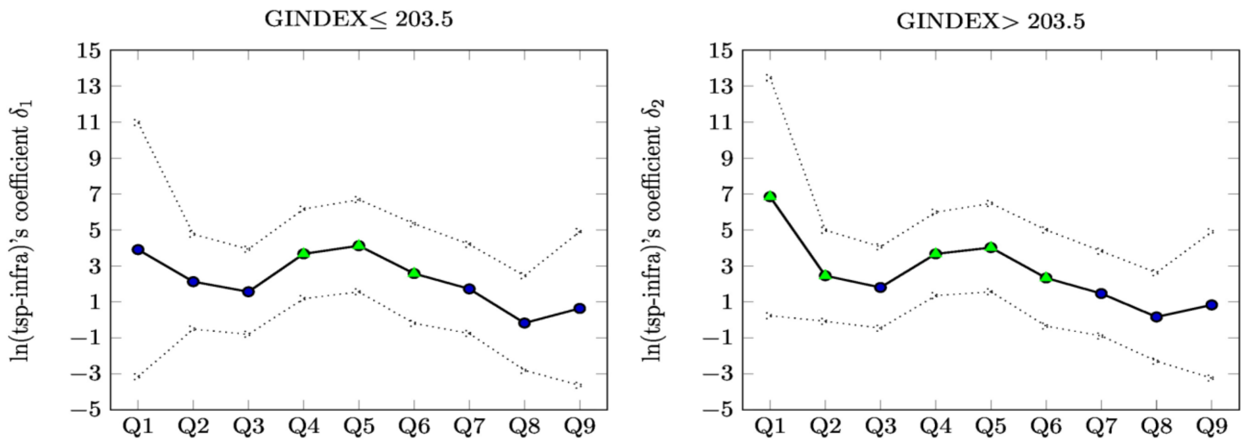
Figure 3 Quantile Regression for Overall Infrastructure Index by Governance Threshold



Note: The solid line denotes the estimated coefficients, and the dotted lines represent the upper and lower confidences bands.

Figure 4 shows that the quantile regression results for the impact of the transport infrastructure on economic growth by governance threshold. From the graph, we observe that the impact of the transport infrastructure is positive for all growth quantiles in both regimes, even though the impact is clearly larger for countries in the lower growth quantiles in the good governance regime relative to their counterparts in poor governance regime. This observation is indicative of the fact that good governance can magnify the positive impact of transport infrastructure development, especially for low growth countries.

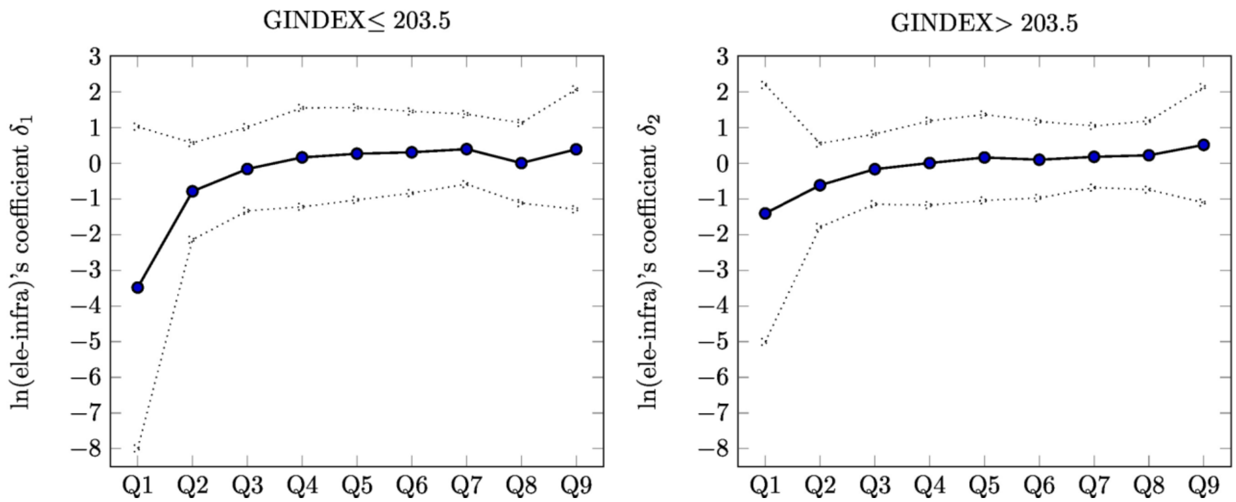
Figure 4 Quantile Regression for Transport Infrastructure Index by Governance Threshold



Note: The solid line denotes the estimated coefficients, and the dotted lines represent the upper and lower confidences bands.

Figure 5 presents the quantile regression findings for the impact of electricity infrastructure below and above the governance threshold respectively. The results for both regimes are very similar to the coefficients for the good governance economies being slightly better, however, we observe that the impact of electricity infrastructure is still minuscule in both regimes. Thus, we can conclude even though good governance helps in slightly magnifying the growth impact of electricity, it is not enough to eliminate the inefficiencies of this sector in Africa which is limiting the role that this type of infrastructure can play in their quest for sustainable growth.

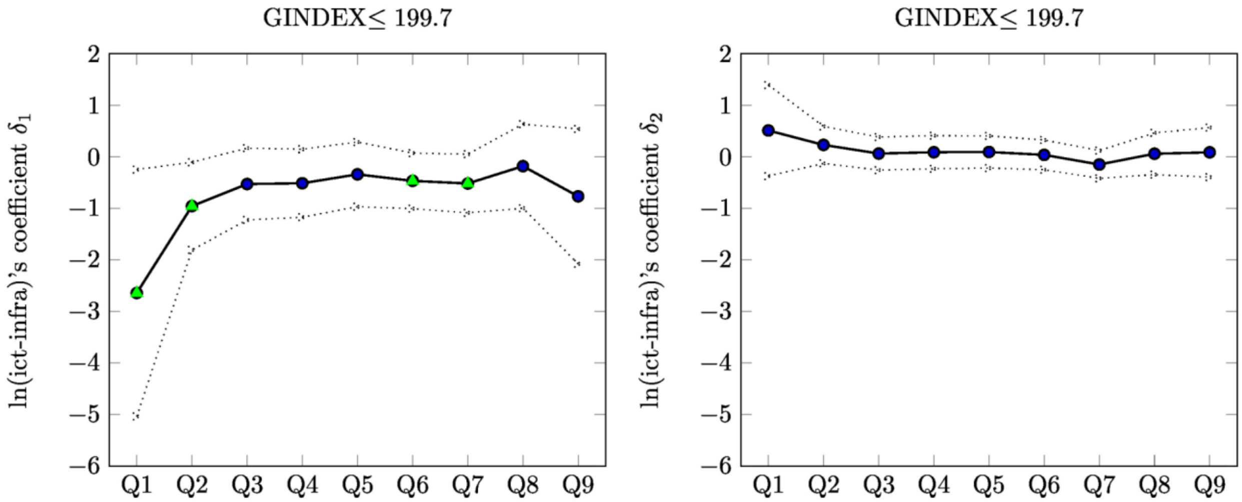
Figure 5 Quantile Regression for Electricity Infrastructure Index by Governance Threshold



Note: The solid line denotes the estimated coefficients, and the dotted lines represent the upper and lower confidences bands.

The quantile regression estimation results for ICT infrastructure on economic growth for the poor and good governance regimes are presented in Figure 6. From the graphs, we observe that the impact of ICT infrastructure is slightly positive, or neutral on economic growth across quantiles for good governance economies while the impact is largely negative for low governance economies. This finding may indicate that countries with good governance are able to implement policies that mitigate the negative effect of mass introduction of ICT in developing countries due to the shortage of skilled labor and the loss of low-skilled jobs that come with the implementation of ICT as indicated by Sassi and Goaied (2013) study. Thus, good governance may play an important role in the proper sourcing, dissemination, and management of the ICT infrastructure for a sustainable growth path in African countries.

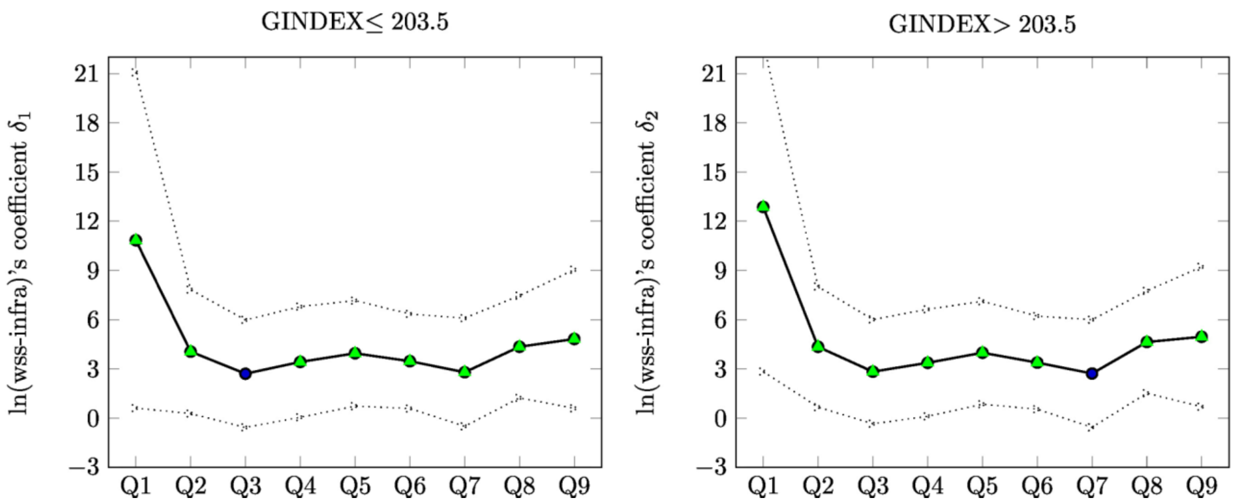
Figure 6 Quantile Regression for ICT Infrastructure Index by Governance Threshold



Note: The solid line denotes the estimated coefficients, and the dotted lines represent the upper and lower confidences bands.

From Figure 7, we observe that on a quantile by quantile basis, the growth impact of WSS is very similar in both regimes. However, the impacts are slightly larger for the lower quantiles of growth for the countries in the good governance regimes than in poor governance regimes. This finding further supports our argument that good governance may magnify the impact of infrastructure development on growth. It must, however, be noted that our threshold analysis failed to confirm a statistically significant governance threshold in the impact of WSS on economic growth.

Figure 7 Quantile Regression for Access to Improved Water Sources and Sanitation Facilities Index by Governance Threshold



Note: The solid line denotes the estimated coefficients, and the dotted lines represent the upper and lower confidences bands.

5. Conclusions

The main focus of this study is to investigate the relationship between public and private infrastructure investments as a composite index and their various individual measures on the per capita income growth rate of African countries. Specifically, the study utilizes a threshold and quantile regression analyses to investigate nonlinearities in the relationship between infrastructure development and the economic growth rate of African countries. The study also contributes to the existing literature by incorporating a more inclusive set of infrastructure indices and the possible nonlinear relationships that may exist between the overall and individual indicators of infrastructure and economic growth rates African countries while controlling the conventional sources of the neoclassical growth models. We find that governance thresholds matter with respect to the effectiveness of the overall infrastructure index, transport infrastructure, electricity, and ICT infrastructure indices on growth, but not so for access to improved water sources and sanitation facilities. By no means does finding negate the vital contribution improved water resources and sanitation as vital investments in the human capital formation in Africa, other developing regions of the world. From the quantile regression analysis, we find that the indices have differential positive impacts in each quantile of economic growth spectrum though the impact may be magnified by prevailing good institutions of governance. For the most part, our results show that the transport, the electricity, the ICT, and water resources and sanitation have a positive impact on the economic growth of African countries in varying degrees depending on the governance quality of each country. The effectiveness of all of the components of infrastructure is typically greater in countries with good governance than those with poor governance. African countries may benefit enormously from investment in the various infrastructure factors by focusing, not only on how much they can invest in public and private infrastructure without crowding out private investments but also by paying particular attention to the prevailing quality of their governance structure.

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Appendix

List of Countries in the Sample

Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Comoros, Congo, Dem. Rep., Congo, Rep., Cote d'Ivoire, Egypt, Equatorial Guinea, Eswatini, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Sudan, Tanzania, Togo, Tunisia, Uganda, Zambia,