Do Public-Private Infrastructural Investments Promote Long-Run Economic Growth? Evidence from African Countries

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Abstract: This paper addresses whether public and private infrastructure investments promote long-run economic growth using panel data taken from the World Bank's Economic Indicators (WDI) for a cross-section of 50 African countries spanning from 1995 to 2012. As measures of infrastructure, we use transportation (*TRANS*), improved access to sanitation (*SANI*), access to clean water (*WATER*), communication infrastructure (*COMMU*), and electricity infrastructure (*ELEC*) indices each of which ranges from 0 to 100 (with 100 denoting robust infrastructure investments). We employ factor analysis to construct the above listed uncorrelated 5 broad infrastructure indices from a series of factors representing infrastructure investments. The panel unit-root test results show that the economic growth variable and the infrastructure indices are stationary in levels and first difference and they also exhibit long-run stable relationship as revealed by the Westerlund's (2007) Error-correction model for panel data co-integration tests. Using Panel Fully Modified OLS (PFMOLS) model, we demonstrate that infrastructure investment indices have a positive and significant effect on the economic growth of African countries. Specifically, we find a bi-causal relationship between transportation, sanitation, communication, and electricity infrastructure and economic growth. On the other hand, we find a unidirectional impact of access to clean water on the economic growth of African countries in the sample. Finally, we find positive and significant long-run response of economic growth (elasticity) to all the measures of infrastructure indices in this study, except for the case of electricity generation capacity while controlling for the conventional sources of economic growth.

Key Words: Infrastructure, Per Capita income, Unit-Root tests, Error Correction Model, Granger Causality, Elasticity, PFMOLS, Panel Data, Africa

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

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1. Introduction

Numerous anecdotal evidences exist which suggest that the African continent is among the world's most deficient regions in terms of infrastructure capacity. Transport, communication, Energy, sanitation, water, and telecommunication infrastructure have long been identified as the major bottlenecks for commerce and regional economic integration in Africa. More specifically, for example energy infrastructure continues to be Africa's largest impediment with more than 30 countries experiencing frequent power outages, leaving a third of Africa's population without access to electricity, reducing its productivity by as much as 40%, and curtailing its annual economic growth by about 2%. Only 30% of Africans have access to electricity relative to 70-90% of other developing countries (Department of Infrastructure and energy of the Program for Infrastructure Development in Africa (PIDA), 2014).[1] Consequently, a serious empirical study of the impact of infrastructure on the economic growth of the African continent is timely and relevant.

The controversial debates on the impact of public infrastructure investments on economic growth in the context of developed countries has 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. This study employs a more comprehensive panel data series for a cross-section of 50 Sub-Sahara African countries over the period 1995 to 2012 and most appropriate empirical methodologies in an effort to disentangle the controversies that surround the impact of infrastructure investment on 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).

The objective of this study is to estimate the long-run relationship between infrastructure investments and economic growth. We ran factor analysis on the measures of infrastructure indicators with full rank data from the WDI to create uncorrelated indices of infrastructure investment and ended with 5 variables (*Transportation*, *Sanitation*, *Water*, *Communication*, and *Electricity*) which capture the essence of all the infrastructure factors.

The study makes some contributions to the existing literature in that it utilizes panel data of a cross-section 50 African countries spanning from 1995 to 2012, applies a newly developed panel unit-root and cointegration tests, employs factor analysis to derive 5 uncorrelated indices which captures the essence of the respective infrastructure factors, applies the newly developed panel granger causality test to analyze infrastructure led growth hypothesis for the case of African countries, and applies the Panel Fully Modified OLS (PFMOLS) to establish the long-run determinants of economic growth and their elasticities in the form of infrastructure investments.

The paper is organized as follows. Section 2 summarizes the existing literature on the impact of infrastructure investment on economic growth in developed and developing countries. Section 3 describes the data and empirical methodology. The findings and interpretations of results of the paper are reported and discussed in section 4. Section 5 summaries the findings, draws conclusions

[1] http://www.au.int/en/sites/default/files/newsevents/workingdocuments/12582-wd-pida-_addressing_the_infrastructure_gap_in_africa_to_speed_up_regional_integration.pdf

based on the results of the study, and makes some policy inferences of based on the results of the study.

2. A Review Selected Literature

In an early empirical study of the impact of infrastructure investment on economic growth in the U.S., Aschauer (1989) found a strong and positive relationship between "core" infrastructure investments (transport, power, and water) and national output and a marginal, or negative impact on the national output of investments in hospitals, educational facilities, conservation and development structures. Follow-up studies by Munnell (1990a, 1990b) found a significantly stronger response of income growth to infrastructure investment for the U.S. as a whole than on the states (elasticity of 0.34 for the U.S. vs only 0.15 for the states). In another study, Kessides (1993) also argues that infrastructure investment can have a positive impact on economic development in the presence of conducive macroeconomic climate and adequate other inputs such as skilled labor which enhance total factor productivity and output.

Using cross-sectional country data, Easterly and Robello (1993) find that infrastructure investment in the form of transport and communication have a significant positive impact on economic growth. Their finding is not surprising considering their use of inappropriate empirical methodology (OLS) with non-stable infrastructure and output time series (Feddereke, et al., 2006).

Among studies which questioned the strong impact of infrastructure investment and economic growth using appropriate estimation methodology, Hulten and Schwab (1991), Holtz-Eakin (1994), and Garcia-Mila, et al. (1996) find a negative, or not statistically different from zero result for the 48 American states. On the other hand, in a study of the relationship between U.S. economic growth and different types public capital expenditures (roads, electricity, gas transit systems, sewerage, water supply, educational and hospital buildings, conservation structures, development structures, and civilian equipment), Pereira (2000) uses a VAR approach and finds that long term public investment crowds in private investment and such that it may be a powerful means of promoting economic growth.

Constructing a structural model of infrastructure and economic growth which considers the institutional and economic factors that mediate in the infrastructure-GDP interactions, Esfahani and Ramirez (2003) also find that the contribution of infrastructure service to GDP growth is substantial. In a study of 19 African countries, Wolde-Rufael (2005) finds that there is a long-run relationship between energy use and economic growth. Wolde-Rufael (2006) also finds that there is a long-run relationship between electricity consumption and economic growth. Using time series data for South Africa, Fedderke, et al. (2006) also find that infrastructure investment has both direct and indirect positive effects on economic growth.

In a recent study, Danning and Pedroni (2008) develop panel cointegration tests for isolating the direction and magnitude of the long-run effects of various types of infrastructure investments on income growth for a panel of countries spanning from 1950 to 1992 while controlling for short-run country heterogeneity. Their findings suggest that while infrastructure tends to contribute to long-run economic growth, there are substantial variations across countries.

To verify the claims of African economic policy makers 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 growth and equity across Africa.

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 underdevelopment, but also to be on the path to sustained growth. Ndulu (2011) 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).

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 (Walassa, 2012). The next section describes the data and specifies the empirical estimation models of the study.

3. Data and Empirical Estimation Models

Data

We employ annual panel data for 50 African countries covering the period between 1995 and 2012. The data are mainly taken from the World Bank's World Development Indicators (WDI). Owing to the fact that WDI data are fraught with too many missing observations, we use panel multiple imputation techniques to fill in the missing observations, dropping from our analysis variables and countries with more than 15 percent missing observations for the period under consideration.

There are several infrastructure related variables that may be important for economic growth; however, due to perennial lack of data for African countries only limited number of infrastructure proxies are selected for our analysis for the period of our study. Another drawback is that the data may not be indicative of quality or reliability, even when available.

Our main dependent variable is real per capita income, whereas the infrastructure variables selected include proxies for transportation (*TRANS*), access to improved sanitation (*SANI),* access to water (*WATER*), electricity infrastructure (*ELECT*), and communication infrastructure (*COMMU*). Due to the possibility of collinear relationship among our infrastructure variables, we are unable to use all of them in the same model. On the other hand, using them separately in different models can cause the omitted variable bias problem. In order to take care of these issues efficiently, we employ factor analysis to create uncorrelated infrastructure indices from the factors representing proxies for infrastructure investment. Our analysis yielded 5 factors which we used to create 5 infrastructure indices including transportation infrastructure (*TRANS*), improved sanitation (*SANI*), clean water accessibility (*WATER*), communication infrastructure (*COMMU*), and electricity Infrastructure (*ELEC*) indices each of which ranges from 0 to 100, with 100 denoting the best.[2] In order to ensure that our new infrastructure indices are not highly correlated with each other, we conducted a correlation analysis presented in Table 1.

<<< Insert Table 1 here>>

As one can see in Table 1, the infrastructure indices we created are not highly correlated. Thus, we can ignore multicollinearity of the explanatory variables.

Other control variables included in our analysis are primary school enrolment (*SCHP*), openness to trade (*TRADE*), foreign direct investment (*FDISTK*), age dependency ratio (*DEP*), official development assistant (*ODA*), household consumption expenditure (*HFCE*), official exchange rate (*EXCH*), and inflation (*INFLA*). Table 2 presents variable description and summary statistics for our variables.

<<Table 2 goes here >>>

Unit-Root Tests

In order to assess the degree of stationarity of our variables of choice for this study, we employ recently developed panel unit root tests. The tests available include the LLC tests by Levin, et al. (2002), IPS tests by Im, et al. (2003), ht test by Harris and Tsavalis (1999), the Breitung test by Breitung (2000), LM test by Hadri (2000), and the Fisher-type test which employs ADF and PP tests as described by Choi (2001) and Madalla and Wu (1999). These studies have shown that the panel unit root tests are less likely to be subject to Type II error and as such are more powerful than tests based on times series data. Most panel unit-root tests make the restrictive assumption that all panels share the same autoregressive parameter (see, LLC, ht, and Breitung), except IPS, the Fisher-type, and Hadri tests that allow the specific autoregressive parameter to be panel specific.

Whereas the number of countries in Africa do not change much over time, the number of panels can be taken as static, whereas the number of periods is infinite. Following Hlouskova and Wagner (2006), we choose to use the Fisher-type unit-root tests because of 3 important reasons: (1) it allows for both balanced and unbalanced panel data[3], (2) it allows the autoregressive parameter to be panel specific, and (3) it is the most appropriate test to use when time horizon tends to infinity and the panels are fixed.[4] The ADF specification can be written as:

$$\Delta y_{it} = \rho_i y_{i,t-1} + z'_{it}\gamma_i + v_{it} \qquad (1)$$

[2] See appendix for details on the variables that contribute to each one of our 5 infrastructure indices we created with factor analysis.
[3] See also Maddala and Wu (1999)
[4] See STATA 11 handbook.

where i= 1…..N, t=1…….T, and v_{it} denotes the stationary error term of the i^{th} member in period t, respectively. Δy_{it} refers to the variable being tested, z'_{it} can represent panel-specific means, time trends, or nothing depending on the options specified. If z_{it}= 1, then $z'_{it}\gamma_i$ will denote fixed-effects. On the other hand, we can specify a trend scenario where z'_{it}= (1, t) such that $z'_{it}\gamma_i$ represents fixed-effects and linear time trends. We can also specify non-constant and omit the $z'_{it}\gamma_i$ term altogether.

In testing for panel-data unit roots, the Fisher-type tests conduct the unit-root tests for each panel individually and then combine the *p*-values from these tests to produce an overall test, an approach used mostly in meta-analysis. Note that in this context, we perform a unit-root test on each of our panel units (i) separately and then we use their combined p-values to construct a Fisher-type test to investigate whether or not the series exhibit a unit-root.

For our study we run the fisher-type tests with Dicky Fuller options and 2 lags. Following Levin, Lin and Chu (2002), we subtract the cross-sectional averages from the series to mitigate the impact of cross sectional dependence and run the model twice at levels and also with first difference. The test combines p-values from panel-specific unit-root tests using the methods Choi (2001) proposed. Under this specification, the null hypothesis in this case is H_0: ρ_i=1 for all *i*, versus the alternative hypothesis of H_a: ρ_i< 0 for some *i*. In this case, the null hypothesis is that all panels contain unit root, and for the alternative, we state that the fraction of panels that follow stationary processes is nonzero.

This routine provides 4 different unit-root test methods as proposed by Choi (2001). The first three tests differ in whether they use the inverse chi-square (P), inverse normal (Z), or inverse logit (L) transformation of the *p*-values while the fourth test is a modification of the inverse chi-square method which is suitable when the sample (*N*) is large. Choi (2001) shows that the Z-statistic offers the best trade-off between size and power, and as such suggests its use in applications. In the next sub-section, we address the issue of panel cointegration tests to determine whether GDP per capita and the control variables move together in the long-run.

Cointegration Tests

As a second step to check for long-run relationship between per capita income growth and infrastructure, we employ the Error-correction model for cointegration tests of panel data as described by Westerlund (2007). Unlike models which are based on residual dynamics (such as Pedroni, 2004), these tests propose four new panel tests of the null hypothesis of no cointegration which are based on the structural rather than dynamics and, therefore, do not impose common factor restrictions. Two methods are designed to test the alternative hypothesis that the panel is cointegrated as a whole, while the other two test the alternative hypothesis that there is at least one individual member of the panel that is cointegrated. In a nutshell, if the null hypothesis of no error correction is rejected, then the null hypothesis of no cointegration is also rejected. We note here that the error-correction tests assume the following data-generating process:

$$\Delta \boldsymbol{y}_{\boldsymbol{it}} = \boldsymbol{\delta}'_{\boldsymbol{i}}\boldsymbol{d}_{\boldsymbol{t}} + \boldsymbol{\alpha}_{\boldsymbol{i}}\left(\boldsymbol{y}_{\boldsymbol{i,t-1}} - \boldsymbol{\beta}'_{\boldsymbol{i}}\boldsymbol{x}_{\boldsymbol{in,t-1}}\right) + \sum_{\boldsymbol{j=1}}^{\boldsymbol{p_t}} \boldsymbol{\alpha}_{\boldsymbol{i,t-j}} + \sum_{\boldsymbol{j=-qt}}^{\boldsymbol{p_{t-1}}} \boldsymbol{\gamma}_{\boldsymbol{ij}}\Delta \boldsymbol{x}_{\boldsymbol{in,t-j}} + \boldsymbol{\varepsilon}_{\boldsymbol{it}} \qquad (2)$$

where t = 1, . . . , T and i = 1, . . . ,N denote the time-series and cross-sectional units, respectively; d_t contains the deterministic components for which there are three possible cases that can occur including: (1) $d_t = 0$, thus, equation (1) has no deterministic terms, (2) $d_t = 1$, thus, Δy_{it} is generated with a constant, and (3) $d_t = (1,t)$, thus, Δy_{it} is generated with both a constant and a trend. In our case y_{it} denotes the log of real per GDP capita of country *i* at time *t*, and x_{int} denotes the log of infrastructure index of type n for country *i* at time *t*.

Equation (2) can be rewritten as:

$$\Delta \boldsymbol{y_{it}} = \boldsymbol{\delta'_i d_t} + \boldsymbol{\alpha_i}\left(\boldsymbol{y_{i,t-1}} - \boldsymbol{\lambda'_i x_{in,t-1}}\right) + \sum_{j=1}^{p_t} \boldsymbol{\alpha_{ij}} \boldsymbol{\Delta y_{i.t-j}} + \sum_{j=-qt}^{p_{t-1}} \boldsymbol{\gamma_{ij}} \Delta \boldsymbol{x_{in,t-j}} + \boldsymbol{\varepsilon_{it}} \qquad (3)$$

where $\lambda'_i = -\alpha_i \beta'_i$. The parameter α_i determines the speed at which the system $y_{i,t-1} - \beta'_i x_{in,t-1}$ corrects back to the equilibrium relationship after a sudden shock. If $\alpha_i < 0$, then the model is an error-correcting, implying that y_{it} and x_{int} are cointegrated. If $\alpha_i = 0$, then there is no error correction and, thus, no cointegration. We can, thus, state the null hypothesis of no cointegration as H_0: $\alpha_i = 0$ for all i. The alternative hypothesis depends on what is being assumed about the homogeneity of α_i. Westerland (2007) proposes four statistical tests including two group-mean tests and two panel-mean tests. The group-mean tests do not require the α_i's to be equal and as such allow one to test the null hypothesis against the alternative hypothesis of H_g: $\alpha_i < 0$ for at least one i. In the case of the panel-mean statistic, we test the null against the alternative hypothesis of H_p: $\alpha_i = \alpha < 0$ for all *i*. The postulated relationship between our variables of interest allows for a linear time trend:

$$\ln(Y_{it}) = u_i + \tau_i t + \beta_i \ln(X_{it}) + \varepsilon_{it} \qquad (4)$$

We perform the cointegration tests using *AIC* to choose an optimal lag and lead lengths for each series and with the Bartlett kernel window width set according to $4^*(T/100)^{2/9} \sim 3$.[5]

Granger Causality

While the majority of the few studies on the relationship between infrastructure and growth have assumed unidirectional relationship between them, a few of these studies have given consideration to and checked for the nature of causality between infrastructure and growth. For example, Easterly and Rebelo (1993) indicates the possibility of economic development leading infrastructure development[6]. This indicates that the relationship between infrastructure and development may not exist at all, exhibit a unidirectional causality, or lastly exhibit a bidirectional causality. Having checked for the long-run relationship between economic growth and infrastructure, our next obvious question is the direction of causality.

Love and Ziccho (2006) present a Stata program that estimates panel VAR (PVAR) which accounts for individual country heterogeneity.[7] To alleviate the issue of biased coefficients when

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[5] We followed Newey and West (1994)

[6] See also Canning and Pedroni (2004 & 2008)

[7] PVAR fits a multivariate panel regression of each dependent variable on lags of itself, lags of all other dependent variables and exogenous variables. The estimation is by generalized methods of moments (GMM).

using standard mean-differencing simultaneously with fixed effects and dependent lags in the VAR, their program follows Arellano and Bover (1995), which allows untransformed lagged regressors to be used as instruments because the variables are forward mean differenced, and the coefficients can be estimated by a system of generalized method of moments (GMM). The standard errors are drawn from a Monte Carlo simulation. Ambrigo and Love (2015) expand the suite of routines for the original PVAR developed by Love and Ziccho (2006) to include sub-routines to help implement Granger causality tests and optimal moment and model selection, following Andrews and Lu (2001). We apply the PVAR routine with Granger causality post-estimation test options (pvargranger) to help us identify the direction of causality between per capita GDP growth and the infrastructure indices. The pvargranger performs Granger causality Wald tests for each equation of the underlying PVAR model.

Panel Fully Modified OLS (PFMOLS)

Having verified the long-run relationship between the GDP per capita and the control variables, we now turn to the estimation of the long-run impact of the control variables on GDP per capita using Panel Fully Modified Ordinary Least Squares Method (PFMOLS) in the next sub-section.

We employ an autoregressive distributive lag (ARDL) dynamic panel specification in the following form:

$$y_{it} = \sum_{j=1}^{p} \gamma_{ij} y_{i,t-j} + \sum_{j=0}^{q} \delta'_{ij} x_{i,t-j} + \mu_i + \varepsilon_{it} \qquad (5)$$

where y_{it}, I = 1…..,N, t = 1…..T, denotes the real per capita income of the i^{th} country in period t, respectively. X_{it} is a K*1 vector of explanatory variables; $\gamma_{ij}{}'s$ are scalars and δ_{it} are a K*1 vector of coefficients. If the variables in equation (5) are I(1) and cointegrated, then the error term is an I(0) process for all of our groups i. An important feature of variables that are cointegrated is their responsiveness to deviations from the long-run state, suggesting an error-correcting model where the short-run dynamics (shocks) of our variables will adjust to the long-run equilibrium are influenced by deviations from long-run equilibrium. This allows us to re-parameterize equation (5) into an error correction model written as:

$$\Delta y_{it} = \emptyset_i \left(y_{i,t-1} \theta'_i X_{it} \right) + \sum_{j=1}^{p-1} \gamma_{it} \Delta y_{i,t-1} + \sum_{j=0}^{q-1} \delta'_{ij} \Delta X_{i,t-j} + \mu_i + \varepsilon_{it} \qquad (6)$$

where $\emptyset_i$denotes the error-correcting speed of adjustment term. If $\emptyset_i$=0, then there is no evidence for a long-run relationship between the dependent variable and our regressors. The parameter $\emptyset_i$ is expected to be significantly negative under the previous assumption that the variables return to a long-run equilibrium. The vector θ'_i is of particular importance because it contains the long-run relationships (elasticities) between the per capita income and our explanatory variables.[8]

[8] $\emptyset = -\left(1 - \sum_{j=1}^{p} \gamma_{it}\right), \theta_i = \frac{\sum_{j=0}^{q} \delta_{ij}}{(1-\sum_k \gamma_{ik})}, \gamma^*_{ij} = -\sum_{m=j+1}^{p} \gamma_{im} \quad j = 1 \ldots\ldots P-1, and\ \delta^*_{ij} = -\sum_{m=j+1}^{q} \delta_{im} \ \ j = 1 \ldots\ldots\ldots q-1.$

The procedure described above has two key advantages over other commonly used estimators in the literature. Compared to the static fixed-effects estimator, the PFMOLS estimator allows for dynamics while the static fixed-effects model does not. Another pertinent advantage is that the underlying auto-regressive distributed lag (ARDL) structure dispenses with the importance of the unit root pre-testing of the variables in question. As long as there is a unique vector which defines the long-run relationship among our variables of interest, it is of no consequence if the variables are either I(1), or I(0) since the PMG estimates of an ARDL specification will yield consistent estimates. Another point worth noting is that reverse causality is not a problem if the variables are I(1). This is because in that case there exist the superconsistent property.

The command comes with 3 possible estimation procedure options including PMG, MG, and DFE options. The PMG procedure estimates the pooled mean-group model where the long-run effects (betas) are constrained to be equal across all panels and the short-run coefficients (phi) are allowed to differ across panels. On the other hand, the MG procedure estimates the mean-group model where the coefficients of the model are calculated from the unweighted average of the unconstrained and fully heterogeneous model. The DFE procedure estimates the dynamic fixed effects model where all parameters, except intercepts, are constrained to be equal across panels. We can effectively say that the MG and DFE are the two extreme procedures, whereas the PMG is the middle ground. However, our choice of which of the procedures is appropriate for our analysis will be determined by Hausman tests.

4. Empirical Results

Unit-root

As mentioned above, we apply the Fisher-Type ADF unit root tests which produce four different stationarity tests including: Inverse Chi Square (P), Inverse Normal (Z), Inverse Logit (L*), and Modified Inverse Chi Square (Pm). Low Z and L values cast doubt on the null hypothesis of unit-roots whereas large P and Pm values cast doubt on the null hypothesis. Choi (2001) suggests that the inverse normal Z statistic should be used in stationarity tests because it offers the best trade–off between size and power.

<< Insert Table 3 here>>>>

Therefore, even though all four statistics rejects the null hypothesis that all panels contains unit roots for our main variables of interest at the 1% level in both levels and first difference, we chose to present only the inverse normal Z results in Table 3 and present the full results in the appendix. From the results presented in Table 3, we can conclude that our variables of interest are stationary in levels and first difference.

Cointegration

Before going on with our analysis, we need to determine whether there is a long-run relationship between our infrastructure indices and per capita income for the time period under consideration.

We employed the Westurlaud (2007) error-correction model to test for cointegration, results of which is presented in Table 4. The Westerlund error-correction model presents four tests including the group time trend (Gt), the group fixed-effects (Ga), the panel time trend (Pt), and the panel fixed-effects (Pa) statistics. Westerlund (2007) suggests relying more on the Pt test in our analysis because it is more robust. The reasoning is that since the Pa statistic is normalized by T which may cause the test statistic to reject the null too frequently. His simulations also show that the Pt statistics is more robust to cross-sectional correlations.

<<<<Insert Table 4 here >>>

For the most part, all four cointegration tests reject the null of no error-correction at the 1% level except in the cases of Sanitation and access to clean water, both of which are not significant when using the group fixed-effects (Ga) statistic. Using the results presented in Table 4 and Westerlund's (2007) suggestion that researchers should rely more on the Pt test statistics in applications which significantly reject the null in all cases, we interpret our results as evidence of cointegration between growth and the infrastructure indices for African countries over the time period under consideration.

Granger Causality

Prior to this segment, we concluded that there is a long-run relationship between economic growth and the infrastructure indices. We, however, were not able to determine the magnitude and/or the direction of this long-run relationships. In an attempt to discover the direction of causality between our infrastructure indices and economic growth, we employ the panel vector autoregression model (PVAR) with panel Granger causality option presented by Abrigo and Love (2015). The results of this analysis are presented in Table 5.

<<< Insert Table 5 here>>>

From Table 5, we can deduce that African countries exhibit bi-directional causality between all of the infrastructure indices and growth, except for the case of accessibility to clean water where our data exhibit unidirectional causality from accessibility to clean water to growth. We can, therefore, sum up our findings by stating that Infrastructure Granger causes growth, and growth Granger-causes infrastructure development in all cases, except in the case of access to clean water where water infrastructure Granger-causes growth, but not vice versa. These findings show that infrastructure investments are most likely endogenous and, therefore, we should take into consideration this issue of endogeneity in deciding on our choice of models in estimating the long-run elasticities.

PFMOL

Having established that the variables are stationary, exhibit long-run cointegration, and the direction of causality in the previous sub-sections, we now estimate the long-run impact of the infrastructure indices on the economic growth of African countries using the Panel Fully Modified Ordinary Least Squares (PFMOLS) estimator. The choice of the PFMOLS over Ordinary Least Squares (OLS) estimators is based on the fact that it has the dual advantage of correcting for both serial correlation and potential endogeneity problems that arise when the OLS estimators are used. Remember that the PFMOLS provides three possible estimation procedures options including PMG, MG, and DFE options. We estimated our model using all 3 options and then used the Hausman test to select the best fit model for the dynamic fixed-effects model (DFE). The results for the DFE estimation are presented in Table 6.

<<< Insert Table 6 here >>>

The negative and significant values of the ∅ parameter for all our model indicate that there is a long-run relationship between our variables. The results indicate that all of the infrastructure indices have a positive and significant long-run effects on economic growth, except for the case of electricity generation capacity. Comparatively, our results indicate that a 1% increase in transportation infrastructure, sanitation improvements, accessibility of clean water, and improvement in communication infrastructure lead to a 0.28%, 0.86%, 0.36%, and 0.17% long-run economic growth in respectively in Africa. Thus, sanitation development is the most important infrastructure for African economic growth.

In the case of the control variables employed by our model, they all exhibit the expected sign. Official development assistance (*ODA*) and final household consumption expenditures (*HFCE*) are both shown to positively impact growth. Specifically, we find that a 1% increase in *ODA* and *HFCE* lead to 0.07% and 0.01% increase in economic growth. We, however, find that improvements in the official nominal exchange rate (*EXCH*) and inflation (*INFLA*), negatively impact the long-run growth rate of African countries. Specifically, we find that a 1% increase in the official exchange rate (defined as ACU/1$) and inflation rate leads to a -0.04% and -0.16% decrease in the long-run growth rate of African countries, respectively.

5. Summary and Conclusion

The basic objective of this study is demonstrate whether public and private infrastructure investments have positive and significant impact on the per capita income growth in African countries by undertaking a battery of stationarity, cointegration, and Granger causality tests before applying the PFMOLS to examine the existence long-run relationship between infrastructure and per capita income growth by estimating the long-run elasticities. The results show that there is a stable relationship between per capita income and infrastructure investment. The per capita income series and infrastructure variables exhibit a co-movement and there is a long-run positive and significant relationship between infrastructure investments and per capita income for African countries aside from the case of electricity infrastructure proxied by electricity generation. This result is not too surprising since the proxy variable used may not be the best for the electricity infrastructure as it doesn't account for inefficiencies such as load shedding which has caused serious economic issues in the case of Ghana resulting in the coinage of the term "dumsor," a new term in the local Ghanaian parlance which refers to the off-and-on service of electricity in that country.

Infrastructure investments may positively impact per capita income growth via many channels including increased efficiency of private investment (crowding in rather out), reducing the chronic problem of widespread unemployment (particularly of the youth) and income inequality, and promoting regional integration and increasing domestic commercial activities. It is quite interesting that we find of sanitation development (SANI) variable to have the largest infrastructure elasticity.

Tropical diseases encompass all diseases that occur solely, or principally, in the tropics. In practice, the term is often taken to refer to infectious diseases that thrive in hot, humid conditions, such as malaria, leishmaniasis, schistosomiasis, onchocerciasis, lymphatic filariasis, Chagas disease, African trypanosomiasis, and dengue. With such diseases thriving in this region, it is not surprising that sanitation is an important vehicle for human development resulting in improved productivity and the economic growth of the region.

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Table 1. Correlation Matrix for Infrastructure Indices

	TRANS	*SANI*	*WATER*	*COMMU*	*ELEC*
TRANS	1.000				
SANI	0.333	1.000			
WATER	0.213	0.000	1.000		
COMMU	0.373	0.487	0.345	1.000	
ELEC	-0.055	0.087	0.062	0.000	1.000

Table 2. Variable Description and Summary Statistics

Variable	Description	Mean	Std. Dev	Min	Max
GDPPC	Real GDP per capita (constant 2005 US$)	1,580.62	2,448.29	50.04	15,098.60
TRANS	Transportation Infrastructure Index	19.44	9.72	13.55	100.00
SANI	Sanitation Infrastructure Index	49.82	16.61	27.72	100.00
WATER	Clean Water Accessibility Infrastructure Index	70.25	17.56	19.36	100.00
COMMU	Communication Infrastructure Index	21.78	10.89	12.81	100.00
ELEC	Electricity Production Infrastructure Index	49.81	16.60	20.81	100.00
SCHP	School enrollment, primary (% net)	70.05	20.57	21.98	99.80
TRADE	Trade (% of GDP)	78.73	49.25	14.77	531.74
FDISTK	Foreign direct investment (stock)	5,796.78	16,093.29	0.00	179,564.00
DEP	Age dependency ratio (% of working-age population)	83.80	15.17	39.96	110.96
ODA	Net ODA received per capita (current US$)	59.16	69.90	-11.56	688.77
HFCE	Household final consumption expenditure (constant 2005 US$)	1,250.00	4,980.00	0.31	32,000.00
EXCH	Official exchange rate (LCU per US$, period average)	426.72	716.23	0.00	6,658.03
INFLA	Inflation, consumer prices ((annual %+20)/100)	0.40	1.69	0.10	41.65

Table 3. Panel Unit Root Tests

Variable	Description	Levels		First Difference	
		Inverse normal Z	P-Value	Inverse normal Z	P-Value
GDPPC	GDP per capita (constant 2005 US$)	-6.422	0.000	-13.039	0.000
TRANS	Transportation Infrastructure Index	-7.026	0.000	-15.389	0.000
SANI	Sanitation Infrastructure Index	-3.920	0.000	-13.060	0.000
WATER	Clean Water Accessibility Infrastructure Index	-13.264	0.000	-10.683	0.000
COMMU	Communication Infrastructure Index	-3.846	0.000	-12.641	0.000
ELEC	Electricity Production Infrastructure Index	-3.094	0.001	-11.706	0.000
SCHP	School enrollment, primary (% net)	-11.008	0.000	-17.067	0.000
TRADE	Trade (% of GDP)	-8.997	0.000	-14.535	0.000
FDISTK	Foreign direct investment (stock)	-8.431	0.000	-14.184	0.000
DEP	Age dependency ratio (% of working-age population)	-10.666	0.000	-4.708	0.000
ODA	Net ODA received per capita (current US$)	-9.965	0.000	-14.690	0.000
HFCE	Household final consumption expenditure (constant 2005 US$)	-13.133	0.000	-15.424	0.000
EXCH	Official exchange rate (LCU per US$, period average)	-17.006	0.000	-10.951	0.000
INFLA	Inflation, consumer prices (annual %)	-14.612	0.000	-26.526	0.000

Note: the models were ran in logs using the Fisher-type tests with Dicky Fuller, and demean options, with two lags

Table 4. Panel Cointegration Tests

Infrastructure Index	Test	Value	P-value	Infrastructure Index	Test	Value	P-value
Transportation	*Gt*	-2.911	0.000	Communication	*Gt*	-3.702	0.000
	Ga	-24.148	0.000		*Ga*	-18.422	0.000
	Pt	-21.257	0.000		*Pt*	-20.959	0.000
	Pa	-20.673	0.000		*Pa*	-18.981	0.000
Sanitation	*Gt*	-3.100	0.000	Electricity	*Gt*	-3.014	0.000
	Ga	-7.855	0.145		*Ga*	-15.661	0.000
	Pt	-23.171	0.000		*Pt*	-21.397	0.000
	Pa	-13.938	0.000		*Pa*	-21.407	0.000
Water	*Gt*	-3.633	0.000				
	Ga	-8.157	0.123				
	Pt	-23.518	0.000				
	Pa	-14.670	0.000				

Note: The models were run in logs and the dependent variable for all models is the real GDP per capita

Table 5. Panel Granger Causality Tests

Causality from Infrastructure to Growth		
Causality Direction	chi2	Prob > chi2
TRAN does not cause Y	7.101	0.008
SANI does not cause Y	23.157	0.000
WATER does not cause Y	14.418	0.000
COMMU does not cause Y	7.392	0.007
ELEC does not cause Y	16.066	0.000

Causality from Growth Infrastructure to Growth		
Y does not cause TRAN	22.253	0.000
Y does not cause SANI	24.922	0.000
Y does not cause WATER	0.250	0.616
Y does not cause COMMU	26.970	0.000
Y does not cause ELEC	12.481	0.000

Note: Tests were done with Abrigo and Love (2015) PVAR package

Table 6. Panel Fully Modified Ordinary Least Squares Model (PFMOLS)

Variable	Description	PFMOLS	
TRANS	Transportation Infrastructure Index	0.2832	*
		(0.1707)	
SANI	Sanitation Infrastructure Index	0.8584	**
		(0.4003)	
WATER	Clean Water Accessibility Infrastructure Index	0.3574	*
		(0.2030)	
COMMU	Communication Infrastructure Index	0.1664	*
		(0.0974)	
ELEC	Electricity Production Infrastructure Index	0.1009	
		(0.1621)	
SCHP	School enrollment, primary (% net)	0.0939	
		(0.0752)	
TRADE	Trade (% of GDP)	0.1033	
		(0.0865)	
FDISTK	Foreign direct investment (stock)	0.0191	
		(0.0145)	
DEP	Age dependency ratio (% of working-age population)	0.2547	
		(0.2549)	
ODA	Net ODA received per capita (current US$)	0.0709	***
		(0.0227)	
HFCE	Household final consumption expenditure (constant 2005 US$)	0.0114	*
		(0.0063)	
EXCH	Official exchange rate (LCU per US$, period average)	-0.0405	***
		(0.0147)	
INFLA	Inflation, consumer prices ((annual %+20)/100))	-0.1571	***
		(0.0493)	
(φ)	Speed of Error-Correction	-0.1851	***
		(0.0223)	

Note: *, **, *** denotes significance at the 1%, 5% and the 10% levels of confidence respectively. The numbers in parenthesis are the standard errors.

Appendices

Table A1. Contributing Variables for the Infrastructure Indices

Transportation (TRANS)	Communication (COMM)
Air transport, freight (million ton-km)	Fixed broadband Internet subscribers (per 100 people)
Air transport, passengers carried	Internet users (per 100 people)
Air transport, registered carrier departures worldwide	Mobile cellular subscriptions (per 100 people)
Roads, paved (% of total roads)	Telephone lines (per 100 people)
Roads, total network (km)	
Water (WATER)	**Sanitation (SANI)**
Improved water source (% of population with access)	Improved sanitation facilities (% of population with access)
Improved water source, rural (% of rural population with access)	Improved sanitation facilities, rural (% of rural population with access)
Improved water source, urban (% of urban population with access)	Improved sanitation facilities, urban (% of urban population with access)
Electricity (ELEC)	
Electricity production from hydroelectric sources (% of total)	

Table A2. Full Panel Unit Root Tests

Tests	GDPPC	TRANS	SANI	WATER	COMMU	ELEC	SCHP	TRADE	FDISTK	DEP	ODA	EXCH	CPI	INFLA
Levels														
Inverse chi-squared(100) P	228.55	218.79	178.86	387.59	178.74	177.49	315.53	247.97	257.20	419.23	279.74	540.51	427.66	403.66
P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inverse normal Z	-6.42	-7.03	-3.92	-13.26	-3.85	-3.09	-11.01	-9.00	-8.43	-10.67	-9.96	-17.01	-13.32	-14.61
P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inverse logit t(254) L*	-6.72	-7.01	-4.00	-14.60	-3.84	-3.25	-11.74	-8.98	-8.90	-13.28	-10.21	-20.95	-15.91	-15.65
P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Modified inv. chi-squared PM	9.09	8.40	5.58	20.34	5.57	5.48	15.24	10.46	11.12	22.57	12.71	31.15	23.55	21.47
P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
First Difference														
Inverse chi-squared(100) P	361.48	445.46	360.25	317.84	351.66	334.81	504.31	413.48	402.68	203.13	409.22	327.19	286.48	955.85
P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inverse normal Z	-13.04	-15.39	-13.06	-10.68	-12.64	-11.71	-17.07	-14.54	-14.18	-4.71	-14.69	-10.95	-10.85	-26.53
P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inverse logit t(254) L*	-13.83	-17.20	-13.76	-11.47	-11.47	-12.54	-19.61	-15.89	-15.48	-5.34	-15.86	-12.23	-10.94	-37.33
P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Modified inv. chi-squared PM	18.49	24.43	18.40	15.40	15.40	16.60	28.59	22.17	21.40	7.29	21.87	16.06	13.46	60.52
P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note: the models were ran in logs using the Fisher-type tests with Dicky Fuller, and demean options, with two lags

Table A3. List of Countries

Country Name	Code	Country Name	Code
Angola	AGO	Morocco	MAR
Burundi	BDI	Madagascar	MDG
Benin	BEN	Mali	MLI
Burkina Faso	BFA	Mozambique	MOZ
Botswana	BWA	Mauritania	MRT
Central African Republic	CAF	Mauritius	MUS
Cote d'Ivoire	CIV	Malawi	MWI
Cameroon	CMR	Namibia	NAM
Congo Rep.	COG	Niger	NER
Comoros	COM	Nigeria	NGA
Cabo Verde	CPV	Rwanda	RWA
Djibouti	DJI	Sudan	SDN
Algeria	DZA	Senegal	SEN
Egypt	EGY	Sierra Leone	SLE
Eritrea	ERI	Swaziland	SWZ
Ethiopia	ETH	Seychelles	SYC
Gabon	GAB	Chad	TCD
Ghana	GHA	Togo	TGO
Guinea	GIN	Tunisia	TUN
Gambia	GMB	Tanzania	TZA
Guinea-Bissau	GNB	Uganda	UGA
Equatorial	GNQ	South Africa	ZAF
Kenya	KEN	Congo Dem. Rep	ZAR
Liberia	LBR	Zambia	ZMB
Lesotho	LSO	Zimbabwe	ZWE