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RESEARCH ARTICLE

Spillover effects of aggregate infrastructure stock and quality

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Abstract: This paper analyses spillover effects of aggregate infrastructure stock and quality in Sub Saharan Africa (SSA). Using a panel vector autoregressive (VAR) approach that does the estimations in a generalised method of moments (GMM) framework, we found positive spillover effects from foreign aggregate infrastructure quality. Although infrastructure quality enhancement invigorates the surrounding regions, we argue that infrastructure stock development provides a competitive advantage that draws economic factors from the surrounding regions and exerts negative pressure on their respective economic activity. Domestic aggregate infrastructure quality (stock) shows positive (negative) growth effects.

Keywords: Aggregate Infrastructure; Spillover; Panel VAR; Africa.

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1 Introduction

Spillover effects from infrastructure raise important policy inferences about the effectiveness and efficiency of infrastructure investments. Since the seminal work of Aschauer (1989), there has been an incredible interest in the economic impact of public infrastructure from the empirical perspective. Besides the role of infrastructure in stimulating domestic economic activity, it is commonly accepted that a country's infrastructure gives impetus to the development of the surrounding countries and communities. The economic growth literature shows that fast-growing economies cluster together, and hence location matters

(Alvarez et al., 2006). It is the importance of proximity that many studies often quantify the infrastructure spillover effects using a neighbour weighting criterion (focusing on areas that share borders). Spillovers may happen beyond common borders; therefore, distance and trade-based weights are other considerations that have been exploited.

Domestic infrastructures may generate economic benefits in the locality and positive or negative spillovers to other areas (see Moreno and Lopez-Bazo, 2007). Thus, while infrastructure spillovers from other areas may have benefits (see Pereira and Roca-Sagales, 2003), the impact of these spillovers to a place could be negative (for example, Sloboda and Yao, 2008; Zhang, 2008 2013). Negative spillovers may occur when good infrastructure development in a region draws production factors (human, financial and physical capital) away from the regions with poor infrastructure and creates a competitive advantage. This is due to the relocation of economic factors and firms to areas with greater accessibility from strong transport and telecommunication networks (Condeco-Melhorado et al., 2014), reliable energy supply, improved water, and sanitation. Omitting these spillover effects could cause systematic bias regarding the effective growth impact of infrastructure. Most studies (for example, Fedderke and Garlick, 2008; Loayza and Odawara, 2010; Chakamera and Alagidede, 2017) assessed the economic impact of local infrastructure on economic growth, yet analysis of infrastructure spillovers among regional countries, especially in Sub Saharan Africa (SSA), is still thin. The studies that investigated spillovers have focused on the spillovers from individual infrastructure types (mainly transport). For instance, Arbues et al. (2015) demonstrated positive spillovers from road, and Yoshino and Abidhadjaev (2017) from rail infrastructure development. More so, failure to account for infrastructure quality remains a serious problem. This is because policymakers may continue to invest more in additional infrastructure while less attention is given to the quality of the existing infrastructure. Africa is suffering from poor conditions and expensive infrastructure services compared to other regions in the world, which hinder productivity by up to 40% and lower Africa's GDP by approximately 2% annually (Mofor, 2019).

Given the empirical gaps in the literature, our contribution is threefold: First is the creation and application of aggregate infrastructure indices to model spillovers across SSA states. This allows us to know the combined spillover effects that emerge from the core infrastructure sectors (electricity, transport, telecommunication, & water) of an economy . With this as a background, one will say that country A's infrastructure can generate significant spillovers that impacts country B's economic development. While some single infrastructures may suggest positive or negative spillovers, the aggregate measures encapsulate spillovers effects for the entire economy. Second, we go beyond the prevailing literature by accounting for aggregate infrastructure quality. Third, an important contribution drawn from our findings is the different dynamics under which infrastructure spillovers may occur between aggregate infrastructure stock and quality. We argue in this paper that the development of foreign infrastructure stock may exert negative pressure on domestic economic development. However, the development of foreign aggregate infrastructure quality tends to stimulate domestic economic development. We believe this is a novel way to inspect spillover effects of aggregate infrastructure stock and quality in a panel vector autoregressive (VAR) framework. Evidence of spillover effects (positive and negative) have key policy implications, including, but not limited to ensuring optimal infrastructure investments and cost-sharing among African countries. With this understanding, *we hypothesise that the aggregate infrastructure stock and quality in a country may produce positive or negative spillover effects on other regional countries*. Following the original works of Love and

Zicchino (2006) and Abrigo and Love (2016), a panel VAR approach that does the estimations in a generalised method of moments (GMM) framework is implemented to test for the existence of spillovers.

The next section provides a brief survey of the related literature. This is followed by the panel VAR and GMM, leading to the estimations, discussion of results and the corresponding policy implications of our findings.

2 Brief literature survey

The provision of adequate infrastructure is fundamental to the viability of every economy. It may enter as an input of production (Barro, 1990; Ayogu, 1994). Public infrastructure complements other private inputs of production. Since Aschauer (1989), plenty of empirical literature has examined the nexus between infrastructure and growth. In these studies, the importance of spillovers from infrastructure development has consistently received much attention. Infrastructure (mostly economic infrastructure) possess network and scale effects that may influence the surrounding areas via positive or negative spillovers (see Li et al., 2017a). Dembour and Wauthy (2009) pointed that as much as spatial externalities are concerned, if regions are genuinely contiguous, then physical location in one area than another does not matter. Theoretically, the development of infrastructures such as good transport networks, power plants, and telecommunication promotes development in the surrounding areas. Other countries will directly use transportation infrastructure (for example, highways, seaports, railways and airports) during trade; electricity can be imported, and advanced telecommunication technology in a country can be transferred and adopted in other regions.

Substantial empirical work exists in terms of spillovers from transport infrastructure. Li et al. (2017b) assessed the returns of road infrastructure investment in China. Their results suggested a roughly 11% rate of return per annum from productivity gains, somewhat due to positive spillovers. Their findings did not support the idea that China's road investment is excessive. Moreover, the importance of road infrastructure spillovers among municipalities in the Dutch province was documented by Condeco-Melhorado et al. (2014). They estimated the benefits of extra road links in the form of monetary gains and travel time savings. In the case of Spanish provinces, Arbues et al. (2015) investigated spillovers of roadways, airports, seaports and railways. While they found road infrastructure to impact the area of location and neighbouring provinces positively, the other transportation modes showed no significant effects on average. Furthermore, investigating the effects of transport infrastructure on agricultural output across 44 states in the United States (US), Tong et al. (2013) results indicated that road disbursement in a particular state would positively contribute to its agricultural output and spillover effects on other neighbouring states. Another great observation of their study was the variability of spillover effects based on the spatial weight matrix applied in the model.

In the case of Mexico, Duran-Fernandez and Santos (2014) found roads to have a positive and significant effect on regional variations in productivity. Their findings suggested that the unexplained output per worker at the regional level was associated with regional variables. Interestingly, they also documented that not all elements of the road system have similar effects. Yoshino and Abidhadjaev (2017) investigated the impact of Uzbekistan's TBK railway connection, and their results indicated positive effects in the regions crisscrossed by the railway. However, the effects were statistically significant only in the medium and long periods, while negative effects were recorded for the outlying regions in the short term. In addition, Zhang (2008) found transport infrastructure spillovers to be largely positive. However, negative spillovers were established with the population density spatial weights matrix model.

Bouwmeester and Scholtens (2017) examined cross-border spillover effects associated with investment expenditure of 5 Western European economies using a multi-regional input-output model. They found evidence for spillovers, which were distributed unevenly among the economies. In particular, the effect of gas infrastructure on both domestic values added and cross-border leakages was found to differ significantly among the countries. In the case of Spanish provinces, Alvarez et al. (2016) analysed the growth effects of imported capital stock connected to the utilisation of infrastructures in neighbouring areas. Their results confirmed the hypothesis that the imported capital has a positive impact on production.

Furthermore, Peng and Hong (2013) investigated spillovers at the sectoral level in China. They found economic growth in a sector to be explained by spillover effects among sectors that are connected via flows of commodities, with economic distance assuming a major role in stimulating productivity than spatial distance. Additionally, their results suggested the significance of infrastructure spillovers in enhancing labour productivity in related sectors and that agglomeration diseconomies of scale may partly be lowered by infrastructure investment.

In so far as the role of infrastructure spillovers on productivity is concerned, Owyong and Thangavelu (2001) also reported positive spillovers from the US public capital to Canada's productivity. More so, positive effects of public infrastructure on regional productivity of neighbouring regions were demonstrated by Bronzini and Piselli (2009) in the case of Italian regions. They also found evidence of a one-way causality from public infrastructure to productivity. Wang (2014) showed that growth is strictly endogenous in the presence of considerable public infrastructure spillovers. Despite the importance of spillovers, the development of infrastructure may also lead to congestion spillover effects. Gudmundsson et al. (2014) found congestion spillovers to the nearest airports within multiple airport regions (MARs) and the distant airports outside the MARs. In particular, the spillovers of intercontinental flights impact demand patterns, new flight offerings and flight influences in the United Kingdom and secondary airports within and outside the London MAR.

In the African context, Richaud et al. (1999) investigated growth spillovers among African countries and the importance of infrastructure in their transmission. Their findings revealed the role of infrastructure development in lifting the profitability of domestic and foreign investments. Most importantly, they argued that infrastructure investment at the national level could be sub-optimal in the presence of spillovers. Furthermore, Roberts and Deichmann (2009) examined the growth spillover effects of telecommunication and transport infrastructure. Their results suggested heterogeneous growth spillovers, which were more robust among the OECD nations while absent in SSA. Evidence was found for strong interaction between infrastructure and being a landlocked state, implying spillovers depended on how spillover effects could spread (infrastructure endowments being central). In Roberts and Deichmann (2011), negative and positive values were linked to the infrastructures that were low or high, respectively. When Equatorial Guinea was excluded from the sample of several states (including non-African), there were no significant interaction effects involving spillover.

Regarding the mixed outcomes of the infrastructure-growth nexus, Elburz et al.'s (2017) meta-analysis revealed that studies that consider interprovincial, interregional and interstate relations have a high probability of obtaining negative effects giving an idea concerning the spillovers of these investments. Likewise, the kinds of infrastructure, time frame, methodology, geographical scale, and types of infrastructure measure can affect the results of the primary studies.

From the foregoing, substantial empirical evidence exists in support of positive spillover effects from infrastructure. Therefore, infrastructure development in a region (or province) can facilitate economic development in the surrounding regions (or provinces). If the spillovers are always positive, then it might be logical that the originators of spillovers would seek ways to internalise the effects. In this scenario, policymakers at both national and regional levels may focus on finding appropriate cost-sharing arrangements among beneficiaries, hence not discouraging the positive spillovers. However, some studies have demonstrated evidence of negative spillovers from infrastructure, while others could not find the existence of spillovers. It becomes even harder for policy purposes when different results are documented for the same infrastructure, same period and same geographical area. Besides the mixed outcomes, it seems most studies examined spillovers from transport infrastructure. The primary research gap is the lack of knowledge regarding spillover effects from the perspective of aggregate infrastructure stock and quality. Failure to account for infrastructure quality has been the most critical challenge. Consequently, this study seeks to address these problems by employing aggregate infrastructure stock and quality measures. The aggregates carry information of four infrastructure sectors (electricity, transport, telecommunication, and water).

3 Methodology and Data

3.1 Data

This study considers stock and quality measures of electricity, telecommunication, road, airport, and water infrastructures for a panel of 39 SSA countries over 2000-2014.[1] Our interest is not on the individual infrastructure types per se but rather on their aggregate impact. Subsequently, principal component analysis (PCA) is used to cluster the different infrastructure stock measures, thus, developing an aggregate infrastructure stock index (AIS) for each country. The same is applicable in terms of aggregate infrastructure quality index (AIQ). This study calls the AIS and AIQ for any country i domestic aggregate infrastructure stock (DAIS) and domestic aggregate infrastructure quality (DAIQ), respectively. From the perspective of any country i, the combination of the AIS variables of other regional countries creates a foreign aggregate infrastructure stock (FAIS) variable that enters the country i's output function. The same holds in the development of a foreign aggregate infrastructure quality (FAIQ). Accordingly, FAIS and FAIQ are the central variables used to assess the spillover effects of aggregate infrastructure endowments of other countries. The

[1] Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Chad, Comoros, Congo Republic, Cote d'Ivoire, Democratic Republic of Congo, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Kenya, Lesotho, Madagascar, Malawi, Mali, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome Principe, Senegal, Seychelles, Sierra Leone, South Africa, Swaziland, Tanzania, Togo, Uganda, Zambia, and Zimbabwe.

calculation of FAIS and FAIQ involves weights based on proximity, which matters in the dynamics of spillovers across regions as discussed below.

3.2 Econometric Approach

3.2.1 Model

This study proposes an output function of the following form

$$gdp_{it} = f\left(\text{ dais }_{it},\text{ daiq }_{it},\text{ fais }_{jt}^{\text{wij}}\text{ faiq }_{jt}^{wij}\right) \quad i = 1,\ldots,N; t = 1,\ldots,T \tag{1}$$

where dais s_{it} is the domestic aggregate infrastructure stock and daiq it is the domestic aggregate infrastructure quality. Added to the output function of any country i are the foreign aggregate infrastructure stock $\left(fais_{it}^{wij}\right)$ and foreign aggregate infrastructure quality $\left(faiq_{it}^{wij}\right)$ variables of any other regional country j, and w_{ij} is the weight for any pair of countries i and j. We assume that foreign infrastructures of other regional countries influence the growth performance of the domestic country.

The choice of a weight matrix is vital in this kind of analysis. Most studies applied a neighbour weighting matrix whereby a weight of 1 is attached to countries that share borders and 0 otherwise. Adjacent countries are believed to have more influence on each other's growth through spillovers. However, this criterion has a problem of attaching the same weights to the neighbouring countries while others can be more important (Condeco-Melhorado et al., 2014). More so, it excludes several other regional countries that do not share similar borders though they may have significant spillovers. The distance-based weighting criterion is an alternative that can be used to include all countries within a region or sample. This approach gives more weight to the countries that are closer to each other.

Recently, a trade-based weighting matrix has been of interest. Unlike the proximity (neighbours and distance) criteria's implied assumption that the closer the regions, the greater the spillover effects, the latter views the level of trade as another channel through which regions can benefit from each other's infrastructure development. However, the challenge with a bilateral trade-based weight matrix, especially in Africa, is the high degree of informal trade that remains unrecorded. Moreover, formal bilateral trading data for some pairs of SSA countries or years are difficult to find. Thus, in this study, the distance weighting criterion is applied in developing foreign infrastructure variables. The weights are computed based on percentage distance $(1/D^{*}100)$, where D is the distance between capital cities. The numerator is one such that the closer the capital cities, the greater the percentage weight. Given equation (1), we estimate the following empirical panel model for any country i :

$$gdp_{it} = \alpha_0 + \beta_{it}' ldais_{it} + \varphi_{it}' ldaiq_{it} + \lambda_{it}' \sum_{j=1}^{N} w_{ij} lfais_{jt} + \psi_{it}' \sum_{j=1}^{N} w_{ij} lfaiq_{jt} + u_{it} \tag{2}$$

where α_0 is an intercept, u_{it} is the disturbance term, N denotes the number of countries, l denotes the logs of the variables defined in equation (1) and $\beta, \varphi, \lambda \& \psi$ are parameters to be estimated. Alvarez et al. (2006) talk about the effective stock of public capital that combines both domestic and foreign infrastructure. Consequently, we consider another empirical model for effective infrastructure stock and quality as follows:

$$gdp = \alpha_0 + \beta'_{it} leais_{it} + \varphi'_{it} leaiq_{it} + \mu_{it} \tag{3}$$

whereby:

$$leais^e_{it} = ldais_{it} * \sum_{i=1}^{N} w_{ij} lfais_{jt} \tag{4}$$

$$leaiq^e_{it} = ldaiq_{it} * \sum_{i=1}^{N} w_{ij} lfaiq_{jt} \tag{5}$$

where $leais$ is the effective aggregate infrastructure stock, $leaiq$ is the effective aggregate infrastructure quality, $ldais$ and $ldaiq$ are the within-country infrastructure aggregates while $lfais$ and $lfaiq$ are the foreign infrastructure. As shown in equations (4) and (5), we apply a product combination, but one may also consider a linear aggregator to develop the effective infrastructure variables, as shown in Alvarez et al. (2006). The merit of our product combination is that one may also think of the foreign infrastructures as potential moderators that improve the infrastructure-growth nexus when captured. [2]

3.2.2 Panel VAR

While equations (1) to (3) show our central objective of whether GDP growth depends on domestic and foreign infrastructure, the panel VAR model also checks for a reverse effect. There might be a reverse effect from GDP growth to infrastructure development. In terms of domestic infrastructure, some empirical studies (for example, Chakamera and Alagidede, 2017; Calderon, 2009) found support for a positive effect of infrastructure on economic growth. The main reason is that public infrastructure may act as an additional input of production or complement private capital, impacting the national output. In other words, businesses depend not only on their capital, technology, and labour but also on the complimentary infrastructures that include telecommunication, electricity, transportation, sanitation, and water (see Owyong and Thangavelu, 2001).

About the role of foreign infrastructure, national GDP may also be affected by the foreign infrastructure development through spillover effects (Richaud et al., 1999; Roberts and Deichmann, 2009; Alvarez et al., 2016). The broad issue and relevance of spillover effects are also based on the observation that countries often do well when their neighbours do well (see Roberts and Deichmann, 2009). Roberts and Deichmann (2009) gave the example of the industrial revolution in England that spread in the continent like contagion-like process and the "East Asian miracle". Alvarez et al. (2016) demonstrated the importance of imported capital stock that represent spillovers obtainable from utilising roads located in neighbouring and non-adjacent locations. These infrastructures, such as local and foreign road networks and telecommunication systems, are used to facilitate trade and access markets.

[2] This might be judged when one has conducted moderation analysis or checked the R-squared changes when the foreign variables are captured in the model. However, our panel VAR approach does not show R-squared, but we might have a clue from the standard errors, which are relatively low in Equation (2), i.e., model B. Despite the fact, Equation (1) remains extremely important as it is the one that reveals spillover effects.

A VAR model can be used to allow for possible feedback effects on the potential reverse effect aspect. Specifically, this study employs the panel VAR approach focusing mainly on the impact of both domestic and foreign infrastructure on economic growth. We apply the panel VAR approach by Love and Zicchino (2006) and Abrigo and Love (2016) that runs in a GMM framework.

3.2.2.1. Rationale

Panel VAR is one of the robust techniques to examine the nature and degree of spillovers (see Koop and Korobilis, 2016). Among the merits, one does not need to worry about endogenous variables as the approach treats all variables as endogenous and interdependent, but exogenous variables can be included (Canova and Ciccarelli, 2013). Moreover, panel VAR's estimations and inferences are conducted in a GMM framework, one of the best approaches to overcome the endogeneity problem. It permits for efficient estimation of coefficients in a system with endogenous variables. Allowing the lagged variables from each country to influence other countries is another advantage. Furthermore, the panel VAR technique also estimates the impulse response functions (IRF) that reveal the time path of each variable after a shock to other variables in the system.

3.2.2.2. P-VAR framework

This study considers a panel VAR for any country p described by the following system of linear equations:

$$\begin{aligned} & y_{it} = \eta_1 y_{t-1} + \ldots + \eta_p y_{t-p} + \gamma_i + \varepsilon_{it} \\ & i = \{1, 2, \ldots, N\} t = \{1, 2, \ldots T\} \end{aligned} \tag{6}$$

where y_{it} is a $1 \times k$ vector of endogenous variables, $\eta_{1,\ldots,}, \eta_p$ is a $k \times k$ matrix of parameters to be estimated, p denotes the number of lags included, γ_i and ε_{it} are $1 \times k$ vectors of dependent variable-specific fixed effects and error terms, respectively. The disturbances are assumed to have the following features: $E\left(\varepsilon_{it}\right) = 0, E\left[\varepsilon_{it}'\varepsilon_{it}\right] = \sum$ and $E\left[\varepsilon_{it}'\varepsilon_{is}\right] = 0$ for all $t > s$.

Estimating equation (6) with a standard method such as ordinary least squares (OLS) would yield biased estimates due to the presence of lagged dependent variables on the righthand side of the system of equations. As a remedy, the panel VAR is designed to run in a GMM framework, which was developed by Arellano and Bond (1991) and further modified by Arellano and Bover (1995) and Blundell and Bond (1998). Therefore, based on Abrigo and Love (2016), the transformed panel VAR is as follows:

$$\begin{aligned} Y_{iy}^{*} &= \bar{Y}_{it} A + \varepsilon_{it}^{*} \\ Y_{it}^{*} &= \left[y_{it}^{1*} y_{it}^{2*} \ldots y_{it}^{k-1*} y_{it}^{k*}\right] \\ \bar{Y}_{it}^{*} &= \left[Y_{it-1}^{*} Y_{it-2}^{*} \ldots Y_{it-p+1}^{*} Y_{it-p}^{*} X_{it}^{*}\right] \\ \varepsilon_{it}^{*} &= \left[\varepsilon_{it}^{1*} \varepsilon_{it}^{2*} \ldots \varepsilon_{it}^{k-1*} \varepsilon_{it}^{k*}\right] \\ A' &= \left[A_1' A_2' \ldots A_{p-1}' A_p' B'\right] \end{aligned} \tag{7}$$

where the asterisk $(^*)$ represents transformation of the original variable, for instance, if x_{it} is the original variable, the first difference transformation suggests that $x_{it}^{*} = \left(x_{it} - \bar{x}_{it}\right)$. The forward moving orthogonal deviation is $x_{it}^{*} = \left(x_{it} - \bar{x}_{it}\right) \sqrt{T_{it} / \left(T_{it} + 1\right)}$.

One of the key aspects of the panel VAR is model selection. This involves the choice of appropriate lags. The procedure is done based on the Andrews and Lu (2001) consistent moment and model selection (MMSC) for GMM. The criteria choose a pair of vectors (m, q) that minimises:

$$\mathrm{MMSC}_{BIC,n}(k,m,q) = J_n\left(k^2m, k^2q\right) - \left(|q| - |m|k^2 \ln n\right. \tag{8}$$

$$\mathrm{MMSC}_{AIC,n}(k,m,q) = J_n\left(k^2m, k^2q\right) - 2k^2(|q| - |m|) \tag{9}$$

$$\mathrm{MMSC}_{HQIC,n}(m,q) = J_n\left(k^2m, k^2q\right) - Rk^2(|q| - |m|)\ln nR > 2 \tag{10}$$

where $J_n(k,m,q)$ represents the J-statistic of over-identifying restriction for a k-variate panel VAR of order m and moment conditions given q lags of dependent variables with n sample size. The other aspect of the panel VAR is estimation of impulse response. The impulse response function Φ_i may be estimated by rewriting the model as an infinite vector of moving average (VMA), that is

$$\Phi_i = \begin{cases} I_k, i = 0 \\ \sum_{j=1}^{i} \Phi_{t-j}\eta_j, i = 1, 2, \ldots \end{cases} \tag{11}$$

where Φ_i denotes the VMA parameters. We believe the panel VAR approach with its post-estimation considerations (i.e., panel Granger causality test, stability condition test, and impulse response test) is most appropriate in this research.

4 Results

4.1 PCA outcomes

Table 1 presents the PCA results for both stock and quality variables of infrastructure. A common criterion is to retain the principal components (PCs) with eigenvalues greater or equal to one. Applying this criterion would mean retaining the first and second PCs for both infrastructure stock and quality. A limitation of this approach is that the suggested PCs may still have a small cumulative proportion of variance. In our case, the cumulative proportions of PC1 and PC2 are 0.69% and 0.85% for stock and quality variables, respectively. That leaves 31% and 0.15% of the data processes uncaptured.

In this study, the researchers prefer to improve the explanation of the infrastructure data (i.e., raising the proportion of variance), and hence 4 PCs are retained in both cases. We chose to have a single aggregate infrastructure stock (AIS) and aggregate infrastructure quality (AIQ) for analytical and interpretational convenience. This is achieved by taking an average of the selected PCs, thus, having a single aggregate infrastructure index, which is believed to be better than PC1 and PC2 separately. This study does not discuss the eigenvectors of the principal components but are shown in the Appendix, Table A1. Eigenvectors or loadings show the weights of individual infrastructures in each principal component.

4.2 Summary statistics

Table 2 presents the descriptive statistics of the variables. The variables are the logarithms of GDP per capita (LGDP), domestic aggregate infrastructure stock (LDAIS), domestic

Table 1: Eigenvalues

	Eigenvalue	Proportion	Cumulative
Panel A: PCA for infrastructure stock			
PC1	2.277	0.456	0.456
PC2	1.162	0.232	0.688
PC3	0.788	0.158	0.846
PC4	0.539	0.108	0.953
PC5	0.234	0.047	1.000
Panel B: PCA for infrastructure quality			0.478
PC1	2.390	0.478	0.700
PC2	1.111	0.222	0.853
PC3	0.763	0.153	0.947
PC4	0.472	0.094	1.000
PC5	0.265	0.053	

Notes: Eviews 9 estimates. PC denotes principal component. The fourth column is the cumulative proportion.

aggregate infrastructure quality (LDAIQ), foreign aggregate infrastructure stock (LFAIS), foreign aggregate infrastructure quality (LFAIQ), effective aggregate infrastructure stock (LEAIS) and effective aggregate infrastructure quality (LEAIQ).

Table 2: Summary Statistics

Variable	Obs	Mean	St.Dev.	Min	Max
LGDP	585	6.753	1.134	4.691	9.628
LDAIS	585	0.000	0.546	−1.793	1.753
LDAIQ	585	0.000	0.544	−1.451	1.072
LFAIS	585	−0.413	2.656	−25.729	2.295
LFAIQ	585	−0.472	2.354	−21.044	0.872
LEAIS	585	0.020	0.730	−4.277	4.837
LEAIQ	585	0.345	3.050	−1.331	35.947

Note that the effective infrastructure variables combine both domestic and foreign infrastructure features. LFAIS and LFAIQ are constructed using a distance-based weighting matrix, as discussed in section 3. The table displays the summary statistics (Observations, Mean, Standard deviation, Minimum and Maximum) of the variables in logs.

4.3 Panel unit root

The next step is to check the stationarity properties of the variables. The unit root approach by Im, Pesaran and Shin (IPS) is used to test for stationarity. Unlike the Levin, Lin and Chu (LLC) approach, one of the key advantages of the IPS is that it assumes an individual unit root process. This study considers automatic lag selection based on the Akaike information criterion (AIC) with an intercept included. We reject the null hypothesis that all panels contain unit roots across all variables in level. Nevertheless, all the variables are stationary in their first differences.

Our panel VAR technique that runs estimation in a GMM framework overcomes any potential threat linked to stationarity properties of the data by employing differenced lag instruments. The estimations are validated by checking the appropriateness of model specifications using Hansen's J-statistic and further carry out model stability condition checks.

Table 3: Stationarity Test

	Level	First Difference
	W-t-bar	W-t-bar
LGDP	2.773	-11.843^{***}
LDAIS	1.874	-12.982^{***}
LDAIQ	0.610	-16.753^{***}
LEAIS	1.796	-14.286^{***}
LEAIQ	2.378	-12.541^{***}
LFAIS	5.368	-13.132^{***}
LFAIQ	0.808	-17.457^{***}

Notes: IPS unit root tests. Eviews 9 estimates.

4.4 Panel VAR estimations

Our major purpose is to provide an insight into the economic growth effects of aggregate infrastructure spillovers across SSA states. We employ a Stata code for panel VAR by Abrigo and Love (2016) to achieve this purpose. The first thing is to determine the order of a panel VAR model, which is to select appropriate lags. Second, we estimate the preferred panel VAR model. After running the main model, there are other post-estimation considerations. These include the granger causality test, checking the stability condition and estimating the impulse-response functions.

4.4.1 Model fit

Table 4 displays the results used to identify appropriate panel VAR models. Model A is the estimated results of equation (2) for domestic and foreign aggregate infrastructure variables. Model B shows the results of equation (3) for the effective aggregate infrastructure that combines domestic and foreign infrastructure. Infrastructure may reasonably influence economic growth after some lags; thus, this article considers model selection estimates for the first to fifth-order panel VAR. However, given our sample size and data features, Model A cannot run a fifth-order maybe because of relatively more variables. Hence, a fourth-order panel VAR is applied (see panel I, Table 4). The lags of instruments for Model A and B are 5 and 7, respectively. The model selection criteria by Andrew and Lu (2001) suggest that a first-order panel VAR is most appropriate across the two models, having the lowest MBIC, MAIC and MQIC. Moreover, the J-statistics of over-identifying restriction for the selected models are not significant, and hence we cannot reject the null hypothesis of the correct specification. The coefficient of determination (CD) depicts the proportion of variation explained by the panel VAR.

4.4.2 Infrastructure spillover analysis

The first-order panel VAR of equations (2) and (3) is estimated using Stata in a GMM style. Table 5 presents the results of the growth elasticities for domestic and foreign aggregate infrastructure from the estimation of equation (2). The key results of interest are those

Table 4: Caption

Lag	CD	J-statistic	(P-value)	MBIC	MAIC	MQIC
Panel I: Model $\boldsymbol{A}$ - Domestic & Foreign infrastructure variables						
Lag	CD	J-statistic	(P-value)	MBIC	MAIC	MQIC
1	0.999	112.236	(0.190)	−473.843	−87.764	−241.421
2	0.999	96.479	(0.048)	−343.080	−53.521	−168.763
3	0.999	71.326	(0.025)	−221.713	−28.674	−105.502
4	0.999	41.757	(0.019)	−104.763	−8.243	−46.657
Panel II: Model $\boldsymbol{B}$— Effective infrastructure variables						
Lag	CD	J-statistic	(P-value)	MBIC	MAIC	MQIC
1	0.999	66.455	(0.119)	−236.456	−41.545	−119.786
2	0.999	81.152	(0.001)	−171.275	−8.848	−74.050
3	0.999	52.620	(0.036)	−149.321	−19.380	−71.541
4	0.999	38.689	(0.068)	−112.766	−15.311	−54.431
5	0.999	24.696	(0.134)	−76.275	−11.304	−37.384

Notes: Stata codes: Model A: pvarsoc lGDP ldais ldaiq lfais lfaiq, maxlag (4) pvaropts (instl (1/5)).
Model B: pvarsoc lGDP leais leaiq, maxlag (5) pvaropts (instl (1/7)).

displayed in panel I with log GDP per capita as the dependent variable. In the table, the coefficients of $LFAIS$ and $LFAIQ$ show evidence of spillover effects from foreign aggregate infrastructure stock and quality, respectively. The results suggest that a 1% increase in the foreign aggregate infrastructure stock will lead to an annual decrease in GDP per capita by roughly 0.04%. Thus, increased infrastructure stocks in SSA countries tend to create negative spillovers on other countries, especially the nearest areas (having used distance weights). As previously discussed, negative spillovers are feasible (see, for example, Yilmaz et al., 2002 (telecommunication); Moreno and Lopez-Bazo, 2003 (transport); Baird, 2005 (transport)). As an explanation, Yilmaz et al. (2002) argue that communication technologies enhance the locational freedom of firms, and the firms could use this infrastructure as a competitive tool for pulling production factors. Similarly, we believe that certain SSA states (such as South Africa) with relatively well-developed infrastructure stocks may attract more investment than their regional counterparts.

Negative spillovers to the surrounding countries may happen when production factors (human, financial and physical capital) are drawn to the economies with relatively high infrastructure stocks at the expense of those with less infrastructure.[3] Relocation of production factors, thus, may cause the lagging areas to experience weak economic activity and ultimately poor economic growth.

Remarkably, the coefficient for $LFAIQ$ is positive (0.09) and significant, suggesting positive spillover effects from foreign aggregate infrastructure quality. Upgrading a country's infrastructure quality is beneficial to the domestic economy and can also instigate economic growth in the surrounding countries. For instance, paved roads make it much easier for countries to transport cargo across borders. Improvement in the quality of electricity augments the amount of electricity available to end-users, including the ability to export power for foreign consumption. Innovations in the telecommunication sector consistently break the distance-related barriers. Consequently, the quality feature of aggregate infrastructure creates positive spillovers among SSA countries.

[3]The issue of brain drain may also play an important role in this case.

Table 5: Model A: Panel VAR Results - Gmmstyle Based

DV	IV	Coefficient.	Std.Error	[Confidence Interval]	
LGDP					
Panel I	LGDP (-1)	0.819***	0.024	0.772	0.866
	LDAIS (-1)	-0.641***	0.018	-0.676	-0.605
	LDAIQ (-1)	0.719***	0.051	0.619	0.819
	LFAIS (-1)	-0.036***	0.001	-0.039	-0.034
	LFAIQ (-1)	0.092***	0.002	0.088	0.096
LDAIS					
Panel II	LGDP (-1)	-0.068***	0.020	-0.107	-0.029
	LDAIS (-1)	0.650***	0.016	0.618	0.682
	LDAIQ (-1)	0.465***	0.045	0.378	0.553
	LFAIS (-1)	-0.005***	0.001	-0.007	-0.002
	LFAIQ (-1)	0.028***	0.002	0.023	0.032
LDAIQ					
Panel III	LGDP (-1)	0,014	0,011	-0,007	0,035
	LDAIS (-1)	-0,061***	0,011	-0,082	-0,039
	LDAIQ (-1)	0,910***	0,032	0,848	0,972
	LFAIS (-1)	-0,001	0,001	-0,003	0,000
	LFAIQ (-1)	0,009***	0,001	0,006	0,011
LFAIS					
Panel IV	LGDP (-1)	2,230***	0,239	1,762	2,698
	LDAIS (-1)	0,782***	0,201	0,388	1,176
	LDAIQ (-1)	-8,073***	0,640	-9,327	-6,819
	LFAIS (-1)	0,926***	0,014	0,898	0,954
	LFAIQ (-1)	0,174***	0,034	0,108	0,241
LFAIQ					
Panel V	LGDP (-1)	1,082***	0,110	0,866	1,298
	LDAIS (-1)	0,820***	0,086	0,652	0,987
	LDAIQ (-1)	-4,059***	0,300	-4,646	-3,472
	LFAIS (-1)	0,117***	0,007	0,103	0,131
	LFAIQ (-1)	0,776***	0,011	0,755	0,797
No. of Panels = 39					
No. of Obs = 507					

Notes: DV stands for dependent variable. IV stands for independent variable. Stata code: pvar lGDP ldais ldaiq lfais lfaiq, lags (1) instl (1/5) gmmstyle.

Contrary to other studies (for instance, Calderon and Serven, 2004; Calderon, 2009) that examined the infrastructure-growth nexus in Africa based on aggregate infrastructure, our results show evidence of negative growth impact from domestic aggregate infrastructure stock. In particular, a percentage increase in infrastructure stock reduces GDP per capita by 0.64%. Therefore, the panel VAR model suggests a negative growth effect from domestic infrastructure stock in this case. Several factors might be responsible for the negative pressure on growth. First, it could be due to diverting resources from other competing investments, which may overwhelm the gains of having additional infrastructure (Canning and Pedroni, 2008; Chakamera and Alagidede, 2017). This might be relevant in the African context, given the wider financing gaps. Thus, increased infrastructure investment will be associated with huge opportunity costs in terms of alternatives investment that would have been sacrificed.

Second, economic growth may fall when an increase in public infrastructure is funded by income tax (see Barro, 1990). A dilemma happens when the positive effect of a "supply-side" measure (i.e., infrastructure development) implemented to stimulate economic growth via augmentation of production function is canceled by negative effects from the "demand-side" of the economy due to tax burden. Looking at the components of GDP {C + I + G +(X-M)}, we can also speak of a situation where tax revenue (used to fund public infrastructure) raises government spending (G) while possibly posing negative pressure on consumption (C), investment (I) and net export (X-M) depending on how quick the effects of G translate into economic benefits, ceteris paribus. The negative effects could be more pronounced when a country imports resources to be used to construct infrastructure, and the new infrastructure further takes several lags to be fully beneficial while demand will be sensitive to the tax burden.

Third, we believe that the negative effects from aggregate infrastructure stock could be related to the unproductive utilisation of infrastructure in most SSA states. Economic hardships associated with low economic activity and high levels of unemployment may lead to unproductive uses of the infrastructure and fail to yield benefits over and above the construction costs of infrastructure. Unproductive use of infrastructure includes the non-business related use of telecommunication devices (for example, mobile networks on social media), which barely produce economic benefits. Again, the non-economic use of roads while increasing pollution and congestion is problematic. Moreover, the negative effects on growth might result from certain types of infrastructure in the aggregate indices rather than all the individual infrastructures.

Unlike infrastructure stock, a 1% increase in domestic aggregate infrastructure quality raises GDP per capita by approximately 0.72%. Therefore, the quality of infrastructure is central to increased growth. This is in line with our theoretical expectation that better public infrastructures (paved roads, airports with paved runways, decrease in electricity transmission and distribution losses, enhanced telecommunication services, and improved drinking water) facilitate productivity. From a social perspective, improved water reduces the likelihood of getting infected with water-borne diseases and hence lessens health expenses. Also, in panel I, the first lag of GDP shows a positive and significant effect on current GDP. Approximately 0.82% of GDP per capita in a current year will result from a percentage rise in GDP per capita in the previous year. Thus, high annual GDP can trigger economic activity in the following year and ultimately raising economic growth.

This study does not dwell much on other results where the infrastructure measures become dependent variables. We observe that the domestic infrastructure stock is positively influenced by its own lag, domestic infrastructure quality and foreign infrastructure quality. However, previous GDP levels and foreign infrastructure stocks do not necessarily translate into more infrastructure stock but rather tend to lower the current stock levels. As expected, the results indicate that the previous levels of infrastructure quality (both domestic and foreign) can positively influence the current domestic infrastructure quality. Nevertheless, the infrastructure stocks (domestic and foreign) suggest a negative effect on current infrastructure quality. A possible explanation is that when the respective governments invest more in infrastructure quality enhancement, they may cut the proportion towards additional stocks. Accordingly, the results of panels II and III imply that improvement in infrastructure quality is often associated with more infrastructure stocks in the following year, but more stocks may lead to minor quality improvement. In panels IV and V, the foreign variables are positively affected by previous GDP levels and domestic infrastructure stocks. It shows improved consumption of foreign infrastructures based on preceding high income and infrastructure stock levels. This may probably confirm why foreign infrastructure stocks show evidence of negative spillovers. When considerable consumption of foreign infrastructure significantly promotes foreign markets, negative spillovers may occur in the domestic market. On the contrary, the results imply that when earlier domestic quality levels ($LDAIQ$) are high in the economy, the relevance of foreign infrastructure variables ($LFAIS, LFAIQ$) to the domestic production function tends to decline. Therefore, as long as the domestic infrastructure quality is super, the consumption of foreign infrastructure shrinks.

Table 6: Model B: Panel VAR Results - Gmmstyle Based

	DV	IV	Coefficient.	Std.Error	z	P>z	[Confidence Interval]	
	LGDP							
Panel I		LGDP (-1)	0.919	0.009	97.520	0.000	0.900	0.937
		LEAIS (-1)	0.018	0.000	41.050	0.000	0.018	0.019
		LEAIQ (-1)	0.002	0.000	8.390	0.000	0.001	0.002
	LEAIS							
Panel II		LGDP (-1)	-0.004	0.004	-1.160	0.248	-0.011	0.003
		LEAIS (-1)	0.915	0.004	245.260	0.000	0.908	0.923
		LEAIQ (-1)	0.065	0.002	34.660	0.000	0.061	0.069
	LEAIQ							
Panel III		LGDP (-1)	0.003	0.011	0.250	0.804	-0.018	0.024
		LEAIS (-1)	-0.550	0.013	-43.050	0.000	-0.575	-0.525
		LEAIQ (-1)	0.731	0.003	249.670	0.000	0.725	0.737
	No. of panels = 39							
	No. of Observations = 507							

Notes: DV stands for dependent variable. IV stands for independent variable. Stata code: pvar lGDP leais leaiq, lags (1) instl (1/7) gmmstyle.

Table 6 shows the growth contributions from effective infrastructure stock and quality. In panel I, the growth effects of both effective infrastructure stock and quality are positive and statistically significant. The contribution of effective infrastructure quality is lower than the spillover effects from foreign infrastructure quality. Although the separate effects of domestic and foreign infrastructure stocks are negative (see Table 5), their combined effect is positive (0.018). The changes in growth coefficients should be interpreted with caution because this could be a statistical or econometric related issue. After the panel VAR estimations, the following sub-sections are part of post-estimation considerations.

4.4.3 Panel Granger causality test

It seems vital to perform panel Granger causality to determine whether each explanatory variable in our regression models can really cause changes in the dependent variable. In the estimated models (equations 2 and 3), this approach checks the potential causality of any excluded (or restricted) variable. The null hypothesis is that the excluded variable does not Granger cause equation variable against the alternative hypothesis that excluded variable Granger causes equation variable. Table 7 presents the panel Granger causality results for Model A.

We are mainly interested in the first panel. The Chi-squared statistics for the aggregate infrastructure variables are highly significant; therefore, we reject the null hypothesis and conclude that both domestic and foreign aggregate infrastructure stock and quality Granger cause GDP per capita. The joint causality of all the four infrastructure variables as shown by the Chi-squared statistic of "ALL" is also significant and hence all the infrastructures jointly Granger cause economic growth. The causality outcomes buttress our initial findings of significant domestic and foreign infrastructure (stock and quality) impacts on economic growth. Thus, the evidence of infrastructure-growth relationships as depicted in Table 5 are not coincidental but rather plausible and robust. Except for $LDAIQ$ versus $LGDP$ and $LDAIQ$ versus $LFAIS$ under panel III, all other pairs of variables show bi-directional Granger causality evidence. Thus, only the following show unidirectional causality: $LDAIQ \rightarrow LGDP$ and $LDAIQ \rightarrow LFAIS$.

Table 7: Model A: Panel Granger Causality Wald Test

	Equation/Excluded	chi2	P>chi2
LGDP			
Panel I	LDAIS	1222.531	0.000
	LDAIQ	199.832	0.000
	LFAIS	709.215	0.000
	LFAIQ	2050.961	0.000
	ALL	2883.179	0.000
LDAIS			
Panel II	LGDP	11.969	0.001
	LDAIQ	109.311	0.000
	LFAIS	17.298	0.000
	LFAIQ	136.232	0.000
	ALL	301.984	0.000
LDAIQ			
Panel III	LGDP	1.799	0.180
	LDAIS	30.762	0.000
	LFAIS	2.187	0.139
	LFAIQ	54.133	0.000
	ALL	170.081	0.000
LFAIS			
Panel IV	LGDP	87.119	0.000
	LDAIS	15.125	0.000
	LDAIQ	159.153	0.000
	LFAIQ	26.706	0.000
	ALL	682.658	0.000
LFAIQ			
Panel V	LGDP	96.531	0.000
	LDAIS	91.846	0.000
	LDAIQ	183.607	0.000
	LFAIS	259.737	0.000
	ALL	403.300	0.000

Notes: Stata code: pvargranger.
H0: Excluded variable does not Granger cause Equation variable.
H1: Excluded variable Granger causes Equation variable.

Table 8: Model B: Panel Granger Causality Wald Test

	Equation/Excluded	chi2	P>chi2
LGDP			
Panel I	LEAIS	1684.736	0.000
	LEAIQ	70.450	0.000
	ALL	3041.882	0.000
LEAIS			
Panel II	LGDP	1.337	0.248
	LEAIQ	1201.173	0.000
	ALL	1301.801	0.000
LEAIQ			
Panel III	LGDP	0.061	0.804
	LEAIS	1853.561	0.000
	ALL	1876.334	0.000

Notes: See footnotes under Table 7.

Table 8 shows Granger causality outcomes for Model B. Both effective infrastructure stock and quality Granger cause economic growth, as indicated in panel I. One way Granger causality is only implied from the effective infrastructure variables to LGDP ($LEAIS \rightarrow LGDP$, $LEAIQ \rightarrow LGDP$) as the Chi-squared statistics for LGDP are not statistically significant in panels II and III.

4.4.4 Stability condition checks

Before the estimation of impulse response functions, the estimated panel VAR models are checked for stability. Table 9 shows the results for both Model A and Model B.

Table 9: Model B: Stability Test

Model A			Model B		
Eigenvalues			Eigenvalues		
Real	Imaginary	Modulus	Real	Imaginary	Modulus
0.976	0.103	0.981	0.918	0.000	0.918
0.976	-0.103	0.981	0.823	0.165	0.840
0.908	0.000	0.908	0.823	-0.165	0.840
0.756	0.000	0.756	-----	-----	-----
0.464	0.000	0.464	-----	-----	-----

Notes: All eigenvalues lie inside the unit circle; thus, panel VAR satisfies the stability condition. Stata code: pvarstable.

These results are accompanied by graphs (Figures 1 and 2). As confirmed by the values in the table and the dots in figures 1 and 2 below, all the eigenvalues lie within the unit circle in each case. Consequently, our panel VAR models satisfy the stability condition, and we proceed to run the impulse response tests.

Figure 1: Model A - Stability Condition

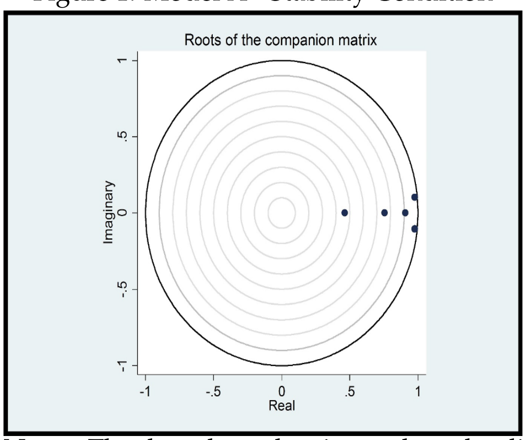
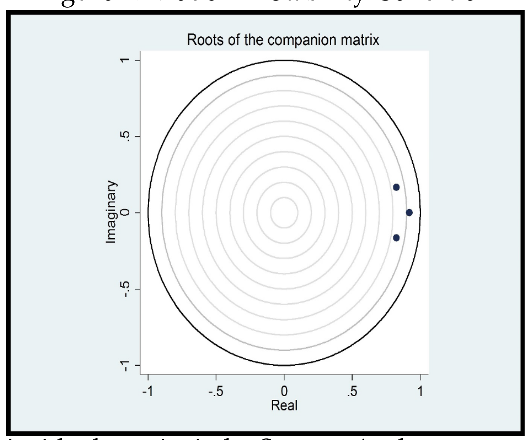


Figure 2: Model B - Stability Condition



Notes: The dots show the eigenvalues that lie inside the unit circle. Source: Authors

4.4.5 Impulse response

The impulse response results for Model A are displayed in Table 10. Panel I, which shows the percentage of variation in GDP per capita explained by variations in the aggregate infrastructure variables, is our main interest. It is revealed in panel I that economic growth is greatly explained by domestic aggregate infrastructure stock. The percentage of variation explained by LDAIS increases from 11% in lag 2 to 52% in lag 10. Moreover, the percentage of variation in growth explained by the foreign variables (LFAIS and LFAIQ) increases with the number of lags. Thus, the impact of the infrastructure variables on growth is more pronounced in the long run. However, the response of GDP to domestic aggregate infrastructure quality ($LDAIQ$) tend to depict an inverted U-shaped relationship. The percentage of variation in GDP starts small (5%), rises to 9% in the space of 4 years and then declines as the number of years from initial quality enhancement increases.

Overall, the response of GDP to changes in domestic and foreign infrastructure stock persistently increases and tend to long last. On the other hand, GDP's response to changes

Table 10: Forecast-Error Variance Decomposition – Model A

	Response variable		Impulse variable				
			LGDP	LDAIS	LDAIQ	LFAIS	LFAIQ
Panel I	LGDP	lag					
		2	0.785	0.111	0.057	0.004	0.044
		4	0.488	0.309	0.092	0.009	0.102
		6	0.372	0.419	0.075	0.011	0.122
		8	0.316	0.483	0.058	0.014	0.128
		10	0.285	0.520	0.048	0.019	0.128
Panel II	LDAIS						
		2	0.036	0.920	0.037	0.000	0.006
		4	0.027	0.827	0.114	0.009	0.022
		6	0.025	0.764	0.138	0.034	0.039
		8	0.025	0.713	0.131	0.070	0.061
		10	0.026	0.657	0.130	0.102	0.085
Panel III	LDAIQ						
		2	0.045	0.011	0.942	0.000	0.002
		4	0.047	0.021	0.920	0.002	0.010
		6	0.055	0.058	0.860	0.005	0.022
		8	0.064	0.116	0.774	0.008	0.038
		10	0.071	0.184	0.681	0.010	0.054
Panel IV	LFAIS						
		2	0.053	0.208	0.082	0.656	0.002
		4	0.022	0.201	0.266	0.494	0.017
		6	0.015	0.214	0.379	0.353	0.039
		8	0.014	0.232	0.439	0.258	0.057
		10	0.015	0.249	0.472	0.195	0.069
Panel V	LFAIQ						
		2	0.078	0.076	0.093	0.318	0.434
		4	0.032	0.088	0.295	0.303	0.282
		6	0.019	0.125	0.403	0.244	0.210
		8	0.017	0.164	0.455	0.190	0.174
		10	0.017	0.197	0.482	0.148	0.155

Notes: Stata code: pvarfevd. FEVD standard errors and confidence intervals based on 200 Monte Carlo simulations.

in domestic infrastructure quality tends to quickly diminish, thus, short-lived. The responses of the infrastructure variables to each other and changes in the GDP level are demonstrated in panels II, III, IV and V of Table 10. Most notably are the responses of infrastructure development to changes in GDP level, which are in the range of 1% - 8% across the lags.

Table 11 shows the impulse response results for the effective infrastructure model. Under panel I of the table, as much as 6% of the variation in GDP per capita can be explained by the effective stock of infrastructure, while the effective infrastructure quality explains as much as 2% of the variation. The percentage of variation increases with the number of lags. Thus, the response of GDP to changes in the effective aggregate infrastructure level is relatively great in the long term. However, the effective infrastructure stock and quality could not respond to changes in GDP (see panels II and III).

Regarding the IRF graphs (Figure 3), we are interested in the last plots on the far right, which have $LGDP$ as the response variable. As shown by the impulse response plots for $LDAIQ : LGDP$ and $LFAIQ : LGDP$, positive shocks on domestic and foreign aggregate infrastructure quality can lead to increased GDP but the effects are short-lived. The impacts on GDP diminish in the long-term. Consequently, the impulse response of GDP levels to changes in infrastructure quality levels follows an inverted U-shaped relation.

The IRF plot for $LDAIS : LGDP$ shows that positive shocks in domestic aggregate infrastructure stock exert negative pressure on economic growth. However, the negative impacts become better in the long run. In the long-term, the infrastructure stocks probably become more beneficial, recouping the cost of their construction and hence lessening

Table 11: Forecast-Error Variance Decomposition – Model B

	Response variable		Impulse variable		
			LGDP	LEAIS	LEAIQ
Panel I	LGDP	lag			
		2	0.996	0.004	0.000
		4	0.979	0.020	0.001
		6	0.958	0.037	0.005
		8	0.940	0.050	0.010
		10	0.926	0.059	0.015
Panel II	LEAIS				
		2	0.000	0.991	0.009
		4	0.000	0.956	0.044
		6	0.000	0.917	0.083
		8	0.000	0.888	0.112
		10	0.000	0.873	0.127
Panel III	LEAIQ				
		2	0.000	0.277	0.723
		4	0.000	0.459	0.541
		6	0.000	0.564	0.436
		8	0.000	0.608	0.392
		10	0.000	0.619	0.381

Notes: Stata code: pvarfevd. FEVD standard errors and confidence intervals based on 200 Monte Carlo simulations.

the negative impacts. The $LFAIS : LGDP$ plot depicts that a positive shock on foreign aggregate infrastructure stock can lead to a continuous decrease in GDP and long-lasting impacts. This is linked to the previous argument that foreign infrastructure development may act as a competitive tool that improves a region with better infrastructure stock at the expense of the lagging surrounding areas. On average, those with poor infrastructure may persistently experience negative growth.

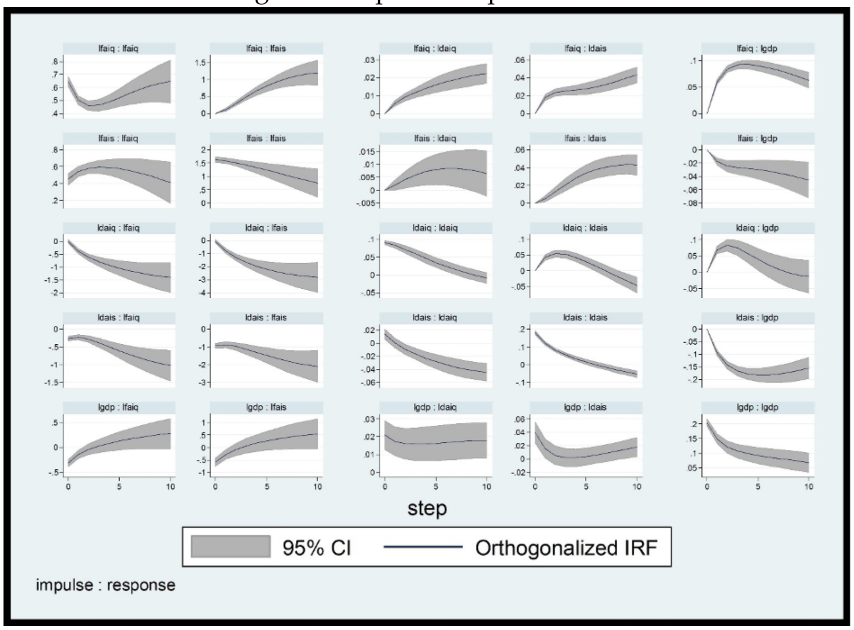
In terms of the effective infrastructure model, the IRF plot for $LEAIQ : LGDP$ (Figure 4) suggests that a shock in the effective aggregate infrastructure quality can increase GDP. The positive impacts can exist for several years though at a diminishing rate. The plot for $LEAIS : LGDP$ shows a positive impact on growth in the short to medium term, yet the impact becomes negative in the long term.

In addition to the discussion above, we also believe that spatial density, which deals with space, may play a role in the provision of quality infrastructure. While further research is required on the impact of spatial density on infrastructure provision and quality, it influences the plans for the various infrastructure projects and the accompanying costs. Furthermore, our analysis is somehow linked to "New economic geography" (NEG). However, we do not go deeper into the application of the canonical new economic geography model that gives insight regarding the aspect of agglomeration forces. We, therefore, leave this issue as one of the areas for further study.

5 Implications of results

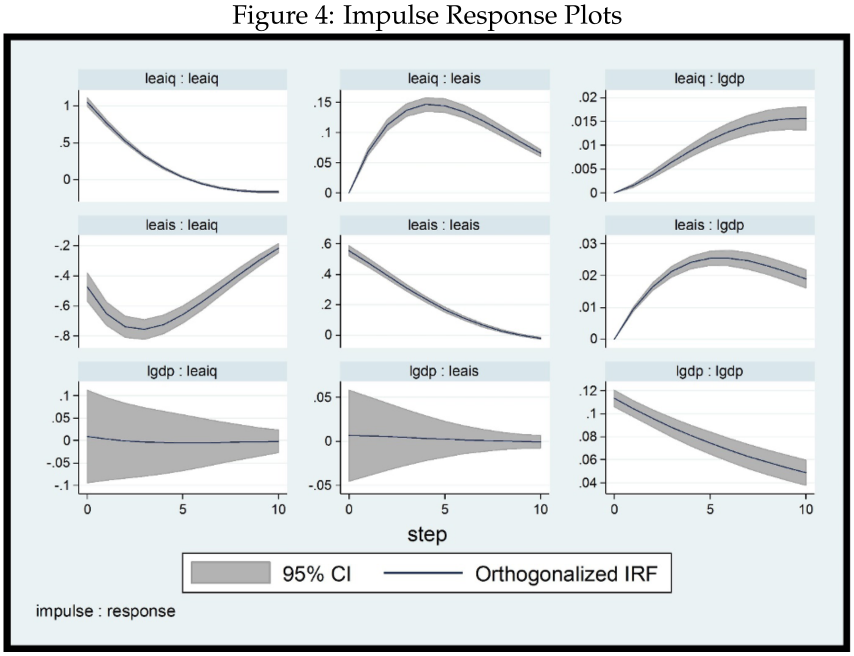
This paper has important policy implications. First, with increasing globalisation, raising infrastructure stock may act as a competitive tool to draw economic factors (human, financial and physical resources) from the surrounding countries with poor infrastructure networks. This implication is drawn from the negative spillover effects suggested by the

Figure 3: Impulse Response Plots



Source: Authors

Figure 4: Impulse Response Plots



Source: Authors

coefficient for foreign aggregate infrastructure stock. Moreover, countries with better infrastructure may become lucrative destinations for foreign direct investment (FDI) and multinational companies. Under such circumstances, the areas with poor infrastructure stock may experience negative spillovers as they lose production factors to those with better infrastructure. For instance, South Africa has been attracting human capital from other African countries. The IDC (2021) indicated that South Africa is a lucrative destination for foreign investors, as they can leverage on, among other things competitive advantages, exceptional physical infrastructure and extensive logistics and transport network.

Second, the occurrence of spillover effects through infrastructure stock and quality may differ. Our results demonstrated positive spillovers from foreign aggregate infrastructure quality but negative spillovers from foreign aggregate infrastructure stock development. Thus, the combined effect of paved roads, paved airport runways, reduced electricity transmission and distribution losses, enhanced IT infrastructure, and safe water will stimulate economic growth in the surrounding regions. For instance, paved roads enhance the use of road transport for long distances between two regions, and IT infrastructure improves communication and conduct of business deals between countries. Another important aspect of IT is its transferability across regional economies. Therefore, our results strongly suggest that it is not adequate to make policy based on spillovers of aggregate infrastructure stock alone as the quality features of infrastructure may produce vital spillovers, with a bearing on spillover-related policies. For instance, paved roadways and efficient ports play a key role in facilitating trade in Africa, especially given that in a total of 55 countries, the continent constitutes 16 landlocked countries. These landlocked African states need fast and reliable access to ports to facilitate trade (Kosmala, 2021). Improving infrastructure quality is among the measures that reduce trade barriers and increase connectivity in Africa, enhancing the movement of physical and human capital. The African Trade Policy Centre's (2017:1) report mentioned that "Connectivity across the continent and on various fronts will need to be improved to reduce trade barriers between African countries and to realize the promise of the Continental Free Trade Area. . . ." Addressing the quality of roadways, airports and telecommunication breaks physical barriers amongst African nations, while electricity can also be exported and facilitates production in regional countries. For example, Zimbabwe has been importing electricity from Zambia and Mozambique.

Third, the existence of spillovers brings out two major concerns for policymaking: (i) whether there should be some form of cost-sharing arrangements between the regional economies that benefit from infrastructure spillovers, and (ii) the extent to which infrastructure investments are optimal in the presence of spillovers. A reasonable argument can be made for cost-sharing among beneficiaries to ease the investment burdens of the economies that bear the costs of infrastructures responsible for major spillovers (or externalities). An example is when a coastal country's (e.g., South Africa) seaports or harbour generate enormous spillovers that benefit the surrounding landlocked countries (e.g., Zimbabwe). Zimbabwe can benefit from South African harbour and its other transport infrastructures such as highways and railways from the seaports to the border. Despite the plausibility of sharing costs, it could be difficult to determine the cost-sharing structure that ensures a win-win situation. Maybe the best strategy in the presence of spillovers is to consider bilateral or multilateral investment cooperations. This is when countries consider joint infrastructure projects. A typical case for the applicability of continental transport projects is the Kenya-Uganda rail freight corridor (Kosmala, 2021). In this case, the two governments (Kenya and

Uganda) agreed in 2004 to concession their railways together. This can relieve the potential cost burden that would have been borne by each country separately.

On the issue of optimisation, some authors (for instance, Richaud et al., 1999) argue that infrastructure investment decisions at the national level can be sub-optimal in the presence of spillovers and hence the decisions can best be made at a regional level. We concur with this argument and believe that certain investment decisions at a regional level would help lift the SSA region. This can be helpful when directing donor funds or other support from the African Development Bank towards infrastructure development in SSA.

Fourth, the possible negative growth effects from domestic infrastructure stock development are a matter of concern. While policymakers might consider crowding out of the private investment as a possible reason for negative impacts, we strongly argue that unproductive utilisation of the infrastructure could stand out. Public infrastructure might be under-utilised because of low economic activity, high unemployment, poor institutional qualities (e.g., violation of the rule of law, political instability, poor democracy, high corruption levels) and limited investment funds in most SSA countries. Thus, in the absence of a favourable environment that fosters investment, public infrastructure may not yield returns above their construction costs.

Fifth, policy-wise, thoughtful investment priorities are vital, especially in SSA, where financial gaps are wider as investments in infrastructure stocks may divert significant resources from other competing investments and possibly strain economic growth. Therefore, policymakers will do well to ensure balanced and optimal investments between public infrastructure and other investments, which requires a cost-benefit analysis. Additionally, funding public infrastructure from increased taxation demands careful attention since this may discourage consumption and drags per capita economic growth. To assist governments in the provision of infrastructure, policymakers need to consider private players. This will bring the necessary investment funds needed to increase the infrastructure stock levels. Sixth, decision-makers need to be aware of several lags involved before infrastructure's impact becomes substantial. The aggregate quality effects are more pronounced in short to medium terms and eventually diminish in the long run as observed from our impulse response results. This knowledge is vital when making infrastructure investment projections. Lastly, positive infrastructure spillovers may facilitate regional take-off by creating important externalities, which enable the sound economic performance of some key economies to lift other regional states. Additionally, the positive effects of GDP lags on current GDP imply that it is possible for SSA countries to have a vicious cycle of economic growth, which is necessary for convergence and take-off. In the realm of the neoclassical convergence theory, higher impact from previous economic growth may suggest an expansionary gap (or catch-up gap) that still exist in SSA before reaching the maturity stage. Such countries should experience higher growth rates and present great opportunities, which are imperative for investment decisions.

SSA countries should ensure an appropriate budget towards quality enhancement, which stands to benefit not only the domestic economy but stimulate the surrounding areas through positive spillovers. Consequently, while SSA economies make efforts to address the infrastructure shortage problem, improving the quality of existing infrastructure is extremely necessary.

6 Concluding remarks

This paper discusses the engineering viability and properties of stabilized mud blocks. The clay identification tests are important because they allow defining characteristics of the earth, to situate them concerning the suitability criteria, and therefore orient the choice of the stabilizer. The behavior of the blocks differs depending on the treatment and dosage incorporated. The compressive strengths in dry and wet conditions increase with the dosage of the binder. Mixing cement and lime yielded the best resistance. The different formulations have determined the best treatment. It is the mixture of cement and lime which has proved the best suitable treatment with reference to strength and durability. Twelve percent cement stabilization can be used for outer wall construction and a lower percentage of cement can be used for inner wall construction. Compressed Stabilized Earth Block (CSEB) does not produce harmful gases during production as they do not require coal or burning material. So, CSEB is an eco-friendly building material (Patowary et al., 2015). CSEB could be a great alternative to a mud house in the rural regions of developing countries.

Most previous studies have examined spillovers from single infrastructure stocks and what has been lacking is the knowledge from aggregated infrastructure perspective while accounting for quality features. The aggregate infrastructure measures provide an additional understanding regarding the spillovers from the general infrastructure system of an economy. Important spillovers may emanate from infrastructure quality, which may manifest differently from the stock spillovers. It is therefore encouraging to know the extent of spillover effects from both aggregate infrastructure stock and quality. This research investigated spillover effects of aggregate infrastructure stock and quality in SSA. Each aggregate infrastructure index is a combination of electricity, roads, airports, telecommunication, and water infrastructure. We created foreign aggregate infrastructure stock and quality indices using a distance-based weighting criterion. THE Panel VAR approach is used to do the estimations.

The results suggest positive spillover effects from aggregate infrastructure quality while the aggregate stock implies negative spillovers. Domestic aggregate infrastructure quality (stock) shows positive (negative) growth effects. These findings are bolstered by the panel Granger causality outcomes

$$\text{LDAIS} \Leftrightarrow \text{LGDP}$$
$$\text{LDAIQ} \rightarrow \text{LGDP}$$
$$\text{LFAIS} \Leftrightarrow \text{LGDP}$$
$$\text{LFAIQ} \Leftrightarrow \text{LGDP}$$
$$\text{LEAIS} \rightarrow \text{LGDP}$$
$$\text{LEAIQ} \rightarrow \text{LGDP}$$

The existence of spillovers may necessitate infrastructure investment decisions being made at the regional level than at the country level. This allows the regional providers of infrastructure funds to look at SSA as a whole, deciding the appropriate funds that each country should receive while accounting for spillovers in the projections. Furthermore, the formulation and implementation of cost-sharing arrangements among beneficiaries could be necessary in the presence of substantial positive spillover effects. The results of this study are plausible and robust; however, future research should consider other weighting criteria such as neighbourbased weights and/or trade-based weights while still accounting for infrastructure stock and quality.

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Appendix

Table A1: Eigenvectors or Loadings

	Components				
Variable	**PC 1**	**PC 2**	**PC 3**	**PC 4**	**PC 5**
Eigenvectors for infrastructure stock					
LELES	0.505	0.122	-0.507	0.541	0.425
LAIRS	0.548	-0.348	0.178	0.274	-0.687
LTELS	0.428	0.453	-0.360	-0.651	-0.241
LWATS	0.125	0.746	0.591	0.280	-0.013
LROADS	0.496	-0.319	0.482	-0.362	0.538
Eigenvectors for infrastructure quality					
LELEQ	-0.015	0.838	0.530	0.054	0.114
LAIRQ	0.378	0.461	-0.685	0.300	-0.293
LTELQ	0.525	-0.205	0.475	0.083	-0.671
LWATQ	0.552	-0.186	0.123	0.490	0.636
LROADQ	0.525	0.093	-0.096	-0.812	0.215

Notes: Eviews 9 estimates. Eigenvectors shows the weight carried by each variable in the principal components.