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Article

Infrastructure development, informal economy, and gender inequality in Sub-Saharan Africa

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Abstract: Infrastructure development policies have been criticised for lacking a deliberate pro-gender and pro-informal sector orientation. Since African economies are dual enclaves, with the traditional and informal sectors female-dominated, failure to have gendered infrastructure development planning and investment exacerbates gender inequality. The paper examines the effect of the infrastructure development index, the size of the informal economy, and the level of economic development on gender inequality. The paper applies the panel autoregressive distributed lag method to data on the gender inequality index, infrastructure development index, GDP per capita, and size of the informal sector for the period 2005–2018. The sample consists of 44 African countries. The research established that the infrastructure development index, its sub-indices, GDP per capita, and the size of the informal sector are crucial dynamics that governments need to consider carefully when formulating development policies to reduce gender inequality. The research found that investment in infrastructure in general, transport infrastructure, and energy infrastructure reduces gender inequality. infrastructure development has gender inequality increasing effects in some countries and gender inequality reducing effects in others. The pattern suggests that at the continental level a Kuznets-type patten in the relationship between gender inequality and infrastructure development, gender inequality and size of informal sector, and gender inequality and GDP per capita exists. Some countries are in the region where changes in these covariates positively correlate with gender inequality, while others are in the region where further increases in the covariates reduce gender inequality.

Keywords: gender inequality; infrastructure development; transport infrastructure; energy infrastructure; informal sector; income per capita
JEL Codes: B54; H54; R42

1. Introduction

The development of Infrastructure, decrease in the level of inequality and growing employment opportunities are the vital requirements to get on the path of sustainable development (Asian Development Bank, 2012). However, Sub-Saharan African (SSA) countries at present are facing a lack of adequate infrastructure, a high level of inequality and an increasing unemployment rate over the years (Selassie and Hakobyan, 2021). As per McKinsey's (2020) report, most of the infrastructure-related projects in Sub-Saharan Africa did not move beyond the planning stage even though international investors are ready to provide capital to finance infrastructure projects in the region. The SSA region has made some progress in terms of the Sustainable Development Goals Gender Index [DGGI], but the score is still under the category of very poor (Equal Measures 2030, 2022). In the region, compared to the global level

(24 percent) for both formal and informal sector, the gender pay gap is also 30 percent. More than 89 percent of the women are working in the informal sector in order to fulfil their care responsibilities. Trapped in low-paid, poor-quality work in the labour market, women face many issues and challenges (UN Women, 2023). In addition to that, in the face of Covid-19 and growing dependence on technology for remote work, access to reliable sources of electricity is also a big challenge (Holtz and Heitzig, 2021; McKinsey and Company, 2020). Further, despite being one of the world's lowest carbon dioxide emitters, communities in Sub-Saharan Africa are some of the most vulnerable to climate change (Ahn, 2023).

According to the data available from World Bank, compared to the United States, in many countries of Sub-Saharan Africa, the per capita income is much smaller. In 2022, its growth dropped to 3.6 percent compared to 2021 (4.1 percent) because of lingering inflation, high debt financial conditions and slow global economic growth (The World Bank, 2023). In 2019 in Sub-Saharan Africa, around 38 percent of the people were living in extreme poverty while 10 percent for the rest of the world lived in extreme poverty, which leads to social and physical damage along with a lack of opportunities for the development of human capital. Moreover, those under the age of fifteen years, population is dependent on their parent's income for survival (Beegle and Christiaensen, 2019). According to the United Nations (2021), the COVID-19 pandemic has also impacted the rural poor in terms of food security, limited mobility and reduction in income levels. This also had an additional impact in rural areas of Sub-Saharan Africa where more than 50 percent of the people are below the poverty line (Castañeda et al., 2018).

Before COVID-19, many Sub-Saharan African economies have shown commendable growth in GDP. Economies like Kenya, Ghana and Ethiopia have seen growing investments, and Rwanda and Ethiopia have seen the fastest growth rate 7.5 percent (International Monetary Fund, 2022). However, the ground reality is different in terms of the share of economic gains shared inequitably across regions within each country. A global shift from South Asia to Africa is seen in recent years in terms of poverty concentration. Various forecasts suggest that soon poverty will become an African phenomenon (Beegle and Christiaensen, 2019). Some of the reasons for slower poverty reduction or increasing inequality in the region are high fertility and population growth, poor growth in the initial years and the composition of growth of the Sub-Saharan Region (Beegle and Christiaensen, 2019; Sembene, 2015). This significantly shows that there is need for social and economic redistribution policies for better growth in inclusive terms. According to the information made available by World Bank (2023) by 2050 half of the population in Sub-Saharan Africa is going to be under 25 years, which will offer human resources to it for utilizing natural resources and the opportunities for reduction in poverty and inclusive growth of the region.

2. Review of literature

2.1. Transport infrastructure and gender inequality

Tucho (2022) demonstrated that poor transport system in Sub-Saharan region undermined efforts to reduce inequality and achieve sustainability. In addition, the study also focused on how institutional changes and available transport modes

preferences got affected by historical transport infrastructure development and changes in the socio-economic structure. To understand this perspective a systematic review of various literatures has been carried out. The findings of the study suggested that related value system, economic transitions, socio-technical changes, and local socio-economic contexts shaped by historical pretexts are the vital factors impacting transport demand in the region.

Mutiiria et al. (2020) constructed an inclusive growth index to study the nexus between infrastructure and inclusive growth. In addition, the study also investigated the distributive impact of infrastructure failure on income groups. The findings of the study showed that there is a positive association between inclusive growth and infrastructure mainly information and communication technology, transport and energy. It is concluded that infrastructure plays a significant role in the distribution of income, with poor people gaining more benefits than the rich from the listed infrastructures. The authors suggested that in the Sub-Saharan Africa region, to enhance shared prosperity and reduce disparities in income, infrastructure services and policies should be framed in terms of increasing their accessibility and affordability.

Women face many barriers to accessing urban spaces because of transport infrastructure problems. Mejía-Dorantes and Villagrán (2020) found that urban and transport planning in Mexico City had worsened gender inequality in terms of both physical and economic access to the city. They argue that transport infrastructure planning marginalises security issues that women face, and that urban transport spaces tend to focus on the being of the masculine gender. They concluded that in the Mexican city there was gendered urban exclusion. Van Eldijk and Gil (2020) also concluded that urban infrastructure projects displaced women and reduced their accessibility to economic hubs. Alarcón-García et al. (2022) and Parikh et al. (2015) concur, arguing that accessibility of transport infrastructure equalises gender capabilities, functioning and ultimately, female wellbeing. They argue that all dimensions of infrastructure are crucial for female wellbeing. Siemiatycki et al. (2020) have contributed to this debate by demonstrating that the negative impacts of infrastructure development are inordinately bone by women because of which infrastructure planning must carefully consider the gendered dimensions of infrastructure production. They observed the deep embedding of masculinity in organisational arrangements for infrastructure delivery, thus a ‘systematic gender bias’ (Siemiatycki et al., 2020, p. 309). Overall, infrastructure development in Africa is characterised by poor governance that fails to cultivate principles of gender inclusivity. Thus, the marginalisation of gender issues create real barriers to women in terms of access to the economy and livelihoods.

2.2. Energy infrastructure and gender inequality

Li et al. (2023) studied the association between energy-related external aid, carbon emissions, per capita GDP, and electricity access using econometric analysis for a sample of 30 Sub-Saharan African counties. The results showed that there is no direct impact of energy-related aid on electricity access, however, all types of energy aid facilitate economic growth in the long run. Moreover, in both rural and urban areas an increase in per capita GDP is positively associated with electricity access. Also, in the mitigation of carbon emission, energy related aid has a role to play. The paper

further suggested that to confront shared energy challenges, there should be regional cooperation among Sub-Saharan African countries as a collective effort.

Appiah et al. (2022) analysed the pressing needs for critical infrastructures, the roles of governance and institutions in infrastructural developments in the Sub-Sahara African region using mainly the Common Correlated Efficient Mean Group (CCEMG) and Dynamic CCEMG methods. The findings of the study showed that, to enhance the existing infrastructural development in SSA, governance and institutional quality are highly critical and significant. In addition, industrialization and growth also have a positive impact on infrastructure development, however, there is no significant impact of infrastructural development in the region.

2.3. ICT infrastructure and gender inequality

Kouladoum (2023) analysed the impact of the inclusive growth aspect of digital infrastructure development in Sub-Saharan African economies for 20 years using the Driscoll–Kraay strategy and Newey–West standard errors on four indicators of digital infrastructure. The findings of the study revealed that mobile cellular subscriptions per 100 adults, the number of fixed broadband subscribers, fixed telephone and the number of individuals using the internet have a positive and significant impact on the inclusive growth of the region. Further, digital infrastructure increased the level of inclusive growth regardless of the different income group (Low, middle, and Upper) of countries of the region. Therefore, the study suggested investments in human capital and digital infrastructure growth. Odhiambo (2022) examined the relationship between economic growth, ICT and income inequality in SSA using the Generalised Method of Moments technique. The study found that ICT development has a positive impact on the economic growth of the selected countries of the region. Further, the study suggested that for the positive impact of ICT on economic growth the level of income inequality should not exceed the threshold limit provided. Ndubuisi et al. (2021) examined the effect of digital infrastructure on services sector employment in 45 Sub-Saharan African countries. The conclusions of the study showed that digital infrastructure has a role to play in the employment in the services sector of the selected sample size. Moreover, education, institutional quality, and macroeconomic conditions as captured by the inflation rate are the main factors behind the positive effect of digital infrastructure on services sector employment. Also, as institutional quality becomes better an increase in the positive effect of digital infrastructure can be seen in services sector employment, while, a decrease can be seen with poor macroeconomic conditions.

Azolibe and Okonkwo (2020) investigated for 17 Sub-Saharan African countries the role of infrastructure development in stimulating industrial sector productivity using the panel least square estimation technique. The outcome of the study showed that the quantity and quality of telecommunication infrastructure is the major factor that influences industrial sector productivity in Sub-Saharan Africa and the reason for the low level of industrial sector productivity in the region is mainly because of poor transport and electricity infrastructure along with underutilization of water supply and sanitation infrastructure. The study suggested that the government of the region should

collaborate with developed countries like Japan, Germany, Austria, the United States etc. for the development and growth of their infrastructure.

2.4. Water and sanitation services infrastructure and gender inequality

Atangana and Oberholster (2023) assessed that the challenges present in the Sub-Saharan Africa for clean drinking water, sanitation, and hygiene. Through applying regression trend estimation, the study observed that on the elimination of open defecation by 2030, rural and urban population growth had a statistically significant detrimental influence. Further, by 2030–2035, the urban population of the region would be 65, 25, and 10 million in all the three defined income group categories as per the predicted data model. Ohwo (2019) assessed the dimensions of water, sanitation and hygiene (WASH) under the achievement of sustainable development goals by eliminating different forms of inequalities in urban and rural WASH services in sub-Saharan Africa. Using descriptive design based on various secondary sources of the database the study concluded that between urban and rural areas, there exist inequalities in WASH services at different levels of the selected region. The study suggested that the adoption of policies in terms of promotion of education, poverty reduction, reduction of corruption in the WASH sector and promotion and development of institutions through improved funding and accountability. Sultana (2020) has argued that water infrastructure planners and developers tend to miss the crucial element of the intersection of gender and water and sanitation infrastructure. The time and space dimensions of the infrastructure continues to be marginalised and this explains why many projects fail to close the gender inequality gap in terms of access to water and sanitation.

Calderon (2018) worked on the vitality of the infrastructure towards the growth and productivity of Sub-Saharan Africa. The study focused mainly on four sectors i.e., water and sanitation, transportation, electric power and telecommunications in terms of quality, quantity and accessibility. The outcome of the study showed that there is the existence of a large gap in the region for infrastructure mainly in terms of financing requirements and the public sector is not sufficient to meet these. The study suggests that there is space to make efforts in terms of improving the efficiency of the infrastructure spending by the public sector which will have an impact on the output multiplier of investment spending in positive terms.

2.5. Infrastructure and the informal sector produce certain patterns of gender inequality

The informal sector plays a crucial role in gender inequality dynamics. The broadly accepted definition is that the informal sector comprises legitimate market-based economic activities that, nonetheless, are concealed from public authorities for reasons such as taxation of income (Elgin et al., 2021). Van et al. (2023) studied, with reference to the Sub-Saharan Africa, the impact of structural transformation for gender equality. The study found that the ex-ante effect of structural transformation on gender gap is not clear, however it impacts access to decent work, poverty and growth. Further, it provides that rural areas and informal (self-)employment is often excluded when we talk about the gender pay gap evidence in the region. Differences in sector, occupation,

and education are some of the workers' characteristics that explains the gender pay gap. The study suggests that equal pay for men and women should be ensured in order to fulfil the gap associated with gender pay.

Ahinkorah et al. (2021) studied the impact of Covid-19 pandemic along with the other structural inequalities mainly from the perspective of girls and women across the region of Sub-Saharan Africa. The impact was visible mostly in the form of issues related to health care, housing inequities, reproductive health aspects, work inequalities, educational inequalities and household inequalities. The paper suggested that the adoption of low-cost preventive measures to curb the spread of the virus along with the broad set of policy initiatives to deal with complex interrelated disparities to reduce the issues faced by many women in the region.

2.6. Some other studies on inequality perspective of SSA

Awad and Hussain (2021) studied six Sub-Saharan African countries and demonstrated how factors beyond the control of youths have determined their chance to find employment. The research found that parental occupation is a key aspect among factors beyond the control of youths that determined their chance to find employment. Further, in defining the status of youths in the labour market the effort-based inequalities and not inequality caused by factors beyond individual control played a noteworthy role.

Cerra et al. (2021) sought to answer the question whether raising the growth of an economy will have an impact on reducing inequality and poverty. The study suggested that growth plays a crucial role in reducing poverty. However, its impact on inequality reduction is not that clear and mostly depends on the basic sources of growth. In the long run, it has been proved that poverty and inequality do have a negative impact on growth. Further, to improve equality of opportunity to improve inclusiveness and growth government policies play a very significant role.

Gimba et al. (2021) applied bootstrap cointegration and autoregressive distributed lag (ARDL) model to study income inequality in Sub-Saharan Africa and its sub-regions in the long-run and short-run. The results showed that the uneven distribution of income can be decreased by economic growth in the long run for the selected region. While in the long run as well as in short run, a reduction in corruption leads to a fall in the level of inequality. Further, in the long run and short run, population growth and a rise in the rate of unemployment intensifies the distribution of income, while the impact of trade globalization increases the level of inequality.

Onogwu (2021) emphasized for the Sub-Saharan Africa that how the presence of women is way less than men in various political and economic spheres of the region leading to the ultimate decline in the overall productivity. Through applying panel regression on 29 countries data, the study found that on economic development, gender inequality has a significant negative impact. Further, population growth, trade openness and capital accumulation are the vital components driving the economic development of the region. The paper recommended that for the smooth development of the region, growth of health population, trade openness and promotion of gender equity should be the main focus of the policy initiatives in the region.

Workneh (2020) analysed the effects of gender inequality and governance on poverty in 34 countries in Sub-Saharan Africa by applying maximum likelihood estimation of random effect models. The research showed that on increasing poverty level in the selected region, the net effect from the interaction of gender inequality and absence of good governance has a significant role to play. The study suggested human development and refining frameworks leading to improvement in institutional quality through voice and accountability, regulations, and government effectiveness on socioeconomic issues as a needed aspect to work upon to decrease inequality and poverty.

Adesina (2016) observed that for the Sub-Saharan Africa region, the average GINI index is among the world's highest. The author found that an improvement in the well-being of the people was observed since 2000 due to a reduction in the level of inequalities in gender, health, and education.

Calderon and Servén (2013) studied the impact of infrastructure development on growth and inequality in Sub-Saharan Africa. The study using growth and inequality equations emphasized on adequate supply of infrastructure services as a key ingredient for economic development. It further showed that deficient infrastructure is a major obstacle to growth and poverty reduction across the Sub-Saharan Africa region. Calderón, and Servén (2010) also examined the reasons for Sub-Saharan Africa ranking lowest in terms of infrastructure development compared to all other developing regions. The study empirically analysed quantity and quality indicators of infrastructure by applying a cross-regional perspective. The findings of the study validated the substantial contribution of infrastructure development towards growth and equity across Africa.

As the foregoing review shows, there is no clear body of literature examining the role of infrastructure development in inequality reduction. Much of the literature focuses on the effect of infrastructure development on growth, employment and poverty reduction. Further, existing literature has not examined the effects of all the sub-indices of the infrastructure development index. The paper contributes towards literature by examining how the different dimensions of infrastructure development index, GDP per capita, and the size of the informal economy affect gender inequality. The majority participants in the informal sector are women and government policies in support of the sector fall far short of expectations and in some cases, there are no policies in place. One of the enduring challenges is the failure of big national and multilateral infrastructure projects to mainstream gender dynamics (Ferguson and Harman, 2015). Since most of the women work at a subsistence level in the informal sector, failure to develop infrastructure with a purpose to cure gender inequality means that billions spent infrastructure might not even cause a dent on gender inequality and in some cases might compound gender inequality since they will inadvertently benefit male-dominated sectors.

3. Methods and data

As is shown later, the variables have mixed orders of integration—I(0) and I(1). This makes the panel ARDL regression technique ideal (Pesaran, 2015). To examine

the effect of infrastructure development on gender inequality, the paper specifies the panel autoregressive distributed lag (ARDL) model as:

$$gii_{i,t} = \sum_{j=1}^{q} \beta_j gii_{i,t-j} + \sum_{h=0}^{p} \gamma_h IDI_{i,t-h} + \sum_{h=0}^{p} \delta_h Z_{i,t-h} + \mu_{it} \quad (1)$$

In Equation (1), the gender inequality index depends on its history and the contemporaneous and past levels of the infrastructure development index (IDI) and other controls—the size of the informal sector and the level of economic development as measured by the real GDP per capita. The IDI in Equation (1) can be replaced by its sub-indices to estimate the effect of specific infrastructure indices. Model (1) is reparameterised to capture the long run relationship and short run dynamics as follows:

$$\Delta gii_{i,t} = \sum_{j=1}^{q} \beta_j \Delta gii_{i,t-j} + \sum_{h=0}^{p} \gamma_h \Delta IDI_{i,t-h} + \sum_{h=0}^{p} \delta_h \Delta Z_{i,t-h} + \varphi_{i1} \Delta gii_{i,t-1} + \varphi_{i2} \Delta IDI_{i,t-1} + \varphi_{i3} Z_{i,t-h} + \varepsilon_{i,t} \quad (2)$$

In Equation (2), β_j, γ_h, and δ_h are short run coefficients, while $\varphi_{i1}, \varphi_{i2}, \varphi_{i3}$ are long run coefficients. If both short run and long run coefficients are significant, there is evidence of strong causality. If only short run coefficients are significant, there is short run causality. If long run coefficients are significant, there is long run causality. The assumption of the panel ARDL model is that there is a common long run relationship for all countries in the sample, but different short run dynamics for each country (Pesaran, 2015). More compactly, Equation (2) can be simplified to:

$$\Delta gii_{i,t} = \sum_{j=1}^{q} \beta_j \Delta gii_{i,t-j} + \sum_{h=0}^{p} \gamma_h \Delta IDI_{i,t-h} + \sum_{h=0}^{p} \delta_h \Delta Z_{i,t-h} + \varphi_i ECT_{i,t-1} + \varepsilon_{i,t} \quad (3)$$

In Equation (3), the ECT is the country specific error correction term. The coefficient $\varphi_i \in (-1,0)$, but in empirical literature, oscillatory convergence is often permitted and satisfies the condition $\varphi_i \in (-2,0)$ (Narayan and Smyth, 2006).

Unit root tests to ensure that all variables are integrated of order zero or one were carried out before estimating the ARDL model. The Fisher-type Augmented Dickey-Fuller tests was employed. The Fisher ADF test is implemented for each panel. The null hypothesis is that all panels contain unit root tests against an alternative which states that at least one panel does not have a unit root problem. The Fisher ADF tests computes several test statistics, of which the p-statistic is suitable for finite samples, while the z-statistic, the inverse logit and the modified inverse Chi-squared are suitable for finite and infinite samples. In each case, the probability value must be less than the conventional 5% critical value in order to reject the null hypothesis.

The data used in the paper was collected from the African Development Bank's Infrastructure Development Index, which has transport, ICT, energy, and water and sanitation dimensions. The data was available from 2005–2018. The sample had 44 African countries, namely Mauritius (MUS), South Africa (ZAF), Namibia (NAM), Lesotho (LSO), Botswana (BWA), Cameroon (CMR), Algeria (DZA), Kenya (KEN), Mauritania (MRT), Egypt (EGY), Morocco (MAR), Togo (TGO), Libya (LBY), Ethiopia (ETH), Rwanda (RWA), Tunisia (TUN), Guinea Bissau (GNB), Mozambique (MOZ), Malawi (MWI), Guinea (GIN), Ghana (GHA), Burundi (BDI), Burkina Faso (BFA), Mali (MLI), Eswatini (SWZ), Uganda (UGA), Niger (NER), Central African Republic (CAF), Madagascar (MDG), Cote D'Ivoire (CIV), Sierra Leone (SLE),

Angola (AGO), Chad (TCD), Senegal (SEN), Liberia (LBR), Congo Republic (COG), Democratic Republic of Congo (COD), The Gambia (GMB), Zambia (ZMB), Benin (BEN), Gabon (GAB), Tanzania (TZA), Nigeria (NGA), and Zimbabwe (ZWE).

Gender inequality was extracted from a sub-index in the United Nations Development Programme's Human Development Index. The gender inequality index has several dimensions, namely maternal mortality, Adolescent birth, political power (number of seats in parliament), education and labour participation. In the paper, we focus on the overall inequality index and leave further analysis for dimensional analysis. The size of the informal sector used in the paper is based on the indirect measure of informal economy output expressed as a share of GDP (Elgin et al., 2021). There are many other alternative measures based on employment that, too, could be used.

4. Results and analysis

4.1. Descriptive analysis

Figure 1 depicts the relationship between infrastructure development and gender inequality in Africa. It reveals that the overall infrastructure development index is inversely related to gender inequality, with a pairwise correlation of −0.76. However, the majority of observations are clustered in the low infrastructure development index region, mostly between zero and 30. The correlation between gender inequality and the transport infrastructure index (**Figure 1**) similarly depicts a strong negative relationship (−0.61), with many observations clustered in the low region of the index. **Figure 1** also reveals a similar pattern with a negative correlation (−0.69) between gender inequality and the energy infrastructure index. The relationship between gender inequality and information and communication technologies (ICT) is moderate, estimated at −0.48 (**Figure 1**). The correlation between gender inequality and water, sewage and sanitation infrastructure is quite strong, estimated at −0.67 (**Figure 1**). The African continent has large informal economies with a large female population. Gender inequality and the degree of informality of the economy are positively correlated, estimated at 0.45 (**Figure 1**). Taken together, the scatter plots show that investing in infrastructure reduces gender inequality, while a growing informal economy tends to entrench gender inequality.

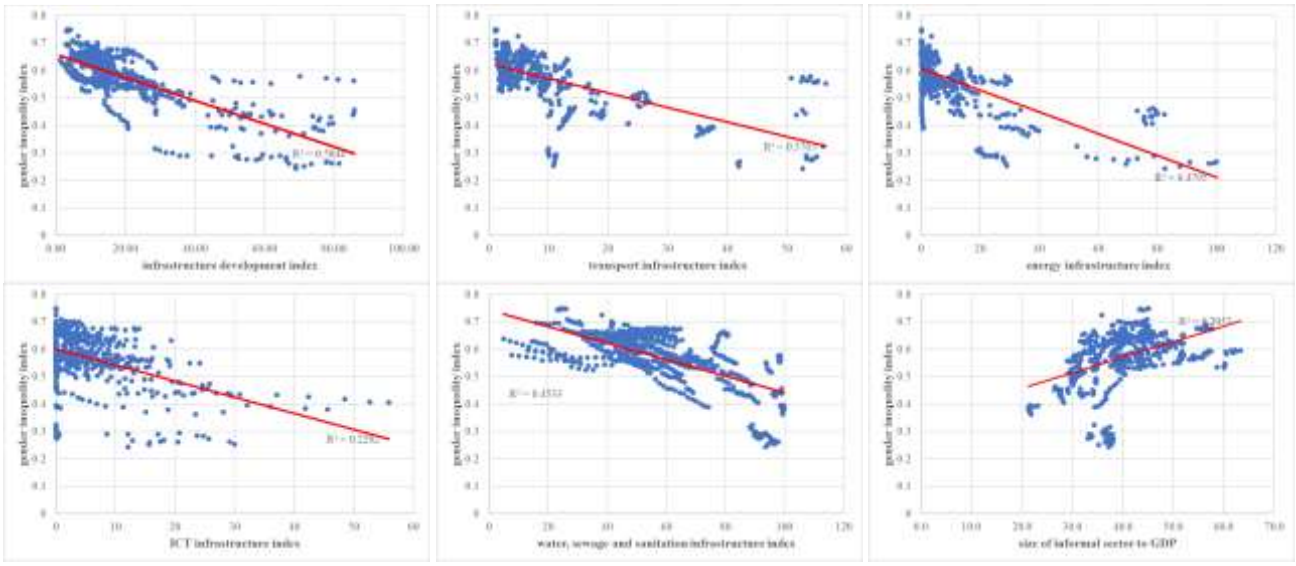

Figure 1. Correlation of gender inequality and infrastructure indices and size of informal sector.
Source: United Nations Development Programme, African Development Bank and World Bank World Development Indicators.

Figure 2 shows that infrastructure development and the size of the informal sector are inversely correlated (−0.44). This suggests that it is important to examine the effect of both infrastructure development and informality on gender inequality.

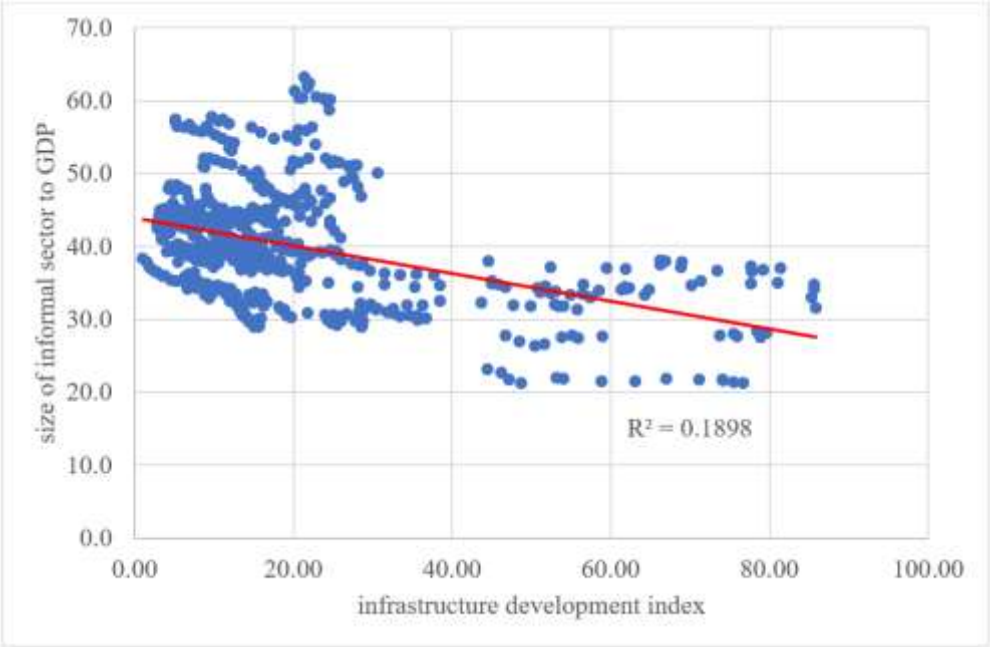

Figure 2. Correlation of infrastructure development index and size of informal sector.
Source: African Development Bank and World Bank World Development Indicators.

Table 1 shows that gender inequality and infrastructure development are negatively correlated. The overall infrastructure development index has a much stronger zero-order correlation (−0.76) with the gender inequality index than the sub-indices. All in all, transport, energy and water and sanitation services have moderately strong negative correlations with the gender inequality index, but the ICT index has a

weak correlation. The level of economic development, as measured by the GDP per capita, is negatively correlated with the gender inequality index (−0.7). It is expected that as economic development increases, gender inequality dissipates, but literature shows that the relationship is Kuznets conformant (Baten et al., 2021; Siemiatycki et al., 2020).

The cross-correlations between explanatory variables do not suggest a severe problem of multicollinearity. For example, all infrastructure indices are positively correlated to GDP per capita, but the correlations do not cross the 0.8 threshold (Gujarati and Porter, 2009). Even the size of the informal sector is negatively and weakly correlated to the level of GDP per capita. Further, the size of the informal sector is negatively and weakly correlated to all infrastructure indices (**Table 1**).

Table 1. Correlation analysis.

Variable	GII	IDI	TII	EII	ICTII	WSSII	SIS	GDPpc
GII	1.00							
IDI	−0.76*	1.00						
TII	−0.61*	0.78*	1.00					
EII	−0.69*	0.82*	0.64*	1.00				
ICTII	−0.48*	0.69*	0.29*	0.48*	1.00			
WSSII	−0.67*	0.84*	0.68*	0.60*	0.52*	1.00		
SIS	0.45*	−0.44*	−0.42*	−0.35*	−0.28*	−0.36*	1.00	
GDPpc	−0.70*	0.75*	0.69*	0.78*	0.44*	0.70*	−0.36*	1.00

Note: * means $p < 0.05$ respectively. GII is gender inequality index; TII is transport infrastructure index; EII is energy infrastructure index; ICTII is ICT infrastructure index; WSSII is water, sewage and sanitation infrastructure index, SIS is size of the informal sector, and GDPpc is GDP per capita in 2015 United States Dollars.

Table 2 shows that the gender inequality index is nearly normally distributed, with the median and the mean almost equal. However, the range is wide, suggesting that countries are not entirely clustered. Unlike the gender inequality index, infrastructure indices have skewed distributions, with the mean several times larger than the median, and the range is even wider. This suggests that African countries differ a lot in terms of their infrastructure development planning and performance.

Table 2. Summary statistics.

Variable	Mean	Std. Dev	Median	Max	Min	Obs
GII	0.57	0.10	0.58	0.75	0.24	616
IDI	20.84	17.83	14.70	85.85	1.12	616
TII	9.94	11.36	5.97	56.51	1.09	616
EII	9.38	17.08	2.63	100.00	0	616
ICTII	5.17	7.95	1.91	55.84	0	616
WSSII	57.23	21.76	56.08	99.79	4.87	616
SIS	39.99	7.81	39.50	63.30	21.30	616
GDPpc	2096.64	2378.50	1069.87	13,729.16	274.13	616

Note: GII is gender inequality index; TII is transport infrastructure index; EII is energy infrastructure index; ICTII is ICT infrastructure index; WSSII is water, sewage and sanitation infrastructure index, SIS is size of the informal sector, and GDPpc is GDP per capita in 2015 United States Dollars.

4.2. Results and analysis

4.2.1. Unit root tests

The unit root tests in **Table 3** indicate that all variables are stationary in levels except the ICT infrastructure index which is stationary after first difference. The mixture of I(0) and I(1) variables makes the ARDL model idea for this analysis.

Table 3. Fisher ADF Stationarity tests.

Variable	Inverse Chi^2 P	Inverse normal Z	Inverse logit L*	Modified inverse Chi^2 P_m
GII	134.09***	−3.53***	−3.459***	3.474***
TII	189.55***	−5.89***	−5.75***	7.65***
EII	115.83**	−2.21**	−2.01**	2.10**
ICTII	58.88	2.06	2.03	−2.20
ΔICTII	160.16***	−5.42***	−5.17***	5.44***
WSSII	124.58***	−1.36*	−1.41*	2.76***
SIS	150.85***	−4.68***	−4.63***	4.74***
GDPPC	156.75***	−3.52***	−3.66***	5.18***

Note: ***, **, * means $p < 0.01, 0.05, 0.10$ respectively. GII is gender inequality index; TII is transport infrastructure index; EII is energy infrastructure index; ICTII is ICT infrastructure index; WSSII is water, sewage and sanitation infrastructure index, SIS is size of the informal sector and GDPPC is gross domestic product per capita in 2015 United States dollars.

4.2.2. Long run relationship

Table 4 reports long run relationships of various model specifications. The long run equation is assumed to be common to all panels. In general, infrastructure indices are significant long run determinants of gender inequality with the exception of the transport infrastructure index and the energy infrastructure index. A one unit increase in the IDI, on average, reduces the gender inequality index by 0.004 units, other things remaining the same. The effect ranges between −0.002 units and −0.004 units for infrastructure sub-indices. On the other hand, a 1%-point increase in the size of the informal sector reduces gender inequality by 0.01 units. Across the various specifications, the effect of the size of the informal sector ranges between −0.003 and −0.009 units. A 1% increase in the GDP per capita reduces the gender inequality index by 0.001 units and the size of the effect holds across all the specifications. From **Table 4**, it can be concluded that both the informal sector and infrastructure development have gender inequality reducing effects.

Table 4. Long run relationships.

GII_{t-1}	Model_IDI	Model_TII	Model_EII	Model_ICTII	Model_WSSII
IDI_{t-1}	−0.004*** (0.0002)				
TII_{t-1}		−0.0002 (0.001)			
EII_{t-1}			0.0002 (0.001)		
$ICTII_{t-1}$				−0.002*** (0.00005)	

Table 4. (*Continued*).

GII_{t-1}	Model_IDI	Model_TII	Model_EII	Model_ICTII	Model_WSSII
$WSSII_{t-1}$					−0.004*** (0.0002)
SIS_{t-1}	−0.009*** (0.001)	−0.009*** (0.001)	0.003*** (0.001)	−0.004*** (0.001)	−0.003*** (0.001)
$loggdppc_{t-1}$	−0.145*** (0.007)	−0.079*** (0.006)	−0.082*** (0.006)	−0.059*** (0.007)	−0.057*** (0.010)

Note: GII is gender inequality index; TII is transport infrastructure index; EII is energy infrastructure index; ICTII is ICT infrastructure index; WSSII is water, sewage and sanitation infrastructure index, SIS is size of the informal sector, and GDPpc is GDP per capita in 2015 United States Dollars.

4.2.3. Short run dynamics

In the regression specification reported in Appendices A to E, country specific short run dynamics are presented. The equilibrium multipliers are depicted in **Figures 3–7**. Of the 44 countries in the sample, only the ones captured in **Figures 3–7** had a long run relationship amongst the gender inequality index, infrastructure development index (or sub-indices), size of the informal sector, and gross domestic product per capita. The error correction term is significant and largely satisfies the (−1, 0) condition, with a few cases exhibiting oscillatory convergence (e.g., the Central African Republic (CAF) and Ethiopia (ETH)). For some country error correction mechanisms, the equilibrium multipliers are large (Algeria, Angola, Botswana, and Guinea Bissau, among others). Small equilibrium multipliers imply that it takes much longer for a shock—negative or positive—to the relationship to be corrected. For example, only 18% of a shock in the inequality-informal sector-infrastructure-per capita income nexus in the previous period is corrected in the current period. This means it is a very slow adjustment process. To put this into perspective, if there is an unusually large infrastructure development project because of more gracious development aid, it takes longer for gender inequality to adjust in line with the new level of infrastructure stock. In the case of Guinea Bissau, for example, 92% of the shock in the previous period is corrected in the current period. The implication is that gender inequality responses quickly to infrastructure shocks, informal sector shocks and per capita income shocks in countries with large equilibrium multipliers.

Appendix A also shows that in the short run the infrastructure development index has a significant positive effect on the gender inequality index in some countries (e.g., Benin, Egypt, Eswatini, Ethiopia, Nigeria, and Zambia, among others) and a negative for others (e.g., Algeria, Chad, Cote d'Ivoire, Gambia, the Central African Republic, Niger, and Zimbabwe). This finding implies that in some countries a gendered approach to infrastructure development is lacking, which makes infrastructure development effects positive on gender inequality, while some countries have mainstreamed gender dynamics in infrastructure development thus facilitating the reduction of gender inequality.

Appendix A also shows that changes in the size of the informal sector have gender inequality increasing effects in countries, such as the DRC, Egypt, Gabon, Liberia, Rwanda and Senegal, and gender inequality reducing effects in other countries, such

as Burundi, Cote d'Ivoire, Libya, Tanzania, Malawi and Siera Leone, among a few others. Similarly, changes in GDP per capita have gender inequality increasing effects in some countries (e.g., the Central African Republic, Rwanda, Niger, Mauritania and Cote d'Ivoire) and gender inequality reducing effects (e.g., Benin, Cameroon, Republic of Congo, Libya. Malawi, Uganda and Tanzania).

Appendices B–E report results for specifications with specific infrastructure sub-indices. **Figures 4–7** report the equilibrium multipliers for the results in Appendices B–E. The pattern of a specific infrastructure sub-index having positive effects on gender inequality for some countries and negative effects for others is repeated, but the composition of the clusters of countries falling into the two groups changes with sub-index. For example, short run effects of transport infrastructure development have gender inequality increasing effects (e.g., in Benin, Republic of Congo, Gabon, Mauritius, Tanzania, and Uganda, among others) and gender inequality reducing effects (e.g., in Angola, DRC, Niger, Senegal and South Africa). Similarly, short run changes in the energy infrastructure index have gender inequality increasing effects (e.g., in Egypt, Guinea Bissau, Senegal and Tanzania), while having gender inequality reducing effects in Gabon, Guinea, Madagascar, Niger, Nigeria and Togo.

Taken together, the short run effects of infrastructure development, the size of the informal sector and income per capita divide the 44 countries into those that experience gender inequality worsening outcomes and those that experience gender inequality improving outcomes. More intuitively the mixed pattern suggests that the 44 countries could be thought of a falling on a Kuznets-type curve on which some countries are still on the rising limb, while others are on the falling limb. On the rising limb improvements in infrastructure, increases in the informal sector and income per capita are associated with rising gender inequality, while on the falling limb the same improvements lead to a reduction in gender inequality.

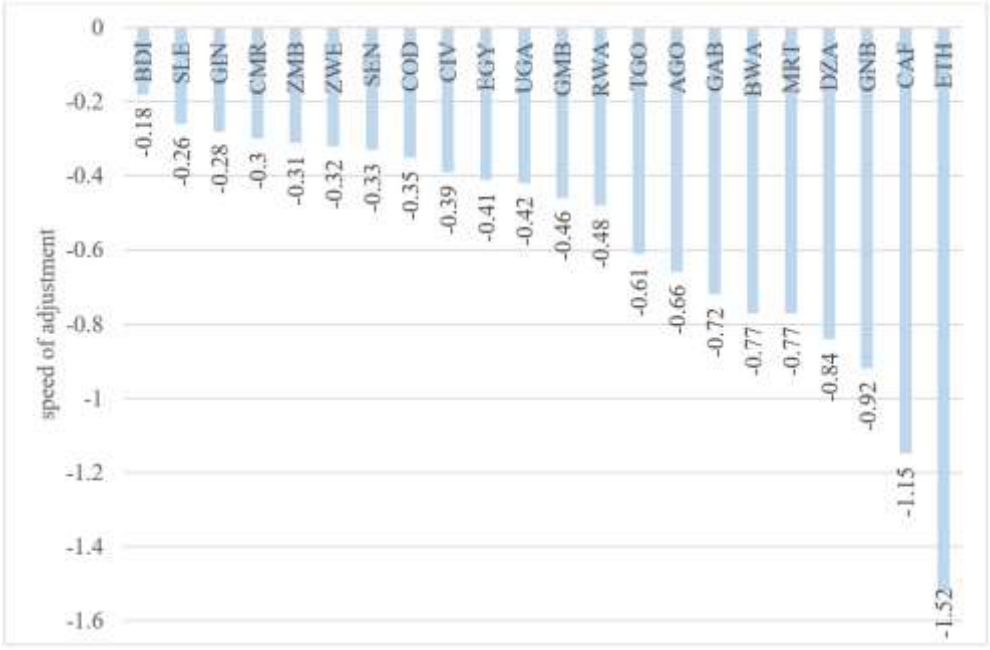

Figure 3. Equilibrium run multipliers in the regression with overall infrastructure development index.

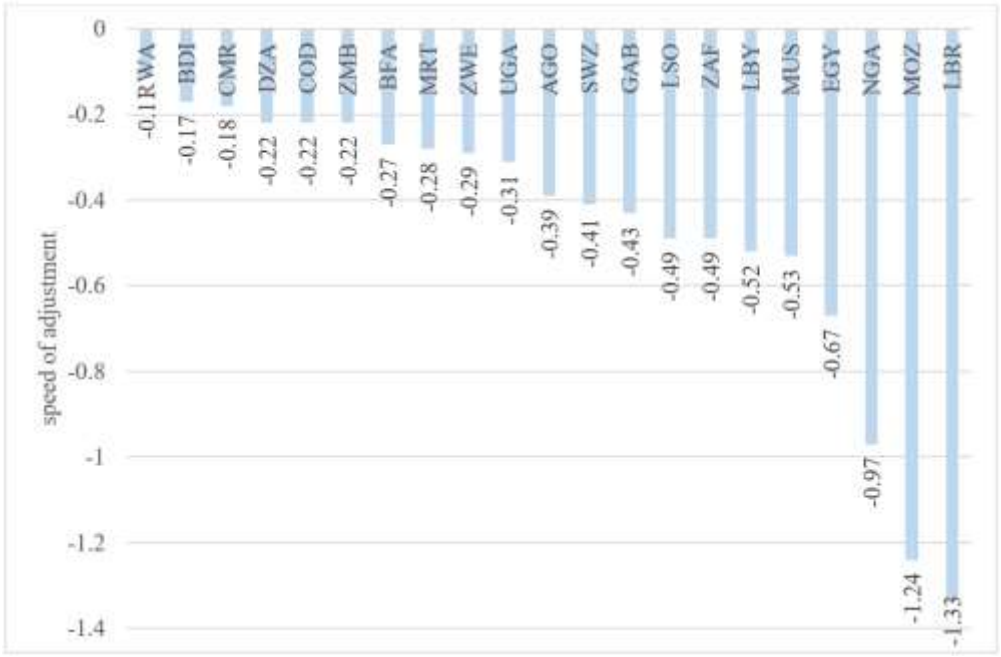

Figure 4. Equilibrium multipliers in the regression with transport infrastructure index.

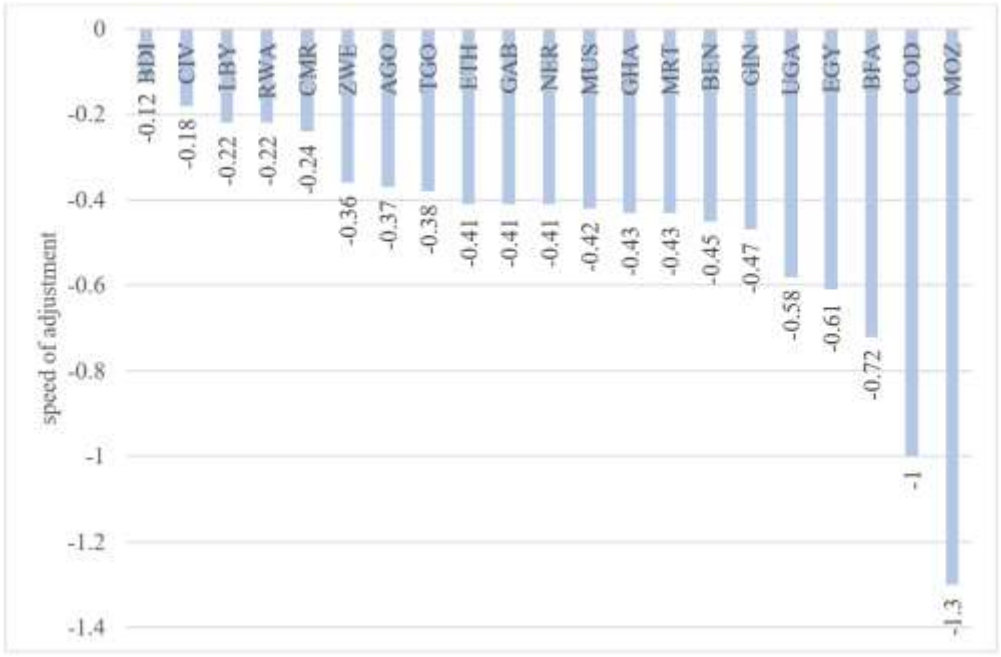

Figure 5. Equilibrium multipliers in the regression with transport infrastructure index.

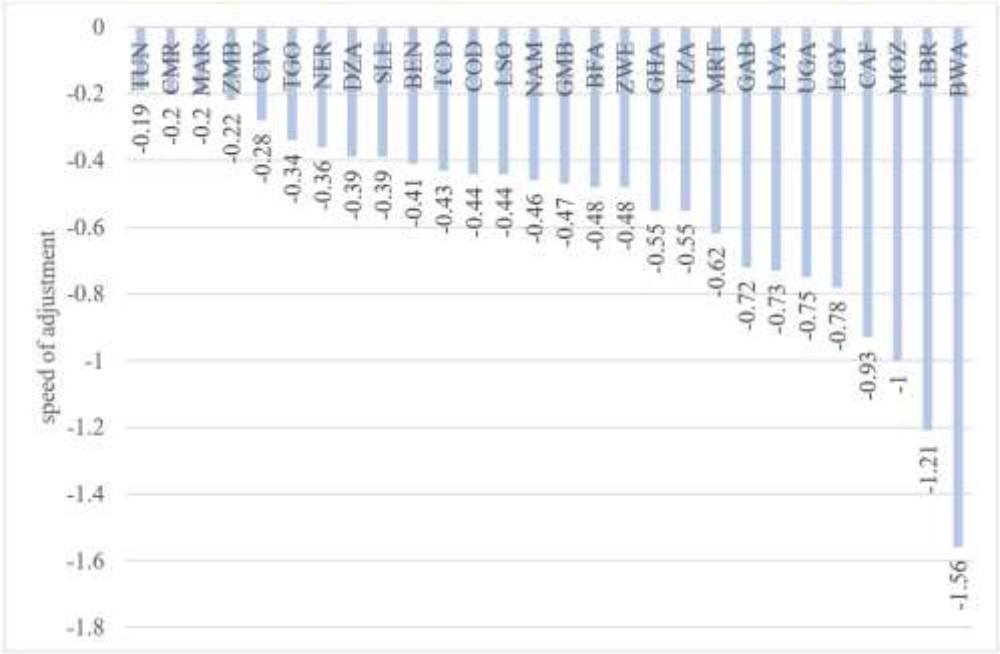

Figure 6. Equilibrium multipliers in the regression with transport infrastructure index.

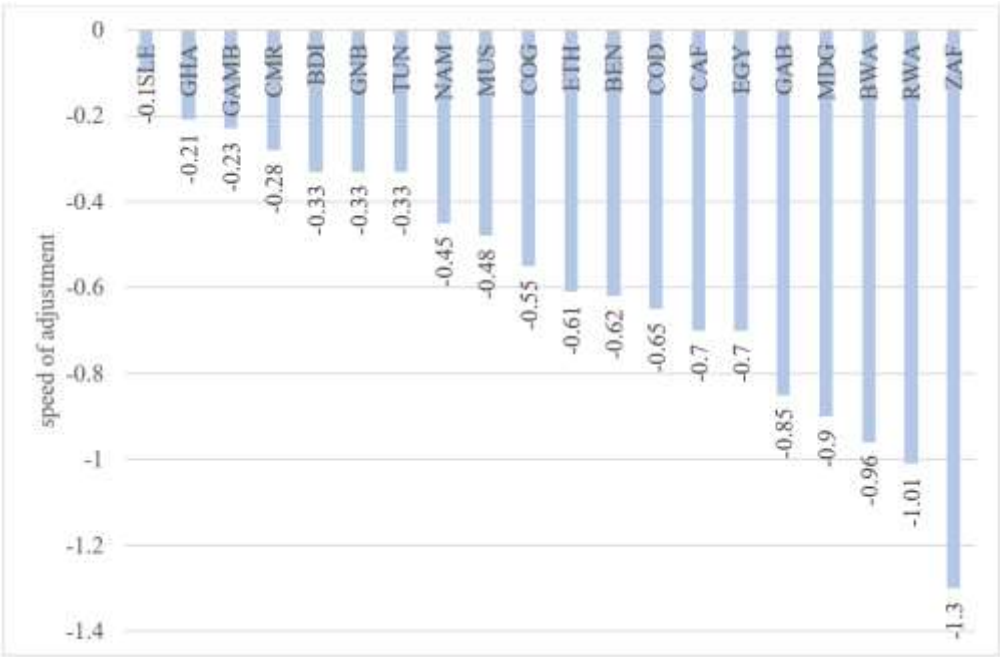

Figure 7. Equilibrium multipliers in the regression with transport infrastructure index.

5. Conclusion and recommendations

Many African economies can be characterised as dual enclaves in which a modern sector coexists with a large traditional and informal sector. Productivity and economic returns to effort are higher in the modern sector than the traditional/informal sectors. The modern sector is largely male-dominated, while the traditional and the informal sector is female-dominated. Government policies on infrastructure tend to have the formal sector in mind as they seek to crowd in domestic and foreign corporate

investment. As a result, the infrastructure development policies tend to lack a deliberate pro-informal sector orientation, which is a pro-gender orientation in infrastructure planning and delivery. The paper also examined the effect of infrastructure development on gender inequality, especially considering the interaction effects of the informal sector and infrastructure development. The paper established that the infrastructure development index, the size of the informal sector, and income per capita play a crucial dynamic that governments need to consider carefully in planning and investing infrastructure to reduce gender inequality. The paper further drew five conclusions.

1) The effect of infrastructure development (including specific infrastructure types) on gender divides countries in the sample into those the experience increasing gender inequality when infrastructure development occurs and those that experience a decline in gender inequality.
2) The effect of the size of the informal sector on gender divides countries in the sample into those the experience increasing gender inequality when the informal sector grows and those that experience a decline in gender inequality.
3) The effect of income per capita on gender divides countries in the sample into those the experience increasing gender inequality when GDP per capita grows and those that experience a decline in gender inequality.
4) Taking conclusions 1-3 together, leads to the conclusion that there is a continental Kuznets curve on which some countries are on the rising gender inequality limb, while others are on the falling gender inequality limb.
5) The implication is that African countries have heterogenous policy approaches to infrastructure development and gender mainstreaming. Literature identifies the failure to mainstream gender into infrastructure planning, development and operationalisation. This means that some countries might have strong infrastructure development strategies but still worsen gender inequality because the infrastructure favours sectors that are male-dominated.

The recommendation of the study is that governments must have deliberate pro-gender infrastructure development strategies and financing. The infrastructure dividend is high since African countries have large informal sectors that hold the key to a brighter continental growth and development path.

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Appendix A. Short run estimates for the model with the overall infrastructure development index (IDI)

ΔGII	ECT	Δidi_t	Δsis_t	$\Delta gdppc_t$	constant
Algeria	−0.838*** (0.210)	−0.006** (0.003)	0.015 (0.011)	−0.419 (0.371)	1.812*** (0.454)
Angola	−0.662*** (0.237)	−0.006 (0.005)	−0.001 (0.008)	0.161 (0.148)	1.437*** (0.521)
Benin	−0.193 (0.217)	0.007** (0.003)	−0.008** (0.004)	−0.366*** (0.140)	0.406 (0.463)
Botswana	−0.765** (0.298)	0.004 (0.003)	0.004 (0.004)	0.012 (0.031)	1.654** (0.645)
Burkina Faso	−0.267 (0.293)	0.002 (0.005)	0.006 (0.005)	0.028 (0.177)	0.519 (0.574)
Burundi	−0.178*** (0.060)	−0.004 (0.004)	−0.013*** (0.002)	0.018 (0.044)	0.312*** (0.107)
Cameroon	−0.302*** (0.100)	0.008 (0.005)	0.004 (0.006)	−0.670*** (0.248)	0.604*** (0.201)
Central African Republic	−1.148*** (0.209)	−0.026*** (0.006)	0.013*** (0.005)	0.217*** (0.074)	2.285*** (0.430)
Chad	−0.192 (0.159)	−0.035*** (0.011)	−0.004 (0.006)	0.047 (0.112)	0.407 (0.332)
Congo	0.166 (0.104)	0.001 (0.002)	−0.003 (0.002)	−0.079* (0.047)	−0.367 (0.226)
DR Congo	−0.349** (0.148)	−0.001 (0.009)	0.007*** (0.003)	0.093 (0.108)	0.686** (0.290)
Cote D'Ivoire	−0.384** (0.149)	−0.003* (0.001)	−0.001 (0.002)	0.073*** (0.026)	0.835** (0.329)
Egypt	−0.405*** (0.125)	0.009*** (0.003)	−0.026 (0.016)	−0.771 (0.586)	0.909*** (0.298)
Eswatini	0.126 (0.091)	0.005** (0.003)	−0.006 (0.006)	−0.182 (0.163)	−0.279 (0.201)
Ethiopia	−1.524*** (0.238)	0.024*** (0.006)	0.015** (0.007)	−0.022 (0.099)	2.770*** (0.448)
Gabon	−0.723*** (0.250)	0.002 (0.002)	0.004* (0.002)	0.093 (0.059)	1.743*** (0.605)
Gambia	−0.459*** (0.098)	−0.005* (0.003)	0.005** (0.002)	0.107 (0.078)	0.965*** (0.205)
Ghana	−0.065 (0.043)	−0.002 (0.002)	0.003 (0.002)	0.057 (0.049)	0.133 (0.089)
Guinea	−0.283*** (0.109)	0.006* (0.003)	0.002 (0.004)	−0.040 (0.070)	0.561*** (0.216)
Guinea Bissau	−0.920*** (0.165)	0.010*** (0.003)	0.001 (0.003)	0.112 (0.075)	1.791*** (0.325)
Kenya	−0.161 (0.137)	−0.001 (0.002)	−0.006 (0.009)	−0.019 (0.250)	0.308 (0.272)
Lesotho	−0.308 (0.245)	0.009 (0.012)	−0.0004 (0.004)	−0.122 (0.077)	0.583 (0.466)
Liberia	0.004 (0.136)	−0.004 (0.004)	−0.003 (0.003)	−0.004 (0.060)	−0.008 (0.277)
Libya	0.107 (0.159)	−0.0003 (0.003)	−0.001 (0.004)	−0.058** (0.027)	−0.242 (0.353)

ΔGII	**ECT**	**Δidi_t**	**Δsis_t**	**$\Delta gdppc_t$**	**constant**
Madagascar	−0.231 (0.166)	−0.001 (0.005)	0.001 (0.005)	−0.006 (0.186)	0.430 (0.315)
Malawi	−0.218 (0.147)	0.0004 (0.003)	−0.019*** (0.006)	−0.349** (0.141)	0.415 (0.282)
Mali	0.052 (0.112)	−0.004 (0.007)	0.008 (0.010)	0.043 (0.192)	−0.101 (0.224)
Mauritania	−0.770*** (0.066)	−0.001 (0.001)	0.010*** (0.002)	0.072** (0.029)	1.589*** (0.129)
Mauritius	−0.030 (0.073)	−0.001 (0.003)	−0.034** (0.016)	−2.097 (1.351)	0.141 (0.195)
Morocco	−0.130 (0.094)	−0.001 (0.001)	−0.006 (0.009)	−0.481** (0.242)	0.284 (0.204)
Mozambique	−0.081 (0.109)	−0.002 (0.004)	0.004 (0.006)	−0.080 (0.080)	0.151 (0.203)
Namibia	−0.149 (0.148)	0.001 (0.001)	0.004 (0.004)	0.093 (0.080)	0.304 (0.307)
Niger	0.030 (0.073)	−0.014** (0.006)	0.014*** (0.004)	0.560*** (0.154)	−0.065 (0.141)
Nigeria	−0.046 (0.081)	0.005** (0.002)	−0.002 (0.002)	−0.037 (0.068)	0.105 (0.193)
Rwanda	−0.481*** (0.114)	0.001 (0.002)	0.013*** (0.004)	0.210*** (0.059)	0.842*** (0.206)
Senegal	−0.333* (0.185)	−0.005 (0.003)	0.005 (0.004)	0.036 (0.222)	0.692* (0.386)
Sierra Leone	−0.255*** (0.096)	0.003 (0.003)	0.0004 (0.002)	−0.003 (0.024)	0.507*** (0.191)
South Africa	0.016 (0.059)	−0.0001 (0.0004)	−0.007 (0.010)	0.118 (0.258)	−0.039 (0.131)
Tanzania	−0.040 (0.133)	0.001 (0.003)	−0.006*** (0.002)	−0.373*** (0.141)	0.091 (0.278)
Togo	−0.606*** (0.164)	0.003 (0.005)	0.006 (0.004)	0.104 (0.084)	1.156*** (0.316)
Tunisia	−0.030 (0.021)	0.001*** (0.0003)	−0.002 (0.004)	−0.132 (0.135)	0.055 (0.045)
Uganda	−0.420** (0.166)	0.003 (0.002)	0.003 (0.003)	−0.201*** (0.060)	0.819** (0.325)
Zambia	−0.305** (0.143)	0.008* (0.005)	0.003 (0.003)	0.105 (0.071)	0.633** (0.303)
Zimbabwe	−0.320** (0.140)	−0.006* (0.003)	0.001 (0.002)	0.022 (0.034)	0.714** (0.312)

Appendix B: Short run estimates for the model with the transport infrastructure index (TII)

ΔGII	ECT	Δtii_t	Δsis_t	$\Delta gdppc_t$	constant
Algeria	−0.226* (0.128)	0.0001 (0.012)	0.027 (0.021)	−0.815 (0.611)	0.324* (0.185)
Angola	−0.390** (0.165)	−0.538* (0.302)	0.009 (0.011)	0.164 (0.168)	0.596** (0.261)
Benin	0.009 (0.119)	0.011** (0.004)	−0.006 (0.004)	−0.224 (0.138)	−0.015 (0.196)
Botswana	0.038 (0.092)	0.0003 (0.002)	0.003 (0.005)	−0.044 (0.029)	−0.059 (0.136)
Burkina Faso	−0.265* (0.152)	0.0004 (0.009)	0.007 (0.004)	0.018 (0.169)	0.394* (0.229)
Burundi	−0.168*** (0.055)	−0.002 (0.002)	−0.013*** (0.003)	−0.006 (0.046)	0.224*** (0.075)
Cameroon	−0.179** (0.070)	0.003 (0.004)	0.004 (0.007)	−0.729** (0.304)	0.268** (0.105)
Central African Republic	−0.254 (0.269)	0.001 (0.067)	0.007 (0.009)	0.100 (0.163)	0.397 (0.418)
Chad	−0.272 (0.185)	0.075 (0.056)	0.006 (0.008)	0.189 (0.175)	0.446 (0.306)
Congo	0.130*** (0.046)	0.013* (0.007)	−0.004** (0.002)	−0.117*** (0.039)	−0.217*** (0.076)
DR Congo	−0.215** (0.098)	−0.140** (0.061)	0.009*** (0.003)	0.004 (0.093)	0.333** (0.151)
Cote D'Ivoire	0.248*** (0.058)	0.009** (0.004)	−0.008*** (0.002)	0.031 (0.024)	−0.414*** (0.093)
Egypt	−0.674** (0.289)	−0.003 (0.005)	0.067** (0.033)	1.063 (0.762)	1.004** (0.437)
Eswatini	−0.409*** (0.091)	0.019 (0.029)	0.003 (0.005)	0.013 (0.136)	0.645*** (0.143)
Ethiopia	0.00004 (0.121)	0.020 (0.014)	−0.004 (0.010)	−0.210 (0.220)	0.003 (0.159)
Gabon	−0.427*** (0.102)	0.022*** (0.007)	0.005** (0.002)	−0.024 (0.051)	0.742*** (0.181)
Gambia	−0.208 (0.190)	−0.0005 (0.002)	0.001 (0.003)	0.023 (0.130)	0.329 (0.303)
Ghana	−0.170 (0.141)	−0.001 (0.001)	0.0002 (0.002)	0.107* (0.061)	0.250 (0.213)
Guinea	−0.114 (0.088)	0.003 (0.004)	0.004 (0.004)	−0.044 (0.075)	0.173 (0.135)
Guinea Bissau	−0.064 (0.143)	−0.004 (0.014)	−0.002 (0.004)	0.048 (0.103)	0.094 (0.216)
Kenya	−0.025 (0.054)	0.001 (0.001)	−0.004 (0.009)	0.015 (0.246)	0.023 (0.079)
Lesotho	−0.488*** (0.181)	0.007 (0.022)	−0.001 (0.003)	−0.088 (0.058)	0.679*** (0.252)
Liberia	−1.329*** (0.336)	−0.018 (0.039)	0.006** (0.003)	−0.021 (0.049)	2.108*** (0.527)
Libya	−0.519*** (0.128)	0.001 (0.001)	−0.004* (0.002)	0.005 (0.014)	0.694*** (0.163)

ΔGII	**ECT**	**Δtii_t**	**Δsis_t**	**$\Delta gdppc_t$**	**constant**
Madagascar	−0.094 (0.119)	0.078 (0.170)	0.0003 (0.005)	−0.009 (0.178)	0.136 (0.173)
Malawi	−0.072 (0.079)	0.003 (0.006)	−0.021*** (0.006)	−0.394*** (0.144)	0.104 (0.113)
Mali	−0.170 (0.236)	−0.004 (0.016)	0.005 (0.012)	0.010 (0.176)	0.266 (0.368)
Mauritania	−0.283*** (0.089)	−0.005 (0.006)	0.008 (0.006)	−0.132** (0.055)	0.435*** (0.138)
Mauritius	−0.529** (0.241)	0.008* (0.004)	−0.011 (0.015)	−0.606 (0.931)	0.713** (0.305)
Morocco	−0.038 (0.102)	0.006 (0.011)	−0.008 (0.009)	−0.324 (0.268)	0.053 (0.145)
Mozambique	−1.240*** (0.235)	−0.013 (0.010)	0.003 (0.003)	0.269*** (0.076)	1.742*** (0.341)
Namibia	0.049 (0.115)	0.001 (0.001)	0.002 (0.004)	0.014 (0.093)	−0.076 (0.163)
Niger	0.073 (0.063)	−0.061* (0.032)	0.012*** (0.004)	0.514*** (0.165)	−0.123 (0.097)
Nigeria	−0.965*** (0.235)	−0.001 (0.003)	0.002 (0.002)	0.098** (0.043)	1.751*** (0.434)
Rwanda	−0.112** (0.048)	0.002 (0.002)	0.011*** (0.004)	0.195* (0.079)	0.133** (0.062)
Senegal	−0.088 (0.080)	−0.032*** (0.011)	0.007** (0.003)	0.256 (0.215)	0.125 (0.127)
Sierra Leone	0.256** (0.111)	0.031** (0.015)	−0.005** (0.002)	−0.082** (0.032)	−0.400** (0.172)
South Africa	−0.490** (0.214)	−0.001* (0.001)	−0.0005 (0.008)	0.213 (0.173)	0.674 (0.302)
Tanzania	−0.053 (0.071)	0.004* (0.002)	−0.005** (0.002)	−0.288** (0.138)	0.091 (0.114)
Togo	−0.152 (0.106)	0.004* (0.002)	0.0004 (0.005)	0.030 (0.091)	0.217 (0.155)
Tunisia	−0.112 (0.168)	0.011* (0.006)	−0.005 (0.005)	−0.098 (0.129)	0.140 (0.216)
Uganda	−0.311* (0.160)	0.006* (0.003)	−0.002 (0.003)	−0.017 (0.117)	0.452* (0.230)
Zambia	−0.220** (0.103)	0.0001 (0.001)	0.002 (0.003)	0.260** (0.102)	0.338** (0.163)
Zimbabwe	−0.292* (0.170)	0.017 (0.016)	0.005 (0.004)	0.029 (0.040)	0.496* (0.290)

Appendix C: Short run estimates for the model with the energy infrastructure index (EII)

ΔGII	ECT	Δeii_{t-1}	Δsis_{t-1}	$\Delta gdppc_{t-1}$	constant
Algeria	−0.195 (0.137)	−0.001 (0.007)	0.024 (0.020)	−0.846 (0.634)	0.205 (0.149)
Angola	−0.365** (0.164)	0.001 (0.009)	−0.005 (0.008)	0.065 (0.141)	0.386** (0.179)
Benin	−0.447** (0.184)	−0.007 (0.010)	−0.006 (0.004)	−0.172 (0.147)	0.460** (0.192)
Botswana	0.055 (0.142)	0.0003 (0.0003)	0.002 (0.005)	−0.043 (0.028)	−0.064 (0.158)
Burkina Faso	−0.717*** (0.254)	0.0003 (0.007)	0.003 (0.004)	0.025 (0.149)	0.726*** (0.262)
Burundi	−0.124*** (0.037)	−0.003 (0.008)	−0.012*** (0.002)	0.008 (0.042)	0.106*** (0.033)
Cameroon	−0.241*** (0.076)	−0.003 (0.002)	0.003 (0.006)	−0.705*** (0.231)	0.268*** (0.085)
Central African Republic	−0.040 (0.083)	0.219 (0.147)	−0.006 (0.012)	−0.098 (0.189)	0.041 (0.087)
Chad	−0.189 (0.181)	0.066 (0.101)	0.003 (0.008)	0.113 (0.162	0.206 (0.203)
Congo	0.009 (0.081)	−0.004 (0.002)	−0.002 (0.002)	−0.046 (0.044)	−0.014 (0.088)
DR Congo	−0.999*** (0.202)	−0.019 (0.014)	−0.002 (0.003)	−0.004 (0.069)	0.994*** (0.207)
Cote D'Ivoire	−0.176* (0.104)	−0.003 (0.004)	−0.003 (0.002)	0.059** (0.029)	0.193 (0.119)
Egypt	−0.611** (0.259)	0.021*** (0.006)	0.066*** (0.023)	0.817 (0.539)	0.637** (0.284)
Eswatini	−0.114 (0.164)	0.002 (0.001)	−0.005 (0.007)	−0.155 (0.178)	0.124 (0.180)
Ethiopia	−0.409* (0.216)	−0.021 (0.022)	−0.012 (0.008)	0.055 (0.182)	0.388* (0.208)
Gabon	−0.405*** (0.069)	−0.002*** (0.0004)	0.000 (0.001)	−0.014 (0.038)	0.453*** (0.085)
Gambia	0.116 (0.082)	0.007 (0.006)	−0.001 (0.003)	−0.0004 (0.128)	-0.122 (0.085)
Ghana	−0.432*** (0.144)	−0.001 (0.002)	0.001 (0.001)	0.065 (0.041)	0.444*** (0.149)
Guinea	−0.472** (0.232)	−0.020** (0.009)	0.006* (0.004)	0.038 (0.073)	0.496** (0.246)
Guinea Bissau	−0.118 (0.144)	0.013* (0.007)	−0.004 (0.003)	0.026 (0.090)	0.120 (0.151)
Kenya	−0.074 (0.082)	−0.005 (0.028)	−0.005 (0.009)	−0.005 (0.267)	0.067 (0.088)
Lesotho	−0.352 (0.224)	0.0002 (0.001)	−0.004 (0.003)	−0.131** (0.064)	0.364 (0.232)
Liberia	−0.105 (0.201)	−0.011 (0.019)	−0.003 (0.002)	−0.014 (0.051)	0.109 (0.212)
Libya	−0.220*** (0.076)	0.0001 (0.003)	−0.003 (0.003)	−0.028** (0.013)	0.193 (0.075)

ΔGII	**ECT**	**Δeii_{t-1}**	**Δsis_{t-1}**	**$\Delta gdppc_{t-1}$**	**constant**
Madagascar	−0.005 (0.067)	−0.007** (0.004)	−0.002 (0.004)	−0.055 (0.158)	−0.001 (0.064)
Malawi	−0.153 (0.155)	0.0003 (0.012)	−0.020*** (0.006)	−0.357** (0.171)	0.149 (0.152)
Mali	−0.127 (0.251)	0.014 (0.009)	0.002 (0.008)	0.017 (0.156)	0.136 (0.270)
Mauritania	−0.433*** (0.088)	−0.003 (0.002)	0.005 (0.006)	−0.089** (0.045)	0.492*** (0.102)
Mauritius	−0.417* (0.234)	−0.012 (0.009)	−0.010 (0.018)	−0.166 (1.190)	0.453* (0.232)
Morocco	−0.018 (0.108)	0.007 (0.010)	−0.008 (0.009)	−0.418 (0.300)	0.016 (0.110)
Mozambique	−1.300*** (0.202)	0.001 (0.001)	−0.001 (0.003)	0.203*** (0.069)	1.221*** (0.208)
Namibia	−0.076 (0.185)	−0.0003 (0.001)	0.003 (0.004)	0.078 (0.107)	0.075 (0.198)
Niger	−0.410** (0.191)	−0.212** (0.095)	0.013*** (0.004)	0.648*** (0.155)	0.422** (0.200)
Nigeria	0.003 (0.108)	−0.009*** (0.003)	−0.007*** (0.002)	−0.025 (0.043)	−0.004 (0.123)
Rwanda	−0.224** (0.098)	−0.005 (0.023)	0.010** (0.004)	0.200** (0.080)	0.179** (0.084)
Senegal	−0.006 (0.058)	0.055*** (0.012)	0.018*** (0.004)	0.722*** (0.157)	−0.014 (0.060)
Sierra Leone	−0.103 (0.064)	−0.006 (0.007)	−0.003 (0.002)	−0.043* (0.023)	0.106 (0.067)
South Africa	−0.141 (0.141)	−0.001 (0.001)	−0.005 (0.009)	0.189 (0.210)	0.143 (0.147)
Tanzania	−0.245 (0.175)	0.005 (0.010)	−0.005** (0.002)	−0.339*** (0.127)	0.240 (0.169)
Togo	−0.376** (0.174)	−0.026* (0.015)	0.002 (0.004)	0.057 (0.082)	0.386** (0.183)
Tunisia	0.263*** (0.071)	0.005*** (0.001)	−0.008*** (0.003)	−0.352*** (0.090)	−0.225*** (0.064)
Uganda	−0.582*** (0.219)	0.001 (0.008)	−0.004 (0.003)	−0.070 (0.061)	0.563*** (0.216)
Zambia	−0.018 (0.141)	−0.003 (0.003)	−0.0002 (0.003)	0.099 (0.102)	0.010 (0.142)
Zimbabwe	−0.362** (0.149)	0.002 (0.002)	0.0004 (0.003)	0.007 (0.029)	0.343 (0.145)

Appendix D: Short run estimates for the model with the ICT infrastructure index (ICTII)

ΔGII	ECT	$\Delta ictii_{t-1}$	Δsis_{t-1}	$\Delta gdppc_{t-1}$	constant
Algeria	−0.387** (0.153)	−0.003 (0.002)	0.031* (0.018)	−1.147** (0.566)	0.435** (0.174)
Angola	−0.229 (0.162)	0.003 (0.004)	−0.005 (0.008)	0.008 (0.143)	0.263 (0.196)
Benin	−0.414* (0.212)	0.001 (0.002)	−0.005 (0.004)	−0.264* (0.148)	0.506* (0.262)
Botswana	−1.563*** (0.153)	0.001*** (0.0003)	0.002 (0.002)	0.017 (0.013)	1.774*** (0.208)
Burkina Faso	−0.483* (0.255)	−0.001 (0.004)	0.006 (0.004)	0.004 (0.161)	0.551* (0.296)
Burundi	−0.085 (0.075)	0.002 (0.002)	−0.012*** (0.002)	−0.003 (0.043)	0.083 (0.077)
Cameroon	−0.200* (0.120)	0.002 (0.003)	0.002 (0.006)	−0.683*** (0.242)	0.232 (0.142)
Central African Republic	−0.928** (0.368)	−0.008 (0.007)	0.002 (0.007)	0.042 (0.115)	1.118** (0.458)
Chad	−0.426*** (0.121)	−0.036*** (0.008)	−0.001 (0.004)	0.032 (0.085)	0.550*** (0.158)
Congo	0.062 (0.089)	−0.004*** (0.001)	−0.002 (0.002)	−0.054 (0.039)	−0.077 (0.110)
DR Congo	−0.436** (0.193)	−0.005 (0.006)	0.006* (0.003)	0.012 (0.104)	0.516** (0.227)
Cote D'Ivoire	−0.279* (0.154)	−0.001*** (0.0005)	−0.002 (0.002)	0.034* (0.020)	0.348* (0.196)
Egypt	−0.780*** (0.274)	−0.007 (0.007)	0.046** (0.022)	−0.183 (0.774)	0.928*** (0.332)
Eswatini	−0.037 (0.116)	0.002* (0.001)	−0.006 (0.006)	−0.178 (0.159)	0.042 (0.139)
Ethiopia	−0.148 (0.205)	−0.001 (0.006)	−0.011 (0.010)	−0.075 (0.218)	0.154 (0.225)
Gabon	−0.718*** (0.130)	0.0004 (0.001)	0.0004 (0.001)	−0.041 (0.043)	0.924*** (0.183)
Gambia	−0.473* (0.254)	−0.002 (0.002)	0.001 (0.003)	−0.010 (0.118)	0.569* (0.309)
Ghana	−0.551*** (0.190)	0.001 (0.001)	0.001 (0.001)	0.074* (0.041)	0.626*** (0.214)
Guinea	−0.314 (0.211)	−0.001 (0.002)	0.005 (0.004)	−0.024 (0.081)	0.369 (0.249)
Guinea Bissau	−0.254 (0.222)	−0.001 (0.003)	−0.002 (0.003)	0.061 (0.106)	0.294 (0.261)
Kenya	−0.127 (0.107)	−0.003 (0.003)	−0.001 (0.010)	0.123 (0.279)	0.134 (0.125)
Lesotho	−0.435*** (0.156)	0.002 (0.001)	−0.003 (0.002)	−0.146** (0.064)	0.471*** (0.171)
Liberia	−1.214*** (0.249)	0.008*** (0.002)	0.002 (0.002)	−0.054 (0.033)	1.463*** (0.314)
Libya	−0.730*** (0.093)	−0.001 (0.0004)	−0.003** (0.001)	0.003 (0.009)	0.700 (0.105)

ΔGII	**ECT**	**$\Delta ictii_{t-1}$**	**Δsis_{t-1}**	**$\Delta gdppc_{t-1}$**	**constant**
Madagascar	−0.078 (0.126)	−0.002 (0.007)	−0.001 (0.005)	−0.036 (0.182)	0.082 (0.141)
Malawi	−0.126 (0.131)	−0.002 (0.006)	−0.021*** (0.006)	−0.384*** (0.145)	0.138 (0.147)
Mali	−0.363 (0.239)	0.007 (0.004)	−0.002 (0.009)	−0.083 (0.172)	0.431 (0.285)
Mauritania	−0.617*** (0.091	−0.001 (0.001)	0.005 (0.004)	−0.025 (0.041)	0.746*** (0.115)
Mauritius	−0.001 (0.092)	−0.002** (0.001)	−0.040*** (0.014)	−2.543*** (0.883)	0.099 (0.099)
Morocco	−0.198* (0.112)	−0.004*** (0.001)	0.009 (0.006)	0.093 (0.173)	0.221 (0.125)
Mozambique	−0.998*** (0.275)	0.004* (0.002)	−0.004 (0.004)	0.192** (0.083)	1.058*** (0.300)
Namibia	−0.456* (0.252)	−0.001 (0.001)	0.002 (0.004)	0.153* (0.093)	0.496* (0.278)
Niger	−0.355*** (0.121)	−0.024*** (0.007)	0.007* (0.004)	0.235 (0.172)	0.424*** (0.148)
Nigeria	−0.201 (0.136)	0.004*** (0.001)	−0.001 (0.001)	0.029 (0.045)	0.264 (0.185)
Rwanda	−0.125 (0.145)	0.0001 (0.003)	0.010** (0.005)	0.189** (0.089)	0.107 (0.139)
Senegal	−0.132 (0.146)	−0.002 (0.003)	0.006 (0.004)	0.271 (0.243)	0.145 (0.174)
Sierra Leone	−0.391** (0.178)	−0.003*** (0.001)	−0.0002 (0.001)	−0.006 (0.023)	0.467** (0.212)
South Africa	−0.049 (0.100)	0.0001 (0.0005)	−0.009 (0.011)	0.035 (0.270)	0.050 (0.110)
Tanzania	−0.553* (0.309)	−0.002 (0.002)	−0.001 (0.003)	−0.153 (0.180)	0.656* (0.370)
Togo	−0.347** (0.173)	0.001 (0.003)	0.002 (0.005)	0.032 (0.100)	0.388* (0.198)
Tunisia	−0.187* (0.102)	0.001 (0.001)	−0.004 (0.004)	−0.181 (0.145)	0.171* (0.097)
Uganda	−0.750*** (0.153)	0.0004 (0.001)	−0.002 (0.002)	0.057 (0.058)	0.820*** (0.178)
Zambia	−0.215*** (0.054)	0.009*** (0.001)	0.0004 (0.001)	0.445*** (0.050)	0.228*** (0.066)
Zimbabwe	−0.476** (0.196)	−0.003 (0.002)	0.002 (0.003)	0.024 (0.033)	0.581** (0.244)

Appendix E: Short run estimates for the model with the water and sanitation services infrastructure index (WSSII)

ΔGII	ECT	$\Delta wssii_{t-1}$	Δsis_{t-1}	$\Delta gdppc_{t-1}$	constant
Algeria	−0.266 (0.199)	0.045 (0.241)	0.024 (0.023)	−0.866 (0.607)	0.374 (0.246)
Angola	−0.328 (0.346)	−0.009 (0.057)	−0.006 (0.008)	−0.013 (0.148)	0.455 (0.437)
Benin	−0.624** (0.249)	−0.013 (0.010)	−0.005 (0.004)	−0.244* (0.141)	0.868** (0.355)
Botswana	−0.961*** (0.230)	0.039*** (0.011)	0.002 (0.03)	−0.037** (0.019)	1.356*** (0.358)
Burkina Faso	−0.053 (0.153)	0.002 (0.013	0.005 (0.005)	0.053 (0.198)	0.063 (0.204)
Burundi	−0.330*** (0.123)	0.013 (0.015)	−0.011*** (0.002)	−0.004 (0.038)	0.397** (0.161)
Cameroon	−0.284*** (0.100)	0.044 (0.042)	0.006 (0.006)	−0.629*** (0.228)	0.363** (0.148)
Central African Republic	−0.695*** (0.207)	−0.082*** (0.023)	0.006 (0.006)	0.116 (0.092)	0.933*** (0.290)
Chad	−0.298 (0.250)	0.006 (0.006)	0.0004 (0.006)	0.063 (0.128)	0.395 (0.357)
Congo	−0.550*** (0.169)	0.010 (0.007)	−0.001 (0.002)	−0.003 (0.034)	0.763*** (0.261)
DR Congo	−0.651*** (0.172)	−0.049** (0.021)	0.002 (0.003)	0.042 (0.078)	0.856*** (0.223)
Cote D'Ivoire	−0.210 (0.250)	0.030*** (0.012)	−0.001 (0.002)	0.049* (0.027)	0.288 (0.371)
Egypt	−0.702** (0.311)	−0.026 (0.183)	0.059* (0.033)	0.910 (0.719)	1.062** (0.475)
Eswatini	0.010 (0.083)	0.032 (0.020)	−0.002 (0.007)	−0.105 (0.194)	−0.057 (0.115)
Ethiopia	−0.606* (0.344)	0.042 (0.032)	−0.003 (0.009)	−0.326* (0.177)	0.606* (0.338)
Gabon	−0.848*** (0.115)	0.057*** (0.019)	0.002 (0.001)	0.025 (0.032)	1.294*** (0.193)
Gambia	−0.232*** (0.085)	−0.083*** (0.015)	0.005*** (0.002)	0.201*** (0.073)	0.312** (0.126)
Ghana	−0.208** (0.090)	0.002 (0.032)	0.001 (0.002)	0.044 (0.046)	0.286 (0.121)
Guinea	−0.053 (0.061)	0.013 (0.017)	0.002 (0.004)	−0.023 (0.081)	0.045 (0.090)
Guinea Bissau	−0.329** (0.139)	0.030 (0.026)	−0.002 (0.003)	0.096 (0.091)	0.383** (0.186)
Kenya	−0.020 (0.081)	0.170** (0.077)	−0.005 (0.008)	−0.082 (0.217)	−0.134 (0.143)
Lesotho	−0.106 (0.133)	−0.019 (0.023)	−0.003 (0.003)	−0.132 (0.083)	0.171 (0.205)
Liberia	−0.067 (0.091)	0.017 (0.022)	−0.002 (0.003)	−0.018 (0.061)	0.073 (0.125)
Libya	0.611*** (0.156)	0.017 (0.053)	−0.003 (0.002)	−0.002 (0.014)	0.783** (0.235)

ΔGII	**ECT**	**Δwssii$_{t-1}$**	**Δsis$_{t-1}$**	**Δgdppc$_{t-1}$**	**constant**
Madagascar	−0.897*** (0.233)	−0.065** (0.026)	−0.0004 (0.003)	−0.151 (0.126)	1.128*** (0.293)
Malawi	−0.224 (0.164)	0.006 (0.018)	−0.020*** (0.006)	−0.409*** (0.124)	0.285 (0.224)
Mali	−0.014 (0.080)	−0.089 (0.068)	0.004 (0.008)	0.025 (0.167)	0.216 (0.228)
Mauritania	0.053 (0.154)	−0.042 (0.042)	0.017* (0.009)	−0.165 (0.112)	0.011 (0.247)
Mauritius	−0.478* (0.287)	0.005 (0.052)	−0.020 (0.016)	−1.006 (1.012)	0.696* (0.385)
Morocco	−0.394* (0.224)	0.081 (0.052)	−0.008 (0.008)	−0.197 (0.248)	0.439 (0.276)
Mozambique	0.002 (0.056)	−0.009 (0.014)	0.003 (0.006)	−0.057 (0.105)	0.021 (0.071)
Namibia	−0.447** (0.202)	0.035** (0.018)	0.002 (0.004)	0.110 (0.071)	0.558** (0.263)
Niger	−0.354 (0.223)	0.034 (0.033)	0.009* (0.005)	0.365* (0.222)	0.387 (0.267)
Nigeria	0.149 (0.156)	−0.031 (0.036)	−0.005 0.002)	0.030 (0.080)	−0.187 (0.203)
Rwanda	−1.005*** (0.170)	−0.001 (0.007)	0.010*** (0.002)	−0.162*** (0.044)	1.198*** (0.216)
Senegal	0.271 (0.220)	−0.018 (0.043)	0.006 (0.004)	0.247 (0.212)	0.392 (0.303)
Sierra Leone	−0.100* (0.054)	0.004 (0.026)	−0.002* (0.001)	−0.048** (0.020)	0.126** (0.050)
South Africa	−1.301*** (0.313)	−0.012 (0.020)	−0.005 (0.006)	−0.202 (0.160)	1.810*** (0.449)
Tanzania	−0.024 (0.045)	0.016 (0.020)	−0.005*** (0.002)	−0.393*** (0.144)	−0.002 (0.039)
Togo	−0.190 (0.171)	−0.005 (0.015)	−0001 (0.005)	0.152 (0.110)	0.242 (0.209)
Tunisia	−0.327* (0.191)	0.062*** (0.019)	−0.008** (0.004)	−0.365*** (0.122)	0.376 (0.243)
Uganda	−0.630*** (0.142)	0.057*** (0.015)	0.007** (0.003)	−0.270*** (0.051)	0.732*** (0.186)
Zambia	−0.188 (0.232)	−0.004 (0.043)	0.001 (0.003)	0.070 (0.093)	0.247 (0.316)
Zimbabwe	−0.182 (0.114)	0.083 (0.056)	0.005 (0.003)	0.022 (0.035)	0.265 (0.168)