Climate finance, institutions and innovation systems in Sub-Saharan Africa

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Abstract

To enhance climate finance's effectiveness in Sub-Saharan Africa (SSA) and explore how it can be deployed to boost innovation, this study has explored the effect of climate finance combined with institutional quality on innovation while emphasizing the multidimensional measurement approach to innovation. Using data from twenty-three (23) countries in SSA spanning the period 2011 to 2022 and the system Generalized Method of Moment (GMM) estimator, the results from the study show a negative and significant effect of climate finance on innovation in SSA. Also, we found that institutional quality has a positive and significant effect on innovation. Further, we realized from the conditional effect results that when the level of institutions in SSA is highly effective, the positive effect of climate finance on innovation is magnified. Given these findings, this study recommends that policies to improve climate finance in SSA should be pursued simultaneously with policies promoting strong institutions.

Keywords: climate finance, innovation, institutions, climate mitigation, climate adaptation, Sub-Saharan Africa

1 INTRODUCTION

Climate change continues to pose significant obstacles to achieving sustainable development goals, with Sub-Saharan Africa disproportionately suffering the consequences despite contributing less than 4% to global greenhouse gas emissions. According to the 2018 World Bank report, climate-related disasters, including rising sea levels, droughts, floods, and episodes of extreme heat, are expected to push more than 100 million people into poverty, with Sub-Saharan Africa and South Asia being the most brutally hit (Mouleye et al., 2019). These challenges are further intensified by the inability of many African countries to mobilise the necessary financial resources to reduce emissions and effectively build their resilience to climate change (Doku et al., 2021a, 2021b; Mekonnen et al., 2021; Mekonnen and Hoekstra, 2014). To address these effects, some developed countries have pledged to mobilise funds from various sources in the form of Official Development Assistance (ODA), classified as climate finance, to support less developed nations to mitigate and adapt to climate change. The commitment has sparked discussions on the impact of climate finance on various development outcomes.

As Trutnevyte et al. (2019) and Shi, Wang and Wang (2018) noted, the pursuit of new and efficient solutions to climate challenges is essential to mitigate the risk of environmental devastation. As a result, innovation is seen as a sure dynamic capability that nations can deploy to achieve sustainable development while improving environmental quality through reduced carbon emissions (Apostu et al., 2023). In 2015, the Paris Agreement strongly affirmed the critical role of innovation, emphasising that "accelerating, encouraging, and enabling innovation is essential for an effective, long-term global response to climate change." Indeed, current literature supports the notion that innovation is a critical driver of sustained economic growth (Anttila and Jussila, 2019; Maradana et al., 2017; Pradhan et al., 2019). Advanced technologies create opportunities to transform products and services and promote sustainable practices (Lopes de Sousa Jabbour, 2018). Innovation is essential for achieving green economy goals, particularly zero pollution, while fostering value creation, employment, and national development (Gerguri and Ramadani, 2010; López and Figueroa, 2016; Pradhan et al., 2019; Silvestre and Ţîrcă, 2019).

Current literature (Lee et al., 2022; Ryan Hogarth, 2012) has theoretically hinted at climate finance's potential impact as a crucial mechanism for facilitating innovation. It is, therefore, unsurprising that some scholarly interest has been expressed in explanations of how climate finance can influence innovation (Ryan Hogarth, 2012; Lee and Shin, 2022; Pradhan et al., 2023).

Despite these interests, the empirical findings on the relationship have been mixed and remarkably inconsistent. Moreover, Sharma, Sousa and Woodward (2022) and Ryan Hogarth (2012) have indicated that the effect of climate finance on innovation is highly context dependent. Accordingly, researchers must account for these relevant boundary conditions when exploring this vital relationship. This notwithstanding, the mechanisms through which climate finance impacts on innovation remain poorly understood in the literature, particularly those regarding SSA.

Our literature scan reveals that one critical and yet-to-be-studied mediating factor in the literature is institutional quality. A closer examination of institutional dynamics can offer valuable insights into how climate finance fosters innovation across different contexts. The quality of institutions may be pivotal in shaping the climate finance-innovation nexus. This is because institutions must establish regulatory and policy frameworks that foster an environment conducive to innovation (Porter and Linde, 1995). Secondly, they are pivotal in safeguarding intellectual property rights (IPR), essential for stimulating innovation (Sharma, Sousa and Woodward, 2022). Institutions also contribute by reducing transaction costs associated with information asymmetry and innovation (Williamson, 1985). Furthermore, they can strengthen the effect of climate finance on innovation by providing financial support and research-and-development (R&D) incentives (Bérubé and Mohnen, 2009; David, Hall and Toole, 2000). Additionally, institutions play a key role in cultivating a culture of innovation by creating environments that value and support creative endeavours (Grindle, 2004). Finally, effective institutions ensure transparency and accountability throughout innovation (North, 1990).

The above assertions establish a foundation for an empirical inquiry. This study addresses a key policy question: Is climate finance directed towards SSA countries effectively fostering innovation on the continent? Furthermore, does the quality of institutions in SSA mediate the relationship between climate finance and innovation on the continent? Several important stylised facts, policy concerns, and gaps in the empirical literature have driven the undertaking of this study. The second question is fundamental because climate change is closely tied to institutional frameworks and ideologies (Hulme, 2009), which is pivotal in shaping how climate finance is utilised. Institutional factors not only directly influence innovation but also have the potential to affect innovation indirectly through their impact on the allocation and effectiveness of climate finance.

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The current study departs from the findings of the reviewed literature in many ways. First, it seeks to investigate the direct and indirect effects of climate finance and institutional quality factors on innovation in SSA. Very little is known about the effects of climate finance on improving innovation in Africa. This study makes a bold claim, asserting that the relationship among climate finance, institutional quality and innovation has yet to be explored in empirical economic literature. The most closely related research is by Pradhan et al. (2023), which examined the relationship between overall foreign aid, institutions, and innovation in middle-income countries. However, our study diverges by focusing specifically on bilateral and multilateral climate finance in Sub-Saharan Africa, as reported by the Organization for Economic Co-operation and Development (OECD), rather than ODA. Additionally, we use the innovation output sub-index from the Global Innovation Index (GII) to measure innovation outcomes, a metric not considered in Pradhan's study. The Innovation Output Index effectively captures critical drivers of innovation, including knowledge and technology outputs (such as knowledge creation, impact, and diffusion) and creative outputs (intangible assets, creative goods, services, and online creativity) (Osei, 2024).

We enhance the measurement of institutional quality using principal component analysis (PCA) on the World Bank's Worldwide Governance Indicators (WGI), providing a more precise measure (Tashtamirov, 2023). We employ the system GMM estimator, which robustly addresses endogeneity, lag differences, and simultaneity rather than error correction and ARDL models, improving on studies by Pradhan et al. (2023) and Nadeem et al. (2020).

Further, Gilder and Rumble (2020) have argued that climate finance is often more donor-centric than recipient-focused; enhancing the effectiveness of climate funding in African countries requires a shared understanding between donor and recipient nations. This study will contribute to that understanding through the examination of the interactions among climate finance, institutions, and innovation in Sub-Saharan Africa. It provides insights that will help improve collaboration and policy alignment, highlighting how effective strategies can bolster institutional development, innovation, and climate finance. These insights aim to shape a more sustainable economic development trajectory for the region.

This paper follows the following structure: section 2 reviews the literature on the interrelationships of climate finance, innovation, and institutional quality, highlighting their interconnections and formulating the study's hypotheses. Section 3 details the data, variables, and econometric model used to test these hypotheses. Section 4 presents the empirical findings and interpretations. The fifth and last sections conclude the study by summarising our contributions, discussing policy implications for policymakers and practitioners, acknowledging the limitations, and suggesting directions for future research.

2 STYLIZED FACTS ABOUT CLIMATE FINANCE IN AFRICA

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The political nature of climate finance has kept its definition subject to ongoing debate, with no universally accepted standard. The United Nations Framework Convention on Climate Change (UNFCCC) offers one of the most widely accepted descriptions, defining climate finance as "local, national, or transnational financing – sourced from public, private, and alternative funds – intended to support mitigation and adaptation efforts aimed at addressing climate change."[1] Gebreyesus (2017) states that one way to classify climate finance is as aid, but as an addition to the "0.7%" ODA target. In Africa, climate finance predominantly takes the form of Official Development Assistance (ODA) due to the continent's limited financial capacity and underdeveloped markets, which restrict access to private sector climate funds.

Of Africa's total climate finance needs, adaptation constitutes only 24%, while mitigation dominates, accounting for 66% of the required funding for 2020-2030. Africa is highly dependent on external public climate finance (86%)[2], which is disbursed as ODA. Unfortunately, the flow of climate finance from external sources in Africa has been low and does not meet the required amount needed for mitigation and adaptation. The Climate Policy Initiative estimates that between 2020 and 2030, African countries will need about 2.8 trillion, or 2,800 billion United States dollars annually, to implement all the Nationally Determined Contributions (NDCs). This is much more than the average of USD 30 billion received annually, which makes up only 12% of the required funding.[3] According to Tamasiga et al. (2023), weak institutional structures are headlined by the absence of any specialist climate finance units, poor coordination between donors and government institutions, and lax legal and regulatory systems. Moreover, unstable and unpredictable climate finance flows compound the challenges, with climate funds flows fluctuating depending on voluntary donor contributions.

Moreover, according to Ahenkan (2020), the allocation of adaptation funds has suffered from poor donor coordination. Some donors continue to bypass multilaterally agreed-upon principles in their disbursement, complicating donor efforts to plan and implement long-term climate projects that require sustained support.

Another problem accounting for the shortfall in climate finance is the failure of developed countries to meet the 2020 $100 billion climate finance target. This has eroded trust and undermined confidence in developed countries' efforts against climate change.

[1] Refer to: https://unfccc.int/topics/introduction-to-climate-finance
[2] See: https://www.weforum.org/agenda/2023/12/cop28-bridging-the-climate-finance-gap-in-africa-and-beyond/
[3] See: https://www.weforum.org/agenda/2023/12/cop28-bridging-the-climate-finance-gap-in-africa-and-beyond/

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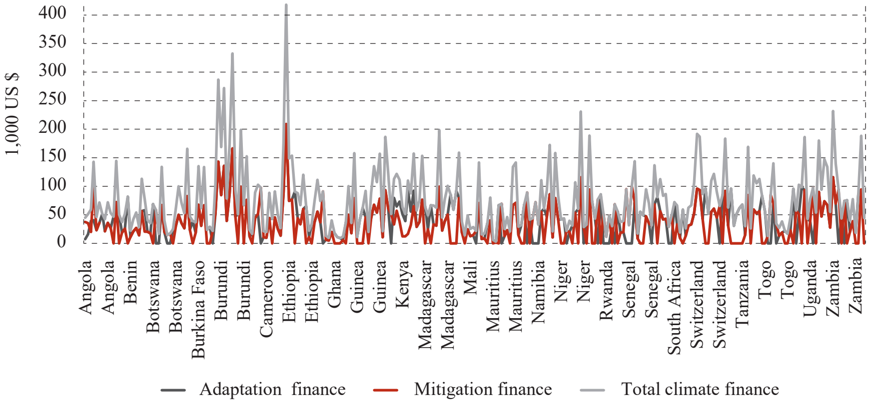
Lastly, according to Musah-Surugu et al. (2018), climate finance seems fragmented. The various funds have different priorities and eligibility criteria, making it difficult for African countries to access them. This fragmentation reflects inefficiencies and deeper political divisions in climate finance (Biermann et al., 2009).

Figure 1 shows that aside from Burkina Faso, Guinea and Cameroon, all the SSA countries sampled in this study have experienced unchanging or decreasing climate finance.

Figure 1

Trend analysis of climate finance among SSA countries



Source: Authors.

3 THEORETICAL REVIEWS

3.1 THE LINK BETWEEN CLIMATE FINANCE AND INNOVATION

We outline two primary channels through which the impact of climate finance on innovation can manifest. Firstly, it can work through investment in green technologies and sustainable practices. Climate change mitigation requires investment in green technologies (e.g., PV installations) and sustainable practices with less environmental impact (Lee et al., 2022; Ryan Hogarth, 2012). Interestingly, providing a conducive environment for green technologies will foster a culture of innovation, encouraging firms and other businesses to innovate in areas like green packaging, renewable energy, energy efficiency, and carbon capture technologies, and finally, through funding for research and development. This channel is critical where climate finance directly aids the development of new technologies and climate-related solutions. Providing financial support for research and development will create the space for researchers and organisations to explore and develop innovative approaches for climate resilience.

3.2 LINK BETWEEN INSTITUTIONAL QUALITY, CLIMATE FINANCE AND INNOVATION

The link between institutional quality, climate finance and innovation can be understood through two broad channels. First, climate finance may be enhanced when some clear policies and measures align with climate goals and commitments. Institutions are crucial in shaping emission levels by implementing environmental regulation policies. Therefore, weak institutions often lead to poor regulations and higher emissions, whereas strong institutions facilitate eco-friendly practices and ensure lower emissions through rigorous regulatory frameworks. This is fundamentally the "Porter hypothesis" basis, further illustrating the link between institutions and the environment. This hypothesis suggests that stringent regulatory policies stimulate innovation in technologies that reduce pollution. Such innovations can provide a competitive edge, ultimately balancing environmental costs and enhancing economic efficiency (Zhang and Baranzini, 2004; Alavuotunki, Haapanen and Pirttilä, 2019).

Concerning the second channel, strong institutions can effectively enforce the rules and regulations that protect intellectual property rights, which are central to innovation development. According to Sharma, Sousa and Woodward (2022), institutions play a crucial role in enhancing innovation because they lower transaction costs arising from information asymmetry, bargaining and coordination and enforcement of contracts. For instance, in an economy where the authorities use their legal discretion to reward cronies (North, 1993; Rodrik, 2000), economic inefficiency will result, impeding innovation development. Further, studies have shown that strong institutions can stimulate innovation performance by providing direct R&D subsidies, tax incentives and knowledge transfer (Bérubé and Mohnen, 2009; David, Hall and Toole, 2000). Institutions thus mediate innovation by directing economic resources to productive sectors that will yield beneficial economic outcomes (Sindzingre, 2005). As Sen (1981) opined, effective institutions play a critical role in fair resource allocation and access, which is crucial for innovation development.

In conclusion, good governance, marked by robust institutional frameworks, is essential for effective climate finance implementation and equitable resource allocation. This necessitates institutions that establish fair laws, administer public services efficiently, cultivate capable human capital, and ensure transparency and public accountability (Grindle, 2004).

3.3 RELEVANT EMPIRICAL REVIEWS

A considerable number of studies have argued that climate finance promotes economic growth and environmental sustainability through better capital allocation (Han and Jun, 2023; Lee et al., 2022; Mahat et al., 2019; Romano et al., 2017; Steckel et al., 2017; Tol, 2009). Their arguments emanate from climate finance serving as a new form of financial buffer that can cushion firms to adopt green technology in their operations to ensure sustained growth and reduce carbon emissions.

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Despite the beneficial influence of climate finance on environmental sustainability and growth, recent literature has highlighted the possible influence of climate finance on innovation. This is because the success of every economy depends mainly on the ability of the productive and distribution sectors to innovate. Notwithstanding, studies in this domain of research have produced remarkably inconsistent findings. For example, Pradhan et al. (2023), Warren (2020), Czarnitzki and Hottenrott (2011) and Dakhli and De Clercq (2004) revealed a restrictive effect of climate finance on innovation. Studies such as those by Ryan Hogarth (2012), Bannert (2020), Gorodnichenko and Schnitzer (2013), and Ryan Hogarth (2012) have shown that climate finance has a beneficial effect on innovation. Interestingly, the study by Blind (2012) found no significant relationship between the two indicators in developing economies and suggested that the impact of climate finance on innovation depends on the structures and fundamentals of an economy and called for better institutional regulation.

Given this call, past studies such as Osei (2024), Sharma, Sousa and Woodward (2022) and Nadeem et al. (2020) investigated the effect of institutional quality on innovation and confirmed that better institutions promote innovation by enforcing rules and regulations that protect intellectual property rights. Also, the authors contended that effective institutions foster policies that can direct climate funds into the productive sectors of the economy to yield positive outcomes on innovation. While the influence of institutions on innovation has been examined at various levels (Pradhan et al., 2023; Rodríguez-Pose and Zhang, 2020; Oluwatobi et al., 2016), there remains a notable vacuum in the literature regarding the mediation effect of institutional quality on climate finance-innovation nexus. A critical examination of the literature suggests that only Nadeem et al. (2020) have investigated the mediation effect of institutional quality in the relationship between the foreign aid-innovation nexus. Thus, the theoretical specification on how institutional quality can be adopted to bridge the climate finance-innovation gap lacks rigorous empirical investigation in the literature, especially that relating to SSA. An important implication of this gap in the literature is that knowledge is lacking on how this relationship works in less-developed economies. Specifically, how institutional qualities can direct climate funds to the productive sectors of the economy to enhance innovation remains unexplored in SSA. Therefore, the current study aims to fill this gap by providing compelling evidence on the African perspective regarding the impact of climate finance on innovation by considering the role that institutional quality plays.

This gap is significant given that SSA economies top the chart as the major recipients of climate finance. Therefore, understanding how this relationship works in the African context is essential to guide policies and laws in the climate finance space.

4 METHODOLOGY

To probe into how climate finance can be adopted to enhance innovation in SSA mediated by institutional quality, we grouped this section into three main subsections: data and variable description, empirical model specification, and estimation methods employed.

4.1 DATA AND VARIABLE DESCRIPTION

This study primarily focused on balanced panel data of twenty-three countries in SSA from 2011 to 2022. It should be noted that the sample frame of this study was chosen due to the easy accessibility and availability of data on the main variable of interest. Also, we sample the twenty-three countries in SSA for this empirical investigation because these countries have complete data for the main constructs. Data for this study were sourced from three different databases. Specifically, innovation and climate finance data were extracted from the World Intellectual Property Organization (WIPO) and the OECD databases, respectively. Moreover, the other variables such as institutional quality index, foreign direct investment, human capital, gross domestic product per capita, digital infrastructure index, inflation and government expenditure were sourced from World Development Indicators (WDI).

This study measured innovation as the innovation output sub-index of the GII as the dependent variable because its focus is to assess the determinants of innovation in SSA, primarily focusing on climate finance and institutional quality. It should be noted that all the control variables were adopted from past studies such as Osei (2024), Pradhan et al. (2023), and Sharma, Sousa and Woodward (2023). We report the abridged version of the data sources and how they were measured in table 1.

Table 1

Variable description

Variable	Notation	Measurement	Source
Dependent variable			
Innovation	INNOV	Innovation output sub-index (score 0–100)	WIPO
Independent variable			
Climate finance	CF	Climate-related development finance Commitment (Current USD thousand)	OECD
Mediating variable			
Institutional quality index	IQ	It is computed as an average of Kaufmann's six indicators of institutional quality (Regulatory quality, government effectiveness, rule of law, control of corruption, voice and accountability, political stability, and lack of violence)	WDI
Control variables			
Human capital	HC	School enrolment, tertiary (% gross)	WDI
GDP per capita	GDPPC	GDP per capita (constant 2015 US$)	WDI
Government expenditure	GE	General government final consumption expenditure (% of GDP)	WDI

Variable	Notation	Measurement	Source
Digital infrastructure	DIFRA	Mobile cellular subscriptions (per 100 people), Individuals using the Internet (% of the population), Fixed telephone subscriptions (per 100 people) and Fixed broadband subscriptions (per 100 people)	WDI
Financial development		Domestic credit to private sector (% of GDP)	WDI

Note: WIPO, OECD and WDI represent the World Intellectual Property Organization, Organization for Economic Co-operation and Development and World Governance Indicators, respectively.

Source: Authors.

4.2 THEORETICAL AND EMPIRICAL MODEL

This study modifies the innovation model proposed by Howitt and Aghion in 1998 to assess the effect of climate finance on innovation in SSA. According to Howitt and Aghion, innovation is determined by knowledge acquisition, human capital development and the financial resources a country controls or possesses. These financial resources include donations, aid, total revenue mobilisation, etc. (Anselmi, Lagarde and Hanson, 2015). Interestingly, this study conceptualizes the financial resources that developing nations receive to mitigate climate emissions as climate finance. According to Romano et al. (2017), climate finance enhances the financial capacity of developing nations. It enables them to develop and deploy new technologies and innovative solutions essential for zero low-carbon emissions. Therefore, this study specifies a linear function relationship between innovation, climate finance and human capital development in equation 1 as follows:

$$INNOV = f(CF, HC) \tag{1}$$

where INNOV, CF and HC represent innovation, climate finance and human capital, respectively. Interestingly, following Osei (2024) and Sharma, Sousa and Woodward (2022), who postulated that innovation in an economy is not dependent solely on human capital and financial resources but on other economic and institutional factors, we extended equation (1) to capture both economic and institutional factors such as institutional quality, GDP per capita, digital infrastructure development, government expenditure and financial development. Hence, equation (1) was remodelled to incorporate these aforementioned factors and the interaction between institutional quality and climate finance as specified in equation (2) below:

$$INNOV = f(CF, IQ, CF * IQ, HC, GDPPC, DIFRA, GE, FD) \tag{2}$$

The symbols IQ, CF*IQ, GDPPC, DIFRA, GE and FD indicate institutional quality, the interaction between climate finance and institutional quality, GDP per capita, digital infrastructure development, government expenditures, and financial development, respectively.

The estimate form of equation (2) is specified in equation (3) as:

$$lnINNOV_{it} = \delta_0 + \theta_1 lnINNOV_{it-1} + \theta_2 CF_{it} + \theta_3 IQ_{it} + \theta_4 (CF * IQ)_{it} + \theta_5 lnGDPPC_{it} + \theta_6 DIFRA_{it} + \theta_7 lnGE_{it} + \theta_8 lnFD_{it} + \epsilon_{it} \quad (3)$$

$$\epsilon_{it} = \mu_{it} + \varphi_i + \vartheta_t \quad (4)$$

It must be noted that all the variables have already been explained. δ_0, ln, ϵ, i and t represent the constant term, natural logarithm, error term, and the number of countries and periods employed. The symbols μ_{it}, φ_i and ϑ_t represent idiosyncratic error term, unobserved country-specific and time-specific effect so, θ's (1, 3…, 8) denote the unknown parameters to be estimated.

4.3 ESTIMATION TECHNIQUE

To assess the effect of the interaction between climate finance and institutional quality on innovations in SSA, we employed the two-step system generalized method of moment (system-GMM) estimator proposed by Blundell and Bond (1998). We adopted the two-step system-GMM in this study because it provides efficient and unbiased results due to the additional moment conditions it uses. The system-GMM estimator is applicable when the time period is smaller than cross-sectional units. Furthermore, it employs the lags of the endogenous regressor as internal instruments to mitigate any potential endogeneity issues that may develop because of the introduction of the lagged dependent variable as part of the regressors. Therefore, the system-GMM specification of equation (3) is expressed as follows:

$$lnINNOV_{it} - lnINNOV_{it-1} = \sigma_0(lnINNOV_{it-1} - lnINNOV_{it-2}) + \rho'(lnX_{it} - lnX_{it-1}) + (\epsilon_{it} - \epsilon_{t-1}) \quad (5)$$

It is interesting to note that all the variables are already explained in the previous equations. X represents a vector of variables captured in the previous equations. In selecting an instrument for this study, we used the first difference of innovation as a valid instrument. This is because Arellano and Bover (1995) suggested that using a lagged level of the dependent variable as the instrument will be a poor instrument, especially if the variable is close to a random walk. As a result, we applied $lnINNOV_{it-2} - lnINNOV_{it-3}$ as an appropriate instrument for $lnINNOV_{it-1} - lnINNOV_{it-2}$. Further, we applied Arellano and Bond (1991) and Hansen (1982) J tests to validate the absence of second-order serial correlation and the validity of the instruments, respectively. The null hypothesis of these tests reveals the absence of second-order serial correlation and instrument validity. Therefore, we tested the null hypothesis against the alternative hypothesis at 5% significance level. Interestingly, we will fail to reject the null hypothesis and conclude that the estimates have no problem if the probability values are higher than 5% significance level.

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After estimating the interactive effect of climate finance and institutional quality, we advanced the analyses. We computed the marginal effect of climate finance and institutional quality for stimulating innovation by applying the partial differentiation method proposed by Brambor, Clark and Golder (2006). Given equation (3), the partial differentiation approach can be written as:

$$\frac{\partial INNOV_{it}}{\partial CF_{it}} = \theta_1 + \theta_3 IQ_{it} \tag{6}$$

This approach allows us to ascertain the actual influence of climate finance on innovation ($\theta_1 + \theta_3 IQ_{it}$) rather than interpreting the unconditional estimate of θ_3.

Further, this study has applied the Dumitrescu and Hurlin (2012) panel causality test to inspect the causal interrelationship of climate finance, institutional quality and innovation in SSA. According to Khan et al. (2020), the Dumitrescu and Hurlin causality test is appropriate regardless of $T > N$ or $T < N$ and controls for cross-sectional dependence and heterogeneity in the slope coefficients. The general specification of this regression is given by:

$$Y_{it} = \varphi_i + \sum_{p=1}^{P} \theta_{ip} Y_{it-p} + \sum_{p=1}^{P} \gamma_{ip} X_{it-p} + \epsilon_{it} \tag{7}$$

It should be noted that Y and X are the stationary variables for country i and period t. The coefficients are allowed to differ across countries but are assumed to be time-independent. The lag order P is assumed to be the same for all the countries, and the panels must be balanced.

From equation (6), we express the null and alternate hypothesis of this test as:

$$H_0: \theta_{i1} = \ldots = \theta_{iP} = 0 \quad \text{for} \quad i = 1, 2, 3, \ldots, N_1 \tag{8}$$

$$H_1: \theta_{i1} \neq \ldots .\ \theta_{iP} \neq 0 \tag{9}$$

The non-rejection of the null hypothesis indicates the absence of any causal relationship among the variables.

Lastly, to ensure that the dataset employed passed preliminary checks like cross-sectional dependency (CD) and no unit root, we used the cross-sectional dependency test by Pesaran (2004) to inspect the cross-sectional dependency of the sampled variables employed. Also, the Im, Pesaran and Shin (2003) and Pesaran (2007) cross-sectionally augmented unit root tests were applied to ascertain the stationary properties of the variables. Interestingly, the null hypothesis of all the tests suggests no cross-sectional independence and unit root, whereas the alternative hypothesis proposes otherwise. Therefore, rejection of the null hypothesis reveals that there is cross-country correlation and non-stationarity in the variables.

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5 INTERPRETATION AND DISCUSSION OF RESULTS

This section presents and discusses the results, including descriptive statistics, correlation among the variables employed, scatter plots, unit root results, and estimated results.

5.1 DESCRIPTIVE STATISTICS

This study reports the descriptive statistics of the sampled variables used in table 2.

Table 2
Descriptive statistics

Variable	Obs.	Mean	Std. dev.	Min.	Max.	Measurement unit
INNO	276	22.152	12.735	0.300	71.800	Index score 0-100
CF	275	43.724	33.943	11.000	209.102	Current USD thousand
IQ	276	0.502	0.310	0.000	1.000	Index score 0-1
GDPPC	276	5,669.880	17,113.000	262.185	90,057.030	US$
HC	276	89.880	72.415	1.000	222.000	%
IFRAI	276	0.525	0.236	0.000	0.992	Index score 0-1
GE	276	15.233	5.837	6.697	36.143	%
FD	276	26.672	27.283	0.000	128.838	%

Note: INNOV, CF, IQ, GDPPC, HC, IFRAD, GE and FD indicate innovation, climate finance, institutional quality index, gross domestic product per capita, human capital, infrastructure development, government expenditure and financial development.
Source: Authors.

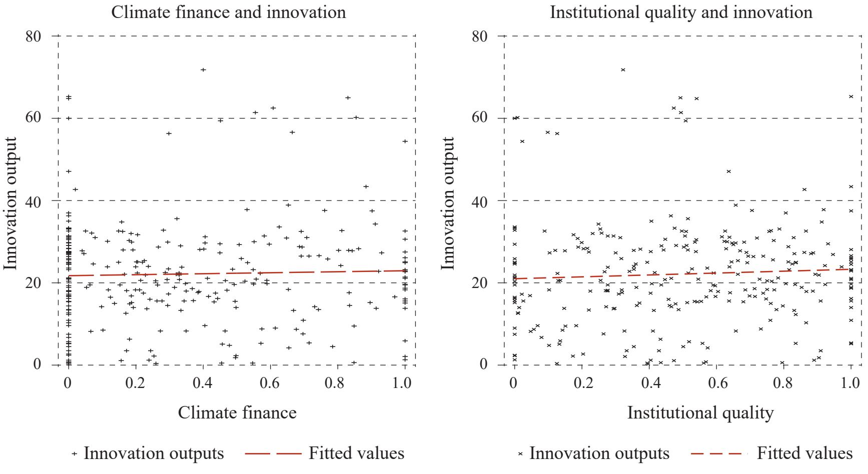
Using innovation output as a measure of innovation in this study, the study found that the mean value of innovation in SSA is 22.15, indicating that, on average, innovation in SSA is low. The difference between the minimum (0.30) and the maximum (71.80) values of innovation reveals the extent of the disparity in innovation among the sampled economies in SSA. This was established by the huge standard deviation value of 12.74. Also, the study detected that climate finance and institutional quality index have a mean value of 43,730 US dollars and a 0.502 score, respectively. Additionally, the results showed that the maximum value of climate finance was 209,100 US dollars. With the control variables, we observed that GDP per capita in SSA averaged 5669.887 US dollars. Further, human capital, infrastructure development index, government expenditure and financial development were found to have mean values of 89.88%, 0.525 scores, 15.23% and 26.67%. Furthermore, we found that the highest standard deviation among the variables used for this analysis is GDP per capita. In conclusion, we realized that all the variables do not deviate significantly from their respective means.

5.2 EXPLORATORY ANALYSIS OF PATTERNS AND RELATIONSHIPS OF CLIMATE FINANCE, INSTITUTIONAL QUALITY AND INNOVATION IN SSA

This section of the study explores the patterns and relationships between innovation, climate finance and institutional quality in SSA and the results are displayed in figure 2.

Figure 2

Scatter plot between climate finance, institutional quality and innovation in SSA



Source: Authors using STATA 15.1.

Figure 2 shows that climate finance and institutional quality demonstrate a modest positive relationship with innovation in SSA. However, institutional quality exerts a more pronounced positive impact on innovation than climate finance.

5.3 CORRELATION MATRIX

In addition to the scatter plots, we conducted a pairwise correlation test to validate the linear association among climate finance, institutional quality, and innovation in SSA. The results for this estimation are reported in table 3.

The results reported in table 3 indicate that except for government expenditure, the rest of the variables used in this study have a positive association with innovation in SSA. It is evident from the correlation coefficients that real GDP per capita has a strong positive correlation with innovation. In contrast, the rest of the indicators showed weak and moderate positive or negative correlations with innovation in SSA. Since climate finance and institutional quality move in tandem with innovation in SSA, we can conclude that enhancing these indicators in SSA will be crucial for innovation development.

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Table 3

Pairwise correlation among the variables

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) INNO	1.000							
(2) CF	0.031	1.000						
(3) IQ	0.056	-0.036	1.000					
(4) GDPPC	0.696	0.082	-0.114	1.000				
(5) HC	0.283	0.036	0.029	0.285	1.000			
(6) IFRAI	0.022	0.023	-0.101	0.157	0.168	1.000		
(7) GE	-0.069	0.026	-0.060	-0.086	0.085	0.050	1.000	
(8) FD	0.207	0.041	0.052	0.060	0.042	0.154	0.307	1.000

Source: Authors.

5.4 WEAKLY CROSS-SECTIONAL DEPENDENCY TEST

Given that cross-country correlation can bias the estimates, we employed Pesaran's (2015) weak cross-sectional dependence test to inspect the cross-sectional dependence among the variables. The results are reported in table 4.

Table 4

Weakly cross-sectional dependency test

Variable	CD test	Prob. value
INNOV	16.921	0.000
CF	9.680	0.000
IQ	2.348	0.019
GDPPC	21.806	0.000
HC	4.205	0.000
INFRAI	11.204	0.000
GE	2.088	0.037
FD	8.552	0.000

Note: The null hypothesis is that errors are weakly cross-sectionally dependent and the alternative hypothesis is that errors are strongly cross-sectionally dependent.

Source: Authors.

In table 4, none of the variables employed for this investigation exhibited cross-sectional dependence. The null hypothesis of weakly cross-sectional dependence is rejected at the 5% and 1% significance levels in all the variables tested. Since there is strong cross-sectional dependence among the variables, we adopted a stationarity tests that accounts for this issues in the variables employed.

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5.5 UNIT ROOT TEST

Table 5 reports the outcomes of Cross-Sectional Augmented Dickey Fuller and Cross-Sectional Augmented IPS (CIPS) unit root test.

Table 5

Unit root test results

	CIPS test		CADF test	
Variable	**I(0)**	**I(1)**	**I(0)**	**I(1)**
INNOV	-1.771	-2.692***	-1.012	-2.610***
CF	-2.455**	-6.279 ***	-1.925*	-2.273**
IQ	-2.311**	-3.044***	-1.954*	-2.740***
GDPPC	-1.545	-2.267**	-2.081**	-2.610***
HC	-1.493	-2.938**	-0.992	-2.610***
INFRAI	-2.645***	-4.061***	-2.034**	-2.475***
GE	-2.129*	-3.533***	-1.450	-2.394***
FD	-0.885	-2.180**	-0.702	-2.611***

*Note: ***, ** and * represent significant at 1%, 5% and 10% significance level. *, **, *** represent stationarity.*

Source: Authors.

Given the results in table 5, we observed that innovation, real GDP per capita and human capital and financial development were not stationary in the levels using both CIPS and cross-sectional augmented Dickey Fuller (CADF) unit root tests. Though institutional quality was stationary in the levels when we applied CIPS, the results were also stationary when we employed the CADF unit root test. However, in both tests, all the variables were stationary at the first difference. After confirming the stationarity properties of the variables, we continued to estimate the unknown parameters.

5.6 EFFECT OF CLIMATE FINANCE AND INSTITUTIONAL QUALITY ON INNOVATION IN SSA (SYSTEM-GMM RESULTS)

Here, we report the estimations obtained for assessing the impact of climate finance and institutional quality on innovation in table 6. It should be noted that we used the difference GMM estimation technique as a robustness check.

The results show that the previous level of innovation has a negative and significant effect on the current innovation level in SSA. Improvement in the previous innovation will lead to a fall in the current level of innovation in SSA by 0.31 to 0.18 scores, holding all the covariates unchanged. This finding indicates that innovation in the context of SSA converged.

Table 6
Effect of climate finance and institutional quality on innovation in SSA

Variable	Coefficient	
	System-GMM	**Difference GMM**
$lnINNOV_{it-1}$	-0.306*** (0.069)	-0.184* (0.108)
lnCF	-1.003*** (0.376)	-0.438** (0.227)
IQ	3.039** (1.334)	1.430* (0.775)
lnCF_IQ	2.074** (0.757)	0.974* (0.580)
lnGDPPC	-0.980 (1.339)	1.413 (4.054)
HC	0.011** (0.004)	0.003 (0.005)
IFRAD	-1.874* (1.084)	-0.918 (1.039)
lnGE	-10.193** (4.511)	-1.441 (2.577)
lnFD	5.289 (3.899)	0.847 (3.372)
Net/marginal effect	3.039** (1.334)	1.430* (0.775)
Constant	19.887 (12.593)	
AR(2) test statistic	-0.670	-0.880
AR(2) P-value	0.505	0.377
Hansen test statistic	4.940	5.890
Hansen P-value	0.895	0.751
No. groups	22	22
No. instruments	20	20

*Note: ***, ** and * represent significant at 1%, 5% and 10% significance level.*
Source: Authors.

Concerning climate finance, we found a negative and statistically significant effect on innovation in SSA. The negative coefficients, which are significant at 5% and 1% levels, indicating that climate finance diminishes innovation. The coefficient suggests that a 1% increase in climate finance will cause innovation to fall by 1.00 and 0.44, respectively. These results imply that international donor communities do not have innovation development in SSA as part of their policy agenda. This is because the climate finance received in SSA comes from international donor communities and governments in developed economies. This is particularly concerning, as innovation must be part of the strategies for combating climate change. If climate finance directed towards Africa fails to prioritize innovation, it poses a significant challenge to the continent's ability to develop sustainable solutions, leaving its prospects uncertain. The lack of emphasis on innovation could be attributed to minimal or non-existent allocation of climate finance to research and development. Consequently, there may be insufficient investment in adaptation and mitigation efforts related to innovation and technology development. However, Warren (2020) contended that these donor communities and governments prioritise sectors like energy and transport systems with rewarding outcomes rather than investing in disruptive innovations. This finding aligns with the empirical evidence by Ryan Hogarth (2012), who highlighted the negative effect of climate finance on innovation in developing economies.

It was also revealed in table 6 that institutional quality has a positive and significant effect on innovation in SSA. The result suggests that improvement in institutions in SSA will enhance innovation by scores of 3.04 and 1.43. This finding implies that an economy with solid institutions can effectively enforce the rules and regulations that protect intellectual property rights and encourage fair competition, which are central to innovation. This result aligns with the evidence provided by Sharma, Sousa and Woodward (2022), Anselmi, Lagarde and Hanson (2015) and Simón-Moya, Revuelto-Taboada and Guerrero (2014), indicating that in countries with more robust political stability, the rule of law and integrity of contracts consistently perform better across a range of economic indicators including innovation. However, the finding contradicts the study by Rodríguez-Pose and Zhang (2020), which argued that innovation tends to be stifled in an economy where acquiring patents and trademarks for innovation is bureaucratic.

Given that institutional quality enhances innovation, we further explored its mediating role in the relationship between climate finance and innovation. As reported in table 6, the interaction term results indicate that robust institutional frameworks are essential for climate finance to positively and significantly impact innovation in SSA. The coefficient of the interaction term reveals that an increase in climate finance can boost innovation scores by 2.07 and 0.97 points when institutions in SSA are effective. This finding is not unexpected, as strong institutions can direct climate finance towards projects with the highest innovation potential. Consequently, effective institutions act as a crucial conduit for enhancing innovation, particularly in SSA, where innovative capacities are currently underdeveloped.

Turning to the control variables, the study found that real GDP per capita negatively and insignificantly affects innovation in the system GMM estimation. In the difference GMM method, the effect was positive but not statistically significant. Specifically, a 1% increase in real GDP per capita is associated with a 1.41-point increase in innovation. This positive relationship aligns with the findings of Saldanha et al. (2021) and Osei (2024). Additionally, human capital was shown to positively and statistically significantly impact innovation. This suggests that human capital accumulation, particularly through tertiary education, is crucial in generating knowledge for innovation. Educated individuals contribute specialised knowledge, creative solutions, and novel approaches that support innovation. This result corroborates the studies by Dakhli and De Clercq (2004) and Oluwatobi et al. (2016). We also found that financial development does not significantly impact innovation, according to both the system GMM and difference GMM methods.

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Additionally, our analysis revealed that government expenditure and infrastructure development in Sub-Saharan Africa appear to hurt innovation.

As the effect of climate finance and institutional quality on innovation may be non-linear, we assessed the non-linear effect of climate finance, institutional quality, and their interaction on innovations in SSA. Even though this estimation is not the prime focus of this study, it made us more optimistic about knowing whether climate finance and institutional quality have a non-linear relationship with innovations. The results are reported in table A1 in the appendix. The results reveal that the square of climate finance negatively affects innovation, implying that overreliance on climate finance in the context of SSA will diminish innovation development. Also, we recognized that the square of institutional quality improves innovations in SSA. This result points to the view that strong institutional systems have an amplificatory effect on the fostering of innovations in SSA. After accounting for the squared interaction between climate finance and institutional quality, we found a negative impact on innovation. Interestingly, this result suggests that SSA economies will not enhance innovation through institutional development if they depend solely on climate finance as their resource construction.

Given that the institutional quality index positively affects innovation systems, we extended the analyses to look into the multidimensional constructs of institutional quality by considering the influence of control of corruption and political stability. The results reported in table A2 in the appendix show that corruption control has a positive effect on innovation in SSA. Additionally, the interaction between climate finance and corruption was found to have a positive and significant effect on innovation, suggesting that corruption control serves as a key channel through which climate finance impacts the innovation system in SSA. As far as political stability is concerned, we realize a positive and significant impact on innovation. Surprisingly, we also found that the interaction between climate finance and political stability as reported in Model 2 in the appendix was positive and significant. This result suggests that political stability is not a prime factor necessary for SSA economies to drive substantial climate finance and enhance innovation. It is important to note that all econometric tests, including the second-order serial correlation test and Hansen test for over-identification restrictions, were passed, as indicated by the non-rejection of the null hypothesis in both AR (2) and Hansen tests.

5.7 MARGINAL EFFECT OF CLIMATE FINANCE ON INNOVATION

Although table 6 indicates that the interaction between climate finance and institutional quality is positive and significant, the actual impact of climate finance on innovation can be determined through the marginal effect (conditional effect). We report the marginal effect result in table 7.

The marginal effect results in table 7 show that at the lower percentile levels (10^{th} and 25^{th}) of institutional development, an increase in climate finance negatively and significantly affects innovation in SSA. Undoubtedly, in an economy where the institutions are weak, climate funds will be diverted and not invested in novel technologies that will drive innovation development. This finding supports the results of Sharma, Sousa and Woodward (2022) and Donges et al. (2023). Further, we noticed that at the medium (50^{th}) percentile of institutional development in SSA, the coefficient of the interaction between climate finance and institutional quality is positive but insignificant.

Table 7

Marginal effect of climate finance on innovation

Percentile	Percentile values	System-GMM	Difference GMM
10	0.021	-0.959** (0.361)	-0.418 (0.316)
25	0.261	-0.461** (0.216)	-0.184 (0.184)
50	0.509	0.053 (0.172)	0.058 (0.084)
75	0.762	0.577* (0.291)	0.304** (0.148)
90	0.922	0.910** (0.397)	0.460** (0.232)

*Note: ** and * represent significance at 5% and 10%, respectively.*

Source: Authors.

The findings connote that at the median level of institutional development, climate finance in SSA will not yield beneficial outcomes in enhancing innovation due to the endemic nature of corruption persisting in SSA. Moreover, at the higher level (75^{th} to 90^{th}) of institutional development in SSA, we found that climate finance positively and significantly affects innovation. The result suggests that the full benefits of climate finance on innovation can be realised when institutions are highly effective. This finding implies that climate funds can be directed to innovative programs only when institutions in SSA experience significant improvement.

5.8 DUMITRESCU–HURLIN PANEL CAUSALITY TEST RESULTS

We adopted Dumitrescu and Hurlin's (2012) panel causality test to analyse the causal link among the main variables of interest. The results are reported in table 8.

Table 8

Dumitrescu-Hurlin panel causality test results

Variables	W-bar-Stat.	Z-bar-Stat.	Prob. value	Conclusion
INNO > CF	2.758	1.818	0.069*	↔
CF > INNOV	3.836	4.403	0.000***	
INNO > IQ	7.047	12.102	0.000***	↔
IQ > INNOV	4.472	5.927	0.000***	
CF > IQ	3.366	3.275	0.001***	↔
IQ > CF	5.222	7.725	0.000***	

*Note: *** and * denote significance at 1% and 10% levels, respectively; > denotes the direction of causality; ↔ signifies a bidirectional causality, and → denotes a one-way causality.*

Source: Authors.

Regarding the result reported in table 8, we discovered a bidirectional causal relationship between climate and innovation in SSA. Although the causal link between innovation and climate finance was weak, the findings suggest that a rise or decline in climate finance will raise or dwindle innovation development in SSA. This outcome is in line with the findings from Pradhan et al. (2023), Kim, Kwon and Kwon (2015), and Udvari and Ampah (2018).

Furthermore, the study detected a bidirectional causality between institutional quality and innovation. This result implies that strong institutions in the context of SSA are necessary to ensure innovation development. The result confirms the evidence by Donges, Meier and Silva (2023) and Sharma, Sousa and Woodward (2022). Lastly, we observed a two-way link between institutional development and climate finance in this study. This finding implies that international donors and private financial institutions closely examine the institutional development level before providing climate funds. Countries with poor institutional structures will attract low climate funds, whereas countries with better institutional structures will amass considerable donations (Ballesteros et al., 2010). Therefore, to secure substantial climate funding, the sub-regions in SSA should strengthen their institutional development.

6 CONCLUSION

Innovation has gained more traction in the 21st century since it is recognized as a sure tool for economic development. Scholars have postulated that innovation is a critical dynamic resource that brings about variations in growth, productivity, and competitiveness among countries and firms. As a result, a nation's ability to enhance its innovative capability is deemed critical. However, empirical evidence on how climate finance can be directed to enhance innovation and achieve competitive advantage has been dominated by data from developed and emerging economies, ignoring less developed nations like those in SSA. As SSA economies top the chart as the highest recipients of climate finance, it is prudent to investigate how climate finance can ensure innovation development. In line with this, the current study examines the effect of climate finance on innovation by allowing the link to be mediated by institutional quality in SSA. Employing the system-GMM estimation technique on a balanced panel dataset covering 2011 to 2022, the results established two impacts of climate finance on innovation: a direct unconditional and a conditional impact. While climate finance directly reduces innovation in SSA, its indirect effect – through institutional quality – is positive, suggesting that strong institutions help channel climate finance toward fostering innovation. Given these findings, the study concludes that climate finance can improve innovation in SSA when strong institutions direct the funds to productive sectors from which innovation will benefit. As a result, making institutions in SSA work better and stronger is necessary to allow the economies to reap the full benefit of climate finance on innovation. Therefore, we recommend that policymakers and governments in SSA institute policy measures geared toward improving the effectiveness and performance of institutions. However, these measures should be tilted towards ensuring political stability and intensifying the rules that specify contract rights and control of corruption. These will ensure a stable environment conducive to the attraction of climate funds and other investment packages to enhance innovation systems in SSA.

Disclosure statement

The authors have no conflict of interest to declare.

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APPENDIX

Table A1

Effect of climate finance and institutional quality on innovation in SSA (non-linear system-GMM results)

Variable	Coefficient		
	Model 1	**Model 2**	**Model 3**
$lnINNOV_{it-1}$	-0.253*** (0.059)	-0.273*** (0.081)	-0.005 (0.012)
SQCF	-1.439* (0.694)		
IQ	1.435** (0.608)		1.541** (0.681)
lnCF		-1.099* (0.570)	-0.052 (0.749)
SQIQ		3.463* (1.871)	
lnCF_IQ	0.805* (0.454)	22.529** (1.078)	
SQCF_SQIQ			-3.085** (1.095)
lnGDPPC	-1.383 (1.549)	-1.369 (1.212)	2.241** (0.788)
HC	0.010 (0.005)	0.015** (0.004)	0.005 (0.005)
IFRAD	-1.464 (1.167)	-0.889 (1.385)	0.046 (0.439)
lnGE	-9.912* (4.972)	-11.830** (4.987)	6.330*** (2.126)
lnFD	6.869* (3.368)	5.634 (3.454)	-7.057*** (1.295)
Net/marginal effect	1.435** (0.608)	3.463* (1.871)	
Constant	18.732 (16.225)	25.500 (17.185)	-8.477 (7.984)
AR(2) test statistic	-1.060	-0.610	0.200
AR(2) P-value	0.290	0.545	0.845
Hansen test statistic	6.880	5.560	10.340
Hansen P-value	0.737	0.724	0.500
No. groups	22	22	22
No. instruments	20	20	20

Table A2
Effect of climate finance and institutional quality on innovation in SSA (system-GMM results)

Variable	Coefficient	
	Model 1 (Corruption)	**Model 2 (Political stability)**
$lnINNOV_{it-1}$	-0.0224*** (0.0077)	-0.0282*** (0.0082)
lnCF	0.2341* (0.1299)	0.2872* (0.1648)
IQ	0.9704 (1.4483)	12.7816*** (4.0337)
lnCF_IQ	0.3464* (0.1786)	0.0278 (0.9146)
lnGDPPC	-2.4345 (1.5679)	-3.2546 (1.6244)
HC	-0.0007 (0.0045)	0.0045 (0.0029)
IFRAD	0.9363 (0.8260)	1.2717** (0.5709)
lnGE	-6.5124 (3.8685)	-6.6579* (3.7287)
lnFD	0.5256 (1.5001)	2.9371 (2.0951)
Constant	35.6356** (17.7762)	36.4524** (17.1689)
AR(2) Test statistic	-0.910	-0.880
AR(2) P-value	0.362	0.379
Hansen test statistic	6.430	7.040
Hansen P-value	0.696	0.633
No. groups	22	22
No. instruments	19	19