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Article

Threshold effects of climate change on banking system stability—The example of Sub-Saharan Africa

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Abstract: The paper assesses the threshold at which climate change impacts banking system stability in selected Sub-Saharan economies by applying the panel threshold regression on data spanning 1996 to 2017. The study found that temperature reported a threshold of −0.7316 °C. Further, precipitation had a threshold of 7.1646 mm, while the greenhouse gas threshold was 3.6680 $GtCO_2eq$. In addition, the climate change index recorded a threshold of −0.1751%. Overall, a non-linear relationship was established between climate change variables and banking system stability in selected Sub-Saharan economies. The study recommends that central banks and policymakers propagate the importance of climate change uncertainties and their threshold effects to banking sectors to ensure effective and stable banking system operations.

Keywords: climate change; banking system stability; Sub-Saharan Africa; climate financial econometrics; panel estimation

1. Introduction

Climate change has become a topical debate in today's world. More importantly, the impact of climate change is evident in its physical and transition exposures. Climate physical risks are risks originating from extreme weather events such as floods, storms, sea level rise, natural disasters, and other events. On the other hand, transition risk stems from risk in line with the transition toward a low-carbon economy. According to Liu et al. (2021), uncertainty is climate change's most striking feature, and fighting climate change is one of the biggest challenges in the 21st century (Fabris, 2020). Carney (2015) highlights that climate change is the tragedy of the horizon. Pari passu, it would be challenging to quantify the cost of climate change repercussions as their effects are complex and incur physical damages, agriculture impacts, economic and financial disruptions, and biodiversity loss, amongst others. Under the Paris Agreement in 2016, the global temperature mean has been set at 1.5 °C coupled with a net zero greenhouse gas emissions as the long-term objective. Against this epiphany, Wu et al. (2023) cite that the negative effects of temperature will increase various risks that would be transmitted across regions.

For some time now, climate change has been recognized as a new source of financial risk (Battiston et al., 2016). Amo-Bediako et al. (2023) cite that climate change is seen as a jeopardy to the overall financial system. In addition, Amo-Bediako et al. (2024) declare that climate change is a challenging issue facing planet Earth, yet the emergence of climate-related issues in the financial sector has called for empirical studies to vividly research various objectives that could help global financial systems. Importantly, a vital question omitted in academic literature in the context of Sub-Saharan Africa (SSA) is that; at what threshold does climate change impact banking system stability in SSA? It is interesting to highlight that scholars such as Alagidede et al. (2015) have determined the threshold of climate change's effect on economic growth in Africa. In addition, Mubenga-Tshikata et al. (2024) estimated the thresholds of climate change impact on agriculture output. However, the same cannot be inferred for the relationship between climate change and banking systems in SSA. Based on this insight, it is imperative to examine the tipping point where climate change affects banking system stability in SSA to determine policy implications. Mubenga-Tshitaka et al. (2024) disclose that at a lower regime of climate change variability, the relationship could either be positive or neutral (non-existent). However, at a higher regime of climate change variability, the relationship is negative. Therefore, if such a non-linear relationship exists, it is paramount to establish a mean point or threshold at which the sign of the relationship between the two variables would switch (Mubenga-Tshitaka et al., 2024). From a climate finance perspective, it has been shown that the impacts of future climate change may be non-linear (International Association of Insurance Supervisors, 2018).

To the best of the authors' knowledge, no empirical study exists for climate change-banking system stability relationships to determine the exact tipping points at which climate change is lethal/promotive to the stability of Sub-Saharan banking operations; as such, this leaves a gap for empirical investigation. It is worth mentioning that this study contributes to the theoretic confirmation on non-linearities in the climate change–banking system stability linkage, which has seen no attention in SSA. Besides, findings on the non-linearity are not novel, as studies such as Do et al. (2022), Agbloyor et al. (2021), and Weitzman (2009) confirm the non-linear relationship between climate change and banking system stability. In particular, the novelty lies in the identification of thresholds (tipping points) below or above which climate change impacts banking system stability in SSA.

The rest of the paper is organized as follows: Section 2 presents the empirical literature. Section 3 is the research methodology. Section 4 discusses the findings, and Section 5 presents the conclusion and the limitations of the study.

2. Literature review

The link between climate change and banking system stability has become a topical debate in both academic and corporate settings. It is worth noting that limited empirical evidence exists for the threshold effects of climate change on banking system stability to the best of the authors' knowledge. Although Agbloyor et al. (2021) explain that the relationship between per capita CO_2 and bank stability is non-linear with respect to time. Indisputably, the authors reported that there exists a threshold value of 40 for the nexus between per capita CO_2 and bank stability using 122 countries over the period 2000–2013 through a panel estimation technique. Further, the non-linear relationship has been confirmed by studies such as Do et al. (2022), Liu et al. (2021), and Weitzman (2009). Liu et al. (2021) proclaim that temperature has a domino effect, and when it exceeds a certain threshold, it multiplies severally. The

Bank for International Settlements (BIS 2021) suggests that a non-linear relationship exists between climate change and financial stability.

Taking the climate change discourse in a conceptual point of view, climate change is regarded as one of the pertinent issues affecting the world, yet its ramifications have been critically challenged. This criticism has revealed the true climate change believers and preachers as well as critics. For instance, the current president of the United States of America, Mr. Donald Trump, has been a staunch critic of climate change. According to a British Broadcasting Corporation (BBC) report on 23 January 2023, Mr. Trump has called climate change a myth, said that it is non-existent, and labeled it as an expensive hoax. Further, the BBC report suggests that Mr. Trump in 2012 mentioned that climate change was created by the Chinese to make the US manufacturing market non-competitive (BBC Report, 2020).

In opposition, the United Nations (UN) mentioned in 2021 that climate change patterns such as extreme heat waves, floods, droughts, and landslides are prevalent in Sub-Saharan economies. According to the Africa Development Bank (AfDB, 2015), SSA is the most susceptible continent to climate change impacts under all scenarios above 1.5 ℃. In contrast, of all countries, SSA economies are the least responsible for climate change, and they have contributed to only a minute part of the greenhouse gas emissions accountable for the climate emergency (Ntinyari and Gweyi-Onyango, 2020). Africa contributes the least to total greenhouse gas emissions and will bear the brunt of climate change's negative impacts (AfDB, 2019). Significantly, climate change is an immediate challenge and a continuous long-term threat for SSA (Émilie and Luc, 2020). A report by AfDB in 2015 suggests that four economies in SSA were among the most affected economies by climate change impact. They are Mozambique (first), Malawi (third), Ghana, and Madagascar (joint eighth position) (AfDB, 2015).

With reference to the global climate change risk index amongst the listed economies, five Sub-Saharan countries were reported to be extremely affected by climate change ramifications. They are ranked as follows: Mozambique, Zimbabwe, Malawi, South Sudan, and Niger. The Africa Development Bank (2015) cites that research conducted by the United Nations Environment Program (UNEP) on climate change impact in Africa proposes that adaptation to climate change across Africa would reach USD 50 billion a year by 2050. More so, AfDB's (2015) report indicates that Africa will need an investment of 3 trillion USD for climate change mitigation and adaptation by 2030. On the forefront, a global climate index report by Eckstein et al. (2021) unveiled that five African countries are among the top ten most affected countries. They are Mozambique, Zimbabwe, Malawi, South Sudan, and Niger. On the other hand, Uganda and Ghana are ranked 31st and 42nd, respectively (Eckstein et al., 2021).

However, a 2021 keynote paper by the Collaborative Africa Budget Reform Initiative (CABRI) revealed that the index does not cater to other important parameters such as rising sea levels, acidification, and ocean warming. In this regard, CABRI (2021) reports that a second index, the world risk index, considers factors such as floods, droughts, sea-level rise, cyclones, and other vulnerabilities to evaluate climate change exposures across countries. Further, with this index, 22 out of 50 most at-risk countries were African economies. Importantly, the transition to low-carbon emissions will directly and indirectly cause financial losses to the banking systems in SSA. It is worth noting that climate change repressions on global financial systems are noted by the Financial Stability Oversight Council (U.S. Department of the Treasury, 2021).

Nonetheless, the integration of climate change policies and their advocacy in SSA banking systems is somewhat new in the region. Although climate change has become customary, monetary authorities are far behind in its enactment in the financial system. For instance, a baseline study by the AfDB, the Global Center on Adaptation, and the United Nations Environment Finance Initiative (UNEFI) in 2021 to assess climate change risk integration in the prudential, financial, regulatory, and supervisory frameworks of various African economies reveals that few financial regulators have published regulations with regard to financial institutions' climate risk management. The study establishes that countries such as Kenya and Mauritius are the two principal SSA economies embracing climate change as a risk factor in their respective financial sectors. It is reported in the study that the Central Bank of Kenya (CBK) on 15 October 2021 issued guidance on climate-related risk management to operational commercial banks to enable them to incorporate climate change risk management in their operations.

On the other hand, the report suggests that on 30 September 2021, the Bank of Mauritius (BOM) published draft guidelines for financial institutions to help guide commercial banks in the integration of climate-related risks in their operations. In addition, the study suggests that countries such as Ghana, Nigeria, South Africa, and Zimbabwe have implemented other important guidelines or regulations, such as best practices, stress testing, and principle-based regulations, to help commercial banks cope with climate change suppressions. For instance, the Bank of Ghana and the Central Bank of Nigeria have implemented sustainable banking principles to help integrate climate change practices in the banking operations in respective countries. Further, the report indicates that countries such as the Democratic Republic of the Congo and Rwanda are among the countries that have not started climate change integration into their regulatory framework, whereas the Malian financial regulatory framework does not explicitly mention climate-related risks.

With reference to the perception of climate change integration in the banking sector, the study reports that a central bank head of supervision revealed that climate risk has not been a priority due to other pressing social concerns that required immediate attention in preference to climate change repercussions on banking activities. The report uncovers that a central bank head of the sustainability department indicated that the repressions of monetary policy have made climate risk an important indicator. According to Green Central Banking (GCB, 2022a), the South African Reserve Bank (SARB) instructed banks under its supervision to enhance their resilience against climate risks. In addition, SARB made provisions for the amendment of its regulatory and supervisory frameworks to account for climate-related risk (GCB, 2022b).

The International Monetary Fund (IMF, 2020) reports that the integration of climate-related risks into financial regulation is challenging. The report highlights that to apprehend climate change risk, it should be evaluated with sophisticated methodologies for a long period. As such, prudential frameworks could give a true reflection of real risks (Adrian et al., 2022). Moreover, the Network for Greening the Financial System (NGFS, 2019) recommends that it is important for banks to integrate climate-related risks into the prudential supervision framework. Also, climate change is one of the many sources of structural changes that affect the financial system (ibid).

Based on the above discussions, this study proposes the following hypotheses:

H_1: Thresholds exist for the climate change and banking system stability relationship.

H_2: The climate change and banking system stability relationship is non-linear.

3. Research method

This section describes the methodology used to investigate the threshold effects of climate change on banking system stability. It documents the data sources as well as the regression models that were applied in the investigation processes.

3.1. Data sources

The study employs 29 selected Sub-Saharan economies based on data availability that spans 1996 to 2017. The list of selected countries is displayed in Appendix. It is worth-mentioning that the study utilizes temperature, precipitation, greenhouse gas emissions and climate change index as climate change variables. The climate change index was created using the principal component analysis (PCA) on the three aforementioned climate change variables: temperature, precipitation, and greenhouse gas emissions. Again, the study proxy bank *Z*-score for banking system stability. It is imperative to emphasize that national aggregate data of bank *Z*-score was used in this study, and the data was obtained from the Global Finance Development database. Moreover, temperature and precipitation were gleaned from the World Bank Climate Change Knowledge Portal (CCKP). The greenhouse gas emissions data was taken from the Climate Watch online database (Climate Watch online database, 2023). Further, the study controlled for net interest margin, bank concentration, money supply, and regulatory quality. That said, net interest margin and bank concentration were taken from the Global Finance Development database, and money supply was sourced from the World Development Indicators platform (WDI). On the other hand, regulatory quality data was obtained from the World Governance Indicators platform (WGI). **Table 1** shows the variable notation, expected signs, and the sources of data.

Table 1. Variable description.

Variables	Notation	Expected Sign	Source
Banking System Stability	BS		Global Finance Development
Temperature	TEMPT	-	CCKP
Precipitation	PPT	-	CCKP
Greenhouse Gas	GHGAS	-	Climate Watch
Climate Change Index	CCI	-	PCA
Net Interest Margin	NIM	+	Global Finance Development
Money Supply	MS	+	WDI
Bank Concentration	BC	+	Global Finance Development
Regulatory Quality	RQ	+	WGI

Source: Authors' construct, 2024.

3.2. The model

To estimate the threshold effect of climate change on banking system stability in selected SSA economies, the study capitalizes on the panel threshold model developed by Hansen (1999) to achieve the objective of the study. Yeh et al. (2010) claim that Hansen's (1999) panel threshold regression is an expansion of the conventional least-squared estimation technique. First, it must be determined whether a threshold exists before estimating the panel threshold. Essentially, there is no threshold if the null hypothesis cannot be ruled out. However, the threshold effect does occur if the null hypothesis is rejected (Yeh et al., 2010).

It is asserted by Hansen (2000) and Chan (1993) that the ordinary least squares (OLS) estimation of the threshold is extremely consistent, and they derive the asymptotic distribution. It was clear that the test statistics could not be employed for statistical inference due to the nuisance problem that results in the nonstandard feature (Chan, 1993). Based on this account, Hansen (1999) proposes a simulated likelihood ratio test to determine the asymptotic distribution to test the threshold. The panel threshold model was estimated using a two-stage OLS approach by Hansen (1999).

As previously stated, climate change is a source of financial risk; however, it should be kept in mind that greater climate change risk might destabilize the entire banking system. Essentially, uncertainty is the key aspect of climate change (Liu et al., 2021). The study examines whether there exists a threshold effect of climate change on banking system stability in selected Sub-Saharan economies. A positive climate change indicates that continued climate change will support the stability of the banking system. In contrast, when climate change exceeds the threshold, a negative climate change emerges, indicating that during this period the increasing climate change is detrimental to the stability of the banking system. To model the panel threshold regression, a single threshold model is constructed as follows:

$$A_{it} = \begin{cases} \mu_i + \theta' h_{it} + \beta d_{it} + \varepsilon_{it} \text{ if } \mathrm{d}_{\mathrm{it}} \leq \gamma \\ \mu_i + \theta' h_{it} + \beta d_{it} + \varepsilon_{it} \text{ if } \mathrm{d}_{\mathrm{it}} > \gamma \end{cases} \tag{1}$$

$$\theta = (\theta_1, \theta_2, \theta_2),\ h_{it} = (m_{it}, s_{it}, c_{it})'$$

where A_{it} = dependent variable, d_{it} = independent variable and γ is the threshold value. h_{it} represents the vector control variables. ε_{it} denotes the error term. μ_i is the fixed effect representing the heterogeneity of countries. In this study, the panel threshold regression for the four panels is expressed as:

$$BS_{it} = \begin{cases} \mu_i + \theta' h_{it} + \delta_1 TEMPT_{it} + \varepsilon_{it} \text{ if } \mathrm{TEMPT}_{\mathrm{it}} \leq \gamma \\ \mu_i + \theta' h_{it} + \delta_2 TEMPT_{it} + \varepsilon_{it} \text{ if } \mathrm{TEMPT}_{\mathrm{it}} > \gamma \end{cases} \tag{2}$$

$$\theta = (\theta_1, \theta_2, \theta_2),\ h_{it} = (m_{it}, s_{it}, c_{it}, q_{it})'$$

$$BS_{it} = \begin{cases} \mu_i + \theta' h_{it} + \beta_1 PPT_{it} + \varepsilon_{it} \text{ if } \mathrm{PPT_{it}} \leq \gamma \\ \mu_i + \theta' h_{it} + \beta_2 PPT_{it} + \varepsilon_{it} \text{ if } \mathrm{PPT_{it}} > \gamma \end{cases} \quad (3)$$

$$\theta = (\theta_1, \theta_2, \theta_2),\ h_{it} = (m_{it}, s_{it}, c_{it}, q_{it})'$$

$$BS_{it} = \begin{cases} \mu_i + \theta' h_{it} + \lambda_1 GHGAS_{it} + \varepsilon_{it} \text{ if } \mathrm{GHGAS_{it}} \leq \gamma \\ \mu_i + \theta' h_{it} + \lambda_2 GHGAS_{it} + \varepsilon_{it} \text{ if } \mathrm{GHGAS_{it}} > \gamma \end{cases} \quad (4)$$

$$\theta = (\theta_1, \theta_2, \theta_2),\ h_{it} = (m_{it}, s_{it}, c_{it}, q_{it})'$$

$$BS_{it} = \begin{cases} \mu_i + \theta' h_{it} + \alpha_1 CCI_{it} + \varepsilon_{it} \text{ if } \mathrm{CCI_{it}} \leq \gamma \\ \mu_i + \theta' h_{it} + \alpha_2 CCI_{it} + \varepsilon_{it} \text{ if } \mathrm{CCI_{it}} > \gamma \end{cases} \quad (5)$$

$$\theta = (\theta_1, \theta_2, \theta_2),\ h_{it} = (m_{it}, s_{it}, c_{it}, q_{it})'$$

where $TEMPT$, $GHGAS$, PPT, CCI represent temperature, greenhouse gas emissions, precipitation and climate change index as climate change variables and threshold variables, respectively. Also, δ_1 and δ_2, β_1 and β_2, λ_1 and λ_2, α_1 and α_2 are the expected threshold coefficients for various threshold values. h_{it} is the vector of 4×1 which is made up of the controlled variables m_{it}, s_{it}, c_{it} and q_{it} while $\theta_1, \theta_2, \theta_3, \theta_4$ are the coefficients of the controlled variables. ε_{it} represents the error term. Therefore, the above equation can be written as:

$$BS_{it} = \mu_i + \delta_1 \ln TEMPT_{it} I(\ln TEMPT_{it} \leq \gamma) + \delta_2 \ln TEMPT_{it} I(\ln TEMPT_{it} > \gamma) + \theta' h_{it} + \varepsilon_{it} \quad (6)$$

$$BS_{it} = \mu_i + \beta_1 \ln PPT_{it} I(\ln PPT_{it} \leq \gamma) + \beta_2 \ln PPT_{it} I(\ln PPT_{it} > \gamma) + \theta' h_{it} + \varepsilon_{it} \quad (7)$$

$$BS_{it} = \mu_i + \lambda_1 \ln GHGAS_{it} I(\ln GHG_{it} \leq \gamma) + \lambda_2 \ln GHGAS_{it} I(\ln GHG_{it} > \gamma) + \theta' h_{it} + \varepsilon_{it} \quad (8)$$

$$BS_{it} = \mu_i + \alpha_1 \ln CCI_{it} I(\ln CCI_{it} \leq \gamma) + \alpha_2 CCI_{it} I(\ln CCI_{it} > \gamma) + \theta' h_{it} + \varepsilon_{it} \quad (9)$$

4. Findings and discussion

It is inferred from **Table 2** that the temperature threshold estimated in this study is −0.7316 ℃ at 95% confidence interval of [−1.558, −0.095]. Regime-dependent coefficients of temperature are statistically significant at 5% and 1% relevant levels, respectively. The results depict that when temperature is below the threshold value of −0.7316 ℃, temperature positively associates with banking system stability in selected Sub-Saharan economies (β_1 = 0.8865). Contrarily, when temperature is above the threshold value, temperature negatively relates with banking system stability (β_2

= −0.5990). It can be deduced that estimation in the low-temperature regime denotes that a percentage increase in temperature will increase banking system stability by 0.8865%. In addition, the result suggests that in the high regime a percentage increase in temperature will decrease banking system stability by 0.5990%, all things being equal.

It is worth noting that the temperature and banking system stability relationship has a non-linear relationship (inverted *U*-shape). It is implied that the threshold value is the minimum value beyond which further decrease in temperature will be ruinous to banking system stability. Sub-Saharan Africa is predominantly a tropical zone, thus featuring high temperatures year-round. That said, a negative shock will be experienced if the temperature falls below the estimated threshold limit. In that case, the weather will be too cold for economic agents to engage in economic activities, thereby reducing financial transactions. A continual reduction in temperature will strongly affect banking system stability as economic activities will be hampered severely.

From **Table 3**, it is deduced that the coefficients of precipitation are statistically insignificant. Though a non-linear *U*-shape is observed. However, the threshold variable estimated for the precipitation is 7.1646 mm with a 95% confidence interval of [6.1295, 8.1997]. The threshold value of precipitation is the maximum turning point above which an increase in precipitation will promote banking system stability. It is well known that SSA is an agrarian continent; hence, the higher the precipitation, the higher the agricultural production. Therefore, in the phase of higher agricultural production, higher income will be generated by farmers to increase bank deposits within a specified period. Further, a booming agricultural economy will naturally promote financial transactions, which will stimulate the stability of banks. Essentially, coefficients of both low- and high-regimes were statistically insignificant.

Despite this revelation, it is deduced in **Table 4** that greenhouse gas passes the single threshold test with a threshold value of 3.6680 $GtCO_2$ eq at 95% confidence interval of [1.5265, 5.8096]. The results indicate that when greenhouse gas is below the threshold variable of 3.6680 $GtCO_2$ eq, greenhouse gas negatively correlates with banking system stability (β_1 = −3.8494). On the contrary, when the estimated greenhouse gas coefficient is above the threshold value of 3.6680 $GtCO_2$eq, greenhouse gas positively correlates with banking system stability; however, an insignificant estimation is reported. A non-linear *U*-shape is observed for the greenhouse gas and banking stability nexus. Essentially, the threshold value measures the mean point above which an increase in greenhouse gas emissions will impact banking system stability. It is worth mentioning that excessive greenhouse gas emissions will cause severe health problems for the labor force, such as vomiting, nausea, memory loss, headache, and other issues. This affects the well-being of the labor force and subsequently affects productivity negatively. That said, the labor will not function properly in their day-to-day activities, which in turn affects activities of financial transactions that form part of the economy. This causes a ripple effect impacting the stability of banks.

Further, it is deduced from **Table 5** that a climate change index threshold of −0.1751% with a 95% confidence interval of [−1.5673, −1.2170] is reported. Estimated results affirm the non-linear U-shape relationship between climate change index and banking system stability. Although insignificant, the coefficient is negative when the climate change index is below the threshold (β_1 = −0.1144) and positive when the climate change index is above the threshold (β_2 = 0.2761). With inferences to the control variables utilized in the study, it is revealed that in the low regime and high regime, as shown in **Table 2**, the net interest margin was statistically insignificant, although the expected sign was attained for the low regime. A significant positive relationship was established between bank concentration and banking system stability in both the low regime and high regime. More so, it is inferred from **Table 2** that money supply reported a negative and insignificant relationship with banking system stability in the low regime. In contrast, the same cannot be said at high regime as the relationship was positive and significant. Regulatory quality reported a negative and positive insignificant relationship with banking system stability at both low and high regimes, respectively. For Equation (7), as depicted in **Table 3**, a significant positive relationship was reported between net interest margin and banking system stability in the low regime. However, the relation between the two estimates was insignificant at the high regime. Bank concentration was statistically insignificant and positive in the low regime; however, the relationship was positively significant in the high regime for Equation (7). It is reported that money supply was insignificant in both regimes (low and high), though its signs differ (positive for the low regime and negative for the high regime). Regulatory quality, on the other hand, recorded a negative and statistically insignificant relationship with banking system stability in the low regime, yet the same is not applicable in the high regime, as a positive and significant relationship was reported for the regulatory quality and banking system stability nexus in Equation (7).

For Equation (8), it is worth highlighting that no significant association was reported for the net interest margin and banking system stability nexus in both the low regime and high regime. Though a positive relationship was reported in the low regime, coupled with a negative connection in the high regime. With reference to bank concentration, a statistically significant relationship was established with banking system stability in the high regime. It is construed that the relationship was negative in the high regime. Per contra, a positive and insignificant relationship was reported for bank concentration and banking system stability in the low regime for Equation (8). Further, a positive and insignificant link was established between money supply and banking system stability in the low regime. In addition, money supply was negative and significant in the high regime. On the part of regulatory quality, it is reported that a positive and insignificant relationship is established in the high regime. More so, a negative and statistically significant relation was found with banking system stability in the low regime. It is observed from **Table 5** for Equation (9) that all control variables were statistically insignificant in both regimes (high and low) except for money supply and regulatory quality, which reported a negative significant coefficient at the low regime. This indicates that both money supply and regulatory quality are negatively related to banking system stability in the low regime. Further, the regime intercept for all equations was statistically significant except for the intercept for Equation (7) with precipitation as the estimated threshold variable. In general, the results align with the research conducted by Agbloyor et al. (2021) who reported a threshold between CO_2 and bank stability. Again, findings from the study strike a chord with studies of Do et al. (2022), Liu et al. (2021) and Weitzman (2009) which revealed a non-linear relationship between climate change and stability of the banking and financial stability, respectively. **Tables 2–5** denote the threshold regression results.

Table 2. Temperature results on threshold regression.

Equation (6)				
Estimated Temperature Threshold				
γ	−0.7316			
95% Confidence Interval	[−1.558, −0.095]			
Impact of Regime-Dependent Regressors				
	Estimated Coefficient	Standard Error		
β_1	0.8865**	0.4058 (0.029)		
β_2	−0.5990***	0.1814 (0.001)		
Impact of Regime-Independent Regressors				
	Estimated Coefficient	Standard Error	Estimated Coefficient	Standard Error
lnNIM	0.0178	0.1764 (0.919)	−0.0509	0.0802 (0.526)
lnBC	0.1923***	0.0683 (0.002)	0.1477**	0.0608 (0.031)
lnMS	−0.4057	0.2536 (0.110)	0.9969**	0.4379 (0.023)
lnRQ *C*	−0.1911 3.0948***	0.2413 (0.428) 0.9781 (0.002)	0.2443	0.3506 (0.486)
	Low-Temperature Regime		High-Temperature Regime	
N	29		29	
Number of Moment Conditions	315		315	

*** and ** indicate significance at 1% and 5%, respectively. *N* refers to the number of countries considered. The value in the brackets (.) measures the respective probability values (*P*-values) of the variables. γ is the threshold of the estimated variable. NIM is net interest margin, BC shows bank concentration, MS represents money supply, RQ signifies regulatory quality. *C* is the intercept.
Source: Authors' construct from computations in STATA 17.

Table 3. Precipitation results on threshold regression.

Equation (7)				
Estimated Precipitation Threshold				
γ	7.1646			
95% Confidence Interval	[6.1295, 8.1997]			
Impact of Regime-Dependent Regressors				
	Estimated Coefficient	Standard Error		
β_1	−0.3364	1.0780 (0.755)		
β_2	0.3920	0.2539 (0.123)		
Impact of Regime-Independent Regressors				
	Estimated Coefficient	Standard Error	Estimated Coefficient	Standard Error
lnNIM	0.1495**	0.0683 (0.029)	0.0470	0.0560 (0.401)
lnBC	0.0114	0.0428 (0.789)	0.0368**	0.0173 (0.033)

Table 3. (*Continued*).

Equation (7)				
Impact of Regime-Independent Regressors				
	Estimated Coefficient	Standard Error	Estimated Coefficient	Standard Error
lnMS	0.1453	0.2206 (0.110)	−0.1058	0.1897 (0.577)
lnRQ	−0.0124	0.1964 (0.949)	0.1681**	0.0813 (0.039)
C	1.2996	8.2891 (0.875)		
	Low-Precipitation Regime		High-Precipitation Regime	
N	29		29	
Number of Moment Conditions	315		315	

** indicate significance at 5%. *N* refers to the number of countries considered. The value in the brackets (.) measures the respective probability values (*P*-values) of the variables. γ is the threshold of the estimated variable. NIM is net interest margin, BC shows bank concentration, MS represents money supply, RQ signifies regulatory quality. *C* is the intercept.
Source: Authors' construct from computations in STATA 17.

Table 4. Greenhouse gas results on threshold regression.

Equation (8)				
Estimated Greenhouse Gas Threshold				
γ	3.6680			
95% Confidence Interval	[1.5265, 5.8096]			
Impact of Regime-Dependent Regressors				
	Estimated Coefficient	Standard Error		
β_1	−3.8494*	2.0341 (0.058)		
β_2	0.8301	1.1086 (0.454)		
Impact of Regime-Independent Regressors				
	Estimated Coefficient	Standard Error	Estimated Coefficient	Standard Error
lnNIM	0.0463	0.0994 (0.641)	−0.0211	0.0770 (0.783)
lnBC	0.0376	0.0630 (0.551)	−0.0734**	0.0294 (0.012)
lnMS	0.0552	0.3607 (0.878)	−0.1282**	0.0508 (0.018)
lnRQ	−1.4885***	0.4347 (0.001)	0.7836	0.0813 (0.489)
C	−16.5147**	6.7211 (0.014)		
	Low-Greenhouse Gas Regime		High-Greenhouse Gas Regime	
N	29		29	
Number of Moment Conditions	315		315	

***and ** indicate significance at 1% and 5% respectively. *N* refers to the number of countries considered. The value in the brackets (.) measures the respective probability values (*P*-values) of the variables. γ is the threshold of the estimated variable. NIM is net interest margin, BC shows bank concentration, MS represents money supply, RQ signifies regulatory quality. *C* is the intercept.
Source: Authors' construct from computations in STATA 17.

Table 5. Climate change index results on threshold regression.

Equation (9)				
Estimated Climate Change Index Threshold				
γ	−0.1751			
95% Confidence Interval	[−1.5673, −1.2170]			
	Impact of Regime-Dependent Regressors			
	Estimated Coefficient	Standard Error		
β_1	−0.1144	0.3283 (0.727)		
β_2	0.2761	0.2109 (0.191)		
Impact of Regime-Independent Regressors				
	Estimated Coefficient	Standard Error	Estimated Coefficient	Standard Error
lnNIM	−0.1262	0.2280 (0.580)	0.0766	0.1692 (0.651)
lnBC	0.0045	0.0926 (0.961)	0.0289	0.0481 (0.548)
lnMS	−1.5102***	0.3154 (0.000)	0.6411	0.4615 (0.165)
lnRQ	−0.3329***	0.3176 (0.001)	0.2238	0.2594 (0.388)
C	3.8114***	1.1665 (0.001)		
	Low-Climate Change Index Regime		High-Climate Change Index Regime	
N	29		29	
Number of Moment Conditions	315		315	

*** indicate significance at 1%. *N* refers to the number of countries considered. The value in the brackets (.) measures the respective probability values (*P*-values) of the variables. γ is the threshold of the estimated variable. NIM is net interest margin, BC shows bank concentration, MS represents money supply, RQ signifies regulatory quality. *C* is the intercept.
Source: Authors' construct from computations in STATA 17.

5. Conclusion and limitations of the study

The study focuses on Sub-Saharan economies where the authors want to gain a deeper understanding of the threshold effects of climate change on banking system stability. On that account, this study is premised to draw conclusions based on the strength of the discussed findings. Evidence suggests that a threshold impact exists for each respective variant econometric model specified in this study. The study concludes that the threshold level (minimum actual temperature) favorable for banking system stability in selected Sub-Saharan economies is −0.7316 ℃. Again, it is concluded that the estimated threshold value for precipitation (optimum long-term average precipitation) is promotive for banking system stability in selected Sub-Saharan economies and is 7.1646 mm. In addition, the study found that the threshold value for greenhouse gas is 3.6680 $GtCO_2eq$. Further, the study discovered that the climate change index reported a minimum threshold of −0.1751%. Overall, the study avows that a non-linear trend exists between climate change and banking system stability in selected Sub-Saharan economies. In such a backdrop, the study recommends that central banks and policymakers propagate the importance of climate change uncertainties and their threshold effects to banking sectors to ensure effective, stable banking system operations.

The study is constrained in that 29 selected Sub-Saharan economies were utilized. It will be an extension of the research idea if this topical debate extends to comprise all the 48 SSA economies. Future studies on the threshold analysis should employ different methodological non-linear frameworks that account for heterogeneity, such as the panel smooth transition regression (PSTR). This methodology (PSTR) will aid in understanding the occurrence of transitions from low-to-high climate change regimes.

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Appendix

Table A1. List of countries.

Angola	**Namibia**
Benin	Senegal
Burkina Faso	Rwanda
Cote D'Ivoire	Tanzania
DR. Congo	Sudan
Gabon	Zambia
Kenya	Botswana
Lesotho	Burundi
Malawi	Eswatini
Mali	Ghana
Mozambique	Madagascar
Nigeria	Mauritius
South Africa	Cameroon
The Gambia	Niger
Togo	

Source: Authors' construct, 2024.