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Does macroeconomic transmission streams matter for climate change and banking system stability relationships in selected Sub-Saharan economies?

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Abstract

This study examines the macroeconomic transmission streams through which climate change impacts banking system stability in selected sub-Saharan economies. Climate change has become a paramount issue facing planet Earth. As a result, numerous empirical studies have emerged examining the impact of climate change on financial activities. Further, the study adopts the quantitative research methodology in a panel data framework and employs the wavelet coherence technique on the basis that it combines both time interval and frequency dimensions in its assessment. The study utilizes 29 selected economies from SSA for the period 1996-2017. The overall findings show that macroeconomic indicators (inflation, labor productivity, real GDP, and real exchange rate) serve as pathways through which climate change impacts banking system stability in selected sub-Saharan economies. It was also revealed that interaction between greenhouse gas emissions and labor productivity has more continuous coherence (both in the short-term and long-term) than any other variable used in this present study. We recommend that central banks, monetary authorities, and government on policy front consider macroeconomic effects in the integration of climate change policies for stable banking system operations in SSA. Macroeconomic indicators are highly sensitive; however, it is well-written that fundamentals of macroeconomic indicators in SSA are weak.

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1. Introduction

For some time now, climate change has been regarded as one of the pertinent issues affecting planet Earth, yet its ramifications have been critically chastised. Indeed, copious scholars have shed their thought on the magnitude of climate change exposures on the banking sector and other financial institutions (Amo-Bediako, Takawira, & Choga, 2023; Clarke, Otto, Stuart-Smith, & Harrington, 2022). A review of Dietz, Bowen, Dixon, and Gradwell (2016) seminal work showed that about 17 percent of financial assets are exposed to climate change ramifications. On the other hand, an indirect exposure of climate change to global financial assets revealed a substantial repercussion amounting to 40-45 percent peril (Battiston, Mandel, Monasterolo, Schütze, & Visentin, 2017; Clarke et al., 2022). Needless to say, the intensity of climate change is lethal to global financial assets, and plausibly, on the verge of causing financial crisis. That notwithstanding, the Bank for International Settlement (BIS) report in 2021 mentions that there are two transmission streams through which climate change can impact banking system stability. These are macroeconomic and microeconomic transmission channels. By definition, Bank for International Settlements (2021) describes transmission channels as pathways through which climate-related risks indirectly affect their counterparts. On the other hand, macroeconomic transmission channel is the mechanism through which climate change drivers affect macroeconomic factors and, in turn, impact banking activities (Bank for International Settlements, 2021). These macroeconomic factors include, labor productivity, economic growth, as well as market variables such as inflation, foreign exchange rate, risk-free rate, and commodities (Bank for International Settlements, 2021). Further, microeconomic transmission channel indirectly affects financial assets held by banks, for example, bonds, equities, and single CDs (*ibid*). Globally, scant evidence can be found for the transmission pathways through which climate change can impact banking system stability. For instance, a notable study on the transmission stream can be accredited to Agbloyor, Dwumfour, Pan, and Yawson (2021) who found that manufacturing value added to gross domestic product (MVA/GDP) ratio serves as a channel through which CO2 can impact banking system stability on a global market. However, it is encouraging to note that, no empirical and quantitative study has yet linked the transmission pathways through which climate change can impact banking system stability in Sub-Saharan Africa (SSA). Significantly, climate change is an immediate challenge and a continuous long-term challenge in the SSA (Amo-Bediako et al., 2023; Émilie & Luc, 2020). Nonetheless, the integration of climate change policies and their advocacy in SSA banking systems is somewhat new in the region. According to Mlachila and Yabara (2013) the financial system in SSA is impoverished, with the banking sector as the highest proposition of the financial system. Akande (2018) on the other hand, posits that the financial system in SSA is not only disadvantaged; however, it is marred with inefficiencies, coupled with weak macroeconomic environment (Jafino, Walsh, Rozenberg, & Hallegatte, 2020). Against this background, we investigate the macroeconomic transmission streams through which climate change can impact banking system stability in SSA. It is worth-noting that the study is sectionalized. Section 2 presents literature review. Section 3 describes climate-aligned policies and financial regulations. In section 4, we discuss the methodology. More so, section 5 discusses the findings. In section 6, we present the conclusion and policy implications. The last section is about the limitations and directions for future research on the studies.

2. Literature Review

Empirically, the literature on the indirect impact assessment of climate change and banking system stability is sparse; however, scholars have recently voiced their concerns in the academic community. Evidence pointing to the aforementioned association is nascent. One study that critically examines the transmission streams of climate-related studies is by Do, Phan, and Nguyen (2023). Do et al. (2023) used the prudent and the growth channel to assess its interaction with natural hazards and its impact on bank stability. The authors found that loan loss provisions aid in mitigating climate risk without impairing capital during periods of distress. Further, Agbloyor et al. (2021) conclude that MVA/GDP serve as a path through which CO_2 impacts banking system stability from a global standpoint. The authors used 122 panel data points over the period 2000-2013.

3. Climate-Aligned Policies and Financial Regulations

The 2015 Paris Agreement has resulted in significant progress worldwide in understanding and mitigating climate change factors (Knight & Ganguly, 2018). Essentially, the alignment of financial flows toward low-emission and climate-resilience is one of the main objectives of the Paris Agreement (Carè & Weber, 2023). According to Giuzio et al. (2019) rising global temperatures have also spurred international action. The Paris Agreement seeks to keep the increase in average global temperature below 2^0C relative to pre-industrial levels and to work toward a 1.5^0C limit (Bank of England, 2022; Giuzio et al., 2019). Again, global warming may exceed 3^0C by the end of this century (The White House, 2023).

On the other hand, Dunz, Essenfelder, Mazzocchetti, Monasterolo, and Raberto (2023) highlight that the Paris Agreement signed at the COP21 proposes the role of private investment financing in transitioning to a low-carbon economy. The aftermath of the proposition has been swift to scale up green investments with climate-aligned policies and financial regulations. In effect, Dunz et al. (2023) suggest that the argument has mainly been based three measurements. Thus, climate change market-based solutions, (for example, carbon taxes), green finance investments such as green bonds, and green supporting factors (GSF). Stolbova, Monasterolo, and Battiston (2018) hint that the most talked about climate policies include, market-based solutions (the introduction of carbon taxes), green macro-prudential regulations (differentiated capital requirements for banks), and green unconventional monetary policies (quantitative easing). Further, Stolbova et al. (2018) mention that the enactment of climate policies signifies a shock to the financial sector.

According to the author, these measures are in line to stun mispricing of climate change risk via signalling investors in the financial system and the economy at large. On the other hand, prior works have distinguished between market-based or private and non-market-based or public (Carè & Weber, 2023; Marke & Sylvester, 2018; Nakhooda, Watson, & Schalatek, 2015). Stiglitz (2018) opines that carbon taxes are the debatable climate change market-based solutions. Hasler, Butman, Jeffrey, and Suski (2016) explain that carbon taxes are called Pigouvian taxes. Pigouvian tax is a tax on market transactions that imposes a negative externality by individuals who are not directly involved in the transaction processes. Also, carbon taxes are fines for polluters. On that note, Dunz et al. (2023) state that carbon taxes aid in the internalization of externalities related to anthropogenic climate change. Again, authors such as Dafermos and Nikolaidi (2021) pinpoint that carbon taxes help generate revenue for government, which gives fiscal space for low-carbon investments. Further, Dunz et al. (2023) claim that most economic research has focused on optimal carbon tax identification via social cost of carbon (SCC) with the application of the Integrated Assessment Models (IAM) which depend on cost-benefit techniques in determining the emission paths. Scholars like Pindyck (2013) and Stern (2013) have criticized the outcomes of IAMs for introducing a higher cost of carbon. Nordhaus (2018) utilized the revised Dynamic Integrated Climate Economy (DICE) model and found that the maximum level of temperature is 35^{0}C by 2100. The finding translates into a social cost of carbon and an optimal carbon tax of USD 31 per ton of CO2 by 2010 (Dunz et al., 2023). Stiglitz (2018) establishes that there will be an upsurge in carbon prices as long as we wait for its introduction. Fiscal policy is the pivotal strength in reducing carbon emissions and enhancing development goals (Dunz et al., 2023; World Bank, 2019). According to Dunz et al. (2023), there should be an introduction of USD 75/tCO2 carbon tax by 2030 for large emitting countries. On the other hand, Schoenmaker (2021) highlights that monetary policies and preferential green investments for European Investment Bank have been analyzed. However, a lack of better understanding of the green taxonomy, and limited green bond share market, and low understanding of banking sectors climate change-related sentiments have the tendency to weaken climate change intervention and have unidentified impacts on banking system stability (Dunz et al., 2023). Again, the introduction of the green supporting factor (GSF) by the European Investment Bank (EIB) is to lower associated risk of green bonds (Campiglio et al., 2018) in a way to stimulate green loan conditions (Dafermos, Gabor, Nikolaidi, Pawloff, & van Lerven, 2021). Dunz et al. (2023) suggest that a better understanding of financial regulation influence on green investments with a focus on minimizing financial stability is highly pertinent for setting out crucial policies.

For some time now, monetary regulators and supervisory authorities have acknowledged that climate change is ruinous to the banking system (NGFS, 2019; Svartzman, Bolton, Despres, Pereira Da Silva, & Samama, 2021). According to Sobhani, Amran, and Zainuddin (2012) banks have a significant influence on directly impacting the environment via their operations and indirectly through financing environmental pollution schemes. Chew, Tan, and Hamid (2016) as cited in Kılıç and Kuzey (2019) highlight that the banking system has an influence on the environment due to its immense input to operate technological devices such as computers and other important electrical devices that power the corporate buildings. On the other hand, (2019) explains that banks influence on the environment is noticeable with regards to paper waste. On the front of the indirect impact, the authors mention that banks influence firm practices with compliance specifications on environmental issues to relation to lending policies. That said, Furrer, Hamprecht, and Hoffmann (2012) disclose that banks can implement intriguing initiatives that dwindle greenhouse gas emissions in their business practices. In line with this, Krasodomska (2015) asserts that the Equator Principles were published with the World Bank and International Finance Corporation standards as strategies for all banking institutions in evaluating environmental and social risk projects.

4. Methodology

4.1. Data

We utilized 29 selected sub-Saharan economies based on available data from 1996-2017, (refer to Appendix 1 for the choice of selected countries). Significantly, we proxy bank Z-score for banking system stability, and the data was sourced from the World Bank Global Finance Development Database. In addition, macroeconomic indicators, which comprise inflation, labor productivity, real GDP, and real exchange rate, were gleaned from World Development Indicators platform. Further, climate change variables such as temperature, precipitation were taken from World Bank Climate Change Knowledge Portal. Again, greenhouse gas emissions data was sourced from Climate Watch online data platform. Further, we create an index for climate change index using the three afore-mentioned climate change variables through a principal component analysis (PCA).

4.2. Wavelet Technique

Wavelet has its origins in filtering methods and Fourier analysis (Crowley, 2005). Crowley (2005) argues that wavelet technique has been extensively used in fields such as physics, medical sciences, engineering, signal processing, forensics, and acoustics. The author highlights the incomplete exploration of wavelet applications in economics and finance. He discloses that the many properties of wavelets are not fully utilized in economics or, to some extent, finance applications. Aawaar (2017) posits that the desired properties of the wavelet methodology make it superior to other alternative methodologies. On the other hand, Boako (2016) asserts that wavelet method has the ability to decompose ex-post variables at varying frequencies. Further, the author suggests that wavelet methods support localization in both the frequency and time domains. In addition, wavelets help in identifying the correlations and impacts of variables. In light of this, Aawaar (2017) contends that wavelets merge time and frequency dimensions and use phase difference approaches to capture structural changes in data. Theoretically, the wavelet framework is a robust one that aids in the identification of areas by using a uniform time interval-frequency space (Graham, Kiviaho, & Nikkinen, 2012; McCarthy & Orlov, 2012). Hathroubi and Aloui (2022) reveal that the wavelet method is based on the estimation of the spectral features that reveal the differences in the time dimension. Hypothetically, Uddin, Arouri, and Tiwari (2014) hypothesized that the use of standardized econometric approaches, which independently consider the frequency and time domains, results in the loss of significant information from one side. To be clear, studies that strongly rely on the time dimension typically lose the frequency component, while majority of the studies that use standardized econometric methodologies retain it. Aloui, Hkiri, Hammoudeh, and Shahbaz (2018) define wavelet as a set of minute waves that develop and dissipate over a short period of time. Normally, wavelet analysis has been employed in time series studies, and its exploration in panel data is very scant. Scant evidence can be found for panel data approaches, for example (Mehmood et al., 2023) and Saldivia, Kristjanpoller, and Olson (2020) who employed the wavelet analysis to determine the nexus between variables across time frames. As such, panel data contains strings of time series properties, making the use of wavelet methodology suitable to examine the macroeconomic transmission streams across time dimensions. Applying other contemporary econometric model could potentially overlook the interactions between climate change and macroeconomic indicators and their impact on banking system stability. To the best of our knowledge, the wavelet analysis tools have not been employed in any work to evaluate the macroeconomic pathways of climate change and its impact on the banking system stability in SSA. More importantly, the lead-lag relationship between climate change and its interaction with macroeconomic indicators against banking system stability is also investigated using the wavelet coherence and phase difference over a range of time scales.

4.3. Empirical Strategy

Aguiar-Conraria, Azevedo, and Soares (2008) explain that the wavelet coherence is the ratio of the cross-spectrum to the product of the spectrum of each series. The movement of climate change variables and their interaction with macroeconomic indicators as well as banking system stability will be determined using the wavelet coherence technique. The wavelet coherence technique helps in determining how climate change variables and their interaction with macroeconomic indicators as well as banking system stability match-up with each other over a period of time. Aawaar (2017) and Boako (2016) suggest that wavelet coherence is very expedient for examining co-movements or cross-correlations between variables in time scales and frequency domains. There are variations between wavelet coherence and correlation coefficient, however, Madaleno and Pinho (2010) claim that they are comparable. The wavelet coherence is defined as;

$$R_n^2(z) = \frac{\left|Z(Z^{-1}W_n^{xy}(z)\right|^2}{Z\left|Z^{-1}\,|W_n^{x}(z))^2\right|Z\left|Z^{-1}W_n^{y}(z))^2\right|} \qquad (1)$$

The $R_n^2(z)$ denotes the wavelet squared coherence. The wavelet squared coherence assesses the local linear correlation between two parameters at a specific time dimension and has a value that ranges from 0 to 1. Z indicate the smoothing operator in both time and scale.

On the other hand, wavelet phase difference is applied to determine the negative and positive correlations to examine the lead-lag nexus of the variables in this present study. Inspired by the work of Aguiar-Conraria et al. (2008) we define the wavelet phase difference as;

$$\phi_{x,y} = \tan^{-1}\left(\frac{I(W_n^{xy})}{R(W_n^{xy})}\right),\ \phi_{xy} \in (-\pi,\pi) \qquad (2)$$

In theory, if $\phi_{xy} \in (0,\pi)$, then the series are said to be in phase with x leading y, however, if $\phi_{xy} \in (-\pi/2, 0)$ then the series is still in phase but y is said to be leading. Conversely, the series are said to be out of phase and x leads y if $\phi_{xy} \in (-\pi, \pi/2)$. In addition, y leads x when $\phi_{xy} \in (\pi/2, \pi)$. In this present study, the arrow in the wavelet coherence indicates the lead-lag association of climate change parameters and their interaction with macroeconomic indicators against banking system stability in selected sub-Saharan economies. For instance, we imply in our study that if the arrow shows ↗ (+) it depicts an in-phase difference with the interaction between climate change parameters and macroeconomic indicators leading. Besides, an arrow pointing ↖ (+) represents an out-of-phase difference with banking system stability leading. More so, an arrow ↙ (-) indicates an out-of-phase difference with interaction between climate change parameters and macroeconomic indicators leading. However, an arrow of ↘ (-) represents an in-phase difference with banking system stability leading. Intuitively, arrows in the right direction → show a positive coherence. Further, arrows pointing to the left ←indicate negative coherence. It should be stressed that arrows pointing right up or left down do not necessarily mean a causal effect. According to Wijesekara et al. (2022) the scales on wavelet graph referenced as upper, middle, and lower divisions are representations of respective short-term, medium-term and long-term. In addition, Oddo and Bosnjak (2021) explain that higher scales are representations of long-term correlations, while lower scales indicate short-term co-movement. In this study, scale bands from 0-16 denote short-term coherence. Further, scale band from 32-128 signifies long-term coherence.

5. Findings and Discussion

The application of the discreetly new technique in this present study was based on statistical decisions of the summary statistics of climate change and the interactive macroeconomic variables against banking system stability variable (See Appendix 2 for summary statistics for the choice of the wavelet coherence technique). The results of the Jarque-Bera test establish the non-normal distribution of variables. More so, variables possess thick tails, hence, employing the conventional econometric technique will not yield a result that is a true reflection of the data. On that note, we present the wavelet coherence results in Figures 1-4. It is important to point out that the wavelet coherence does not only reveal the link between climate change and interactive macroeconomic variables against banking system stability, it also uncovers the activities across different time frequencies. In the wavelet coherence illustrations, the horizontal axis denotes the time window. Likewise, the vertical axis represents the scale in years. The mean power of wavelet coherence is indicated in the colour codes on the colour bar. The colour blue indicates the low power (low correlations), while the colour red represents a high power (high correlations) coherence.

The cone of influence (COI) is the curved white line that represents the edge effects of the regions. Specifically, regions outside the cone of influence do not show any statistical significance. The black contour represents regions with a 5 percent significance level. To begin with, interactions of climate change variables and macroeconomic indicators are presented as lnTEMPT x lnINFL (interaction between temperature and inflation), lnTEMPT x LP (interaction between temperature and labor productivity), lnTEMPT x lnGDP (interaction between temperature and real gross domestic product), and lnTEMPT x EXRate (interaction between temperature and real exchange rate). In addition, we represent lnPPT x lnINFL as (interaction between precipitation and inflation), we denote lnPPT x lnLP (interaction between precipitation and laborr productivity), lnPPT x lnGDP shows (interaction between precipitation and real gross domestic product), lnPPT x lnEXRate stands for (interaction between precipitation and real exchange rate). Again, we symbolize lnGHGAS x lnINFL as (interaction between greenhouse gas and inflation), lnGHGAS x lnLP signifies (interaction between greenhouse gas and labour productivity), lnGHGAS x lnGDP represents (interaction between greenhouse gas and real domestic product), lnGHGAS x lnEXRate connotes (interaction between greenhouse gas and real exchange rate), CCI x lnINFL indicate (interaction between climate change index and inflation), CCI x lnLP implies (interaction between climate change index and labour productivity), CCI x lnGDP exemplifies (interaction between climate change index and real gross domestic product) and CCI x lnEXRate refer to (interaction between climate change index and real exchange rate). Furthermore, the lnBS represents the stability of the banking system. Figure 1 depicts the wavelet graph of the interaction between temperature and macroeconomic indicators against banking system stability.

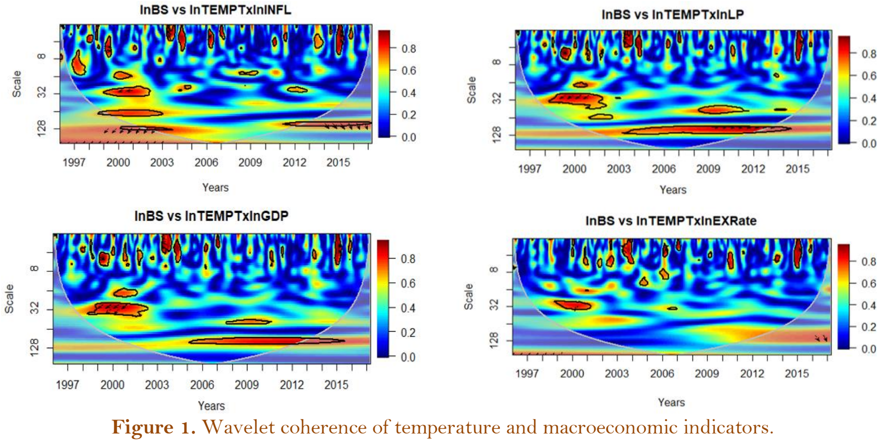

Figure 1. Wavelet coherence of temperature and macroeconomic indicators.

It can be observed from Figure 1 (wavelet coherence of temperature and macro-economic indicators) that all parameters exhibit both short-term and long-term impacts. With reference to the interaction between temperature and inflation against banking system stability, we notice some significance within some periods. For instance, in the short-term, few significant coherences were identified from 1997-2007 on the scale band of 0-16. Likewise, limited significant coherences were recorded for the subsequent years on the aforesaid scale band within the period 2010-2016. It is worth pointing out that in the long-term, significant coherences were observed from 1999-2005. Further, few significant coherences were evident from 2012 in the long-term. We allude that the observable significant lags identified occurred in the period 2004 in the short-term with an out-of-phase difference. This indicates that the banking system's stability is leading. On the other hand, the out-of-phase postulation reveals a significant positive correlation between the interaction of temperature and inflation and banking system stability in the short-term. Further, we construe that in the long-term there exists a significant negative correlation between the interaction of temperature and inflation in the banking system.

To the best of our knowledge, there is no empirical evidence for the interaction between temperature and inflation and its impact on banking system stability. We have documented the association between the temperature and price development. Nonetheless, seasonality is an important factor in the agriculture sector. As such, both favourable and unfavourable temperatures affect agricultural yields. On that note, the growth of agriculture production will be limited in the periods of very low or high temperatures. Likewise, inflation has its ramifications on both the farmer and consumer (high or low inflation) and the overall economic activities. High inflation means a reduction in purchasing power, which affects the cost of living and also increases the cost of factors of production, vice versa. Therefore, interaction between the two estimates is imminent to stabilize or destabilize the banking sector, in its respective short-and long-term impact. In a pragmatic sense, poor yields during a particular season reduce the income of farmers, as limited funds will be generated for deposit purposes. Coupled with inflationary pressures, the demand for farm produce will be less, which cripples' farmer's funds to make deposit at the bank. Moreover, high inflationary pressures affects farmer's capacity to repay their loans as poor agriculture yield looms. Due to losses in production and sales, it reduces farmer's funds to make deposits at the bank. Again, we establish that in the event of favourable temperatures coupled with sound inflationary measures, farmers contribute positively to the stabilization of the banking sector via deposits and frequent payments of loans in the short-term.

With regards to the wavelet coherence analysis for the interaction between temperature and labour productivity against banking system stability, we observe that some significant coherences were evident from 1999 to 2004 on a scale band of 0-16 and patterns of few significant correlations were seen from 2010 to 2015 in the short-term. However, in the long-term some significant correlations were attained in 1998-2002. On the other hand, we observe some significant coherence for the succeeding 8 years in the long term, from 2004-2012. It is important to note that arrows were out of phase in the period 2004 in the short-term. This demonstrated that banking system stability was leading. In addition, it shows that a significant positive coherence exists between the interaction of temperature and labor productivity and banking system stability in the short-term. In the long-term, a significant negative coherence exists between the two variables as interaction between temperature and labor productivity is leading. Thus, variables were out of phase with banking system stability. Taking inspiration from the work of Carleton, Hsiang, and Burke (2016) the authors argue that temperature adversely impacts labor productivity and agricultural yields. Essentially, Somanathan, Somanathan, Sudarshan, and Tewari (2021) disclose that higher temperatures are linked with lower crop yields and lesser non-agricultural sector output. The authors contend that heat stress leads to low productivity as the labor will produce less at the workplace. Also, absenteeism is concomitant with hot days. Less productivity on hot days affects economic activities, with a ripple effect on financial transactions. Undoubtedly, less productivity directly affects funds for both farmers and labors. Besides, less funds for deposits will have a negative impact on stability of banks. Acevedo, Mrkaic, Novta, Pugacheva, and Topalova (2020) explain that extreme temperatures reduce labor productivity in highly exposed temperate zones. However, high efficiency in labour output increases productivity. Thus, with favourable temperatures within a season, agriculture produce are positively affected, which increases farmer's revenue for financial transactions.

We again elaborate on the pass-through effect of temperature and real gross domestic product on banking system stability. We surmise from Figure 1 that in the short-term, patterns of significant coherence were evident from 1998- 2007 on a 0-16 scale band. On the other hand, an apparent coherence was seen in 2011 and 2015- 2016 on the same scale band. Inter alia, the long-term coherence was observed from 1998 to 2002. We construe that in the 2006-2012 period, in the long-term, it was evident that significant coherence existed. The results showed an existing lag, with banking system stability leading in the short-term. Also, the interaction of temperature and real gross domestic product was leading in the long-term. On that note, we deduce that there is a positive and negative significant coherences in the interaction between temperature and real domestic product against banking system stability in the short- term and long-term, respectively. Bastien-Olvera, Granella, and Moore (2022) suggest that temperature impacts the predictors of economic growth and not just economic production. Seemingly, in the wake of slow economic growth, various sectors of the economy are affected, including the agriculture sector. In connection with unfavorable temperature, agriculture produce is negatively affected, which affects financial activities in the general economy, thereby contributing to a spillover effect on stability of banks. In this regard, Dell, Jones, and Olken (2012) disclose that higher temperatures threaten economic growth and affect agriculture and industrial production, which will be detrimental to financial transactions. Needless to say, we posit that favorable temperatures may have a positive impact on the agriculture sector, which drives economic activity. As such, an increase in economic output increases financial transactions of economic agents, which positively affects the banking sector.

On the correlation between the interaction of temperature and real exchange rate against banking system stability, we infer that during the first 5 years, little significant coherence was observed from 2000 to 2004 in the short-term. This significance was not a continual trend, as it was sparsely distributed with the subsequent years up to 2015. However, in the long term, patterns of significant coherences were seen, although, the intensity was low. We infer from Figure 1 that an evidential lag was identified in 2004 period in the short-term, with banking system stability leading. We deduce that a positive significant coherence exists between the two variables. The real exchange rate is a sensitive market risk driver. Fluctuations in exchange rates are very subtle in SSA. Together with favorable temperature within a specified time window, it stimulates trade activities and affects the creditworthiness of both farmers and the government. Further, it affects the exchange rate difference of domestic banks and positively influences rate of borrowing and credit rating of government. Farmers are very prudent in favorable exchange rate movement and auspicious temperature, which undulate banking activities, thereby promoting the stability of the banking sector.

Figure 2 shows the wavelet graph of the interaction of precipitation and macroeconomic indicators against banking system stability.

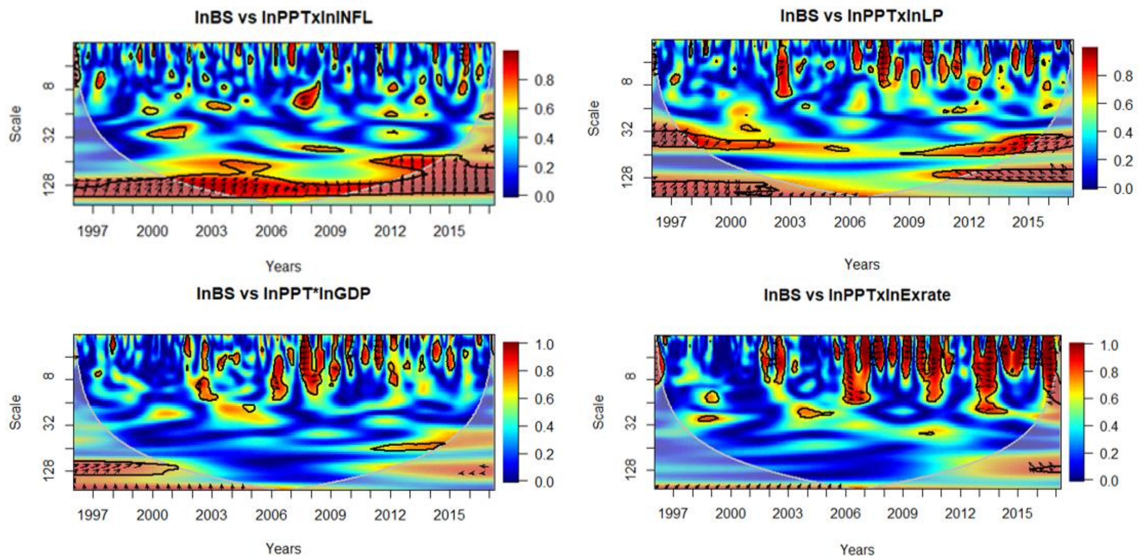

Figure 2. Wavelet coherence of precipitation and macroeconomic indicators.

We crucially analyze the wavelet graphs of the interaction of precipitation and inflation against banking system stability, as shown in Figure 2. We observe a sparingly distributed distribution of coherence significance in both the long term and short term. For instance, in the short-term, on a scale band of 0-16 some significance was observed from 1997-2009. Further, a few significances were evident from 2012 -2016 periods. Despite this, evidence of significant coherence was observed from 2001-2014 in the long term. We deduce that in the short-term, the interaction of precipitation and inflation was leading to an out-of-phase difference. We infer that in the short-term a significant negative coherence exists between the interaction of precipitation and inflation and banking system stability. Per contra, a positive coherence exists between the interaction of precipitation and inflation and banking system stability in the long-term. Unquestionably, agriculture production in SSA is highly dependent on natural rainfall, and rainfall is seasonal. Moreover, during dry season there is a decline in the production of agricultural produce. This in tend result in the shortage of agriculture produce. As such, the shortage of agriculture produces a surge in food inflation. In the event of drought and high food inflation, it implicates the cost of living of consumers, leading to low income as well as low revenue for farmers who are customers of banks. The situation impacts both economic agents and financial transactions. This indicates that low funds will be transferred or deposited from both production units and consumers to the banks. Essentially, it affects the performances of various banking units negatively within a specified time frame in the short-term. In contrast, during favorable precipitation periods, there is a boom in agriculture produce. It increases the supply of agriculture production. Further, the increase in supply of agricultural produce causes a decline in food inflation. On that note, higher purchases of agricultural produce increase the revenues for farmers, which improve the standard of living. Moreover, farmers are able to repay their loans, which reduce the credit risk of banks in the long term. Therefore, the stability of banks increases accounting from more deposits and low credit exposures.

In addition, we observe some significant coherences between the interaction between precipitation and labor productivity and banking system stability in the short-term from 1998-2004. Also, we infer that some significant coherences were observed within the period 2007-2016 in the short-term. However, a positive coherence was evident in 2003. Moreover, a positive coherence was established in 2010 and 2015 in the short term. On the other hand, a negative coherence was observed in 2008 and 2011. Further, we deduce from Figure 2 that a positive coherence was imminent from 1998-2002 with interaction of precipitation and labor productivity leading in the long-term. Likewise, some significant coherence was observed in 2010 and 2015 in the long-term.

More importantly, low precipitation rates result in the decline of agricultural activities. Fundamentally, low labor will be demanded for agricultural work. Agriculture agents, such as farmers and suppliers, are able to save their working capital during that period. Hence, more funds will be available for bank deposits, which increase their liquidity rate. Further, a decline in the agriculture activities, which resulted in a low demand for labor increased the supply of labor, making the cost of labor cheap. Cheap labor is often associated with low income due to a decrease in the amount of money in circulation within the economy. It decreases the number of deposits for banking customers. Low funds available to bank expose them to liquidity risk. In addition, favorable seasonal precipitation will require more labor for agriculture activities, hence, labor revenue increases, which enables farmers to save more. Therefore, a growth in revenue of labors has a positive reflection on the banking operations.

From the foregoing, we surmise the interaction of precipitation with real gross domestic product and banking system stability wavelet graph shown in Figure 2. We infer from Figure 2 that in the short-term, some significant coherences were observed from 2002 to 2016 on a scale band of 0-16. On the other hand, few significances of coherence were evident in the period 2011-2014 in the long-term. We identified some lags with banking system's leading stability. We infer that a negative coherence exists for the period 2006-2012 in the short-term.

It is crucial to state that unfavorable rainfall (drought) or heavy downpours (flooding) result in low agriculture output. It is a burgeoning fact that agricultural output forms part of the economic cycle, as such, a decline in agriculture production as a result of losses in agriculture produce leads to a fall in the real gross domestic product within a specified period. A fall in the real domestic product leads to economic recession, which in turn affects the performance of banks. Therefore, there were low financial transactions for banking activities during the economic period. This results in the contraction of the general economic system and affects sovereign debt, leading to sovereign risk as well as credit downgrades (Takawira & Mwamba, 2020). Essentially, it negatively affects the stability of the banking system.

Again, as a discourse on the wavelet analysis of the interaction between precipitation and exchange rate against banking system stability, we observe that there were little significant coherence in 1997 and 2003 in the short-term.

However, significant coherences were identified in the period 2006-2016. In the long-term, pattern of significant coherence was seen in 2010. We allude to the fact that variables were in-phase in period 2006, with banking system stability leading. A negative coherence exists for the periods 2003, 2006-2007, 2009, 2013, and 2016. Also, significant positive coherence was recognized in 2010-2011 and 2014-2015. Indisputably, it is well documented that the macroeconomic foundations in SSA are weak (Jafino et al., 2020). The sub-region is highly susceptible to exchange rate fluctuations.

We highly anticipate a low economic turnout in the event of unfavourable rainfall and high exchange rate dynamism. The banking sector forms part of the economic chain, and a repercussions of exchange rate volatility and precipitation challenges are ruinous to banking operations. As mentioned above, rainfall is seasonal, and in the new global terrain, most farmers are dependent on trade financing from commercial, rural, agricultural, and development banks. As such, high exchange rate is deleterious and exposes banks to market risk. On the other hand, the appreciation of the local currency stimulates the exchange rate difference, which positively impacts banking operations.

Figure 3 present the wavelet graph of the interaction of greenhouse gas emissions and macroeconomic indicators against banking system stability.

It is a concrete testament in Figure 3 that inferences from the wavelet graph of the interaction of greenhouse gas and inflation against banking system stability show that there was some significance of correlation in the short-term on a scale band of 0-16 within the period 1998-2007 and also from 2010-2016. In addition, some significant coherence was detected in 1999-2003 as well as 2004-2014 in the long-term. It is revealed that some lags were detected in the short term during the 1998 period, with banking system stability leading. However, in the long-term, for period 1999-2006 variables were in-phase, with interaction between greenhouse gases and inflation.

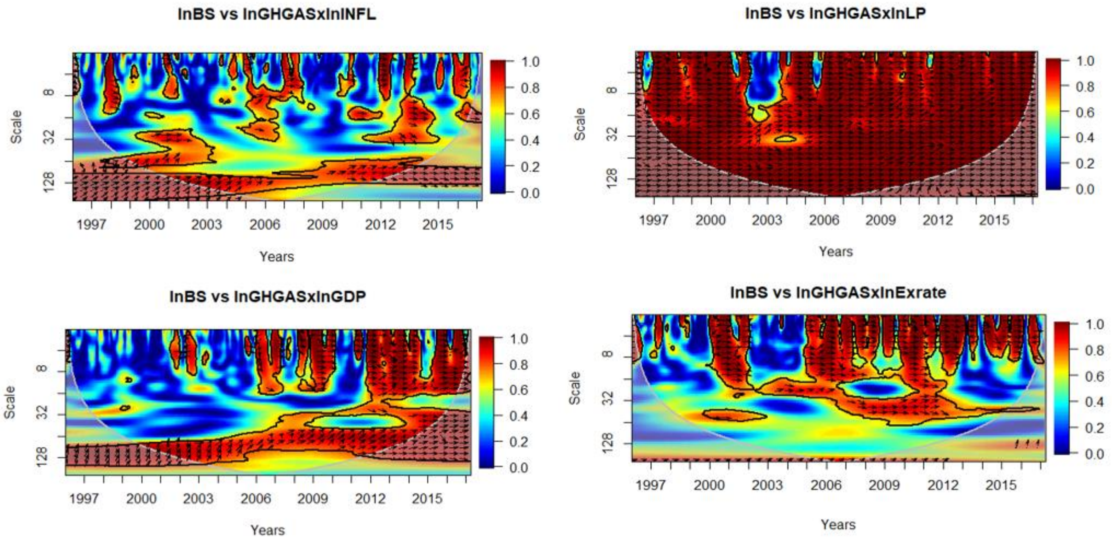

Figure 3. Wavelet coherence of greenhouse gas and macroeconomic indicators.

Both positive and negative coherences were observed in both the short and long-term. Again, we observe from Figure 3 that a continuous significant coherence is evident throughout the period except 1997, 2002-2003, and 2006 in the short-term with the interaction between greenhouse gas and labor productivity against banking system stability. Ostensibly, a continual positive trend was observed in the long-term from 1998-2017, with significant coherence in 2004 in the long term. This indicates that interactions between greenhouse gases and labor productivity are leading. We conclude that extreme greenhouse gas emissions will lead to losses in labor productivity. Labourers will fall sick from various emission diseases. Therefore, the demand for labor increases, leading to an increase in labor wages. Hence, there will be available funds (income) for the laborers to save. This cushions the deposits of banks, which will reduce the liquidity risk of banks.

With regards to the interaction of greenhouse gas and real gross domestic product against banking system stability, some significant correlations were observed in 2002-2003, 2006-2011 in the short-term. However, in the long-term, we observe a continuous trend of significant coherences from 2001-2015. We identify an in-phase phase difference with interaction of greenhouse gas and real gross product leading from 2003-2013 in the long-term. That notwithstanding, a significant positive coherence was evident in both the long-term and short-term. Also, variables were in phase in 2007, with banking system stability leading in the short-term. This demonstrates a negative coherence in the aforesaid period. Essentially, an increase in greenhouse gas emitters has an enormous implication on the production of goods, which affects economic activities with an undulating attack on financial institutions. However, stupendous technological progress in line with infrastructural projects such as manufacturing and other industrial engagements kindles greenhouse gas emissions. Besides, the economy grows, increasing the real domestic product. An increase in the real domestic product affects all economic agents, of which the banking sector is one.

On the other hand, some significant coherences were observed in connection with the interaction of greenhouse gas and exchange rate against banking system stability from 1997-1999. Again, enormously significant coherences were evident from 2001, 2006-2016 in the short-term. In the long-term, we infer that few coherence significances were identified in 2000-2003. In addition, we posit that some significant coherence was also seen from 2007-2014. We deduce that a significant positive coherence was eminent within the specified period for both the short- and long-term. Xu et al. (2021) juxtapose that developed economies are net importers of greenhouse gas emissions, while developing and commodity-dependent countries (CDC) are net exporters of greenhouse gases. Against this backdrop, majority of sub-Saharan economies are commodity-dependent; hence, they get more revenue from exporting greenhouse gas emissions products, which strengthens their exchange rate. In effect, it stabilizes the financial system, and banks are no exception. Figure 4 shows the wavelet graph of the interaction of climate change index and macroeconomic indicators against banking system stability.

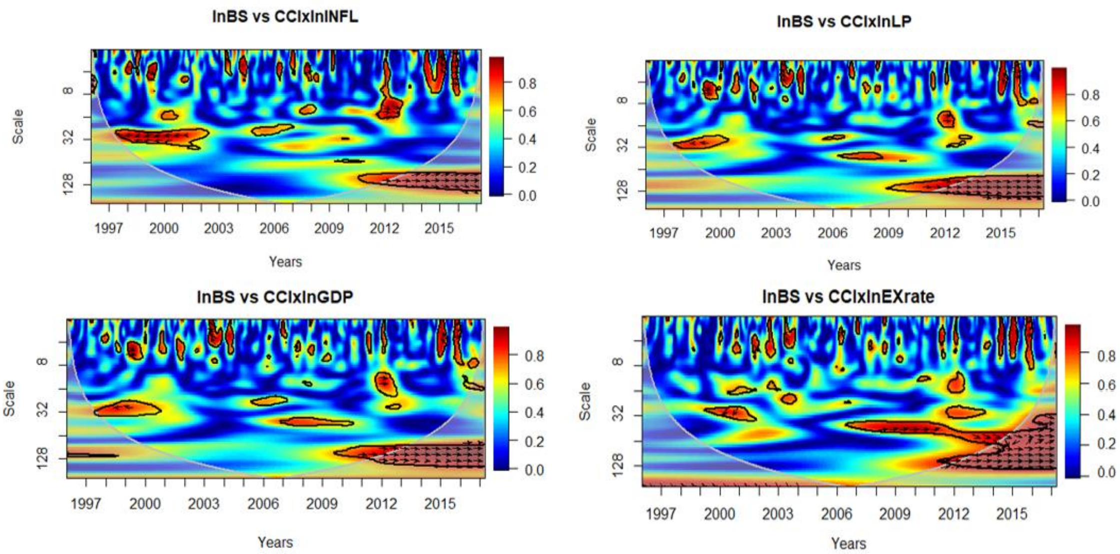

Figure 4. Wavelet coherence of climate change index and macroeconomic indicators.

With reference to Figure 4, we infer that in the short-term, there was some significant coherence identified on the 0-16 scale band for the interaction between climate change index and inflation against banking system stability. This significance was randomly distributed. For example, significant coherence was spotted from 1998-2001. Also, for the period 2004-2009, some significant coherence was dappled. It is evident from the wavelet illustration that patterns of significant correlation were observed from 2012-2016 on the scale band of 0-16 in the short-term. In addition, we make observation from the wavelet graph that some coherences were present from 1997 -2002 and 2011-2012 in the long term. From 1998-2002 variables were in phase with banking system stability leading. We deduced a short-term positive coherence in 2012. Also, a negative coherence was evident in 2000. In addition, a significant negative coherence exists in the long-term from 1998-2001. Empirically, the use of fossil-based inputs causes climate change and inflation. Higher taxes on conventional fuels will add to inflationary pressures. As carbon taxes become more pervasive across industries and geographical settings, their prices soar higher. Another area of concern for consumers under inflationary pressure is food prices. It is said that food and energy costs are highly correlated, as the supply chain for food production is energy intensive. In line with documented literature, unstable inflation affects bank system stability.

It is important to point out that the interactions between climate change and labor productivity against banking system stability exhibited some patterns of significance in the short-term on the scale band of 0-16 from 1998-2004. Further, we observe that few significant correlations were evident from 2008-2009. Unquestionably, the period 2012-2016 showed few coherences in the short-term. On the long-term, it was established that some significance was evident from 1998-2000, 2006-2011. We conclude that some lags were identified with banking system stability leading in the short term in the 2000 period. More so, we observe that in the short term, positive correlations were established. For example, in 1999 and 2004, a positive coherence was observed, as well as in 2012, 2015-2016. In the long-term, a negative coherence was spotted for the period 1999-2000. Contrarily to the aforesaid notion, a positive correlation was evident in 2011-2012. Empirical evidence has revealed that climate change has an effect on the health of the labor. Therefore, its impact on livelihoods and productivity is significant. For instance, heat waves and natural disasters cause injuries and loss of life. The laborers become incapacitated and contribute slowly to the general economic performance. Hence, it affects economic agents and financial transactions. Likewise, in the event of low carbon emissions and natural disasters, the potential risk and cost of health care are abridged, which increases the borrower's capacity to work and repay their loans, hence intensifying banking sector performance.

We are turning our discussion on the interaction between climate change index and real gross domestic product. The wavelength graph's depiction is slightly different from the wavelet presentation of the interaction between the climate change index and labour productivity. We infer that few significances were parsimoniously distributed from 1998-2004 on the 0-16 scale band. We progress to see that few patterns of significance were observed within the period of 2007-2016 on the scale band of 0-16. As an inference to the long-term impact, we infer that some significance was noted from 1998-2001 and also 2008-2011 period. It is revealed that in the short-term for the period 2004 and 2015, an identification of some lags was conceivable with the interaction of banking system leading in the short-term. We disclose that in the short-term, a positive coherence was observed in 1999, 2004 as well as 2015-2016. In the long-term, a negative coherence was spotted from 1998-2000. On the flip side, a positive coherence was evident in 2011-2012. For some time now, the ramifications of climate change have presented enormous effects on various economies, including SSA, through potential reductions in productivity and increases in infrastructure and service costs. This said, a plunge in production would have a repercussion on commodities, making them expensive. Besides, a flow-on effect advances to other areas of the economy, leading to inflation and financial instability. Intuitively, a surge in infrastructure and technological advancement increases economic activity (economic growth), which has a positive impact on banking stability.

For the results of the wavelet graph for the interaction between climate change index, exchange rate, and banking system stability, we surmise that few significant coherences were identified from 1997-2004 and 2006-2012 in the short-term. In addition, some significance was identified in the period 2014-2016 in the short-term. In the long-term, some significance was observed from 2000-2002 as well as 2007-2014. We identify some lags with banking system stability leading in the short and long term in 2004 and 2003, respectively. Further, we deduce that in short-term, positive coherence exists for the respective period of 2002, 2004 and 2015. In the long-term, a negative coherence exists for the periods 2000-2003 and 2010-2014. On the other hand, a negative coherence was evident from 2000-2002. More so, a positive coherence was evident for period 2008-2014 in the long-term. Indubitably, Sub-Saharan economies are mainly bank-based, therefore, in the event of climate change effects such as flooding, drought, excessive carbon emissions, heatwaves, etc., it increases customer's expectations of losses as a result of previous incidences. This will impact trading activities, especially in commodities. Trading performances are sensitive to exchange rates. Therefore, significant fluctuations are likely to occur during climate change events. This impacts banking sector revenue and the overall performance.

6. Conclusion and Policy Implication

A 2021 Bank for International Settlement (BIS) report highlights that banks are exposed to climate change through two major streams, namely, macro- and microeconomic transmission streams. Based on the availability of macroeconomic data, we are inspired by this revelation to examine the interaction of macroeconomic drivers such as inflation, labor productivity, real GDP, and real exchange rate, as well as climate change variables, which include temperature, precipitation, greenhouse gas emissions, and climate change index, on banking system stability in selected sub-Saharan economies. Further, the study employs the wavelet coherence technique and targeted 29 selected sub-Saharan economies for the period 1996-2017. Unlike traditional econometric modelling techniques, the applied model transforms series into timescale dimensions, which makes it novel. The overall findings suggest that macroeconomic indicators (inflation, labor productivity, real GDP, and real exchange rate) serve as pathways through which climate change impacts banking system stability in selected sub-Saharan economies. Indeed, this provides an indirect assessment of the relationship between climate change and banking system stability.

Against this notion, evidence provided by the wavelet coherence shows that macroeconomic transmissions via climate change have evolved over time and space. For instance, across different frequencies and time periods, various activities within the wavelet graph have been pointed out to uncover the relationship between climate change and macroeconomic indicator interaction and banking system stability. From the foregoing, interaction between greenhouse gas emissions and labor productivity has more continuous coherence (both in the short-term and long-term) than any other variable used in this present study. That notwithstanding, the interaction between greenhouse gas emissions and macroeconomic indicators against banking system stability was poignant. In effect, the findings depict the importance of the interplay between climate change parameters and macroeconomic drivers and how their dynamic impact on banking activities affects banking sector conditions and management in Sub-Saharan economies. On that note, we recommend that central banks, monetary authorities, and government at the forefront of policy should consider macroeconomic effects in the integration of climate change policies for stable banking system operations in SSA. Macroeconomic indicators are highly sensitive; however, it is well-written that fundamentals of macroeconomic indicators in SSA are weak. Climate change risks are considered systemic risks and can manifest as credit risk, operational risk, and economic risk (market), amongst others. Therefore, we should carefully outline climate change policies to incorporate macroeconomic sensitivities.

7. Limitations and Direction for Future Research

The study, while attempting to provide a comprehensive understanding of the impact of climate change on banking system stability in sub-Saharan Africa, has certain limitations that provide opportunities for future research. This study contributed to climate change-banking system stability literature by examining the macroeconomic transmission channels through which climate change indirectly impacts banking system stability using the wavelet coherence approach. Although the wavelet coherence technique is a novel methodology, it apprehends the overall structure of the transmission. It is suggested that future studies incorporate wavelet coherence and copula to determine the macroeconomic transmissions. Both methodologies have time- and frequency-varying features, with the copula determining the tail dependence. The study explored macroeconomic transmission streams based on available data. Future studies should investigate the transmission pathways via the microeconomic stream.

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Appendix 1. List of countries.

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

Appendix 2. Summary statistics of variables.

	Ln_Z_ Score	Lnttempt_ X_Lnlnfl	Lntempt_ X_Lnlp	Lntempt_ X_Lngdp	Lntempt_ X_Lnexrate	Lnppt__ Lnlnfl	Lnppt__ Lnlp	Lnppt__ Lngdp	Lnppt__ Lnexrate	Lnghgas_ X_Lnlnfl	Lnghgas_ X_Lnlp	Lnghgas_ X_Lngdp	Lnghgas_ X_Lnexrate	Cci_X_ Lninfl	Cci_X_ Lngdp	Cci_X_ Lnlp	Cci_X_ Lnexrate
Mean	2.344	-0.940	-8.665	-12.875	-2.293	10.972	103.580	155.706	22.457	133.719	46.847	78.485	9.756	1.730	0.728	0.333	-12.248
Median	2.367	-0.418	-6.586	-9.706	-1.416	11.567	105.674	156.707	27.825	27.076	48.904	77.579	7.833	0.000	-0.247	-0.155	-0.522
Maximum	4.571	3.762	16.730	25.937	21.842	57.467	127.327	192.616	57.937	2747.185	106.457	169.919	41.588	299.454	71.086	46.394	366.172
Minimum	0.000	-16.599	-74.770	-115.892	-29.302	-25.135	67.699	107.916	-66.733	-887.033	-23.169	11.549	-35.734	-326.324	-101.955	-62.458	-423.495
Std. dev.	0.654	1.912	11.469	17.008	4.070	8.450	12.675	16.276	27.300	317.835	31.071	36.130	15.614	60.410	27.031	17.815	116.986
Skewness	-0.421	-3.557	-1.465	-1.462	-1.053	0.430	-0.484	-0.479	-1.620	4.546	-0.059	0.157	-0.384	0.055	0.140	0.098	-0.138
Kurtosis	5.219	23.685	6.534	7.003	10.081	6.147	2.615	2.918	5.863	31.900	2.055	2.690	3.808	7.977	3.084	3.083	4.070
Jarque-Bera	149.895	12720.22	560.385	653.623	1451.108	283.024	28.896	24.634	497.181	24401.880	24.106	5.174	33.101	658.885	2.288	1.222	32.520
Probability	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.075	0.000	0.000	0.318	0.542	0.000
Sum	1495.736	-600.356	-5528.744	-8214.333	-1463.013	7000.670	66084.330	99340.940	14327.830	85312.980	29888.610	50073.870	6224.903	1103.795	464.799	212.650	-7814.385
Sum sq. dev.	273.086	2329.408	83793.670	184286.400	10554.470	45489.440	102348.800	168751.100	474768.400	64349327.000	614965.900	831570.700	155300.900	2324719.000	465452.600	202185.100	8717931.000
Observations	638	638	638	638	638	638	638	638	638	638	638	638	638	638	638	638	638