Tanzanian Economic Review, Vol. 13 No. 2, December, 2023: 121–164

The Effects of Climate Variability on Economic Growth in Uganda

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Abstract

A key criticism of Uganda's macroeconomic modelling frameworks is the lack of accounting for the effects of climate change. As a result, the demand for sustainable climate change evidence-based policy actions is higher than ever, making this a key issue in policy discussions. However, climate change research in Uganda has been piecemeal, with a few using case studies of agricultural commodities, regions, or agriculture. Thus, using the endogenous economic growth framework, this study estimated the long-term and short-term direct and indirect-sectoral effects of climate change on Uganda's economic growth using the vector error correction model and Johansen cointegration econometric analysis methods. The results show that climate change (precipitation) affects agriculture and industry sectoral output growth in a positive direction, and service sectoral output growth in a negative direction. Further, climate change (temperature) affects agriculture and industry sectoral output growth in a negative direction, and service sectoral output growth in a positive direction. The study's main conclusion is that an increase in temperature by 1.0 degrees Celsius accounts for a reduction in economic growth by approximately 2.5 percentage points, keeping all other factors constant. The study recommends accounting for climate change effects in macroeconomic growth frameworks, and implementing key sectoral-specific climate sustainability measures.

JEL Classification: C22, 250, 047, Q54

Keywords: climate change, economic growth, vector error correction model, econometrics

1. Background

The demand for sustainable climate change evidence-based policy actions is at its highest now than ever before (Tangney Peter, 2022). According to Rodrik and Stantcheva (2021), the two primary tests of present-day capitalism are climate change and social inclusion. Indeed, there is overwhelming evidence from numerous studies—like Goulden (2008), USAID (2011), MoWE (2015) and (Irish Aid, 2017)—for climate variability in Uganda. Indeed, Uganda uses computable general equilibrium models (CGE) for its macro-economic modelling that is based on the 2016/17 Social Accounting Matrix (SAM). However, although the modelling framework has gone through improvements of the SAM, it still does not take into account the effect of climate change and environmental damage on economic growth (Tran et al., 2019).

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 ♦ https://doi.org/10.56279/ter.v13i2.130

In addition, there is limited empirical evidence of the effect of climate change on economic growth. There are several qualitative policy studies, but a devoid of empirical studies that have studied the impacts of climate change on wider economic outcomes like growth (direct effect) and the indirect or sector (industry, services and agriculture) passthrough effects of climate change on economic outcomes. Some empirical attempts in Uganda focused on the direct impacts on agriculture, most of which take a case study of either select commodities or regions. Such studies like Mwaura and Okoboi (2014) focused on the impacts of climate variability on the sub-sector of crops. Another study by Läderach and Asten (2013) focused on the implications of climate variability on *arabica* coffee production in Uganda, specifically in the Rwenzori mountains.

Climate change may be defined as the variations in the distribution of weather patterns, including temperature and precipitation, observed over long periods (Rahman, 2013). Globally, climate change is projected to generate substantial effects on planned economic outcomes, and pose a severe threat to the livelihoods of many populations across the globe (Markandya et al., 2015). For example, when not well-managed, the increasing level of human activities is expected to raise average temperatures in Uganda by an unprecedented additional 1.5°C every 20 years, with less uncertainty in rainfall variability. Temperature variations are expected to have dire effects on water resources, food security, infrastructure, and human development indicators. Figures 1 and 2 present the monthly rainfall variability for the period 1980-2020 in MM, and the total daily rainfall for Uganda for the period 1990–2010, respectively; with the average annual temperature estimated at 22.8°C.

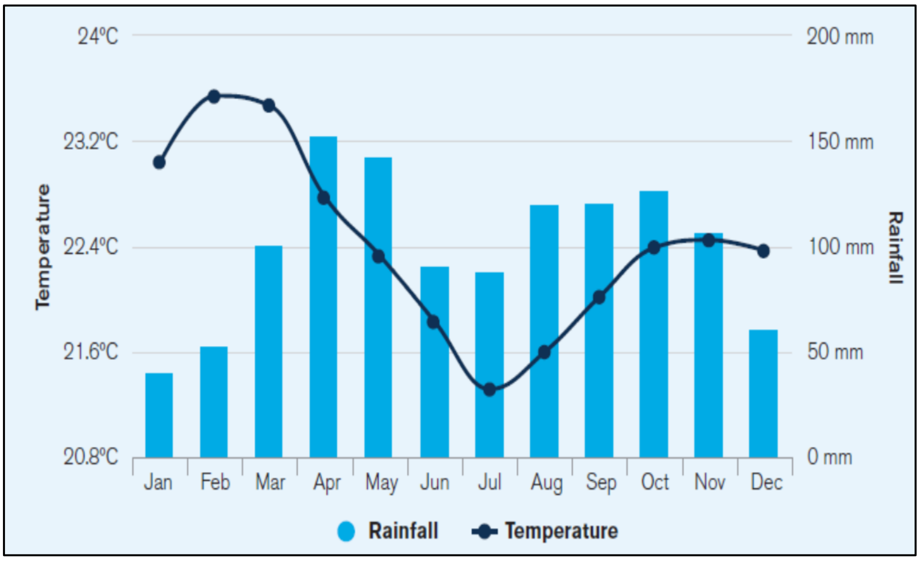

Figure 1: Total Daily Rainfall for Uganda 1990-2010 ((colored).
Source: https://philipomadi.shinyapps.io/UgWeather/

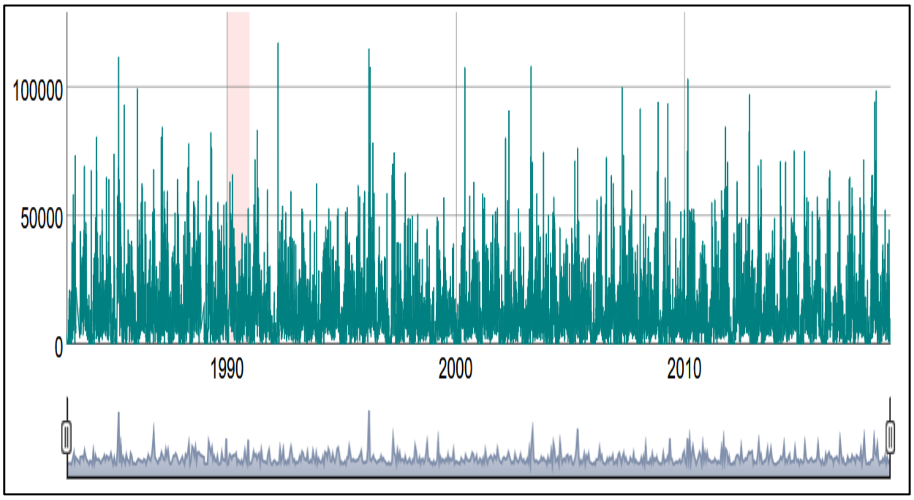

Figure 2: Average Monthly Temperature and Rainfall for Uganda: 1901–2016 (coloured).

Source: WBG Climate Change Knowledge Portal (CCKP, 2020).

Shocking—yet interesting for empirical investigation—is that climate change primarily driven by human activities could stop or invert the country's development path. Climate change is expected to affect the country's export potential as the viability of various economic enterprises is affected. Overall, climate change is expected to have significant direct impacts on the sectors of water, agriculture, and infrastructure, among others; and eventually a substantial impact on economic performance of the country, and subsequently an increased household vulnerability to poverty (Markandya et al., 2015).

While Uganda contributes only about 0.07% to the global Green House Gasses (GHG) emissions—which ranks the country at 176 out of 188 countries in per capita emissions—the country ranks higher (155 out of 181 countries) regarding the ND-GAIN[1] index of vulnerability to climate change. When measured in terms of the ability to cope with adverse climate variability effects in the aspects of poverty, household food consumption, health of the population, water systems, and infrastructure in all their totality, Uganda is the 14th most vulnerable country and 48th least prepared country when ranked according to the ability to the address adverse effects of climate change (Ministry of Foreign Affairs of the Netherlands, 2018).

Figure 3 indicates that, with a 2^{o}C increase in temperature, several regions suitable for robusta coffee farming would no longer be suitable. This illustrates the severe impact that climate change can have on agro-systems, and the overall economic performance of the country noting that coffee is the key cash crop, and its production impacts on several other value-chains.

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[1] Notre Dame country index for measuring vulnerability

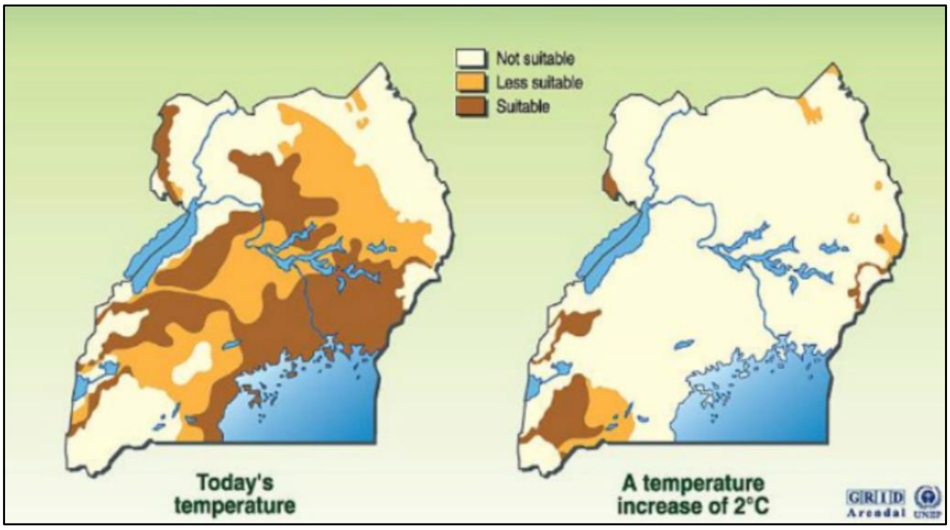

Figure 3: Illustrative Impact of Temperature *Rise* on Robusta *Coffee* Production in Uganda

Source: GRID Arendal /UNEP (http://www.grida.no/publications/vg/climate/page/3090.aspx).

For example, according to Goulden (2008), variabilities in climate and related incidents may cause a change in the feasibility of coffee growing areas, perhaps flashing out about 40% of export revenue as coffee is Uganda's leading export earner. This may also adversely affect the industry and services sectors in the respective value-chains. Further, climate variability directly affects Lake Victoria's water level, affecting the production potential of the country's hydroelectric facilities and the lifespan of the infrastructure (Phoon et al., 2004). This implies that climate change has far-reaching impacts on Uganda's overall economic performance, surpassing the direct observable effects on the agricultural sector.

However, there is a paucity of evidence on the direct effect of climate change on economic growth, together with its indirect sector passthrough effects. This suggests the need for further research in this area. Therefore, this paper examines the direct and sectoral passthrough effects of climate change on economic growth in Uganda. The aim is to identify key priority policy measures to sustain the economy over the medium to long-term in line with the Sustainable Development Goals (SDGs), and Uganda's sectoral, sub-national and national development plans in the face of climate change and variability.

2. Literature Review

Several studies project Uganda's growth to average about 7% to 8% over the next 10 to 25 years (Markandya et al., 2015). This growth estimates are mainly based on a strong assumption of Uganda's ability to successfully implement the SDGs that agitate for the implementation of climate change-sensitive policies to achieve low carbon economic growth.

Several theoretical frameworks are employed in analysing the effects of climate change on economic outcomes. Some of these frameworks include the integrated assessment models (IAMs); RICE models; Mundell-Fleming mechanism and technology; MRICE model (multifactor RICE); MRICES-2012, EMRICES-2014, and CIECIA models (Wang, 2017).

More specifically, two theoretical models are extensively applied in assessing the effects of climate change on economic growth: enumerative, and dynamic approaches (Akram, 2012). The former uses computable general equilibrium (CGE) models and simulation techniques. Studies that applied this method include Bosello et al. (2006) and Sebastian, (2009), who used the static CGE model to analyse the impacts separately sector by sector, for example, on agriculture, health, service and tourism.

The enumerative method for estimating total impacts uses the inner product of the vector of quantities and prices; and market prices are used for traded goods and services (Tol, 2009). The valuation of the monetary value of climate change impacts is based on transfer of benefits by using values used for some few locations, and extrapolating them to the rest of the world; and using values for a given period for the future. To ease interpretation, most studies that rely on the enumerative approach are largely based on controlled experiments (ibid.). The major advantage of the enumerative approach is that it is grounded on natural science experiments, representations and facts. As such, results generated using this approach are realistic and easy to interpret. However, the critical challenge with the approach is that several aspects that vary are assumed to be constant (ibid.).

The dynamic approach—also referred to as the statistical approach—employs diverse stipulations of growth models by incorporating the damage function. This approach is based on direct evaluations of welfare impacts, and uses observed variations in prices and expenditures to discern the effect of climate. The estimates of welfare impacts are undertaken across space within a single country. The assumption is that the observed variation of economic activity with climate over space holds over time as well. The approach relies of climate models to predict the future effect of climate change. The estimates may be undertaken per sector for selected countries, the results of which may also be inferred for selected countries (Tol, 2012). Examples of this approach include the Solow-Swan and Ramsey-Cass-Koopmans models. These are extensively applied growth models when examining the effects of climate change on economic growth (Weil et al., 1992; Fankhauser & Tol, 2005; Akram, 2012). The significant advantage of the statistical technique is that it is based on uncontrolled experiments, and allows everything to vary as it is in reality (Salles, 2019).

Previous empirical studies have examined the presence of climatic variations in Uganda, while others have primarily examined its impact on agricultural productivity. Most recent studies on climate change—e.g., Amarnath et al. (2018), Loboguerrero et al. (2018), and Mittal & Hariharan (2018)—have focused mainly on the effect of climate variability, but with attention to smallholder agro-based households. These studies also try to examine the susceptibility of these households to climate-related risks and their coping mechanisms. Other recent studies, like Mckune et al. (2018), and Mubiru et al. (2018), examined the impact of climate variability on smallholder farmers in Uganda fronted with several agricultural production risks. These studies also examined the climate change-related vulnerability to food insecurity. The studies found a significant effect of climate change on agricultural production and susceptibility to food insecurity. Also, some studies—e.g., Carr and Onzere (2018)—have examined the impact of climate risk management strategies.

Although several empirical studies (e.g., Markandya et al., (2015); Wulf, (2008); Juana et al., (2013); Fankhauser & Tol, (2005); Tol, (2018); Abidoye, (2015); and Kahn et al., (2019)) have pointed to the impact of climate change on economic outcomes, these were not Uganda-specific. Additionally, these studies have focused on the impacts of climate change on the agriculture sector, and their findings cannot be generalized at the national level. Furthermore, as noted by the USAID (2014), though most of these studies are qualitative, they have pointed toward the effect of climate variability on economic outcomes only through the agricultural and services sectors (USAID, 2014). Other studies like Hisali et al. (2011) and Echeverría et al. (2016) also point to these impacts; though implicitly and not explicitly. Therefore, more evidence is needed on the impact of climate change on economic growth putting in consideration other sector passthrough effects.

Unlike previous studies, this study examined the effect of climate change on key economic outcomes for Uganda. The study also analyses the sector channels through which climate change has the most significant impacts on economic growth. The findings of this study can be used to understand the broader economic effects of climate variability on economic growth, and the sectoral (agriculture, industry and services) passthrough effects of climate change on economic outcomes, which can ultimately inform the design of effective climate change and sustainability sensitive policies.

3. Methodology and Conceptual and Theoretical Frameworks

3.1 Data for the Study

Data was obtained from mainly two sources. First, data on climate change variables of temperature and precipitation were obtained from NASA,[2] which provides meteorological data sets. Second, data on other macroeconomic variables were obtained from the World Bank[3] (WDI) (See Table 1).

3.2 Conceptual Framework of the Study

To achieve the study objective, the study expands the conceptual framework developed by the Inter-Governmental Panel on Climate Change (IPCC) of the United Nations Framework Convention on Climate Change (Watson et al., 2001).

[2] Website for NASA Power Prediction of Worldwide Energy Resources: https://power.larc.nasa.gov/
[3] World Bank – World Development Indicators (WDI)

Table 1: Definition of Variables and Sources of Data

Variable	Variable Description	Data Source	Previous Studies
Growth in GDP	Uganda's year-on-year percentage growth in the Gross Domestic Product is measured at market prices based on 2010 prices.	WDI	Ayinde et al. (2011), Mechler (2004), Raddatz (2009), Kahn and Mohaddes, (2019)
Climate change:			
Precipitation	Coefficient of variation of rainfall in Uganda for the period 1980 to 2020.	NASA	Mechler (2004).
Temperature	Coefficient of variation of temperature in Uganda for the period 1980 to 2020.		Dell et al. (2008, 2009), USAID (2014),
Labor	The percentage year-on-year population growth rate between 1980 - 2020.	WDI	Kahn et al. (2019)
Human Capital	Secondary school enrollment as a percent of gross enrolment for Uganda between 1980 - 2020. (Mireille & Marcel, 2005).	WDI	USAID, (2014), Namanya (2009)
Gross Fixed Capital formation	Measures the change in Capital formation as a percentage of GDP year on year between 1980 to 2020.	WDI	Kahn and Mohaddes (2019),
Inflation	Measures the year-on-year average percentage change in consumer prices between the period 1980 to 2020.	WDI	Ayinde et al. (2011), Kahn and Mohaddes (2019), Hisali et al. (2011)
Trade openness	Uganda's exports for goods and services as a % of GDP (Salvatore, 1991 and Feder, 1982) between 1980 and 2020.	WDI	Akram (2012), Kahn and Mohaddes (2019)
Fiscal Policy	Uganda Government Spending as a percentage of GDP between the period 1980 to 2020	WDI	Kahn and Mohaddes (2019), Kahn et al. (2019)
Foreign Direct Investment	Foreign Direct Investment in Uganda as a percentage of GDP between the period 1980 to 2020	WDI	Kahn et al. (2019), Akram (2012)

The conceptual framework in Figure 1 shows how climate change affects—and is also affected by—social, economic and environmental systems that are critical to sustainable economic development. The framework identifies the direct impacts of climate variability on human and natural systems; which helps to understand the impacts of climate change on household vulnerability to poverty through its implications on household consumption patterns. Also, it shows the impacts of climate variability on economic outcomes through its impact on natural systems. The framework has been modified to focus on climate change impacts on economic growth and the sector (agriculture, industry, and services) passthrough effects of climate change on economic outcomes through agro-industry forward value-chain linkages.

In particular, the framework links climate change to its direct impact on natural systems (eco-systems and biodiversity). The framework then links biodiversity passthrough implications of climate change to their direct impact on agricultural production and productivity. Additionally, value-chain linkages of agricultural sector

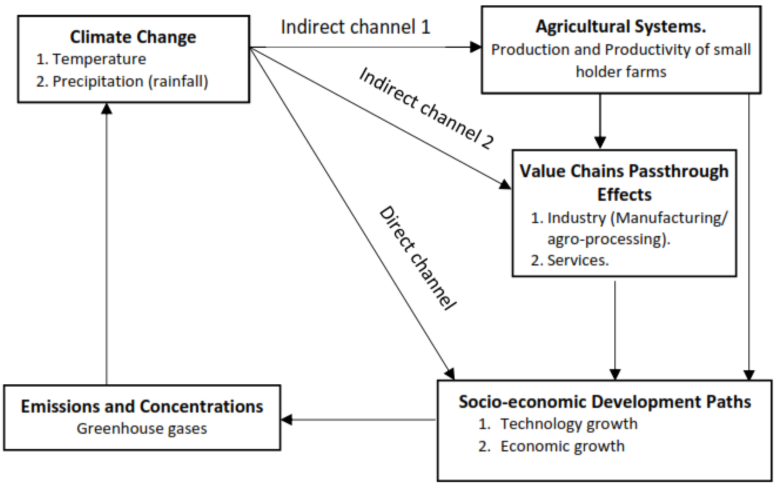

Figure 3: Conceptual Framework for Climate Change and Economic Growth
Source: Adapted and extended from IPCC (2001)

outcomes to industry and services, and further to socio-economic development pathways, are illustrated. These have implications on emissions and concentrations of greenhouse gases, and further impacts on climate change. All these have direct impact on human systems, including food consumption, employment and jobs, household asset holding, human health, and poverty, among others. The study only tracks the implications of climate change on economic growth and vulnerability to poverty.

The conceptual framework in Figure 3 further indicates that the effect of climate change on economic growth can be either direct (direct channel) or indirect. The indirect effect may be in two ways: through the agricultural value-chains impacting spinoff activities in industry and services (indirect channel 1); or indirectly through the economic sectors of agriculture, industry and services (indirect channel 2). The study examines the direct effect of climate change on economic growth and its impact through the sectors of agriculture, industry and services.

3.3 Theoretical Framework.

This paper examines the direct and sectoral passthrough effects of climate change on economic growth in Uganda through the endogenous growth theoretical framework. According to this theoretical framework, the long-run economic growth of any economy is due to new technological knowledge generated through the internal forces of an economic system (Aghion et al., 2015). According to the endogenous theoretical framework, innovation is critical for increasing productivity and stimulating economic growth. This framework is modified to understand the direct and sectoral passthrough effects of precipitation and temperature on Uganda's economic growth.

Within the endogenous growth theory, climate variability is expected to cause the depreciation of capital, thus causing the need for technological innovations to sustain constant or increasing marginal returns to capital. Indeed, a recent paper by the International Monetary Fund (IMF, 2019) identifies that climate change and climate change policies would have a similar impact on the valuation of financial assets, just like new technologies, technological policies and political risks.

To complete the theoretical framework, climate variability (precipitation and temperature) is included as a policy variable in the endogenous growth framework. This approach follows a similar path—but with a modification—of the theoretical framework used by Bhaskara and Rao (2008). The modification allows for the inclusion of climate variability (temperature and precipitation) as a policy variable in the endogenous economic growth framework.

The resultant model builds on a Cobb-Douglas production function in the same way as Muvawala et al. (2021) and Bhaskara & Rao (2008):

$$Y_t = A_t K_t^{\alpha} {L_t}^{1-\alpha} \qquad (1)$$

Dividing through by labour to obtain the intensive form of equation (1), we get:

$$y_t = A_t k_t^{\alpha} \qquad (2)$$

Where: $y_t = Y_t/L_t$ is output per worker; and $k_t = K_t/L_t$ is capital per worker.

From equation (2), we can determine the growth rate of A_t:

$$A_t = A_0 e^{g_A t} \qquad (3)$$

Equation (3) shows that technology grows exogenously at a rate g_A. This is in line with the Solow growth theoretical framework. The critical task is to determine which factors influence the growth rate of technology. The study reviewed previous theoretical and empirical studies to assess the factors that influence the growth rate of technology.

We start with the framework of the Solow growth model. Within this framework, technology is assumed to grow exogenously. The framework further indicates that technology growth rate g_A is influenced by variables like research and development (R&D), technology transfer, and several economic policies.

The second is to determine the economic policies likely to affect technology growth. Climate change policies are among the key economic policies that are likely to influence the growth rate of technology. Policies designed to reduce the negative impact of climate change are likely to impact technology growth. Several previous empirical studies justify this. Indeed, numerous studies like Cramer et al. (2006), Coninck et al. (2007), and Lybbert and Sumner (2012): all have shown how climate change mitigation policies have induced technological innovations.

Therefore, climate variability, i.e., changes in precipitation and temperature variations, is expected to influence the technology growth rate. As a result, climate variability is incorporated into the endogenous growth framework as a policy variable that affects technology. Endogenizing technology growth is in line with Ha and Howitt (2007). Therefore, the growth rate of technology following the findings above can be expressed as:

$$g_A = \frac{\dot{A}}{A} = \theta_0 + \theta_1 Z \qquad (4)$$

Equation (4) indicates that technology growth rate g_A is a function of a vector of several policy variables. From previous studies, such variables include climate change policy choices affecting the level of temperatures and precipitation, macro-economic stability, level of trade openness (exports as a percentage of GDP), fiscal policy choices, and foreign direct investment, to mention but a few.

By substituting equation (4) on the growth rate of technology within equation (3), we obtain:

$$A_t = A_0 e^{(\theta_0 + \theta_1 z)t} \qquad (5)$$

Now, replacing for A_t from equation (5) in equation (2), we get:

$$y_t = A_0 e^{(\theta_0 + \theta_1 Z)t} k_t^{\alpha} \qquad (6)$$

Expressing equation (6) into elasticities and taking the first order condition (differentiation) with respect to time (*t*), we obtain equations (7) and (8), respectively:

$$ln\, y_t = ln\, A_0 + \theta_0 t + \theta_1 Zt + \alpha\, ln\, k_t \qquad (7)$$

$$\Delta\, ln\, y_t = \theta_0 + \theta_1 Z + \alpha \Delta\, ln\, k_t \qquad (8)$$

In a steady state $\Delta lnkt$ = 0. As a result, any growth in y_t (GDP per capita), is due to the growth rate of technological progress. Further, several other policy variables also affect the technology growth rate:

$$\Delta\, ln\, y^* = \theta_0 + \theta_1 Z^* \qquad (9)$$

From equation (9), the steady state condition, GDP growth is determined by policy variables influencing technological growth. However, these variables are generally non-stationary, representing variables like climate change policy choices affecting temperatures and precipitation, macroeconomic stability, level of trade openness (export as a percentage of GDP), fiscal policy choices, and foreign direct investment. Therefore, we estimate equation (7) to control for spurious results. Equation (7) can be represented at the steady state as our theoretical model for estimation, and we obtain equations (10) and (11) as:

$$ln\, y_t^* = ln\, A_0^* + \theta_0 t^* + \theta_1 Zt^* + \alpha\, ln\, k_t^* \qquad (10)$$

Or;

$$lnY_t^* = Intercept + \theta_0 t^* + \theta_1 Zt^* + \alpha\, ln\, K\, PC_t^* \qquad (11)$$

Where Y_t^* is GDP growth rate at time *t*; *Z* is a vector of economic policy variables affecting technology growth that include climate change measured by temperature and precipitation, macroeconomic stability measured by inflation, fiscal policy measured by government expenditure, trade openness measured by exports as a percentage of GDP, and *KPC* is the capital stock.

3.4 Empirical Model

From equations (11), we obtain our initial model for empirical estimation as:

$$lnY_t = \beta_0 + \beta_1 \ln y_{t-1} + \beta_2 ln\dot{L}_t + \beta_3 ln\dot{K}_t + \beta_4 ln\, C_t + \delta_i \sum_{n=1}^{N} X_t + u_t \quad (12)$$

$i = 1, 2, \dots\dots. Nt = 1, 2, \dots\dots.. T.$

$u_t \sim IID(0, \delta_u^2)$; E $(u_t, x_t) = 0$;E $(u_t, C_t) = 0$.

Where Y_t is the GDP growth rate, *Ct* is the vector of climatic factors, including temperature and precipitation; and X_t is a vector of other variables affecting economic growth.

As earlier presented, we note that the impact of climate change on economic growth could be through sectoral channels of agriculture, industry, or services sectors (Kagundu, 2006). To obtain the indirect impact of climate variability on economic growth, we first estimate the impact of climate variability on the sectoral shares of GDP for agriculture, industry and services. Therefore, we obtain the empirical estimation as follows:

$$lnS_t = \beta_0 + \beta_1 \ln S_{t-1} + \beta_2 ln\dot{L}_t + \beta_3 ln\dot{K}_t + \beta_4 ln\, C_t + \delta_i \sum_{n=1}^{N} X_t + u_t \quad (13)$$

$i = 1, 2, \dots\dots. Nt = 1, 2, \dots\dots.. T.$

$u_t \sim IID(0, \delta_u^2)$; E $(u_t, x_t) = 0$; E $(u_t, C_t) = 0$.

Where *St* is a vector of sectoral shares of GDP for agriculture, industry and services sectors; and C_t is a vector of the climatic variables, including precipitation and temperature.

Therefore, to complete our model for the indirect impact of climate change on growth, we include the interaction term between climatic variable (C_t) and sector share to GDP, as well as temperature variation and sector contribution to growth; such that the next model for estimation become:

$$lnY_t = \beta_0 + \beta_1 \ln y_{t-1} + \beta_2 ln\dot{L}_t + \beta_3 ln\dot{K}_t + \beta_4 lnppt_t + \gamma_i \sum_{m=1}^{M} ppt_t\,(lnSect_t) + \delta_i \sum_{n=1}^{N} X_t + u_{it} \quad (14)$$

Where; $E\,(u_t, ppt_t(\ln Sect_t) = 0$, and *Sect* is a vector of agriculture, industry and services sector contribution to GDP.

$$lnY_t = \beta_0 + \beta_1 \ln y_{t-1} + \beta_2 ln\dot{L}_t + \beta_3 ln\dot{K}_t + \beta_4 lnTemp_t$$
$$+\emptyset_i \sum_{m=1}^{M} Temp_t\,(lnSect_t) + \delta_i \sum_{n=1}^{N} X_t + u_{it} \qquad (15)$$

Where; $E(u_t, Temp_t(\ln Sect_t) = 0$; and *Temp* and *Ppt* are temperature and precipitation, respectively.

4. Results and Discussion.

This section presents the empirical results of the study. It builds from the descriptive statistics, shows the long-run and short-run effects of the empirical analysis, and discusses these findings.

4.1 Descriptive Statistics and Diagnostic Tests for Study Variables

4.1.1 Trend Analysis

The trend analysis depicts less evidence pointing to the possibility of stationarity of the study variables, save for the GDP growth. The GDP growth figure shows a somewhat steady movement around the mean, although this is not a sufficient evidence to conclude about the stationarity of the variable. For all other variables, the possibility of stationarity is highly ruled out in line with their trends, as illustrated in Figure A1.

4.1.2 Multicollinearity Test

According to the results in Table A1, precipitation and temperature are highly correlated (-0.85), as expected. This implies that the two variables cannot be used in the same model. The correlation is also extremely high between imports and capital stock (0.943). This implies that most of the imports made in Uganda are capital imports. Thus, to avoid the possibility of multicollinearity, the two variables cannot be used in the same model. In addition, interest rate and inflation are highly and negatively correlated, as expected, at 87 percent; as well as domestic savings and trade openness. According to Gujarati (1995), when explanatory variables are highly correlated, they should not be used in the same model as regressors. Therefore, interest rate, savings and imports were dropped from the model. This was done to avoid multicollinearity problems.

4.1.3 Unit Root Test Results

The augmented Dickey-Fuller (ADF) and Phillips Peron (PP) tests were used to establish the time series characteristics of the variables. The results presented in Table A2 indicate the existence of a unit root in all the variables used in the analysis at levels. However, all the variables become stationary after their first difference in the ADF and the PP models. Therefore, the null hypothesis of unit root existence in the variables' levels could not be rejected at a 5 percent significance level. Still, it was rejected for the first difference, as presented in Table A2. The implication of the unit root test results is that the ordinary least squares estimation technique could not be utilised to estimate the model.

Therefore, a cointegration test was conducted to understand the data's behaviour further. This follows in the next sub-section after discussion of the lag length selection criterion.

4.1.4 Optimal Lag Length Selection

The selection of the lag order is one of the key elements of empirical research, particularly one that is based on the vector autoregressive model, as all inferences in the model are reliant on the right model specification. Economic theory may occasionally serve as a guidance when choosing lag lengths, but there are statistical techniques that can be used to decide how many lags should be included as explanatory variables. In general, adding too many delays causes the standard errors of coefficient estimates to grow, which implies an increase in forecast error; while leaving out necessary lags can lead to estimation bias. In this study, we establish that lag 1 is the ideal lag length using the Akaike information criterion, Schwarz information criterion, and the Hannan-Quinn information criterion (see results of choosing the best lag length in Table A8).

4.1.5 Cointegration Test

This study utilises the Johansen system cointegration test to perform a multivariate test of cointegration. This test procedure estimates a vector autoregressive (VAR) model, which includes differences and levels of the non-stationary variables. In a multivariate cointegration test, the interest was to establish whether at least one cointegrating vector exists. The results of the test are presented in Table A3. Both the trace statistic and the maximum Eigen value statistics indicate the existence of one cointegrating equation at 5 percent significance level. Relaxing the significance level to 10 percent, the trace statistic suggests the existence of two cointegrating equations; while the maximum eigen statistic still indicates the presence of one cointegrating relation. The confirmation of cointegration among the variables indicates that long-run effects exists between them. Consequently, the null hypothesis of no cointegration was rejected.

4.2 Empirical Results

The analysis of the estimated cointegration results explores the long-run dynamics of the estimated model utilising cointegration analysis. In the second part, the Vector Error Correction Model (VECM) is estimated to obtain the short-run dynamics of the estimated model. The estimated VECM is used to generate impulse response functions to trace the impact of shocks to climate variability on economic growth. The short-run effects of shocks by climate change on economic growth are presented in impulse response diagrams.

4.2.1 Climate Change (Precipitation) Effects on Sectoral Output Growth

As stated in the theoretical model, to obtain the indirect impact of climate variability on economic growth, we first estimate the impact of climate variability on the agriculture, industry, and services sectoral shares of GDP. Table 2 shows the effects of climate change (precipitation) on sectoral output growth. Precipitation has a positive impact on agriculture and industry, while having a negative impact on services, as predicted. This is expected since Uganda's agriculture is largely rainfed; and thus precipitation increases agricultural production, which then directly affects inputs into industry through value-chain linkages as food processing is a significant share of manufacturing. However, precipitation has a negative impact on the services sector. This is partly due to the negative impact of prolonged rains on transportation infrastructure and services.

Table 2: Climate Change (Precipitation) Effects on Sectoral Output Growth

AGRI_GDP (-1)		**IND_GDP (-1)**		**SVC_GDP (-1)**	
PRECIP (-1)	0.004278 (0.00080) [5.32288]	PRECIP (-1)	0.005372 (0.00147) [3.66078]	PRECIP (-1)	-0.004130 (0.00117) [-3.53379]
GE (-1)	2.360764 (0.06175) [38.2322]	GE (-1)	-2.194600 (0.12759) [-17.2001]	GE (-1)	-1.684908 (0.08898) [-18.9357]
INF (-1)	-0.047290 (0.00303) [-15.6165]	INF (-1)	0.013207 (0.00521) [2.53329]	INF (-1)	0.056863 (0.00407) [13.9582]
KS (-1)	0.878153 (0.02511) [34.9743]	KS (-1)	-0.682514 (0.04861) [-14.0410]	KS (-1)	-0.385234 (0.03982) [-9.67341]
POP (-1)	19.30622 (0.57651) [33.4881]	POP (-1)	-15.77711 (1.11106) [-14.2000]	POP (-1)	-17.22138 (0.85335) [-20.1808]
FDI (-1)	2.162733 (0.11854) [18.2453]	FDI (-1)	3.129569 (0.24636) [12.7035]	FDI (-1)	-1.244455 (0.17864) [-6.96636]
TO (-1)	0.152006 (0.03866) [3.93220]	TO (-1)	-1.319236 (0.07602) [-17.3536]	TO (-1)	0.374210 (0.05884) [6.35962]
C	-152.5002	C	73.54870	C	44.37284

Source: Author's computations

4.2.2 Climate Change (Temperature) Effects on Sectoral Output Growth

Table 2 shows the effects of climate change (temperature) on sectoral output growth. The results confirm that variations in temperature negatively affect both agriculture and industry sectors as high temperature seasons are directly linked to drought seasons, hence affecting agricultural production and inputs into agro-processing for industry. However, the effect of temperature is positive for service sector output growth.

Table 3: Climate Change (Precipitation) Effects on Sectoral Output Growth

AGRI_GDP (-1)		IND_GDP (-1)		SVC_GDP (-1)	
TEMP (-1)	-2.249368 (0.58334) [-3.85598]	TEMP (-1)	-2.549781 (0.17377) [-14.6733]	TEMP (-1)	4.298253 (1.01409) [4.23854]
GE (-1)	2.657384 (0.08308) [31.9840]	GE (-1)	-1.050476 (0.02776) [-37.8407]	GE (-1)	-1.868760 (0.13358) [-13.9898]
INF (-1)	-0.052386 (0.00397) [-13.2119]	INF (-1)	-0.007653 (0.00111) [-6.87933]	INF (-1)	0.056449 (0.00631) [8.94600]
KS(-1)	0.740788 (0.03198) [23.1666]	KS (-1)	-0.724345 (0.00976) [-74.2155]	KS (-1)	-0.576809 (0.06033) [-9.56025]
POP (-1)	20.73147 (0.76401) [27.1352]	POP (-1)	-9.072826 (0.24216) [-37.4664]	POP (-1)	-19.21710 (1.27863) [-15.0295]
FDI (-1)	1.817568 (0.17513) [10.3784]	FDI (-1)	0.688153 (0.05520) [12.4676]	FDI (-1)	-1.762130 (0.28998) [-6.07670]
TO (-1)	0.477128 (0.06452) [7.39538]	TO (-1)	-0.579418 (0.01900) [-30.5007]	TO (-1)	0.685672 (0.11580) [5.92104]
C	-103.2274	C	102.5526	C	-52.46830

Source: Author's computations

4.2.3 Long-Run Direct effects of Climate change on Economic Growth.

The VEC model and the Johansen cointegration test produce the long-run empirical effects between climate change, GDP growth, inflation and gross capital formation, FDI, imports, savings and trade openness. For economic interpretation of the long-run results, GDP growth was normalised. The results for both models (precipitation and temperature models) are summarised in Table 4.

Overall, the study found that climate change (temperature) negatively and significantly impacts economic growth in the long-run; however, the effect is non-significant in the short-run. The results indicate that an increase in temperature by 1^{0}C reduces economic growth by approximately 2.5 percentage points, keeping all other factors constant. Also, the results suggest that climate change (precipitation) has a positive long-run impact on economic growth. With an increase in precipitation by 1mm, economic growth increases by 0.35 percentage points, keeping all other factors constant. This finding implies that an increase in the amount of precipitation received in any calendar year enhances productivity and production, thus leading to accelerated economic growth. However, this can only be concluded after undertaking a sectoral analysis to understand the sectoral passthrough impact of precipitation and temperature on economic growth.

Table 4: Long-run Impact of Climate Change (Precipitation & Temperature) on Economic Growth

Cointegrating Eq1:	CointEq1	Cointegrating Eq2:	CointEq2
GDPG (-1)	1.000000	GDPG (-1)	1.000000
PRECIPITATION (-1)	0.003498 (0.00079) [4.41504]	TEMPERATURE (-1)	-2.481298 (0.41939) [-5.91644]
GE (-1)	0.089105 (0.06118) [1.45655]	GE (-1)	0.118120 (0.06014) [1.96407]
INF (-1)	- 0.023982 (0.00275) [-8.73579]	INF (-1)	-0.026250 (0.00270) [-9.71656]
KS (-1)	0.079500 (0.02465) [3.22460]	KS (-1)	0.060903 (0.02271) [2.68230]
POP (-1)	0.748402 (0.54130) [1.38261]	POP (-1)	2.590092 (0.55896) [4.63381]
TO(-1)	-0.095035 (0.04410) [-2.15517]	TO(-1)	-0.279181 (0.04788) [-5.83145]
FDI(-1)	0.955136 (0.13727) [6.95803]	FDI(-1)	1.495379 (0.14137) [10.5779]
C	-0.686885	C	56.50472
R-squared	0.529326	R-squared	0.538738
Adj. R-squared	0.108197	Adj. R-squared	0.126031
Sum sq. resids	149.2257	Sum sq. resids	146.2417
S.E. equation	2.802496	S.E. equation	2.774334
F-statistic	1.256922	F-statistic	1.305375
Log-likelihood	-78.29976	Log-likelihood	-77.92607
Akaike AIC	5.205392	Akaike AIC	5.185193

Note: Standard errors in () & t-statistics in [ ]

Source: Author's computations.

The findings of this study are in line with Abidoye (2015), who showed that a 1°C increase in temperature reduces gross domestic product (GDP) growth by

0.67 percentage points. The findings are also in agreement with Kahn and Mohaddes (2019), who used a panel of 174 countries over the years 1960 to 2014, and revealed that per capita real output growth is adversely affected by persistent changes in the temperature above or below its historical norm. The study showed that an increase in average global temperature by 0.04^{0}C per year will reduce real world GDP per capita by more than 7 percent by 2100 (ibid.). The findings of this study are further supported by Kahn et al. (2019), who used data on a sample of 48 US states between 1963 and 2016, and found that climate change has a long-lasting adverse impact on real output in various economic sectors of the states.

4.2.4 Long-run Indirect (Sectoral Passthrough) Effect of Climate Change on Economic Growth

To understand the sectors through which climate change mainly impacts economic growth, we estimated two interacted models between climate change (precipitation and temperature) and sectoral GDP contributions. The transmission results are presented in Tables 5 and 6, respectively.

In the first model, the results indicate that climate change (precipitation) primarily affects economic growth in the agriculture sector positively. Although the impact of climate change (precipitation) on economic growth through industry and service sector is positive, it is not statistically different from zero. The second aspect is that a rise in average temperatures, measured in degrees Celsius, negatively affects Uganda's economic growth. The results have shown that the impact is more substantial in the agriculture and service sectors. Other variables used in the analysis that have a negative effect on economic growth include inflation and trade openness. However, the impact of trade openness is not statistically different from zero since the associated t-statistic is less than the conventional 1.96. Finally, capital stock, population and government expenditure positively impact economic growth in the long-run. However, the impact of government expenditure is not statistically different from zero since the associated t-statistic is less than the conventional 1.96, as seen in Table 5.

This finding is in line with several empirical evidence on global warming that is projected to affect economic performance globally. For example, Arndt et al. (2012) used structural models of agriculture and infrastructure systems to find the implications of climate change on developing countries, and found that climate change complicates the already formidable task of fomenting long-run development. In addition, the findings are in line with a study by Akram (2012). Using a growth model by incorporating temperature and precipitation as proxies for climate change in the production function, and a fixed effect model (FEM) and seemingly unrelated regression to estimate the model, Akram (ibid.) found that economic growth is negatively affected by changes in temperature, precipitation and population growth; and that while agriculture is the most vulnerable sector to climate change, manufacturing is the least affected sector.

Table 5: Long-run Sectoral Passthrough Impact of Climate Change (Precipitation) on Economic Growth

Cointegrating Eq1:	CointEq1	Cointegrating Eq2:	CointEq2	Cointegrating Eq3:	CointEq3
GDPG(-1)	1.000000	GDPG(-1)	1.000000	GDPG(-1)	1.000000
PRECIP (-1)*IND_GDP(-1)	0.000214 (0.00014) [1.58336]	PRECIP (-1)*AGRI_GDP(-1)	7.01E-05 (3.4E-05) [2.05744]	PRECIP (-1)*SVC_GDP(-1)	2.84E-05 (4.6E-05) [0.62218]
GE(-1)	0.166657 (0.13028) [1.27924]	GE(-1)	0.189534 (0.16595) [1.14211]	GE(-1)	0.083757 (0.10696) [0.78307]
INF(-1)	-0.051876 (0.00840) [-6.1770]	INF(-1)	-0.040533 (0.00685) [-5.91491]	INF(-1)	-0.04093 (0.00664) [- 6.1609]
KS(-1)	0.408861 (0.11576) [3.53194]	KS(-1)	0.308943 (0.08312) [3.71686]	KS(-1)	0.143022 (0.05293) [2.70233]
POP(-1)	3.666385 (1.83136) [2.00200]	POP(-1)	0.379597 (1.26447) [0.30020]	POP(-1)	2.785916 (1.49786) [1.85993]
TO(-1)	-0.178054 (0.11658) [-1.52731]	TO(-1)	-0.046901 (0.06099) [-0.76895]	TO(-1)	-0.159168 (0.07579) [-2.10008]
C	-21.68103	C	-18.75778	C	-16.21899
R-squared	0.707019	R-squared	0.655996	R-squared	0.660399
Adj. R-squared	0.497747	Adj. R-squared	0.410279	Adj. R-squared	0.417827
Sum sq. resids	10631.08	Sum sq. resids	6.61E+08	Sum sq. resids	0.083010
S.E. equation	22.49982	S.E. equation	5609.060	S.E. equation	0.062872
F-statistic	3.378471	F-statistic	2.669722	F-statistic	2.722485
Log-likelihood	157.2222	Log-likelihood	-361.4115	Log-likelihood	60.34395
Akaike AIC	9.363361	Akaike AIC	20.40062	Akaike AIC	-2.396970
Schwarz SC	10.05997	Schwarz SC	21.09724	Schwarz SC	-1.700357
Mean dependent	1.254889	Mean dependent	-1240.808	Mean dependent	0.013726
S.D. dependent	31.74811	S.D. dependent	7304.102	S.D. dependent	0.082400

Source: Output from Eviews10

In the second model, the results indicate that climate change (temperature) impacts economic growth through the agriculture and service sectors in a negative direction. However, although the impact of temperature on economic growth through industry is negative, it is not statistically different from zero. In addition, inflation is established to have an adverse long-run impact on economic growth in Uganda. In contrast, capital stock, population, government expenditure and trade openness have a positive long-run effect on economic growth in both models. However, the impact of government expenditure and trade openness are not statistically different from zero since the associated t-statistic is less than the conventional 1.96, as seen in Table 6. This finding agrees with evidence from Ayinde et al. (2011): that temperature change generated a negative effect in Nigeria, while rainfall change positively impacted agricultural productivity using econometric analysis.

Table 6: Long-run Sectoral Passthrough Impact of Climate Change (Temperature) on Economic Growth

Cointegrating Eq1:	CointEq1	Cointegrating Eq2:	CointEq2	Cointegrating Eq3:	CointEq3
GDPG(-1)	1.000000	GDPG(-1)	1.000000	GDPG(-1)	1.000000
TEMP (-1)*IND_GDP(-1)	-0.001931	TEMP (-1)*AGRI_GDP(-1)	-0.007604	TEMP (-1)*SVC_GDP(-1)	-0.042425
	(0.01093)		(0.00249)		(0.00507)
	[-0.17669]		[- 3.05795]		[-8.36193]
GE(-1)	0.000282	GE(-1)	0.457293	GE(-1)	2.346748
	(0.28473)		(0.16454)		(0.30530)
	[0.00099]		[2.77914]		[7.68669]
INF(-1)	-0.086994	INF(-1)	-0.049673	INF(-1)	-0.123615
	(0.00929)		(0.00457)		(0.00883)
	[-9.36668]		[-10.8615]		[-13.9996]
KS(-1)	0.395478	KS(-1)	0.461423	KS(-1)	0.046989
	(0.19195)		(0.06665)		(0.08578)
	[2.06028]		[6.92335]		[0.54781]
POP(-1)	1.740863	POP(-1)	4.242689	POP(-1)	-19.79481
	(2.56801)		(1.28270)		(2.56512)
	[0.67790]		[3.30762]		[-7.71693]
TO(-1)	0.268292	TO(-1)	0.090830	TO(-1)	0.400584
	(0.15385)		(0.05966)		(0.11158)
	[1.74384]		[1.52247]		[3.59006]
C	-7.359666	C	-39.98108	C	46.78241
R-squared	0.644536	R-squared	0.639750	R-squared	0.814148
Adj. R-squared	0.390633	Adj. R-squared	0.382428	Adj. R-squared	0.681397
Sum sq. resids	44.99831	Sum sq. resids	0.088057	Sum sq. resids	6743.798
S.E. equation	1.463823	S.E. equation	0.064755	S.E. equation	17.92019
F-statistic	2.538514	F-statistic	2.486185	F-statistic	6.132893
Log-likelihood	-56.12131	Log-likelihood	59.25193	Log-likelihood	-148.8017
Akaike AIC	3.898449	Akaike AIC	-2.337942	Akaike AIC	8.908203
Schwarz SC	4.595062	Schwarz SC	-1.641329	Schwarz SC	9.604816
Mean dependent	0.086494	Mean dependent	0.013726	Mean dependent	-1.254889
S.D. dependent	1.875206	S.D. dependent	0.082400	S.D. dependent	31.74811

Source: Authors' Computations

In a nutshell, the long-run analysis has established that economic growth is affected by climate change in two aspects. The first one is that the rise in the amount of precipitation or downpours received positively affects economic growth, and the impact is significant in the agriculture sector. This is most likely true since agriculture remains the backbone of Uganda's economy, yet agriculture is majorly rainfed. The second aspect is that the rise in average temperatures, measured in degrees Celsius, negatively affects Uganda's economic growth. But, again, the results have shown that the impact is more substantial in the agriculture and service sectors. This finding is consistent with studies that report the impact of global warming on global economic performance. However, temperature and precipitation have an insignificant short-run direct and indirect impact on economic growth.

4.2.5 Granger Causality Test

The Granger causality test is a statistical test for detecting whether one time series is helpful in anticipating another. The Granger test for causality looks for the direction of causation between groups of independent and dependent variables. Hence, to determine if one time series is helpful in forecasting another, the Granger causality test is used. If it can be demonstrated that the explanatory factors offer statistically significant insights into the future values of the explained variable, the explanatory variable is said to be the Granger cause of the other. There are three possible results for causal effects: the absence of any causal relationship, the unidirectional causality from one variable to another or vice versa, and the bidirectional causality between the two variables. The study added the Granger causality test to empirical results, and the findings are as presented in Table 7.

Table 7: Granger Causality Test Results

Null Hypothesis:	Obs.	F-Statistic	Prob.
LOGPRECIP does not Granger cause AGRI_GDP	39	5.30334	0.0272
AGRI_GDP does not Granger cause LOGPRECIP		1.57722	0.2173
LOGPRECIP does not Granger cause IND_GDP	39	2.50053	0.0975
IND_GDP does not Granger cause LOGPRECIP		0.82959	0.4451
LOGPRECIP does not Granger cause SVC_GDP	39	5.73231	0.0220
SVC_GDP does not Granger cause LOGPRECIP		6.10209	0.0184
LOGTEMP does not Granger cause AGRI_GDP	39	7.37313	0.0101
AGRI_GDP does not Granger cause LOGTEMP		11.1926	0.0019
LOGTEMP does not Granger cause IND_GDP	39	4.43273	0.0197
IND_GDP does not Granger cause LOGTEMP		1.66878	0.2040
LOGTEMP does not Granger cause SVC_GDP	39	13.1379	0.0009
SVC_GDP does not Granger cause LOGTEMP		12.3180	0.0012

Source: Authors' Computations.

The findings revealed a unidirectional causation from precipitation to agriculture GDP, suggesting that rainfall granger caused agriculture GDP to increase, but the reverse was not true. However, there was a bidirectional causation between temperature and agriculture GDP, suggesting that each granger caused the other. In addition, precipitation granger caused industry GDP, though at 10% level of significance; and there was no observed revered causation. This was also the case with temperature. On the other hand, there was observed bidirectional causation between precipitation, temperature and service sector GDP.

4.2.6 Model Diagnostic Checks

In this sub-section, the results of the diagnostic checks conducted on the models estimated to achieve the study's objectives are presented and analysed. These checks were performed to avoid making inferences about results based on unreliable models. In addition, this study considers the serial correlation, normality, and heteroskedasticity tests, as discussed hereunder.

Serial Correlation LM Tests

Serial correlation and heteroskedasticity tests are conducted to ensure that the errors are not serially correlated and heteroscedastic. If the errors are serially correlated and heteroskedastic, it implies that the estimators in this study are inefficient, although they would be consistent. Following the estimation of the VEC model, the VEC residual serial correlation LM test results are presented in Table 8. According to the results, the null hypothesis of no serial correlation could not be rejected since the P-values are higher than the 5 percent level, so there is no serial correlation in the model estimated.

Table 8: VEC Residual Serial Correlation LM Test

Null hypothesis: No serial correlation at Lag *h*						
Lag	***LRE* stat***	***df***	***Prob.***	***Rao F-stat***	***df***	***Prob.***
1	55.22542	64	0.7747	0.687784	(64, 29.6)	0.8937
2	71.23755	64	0.2497	1.035724	(64, 29.6)	0.4713

Source: Author's Computations

Heteroskedasticity Tests

The heteroskedasticity tests are conducted to ensure that the errors are not heteroskedastic. If the errors are heteroskedastic, it implies that the estimators in this study are consistent, although they would be inefficient. Following the estimation of the VEC model, the VEC residual heteroskedasticity test results are presented in Table 9.

Table 9: VEC Residual Heteroskedasticity Tests Results

Joint Test		
Chi-sq.	**df**	**Prob.**
1258.000	1224	0.2437

Source: Author's computations

According to the results, the null hypothesis of homoskedasticity could not be rejected since the P-values are higher than the 5 percent level, so there is no heteroskedasticity in the model estimated.

Normality Tests
This study's normality test of the residuals is based on the skewness, Kurtosis and the joint Jarque-Bera statistic with the corresponding probability value. The test statistics of the skewness, Kurtosis and the joint Jarque-Bera statistic are presented in Table A7. According to the results, corresponding p-values of the skewness and Kurtosis are insignificant for all the components. This implies the normality of the residuals. In addition, the p-values and the joint Jarque-Bera are higher than the conventional 5 percent significance level. The joint Jarque-Bera Statistic of 9.222 and corresponding joint probability value of 0.904 indicate that the residuals are approximately normally distributed with a mean zero and a constant variance. This is necessary to determine the estimated dynamic model's stability and reliability.

Stability Test
The cumulative sums (CUSUM) graphs in Figure 4 show that the coefficient of the short-run lies within the critical limits; and indicates stability in the coefficients over the sample period. Similarly, the inverse roots of the AR characteristics polynomial are all within the circle (Figure 5); suggesting a stable model to make inferences.

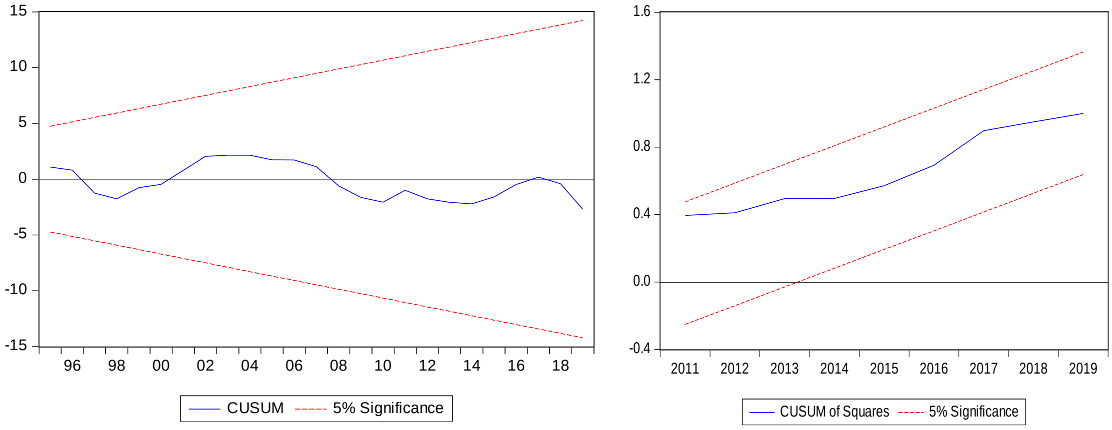

Figure 4: Cumulative Sum Test (CUSUM) and CUSUM of Squares

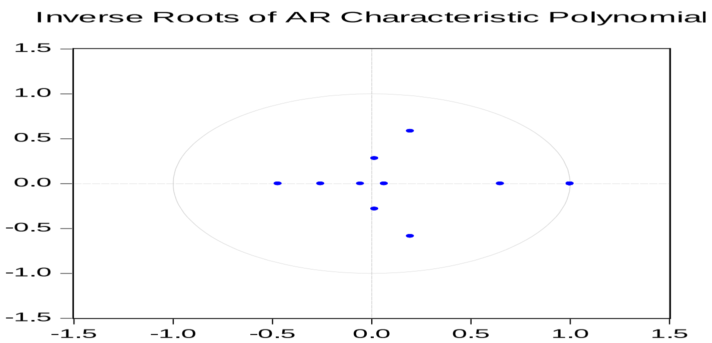

Figure 5: Inverse Roots of AR Characteristics Polynomial

In conclusion, the model diagnostic checks conducted confirm the suitability of the choice of the model used and the reliability of the results.

5. Conclusions and Recommendations

5.1 Conclusions

In conclusion, this study aimed to examine the effects of climate variability on economic growth by examining both the direct and indirect (sectoral passthrough) impacts of climate change on economic growth in Uganda within the framework of the endogenous growth theory. The paper extended and modified the model by Bhaskara and Rao (2008) to allow for the inclusion of climate variability as a policy variable in the endogenous economic growth framework. This model was built on the principles of a Cobb-Douglas production function in line with Bhaskara and Rao, 2008). The study used annual time series data for the period 1980 to 2020. The vector error correction model (VECM) was used in the estimation, in line with the standard time series analysis procedure.

The data on climate change variables (temperature and precipitation) was obtained from NASA Power Prediction of Worldwide Energy Resources, while data on other macroeconomic variables was obtained from the World Development Indicators (WDI) of the World Bank. In this study, we empirically examined the time-series properties of the variables, and the Johansen's cointegration procedure was adopted to test the long-run association between the variables given their non-stationarity in levels. The main conclusion from this analysis is the existence of the long-run effects among climate change, economic growth and all other variables used in the analysis. Furthermore, both the trace statistics and the maximum Eigen value statistics indicated the existence of one cointegrating relation at a 5 percent level of significance.

After estimating, the VEC model indicated that precipitation positively and significantly impacts economic growth. Specifically, an increase in precipitation by 1mm increases economic growth by approximately 0.35 percentage points, keeping all other factors constant. On the other hand, the results indicated that temperature has a negative long-run impact on economic growth. For example, the results showed that an increase in temperature by 1^0C reduces economic growth by approximately 2.5 percentage points, keeping all other factors constant. The results of short-run estimates indicated that although temperature has a negative impact on economic growth, the effect is not statistically significant. The same applies to precipitation, which has positive short-run implications on economic growth, but the effect is not statistically significant.

Regarding the indirect or sectoral paththrough impacts of climate change on economic growth, the study established that climate change (precipitation) impacts economic growth mainly through the agriculture sector, and in a positive direction. According to the results, an increase in precipitation by 1mm increases GDP growth by 7.01E-05 percentage points, holding all other factors constant. On the other hand, although the impact of climate change (precipitation) on economic growth through industry and service sectors was found to be positive, it was not statistically significant. This finding implies that climate change impacts GDP growth through agriculture as the industry and service sectors are less affected by reduced precipitation.

Similarly, the results indicated that climate change (temperature) impacts economic growth mainly through the agriculture and service sectors, and in a negative direction. According to the results, an increase in temperature by 1^0C reduces economic growth by 0.0076 percentage points transmitted through the agriculture sector; and by 0.0424 percentage points transmitted through the service sector. Although the impact of temperature on economic growth through industry was found negative, it is not statistically different from zero.

In a nutshell, the sectoral paythrough effect analysis established that economic growth is affected by climate change in two aspects. The first one is that the rise in the amount of precipitation or downpours received positively affects economic growth, and the impact is significant in the agriculture sector. This is most likely to be true since agriculture remains the backbone of Uganda's economy, though Uganda's agriculture is majorly rainfed. The second aspect is that a rise in average temperatures, measured in degrees Celsius, negatively affects Uganda's economic growth. Again, the results showed that the impact is more robust in the agriculture and service sectors.

5.2 Policy Recommendations

The study has established that climate change manifested through frequent and prolonged dry spells and erratic and poorly distributed rainfall direly affect economic growth directly and indirectly by stifling agriculture production and productivity, accelerating income poverty, suffocating aggregate demand and the general performance of the services sectors. The study thus makes the following policy recommendations.

In the short-run, Uganda should consider accounting for climate change effects in growth accounting frameworks for Uganda. This study has shown the long-term impact of climate change on economic growth, and that the effects may also be in the agriculture, industry and services sectors. However, current growth frameworks do not account for the impacts of climate change by the various growth-enhancing interventions through the sectors of the economy. Therefore, there is need for growth accounting frameworks to consider the damage and improvements in climate change by the various growth-enhancing interventions. This will increase the focus on selecting sustainable development approaches for inclusive and sustainable development.

Additionally, policymakers should promote continuous integration of climate change in planning, budgeting and reporting at national and sector levels. First, Uganda should regularly undertake detailed public expenditure reviews for all sectors to provide information about the tools and information needed to respond to public expenditure policy and management challenges arising from climate change. However, noting that significant resources for climate change-related actions are usually off-budget, it will require establishing statutory provisions that require government ministries, departments and agencies to report off-budget financing. This will enable tracking and reporting on this financing and estimating potential impacts. Climate policy measures should inform all planning and budget processes, including development plans, budgets and guidelines.

In the long-run, the government should invest in building inclusive climate resilient systems while promoting low emissions development at all levels that advance national development goals with minimal or no emission of greenhouse gases. Climate resilient systems include developing models that bring together adaptation to, and mitigation of, climate change impacts to realise sustainable development. While Uganda pursues an ambitious industrialisation agenda, there is a need for a development model that balances increasing growth while accounting for environmental sustainability. As a result, there will be need to advance clean industrialisation technologies. A cost-benefit analysis of the additional cost of these technologies versus the averted cost of environmental destruction should be undertaken.

Moreover, the government should strengthen and establish institutional mechanisms that foster resource inflows from the global climate finance windows to supplement local finances in containing climate change effects. This will require building the capacity of various ministries, departments and agencies to prepare appropriate financing proposals, negotiate to finance, and structure key climate change resilience and adaptation projects and programmes.

Lastly, the government needs to undertake the issuance of carbon footprint certificates to support the industrial sector's move toward carbon neutrality. While it pursues an ambitious industrialisation agenda, there is need to encourage voluntary industrial commitment to promoting decarbonisation, and support initiatives that promote environmental sustainability. This will also enable the concurrent realisation of national development aspirations and sustainable development goals.

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Annexes

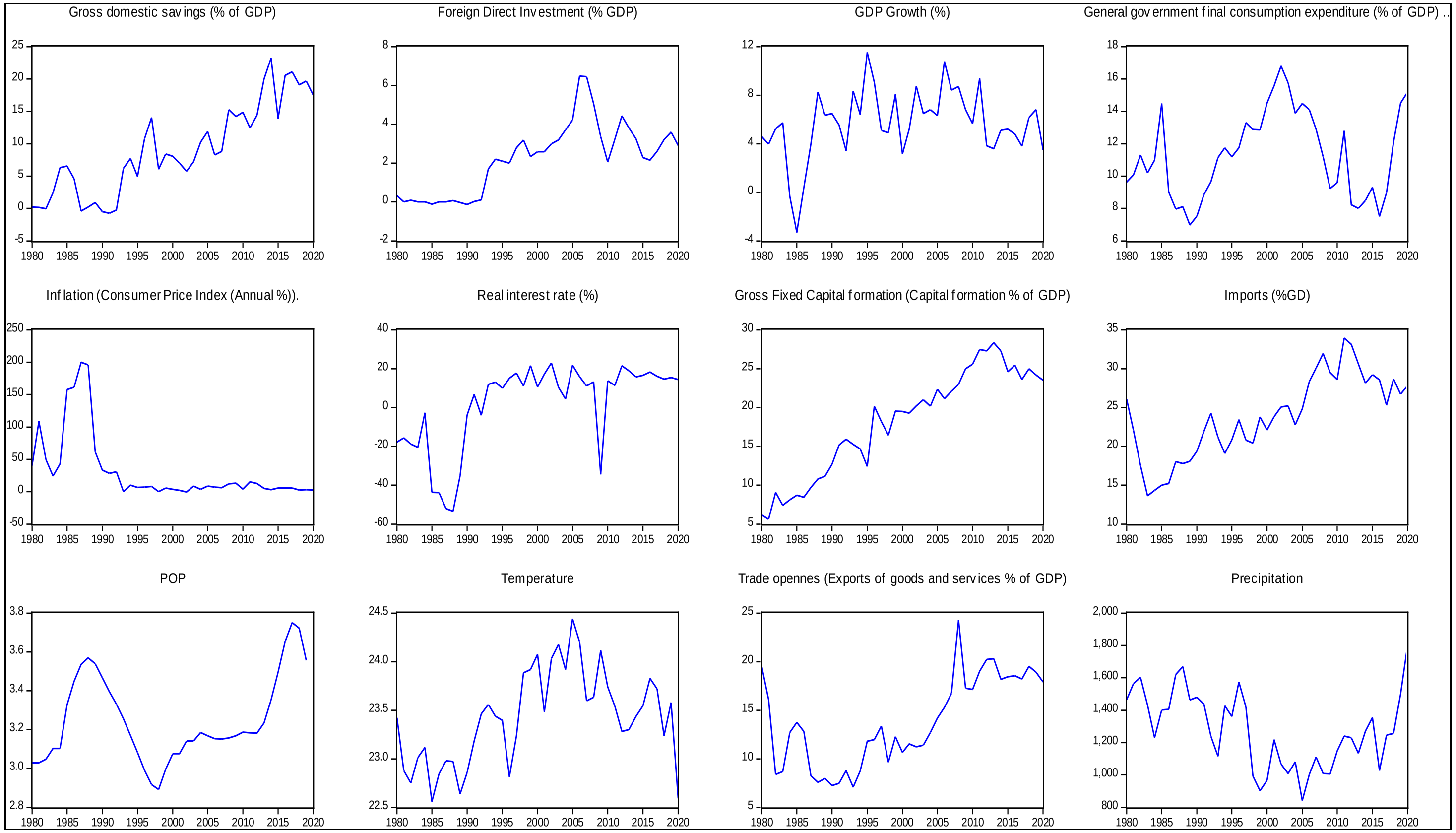


Figure A1: Trend of Study Variables for the Period 1990 – 2020.

Source: Authors' computations

Table A1: Correlation Matrix

	GDP growth	Precipitation	Temperature	Capital	Savings	FDI	Expenditure	Imports	Inflation	Interest Rate	Trade Openness
GDP Growth	1.00										
Precipitation	-0.16	1.00									
Temperature	0.38	-0.85	1.00								
Capital	0.26	-0.39	0.49	1.00							
Savings	-0.02	-0.21	0.25	0.81	1.00						
FDI	0.44	-0.53	0.61	0.73	0.57	1.00					
Expenditure	0.12	-0.27	0.37	0.12	0.05	0.42	1.00				
Imports	0.36	-0.37	0.44	0.94	0.67	0.75	0.06	1.00			
Inflation	-0.38	0.47	-0.52	-0.62	-0.48	-0.57	-0.31	-0.54	1.00		
Interest Rate	0.33	-0.43	0.49	0.67	0.53	0.62	0.37	0.58	-0.87	1.00	
Trade Openness	-0.01	-0.23	0.19	0.71	0.86	0.63	0.02	0.77	-0.33	0.40	1.00

Source: Authors' computations

Table A2: Unit Root Test Results (ADF &PP)

Variables	**ADF**				**Phillips Perron**				**Order of integration**
	Level	***Prob.****	***First Difference***	***Prob.****	***Level***	***Prob.****	***First Difference***	***Prob.****	
Precipitation (with constant only)	-1.927187	0.3192	-12.65648	0.0000	-1.972234	0.2989	-12.65645	0.0000	I(1)
Precipitation (with constant & trend)	-1.598152	0.7898	-12.72037	0.0000	-1.598152	0.7898	-12.72305	0.0000	I(1)
Precipitation (no constant, no trend)	-0.034199	0.6700	-12.68858	0.0000	-0.034406	0.6699	-12.68858	0.0000	I(1)
Temperature (with constant only)	-2.173976	0.2167	-12.65889	0.0000	-2.231678	0.1960	-12.80888	0.0000	I(1)
Temperature (with constant & trend)	-2.131986	0.5238	-12.64945	0.0000	-2.269243	0.4479	-12.89315	0.0000	I(1)
Temperature (no constant, no trend)	-0.396282	0.5398	-12.68858	0.0000	-0.448929	0.5191	-12.84410	0.0000	I(1)
GDP Growth (with constant only)	-3.298416	0.0165	-12.64939	0.0000	-3.450584	0.0106	-13.30837	0.0000	I(0)
GDP Growth (with constant & trend)	-3.310967	0.0681	-12.61757	0.0000	-3.486012	0.0442	-13.28055	0.0000	I(0)
GDP Growth (no constant, no trend)	-1.475042	0.1308	-12.68858	0.0000	-1.291131	0.1810	-13.36352	0.0000	I(1)
Capital stock (with constant only)	-1.604008	0.4782	-12.81329	0.0000	-1.656993	0.4512	-13.86329	0.0000	I(1)
Capital stock (with constant & trend)	-2.275176	0.4447	-12.84876	0.0000	-2.040031	0.5747	-15.12410	0.0000	I(1)
Capital stock (no constant, no trend)	0.790955	0.8827	-12.68858	0.0000	1.218606	0.9428	-12.87559	0.0000	I(1)
FDI (with constant only)	-1.514633	0.5239	-5.259232	0.0000	-1.696889	0.4310	-12.77176	0.0000	I(1)
FDI (with constant & trend)	-1.775776	0.7122	-5.281740	0.0001	-2.181187	0.4964	-12.74647	0.0000	I(1)
FDI (no constant, no trend)	-0.529443	0.4861	-5.245188	0.0000	-0.692069	0.4158	-12.79437	0.0000	I(1)
Expenditure (with constant only)	-1.863437	0.3489	-12.33901	0.0000	-1.922147	0.3215	-12.33899	0.0000	I(1)

Expenditure (with constant & trend)	-1.946970	0.6250	-12.32420	0.0000	-1.974712	0.6101	-12.32412	0.0000	I(1)
Expenditure (no constant, no trend)	-0.080200	0.6544	-12.36932	0.0000	-0.080608	0.6543	-12.36932	0.0000	I(1)
Inflation (with constant only)	-1.971254	0.2993	12.65163	0.0000	-2.119374	0.2374	-12.65162	0.0000	I(1)
Inflation (with constant & trend)	-2.548177	0.3048	-12.61418	0.0000	-2.767766	0.2115	-12.61415	0.0000	I(1)
Inflation (no constant, no trend)	-1.783039	0.0710	-12.68858	0.0000	-1.857236	0.0605	-12.68858	0.0000	I(0)
Interest rate (with constant only)	-2.334257	0.1627	-12.17584	0.0000	-2.239425	0.1934	-13.42527	0.0000	I(1)
Interest rate (with constant & trend)	-2.807763	0.1969	-8.472892	0.0000	-2.822188	0.1917	-13.46821	0.0000	I(1)
Interest rate (no constant, no trend)	-2.268089	0.0230	-12.20656	0.0000	-2.186534	0.0282	-13.30032	0.0000	I(0)
Savings (with constant only)	-1.715122	0.4217	-12.38007	0.0000	-1.576521	0.4922	-13.11375	0.0000	I(1)
Savings (with constant & trend)	-3.441593	0.0497	-12.34068	0.0000	-3.651088	0.0288	-13.05177	0.0000	I(0)
Savings (no constant, no trend)	-0.346253	0.5589	-12.36932	0.0000	0.004953	0.6828	-12.78479	0.0000	I(1)
Imports (with constant only)	-1.378846	0.5916	-12.65017	0.0000	-1.435839	0.5635	-12.65016	0.0000	I(1)
Imports (with constant & trend)	-3.387488	0.0566	-12.65016	0.0000	-3.451996	0.0482	-12.65003	0.0000	I(0)
Imports (no constant, no trend)	-0.182081	0.6192	-12.68858	0.0000	-0.182405	0.6191	-12.68858	0.0000	I(1)
Openness (with constant only)	-1.950007	0.3088	-12.64978	0.0000	-1.966777	0.3013	-12.64996	0.0000	I(1)
Openness (with constant & trend)	-3.659428	0.0280	-12.69268	0.0000	-3.662108	0.0278	-12.69932	0.0000	I(0)
Openness (no constant, no trend)	-0.694841	0.4145	-12.68858	0.0000	-0.690183	0.4166	-12.68933	0.0000	I(1)

Source: Authors' computations

Table A3: Cointegration Test Results

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.397041	303.5802	273.1889	0.0012
At most 1	0.296946	226.1767	228.2979	0.0625
At most 2	0.236563	172.2715	187.4701	0.2259
At most 3	0.189821	130.9730	150.5585	0.3670
At most 4	0.178741	98.76645	117.7082	0.4170
At most 5	0.138674	68.63812	88.80380	0.5604
At most 6	0.100888	45.79789	63.87610	0.6099
At most 7	0.095190	29.52663	42.91525	0.5304
At most 8	0.067034	14.22198	25.87211	0.6393
At most 9	0.023292	3.605765	12.51798	0.7981

Note: Trace test indicates 1 cointegrating eqn(s) at the 0.05 level.
* denotes rejection of the hypothesis at the 0.05 level,
**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesised No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None *	0.397041	77.40352	68.81206	0.0065
At most 1	0.296946	53.90517	62.75215	0.2730
At most 2	0.236563	41.29853	56.70519	0.6576
At most 3	0.189821	32.20652	50.59985	0.8583
At most 4	0.178741	30.12833	44.49720	0.6838
At most 5	0.138674	22.84023	38.33101	0.8135
At most 6	0.100888	16.27126	32.11832	0.8990
At most 7	0.095190	15.30465	25.82321	0.6070
At most 8	0.067034	10.61622	19.38704	0.5533
At most 9	0.023292	3.605765	12.51798	0.7981

Note: Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level.
* denotes rejection of the hypothesis at the 0.05 level.
**MacKinnon-Haug-Michelis (1999) p-values

Source: Author's Computations

Table A4: Short-run Sectoral Passthrough Impact of Climate Change (Precipitation) on Economic Growth

Error Correction1:	D(GDPG)1	Error Correction2:	D(GDPG)2	Error Correction3:	D(GDPG)3
CointEq1	-0.303859	CointEq1	-0.195962	CointEq1	-0.239168
	(0.06910)		(0.05552)		(0.06152)
	[-4.39750]		[-3.52956]		[-3.88789]
D(GDPG(-1))	0.156625	D(GDPG(-1))	0.103423	D(GDPG(-1))	0.118877
	(0.09165)		(0.08766)		(0.08997)
	[1.70904]		[1.17984]		[1.32124]
D(PRECIP(-1)*AGRI_GDP(-1))	-2.54E-05	D(PRECIP(-1)*SVC_GDP(-1))	-5.96E-06	D(PRECIP(-1)*IND_GDP(-1))	-2.85E-05
	(3.4E-05)		(3.1E-05)		(7.1E-05)
	[-0.74178]		[-0.18958]		[-0.40062]
D(GE(-1))	-0.021244	D(GE(-1))	0.024122	D(GE(-1))	0.050929
	(0.13791)		(0.13579)		(0.14214)
	[-0.15404]		[0.17764]		[0.35830]
D(INF(-1))	-0.001759	D(INF(-1))	-0.003159	D(INF(-1))	-0.004750
	(0.00811)		(0.00828)		(0.00796)
	[-0.21674]		[-0.38173]		[-0.59681]
D(KS(-2))	0.024761	D(KS(-2))	-0.132727	D(KS(-2))	0.039732
	(0.12292)		(0.33032)		(0.12907)
	[0.20144]		[-0.40181]		[0.30784]
D(TO(-1))	0.043209	D(TO(-1))	0.038464	D(TO(-1))	0.048660
	(0.08820)		(0.08768)		(0.09037)
	[0.48989]		[0.43869]		[0.53843]
C	0.016693	C	0.020097	C	0.036002
	(0.11864)		(0.11432)		(0.12062)
	[0.14071]		[0.17580]		[0.29847]
R-squared	0.707019	R-squared	0.655996	R-squared	0.660399
Adj. R-squared	0.497747	Adj. R-squared	0.410279	Adj. R-squared	0.417827
Sum sq. resids	10631.08	Sum sq. resids	6.61E+08	Sum sq. resids	0.083010
S.E. equation	22.49982	S.E. equation	5609.060	S.E. equation	0.062872
F-statistic	3.378471	F-statistic	2.669722	F-statistic	2.722485
Log-likelihood	157.2222	Log-likelihood	-361.4115	Log-likelihood	60.34395
Akaike AIC	9.363361	Akaike AIC	20.40062	Akaike AIC	-2.396970
Schwarz SC	10.05997	Schwarz SC	21.09724	Schwarz SC	-1.700357
Mean dependent	1.254889	Mean dependent	-1240.808	Mean dependent	0.013726
S.D. dependent	31.74811	S.D. dependent	7304.102	S.D. dependent	0.082400

Source: Output from Eviews10

Table A5: Short-run Sectoral Passthrough Impact of Climate Change (Temperature) on Economic Growth

Error Correction:	D(GDPG)	Error Correction:	D(GDPG)	Error Correction:	D(GDPG)
CointEq1	-0.167386	CointEq1	-0.288063	CointEq1	-0.261117
	(0.04944)		(0.06318)		(0.06248)
	[-3.38545]		[-4.55976]		[-4.17923]
D(GDPG(-1))	0.082310	D(GDPG(-1))	0.154664	D(GDPG(-1))	0.137626
	(0.08967)		(0.08960)		(0.08978)
	[0.91793]		[1.72619]		[1.53289]
D(TEMP(-1)*IND_GDP(-1))	-0.002603	D(TEMP(-1)*AGRI_GDP(-1))	-0.002197	D(TEMP(-1)*SVC_GDP(-1))	0.000921
	(0.00780)		(0.00268)		(0.00357)
	[-0.33372]		[-0.81901]		[0.25813]
D(GE(-1))	0.063646	D(GE(-1))	-0.056558	D(GE(-1))	0.037851
	(0.14396)		(0.14552)		(0.13926)
	[0.44211]		[-0.38866]		[0.27180]
D(INF(-1))	-0.004372	D(INF(-1))	-0.002737	D(INF(-1))	-0.002491
	(0.00818)		(0.00775)		(0.00783)
	[-0.53469]		[-0.35297]		[-0.31826]
D(KS(-1))	0.042916	D(KS(-1))	0.030021	D(KS(-1))	0.050243
	(0.13531)		(0.12555)		(0.12543)
	[0.31716]		[0.23912]		[0.40055]
D(POP(-1))	-3.764045	D(POP(-1))	-3.251523	D(POP(-1))	-3.985289
	(3.47916)		(3.46654)		(3.45215)
	[-1.08188]		[-0.93797]		[-1.15444]
D(TO(-1))	0.047629	D(TO(-1))	0.026334	D(TO(-1))	0.030915
	(0.09095)		(0.08791)		(0.08878)
	[0.52370]		[0.29954]		[0.34823]
D(FDI(-1))	0.013319	D(FDI(-1))	-0.341083	D(FDI(-1))	-0.250397
	(0.33767)		(0.35321)		(0.35289)
	[0.03944]		[-0.96566]		[-0.70957]
C	0.038068	C	0.009515	C	0.027093
	(0.12370)		(0.11944)		(0.11915)
	[0.30775]		[0.07966]		[0.22739]
R-squared	0.644536	R-squared	0.639750	R-squared	0.814148
Adj. R-squared	0.390633	Adj. R-squared	0.382428	Adj. R-squared	0.681397
Sum sq. resids	44.99831	Sum sq. resids	0.088057	Sum sq. resids	6743.798
S.E. equation	1.463823	S.E. equation	0.064755	S.E. equation	17.92019
F-statistic	2.538514	F-statistic	2.486185	F-statistic	6.132893
Log-likelihood	-56.12131	Log-likelihood	59.25193	Log-likelihood	-148.8017
Akaike AIC	3.898449	Akaike AIC	-2.337942	Akaike AIC	8.908203
Schwarz SC	4.595062	Schwarz SC	-1.641329	Schwarz SC	9.604816
Mean dependent	0.086494	Mean dependent	0.013726	Mean dependent	-1.254889

Source: Author's Computations

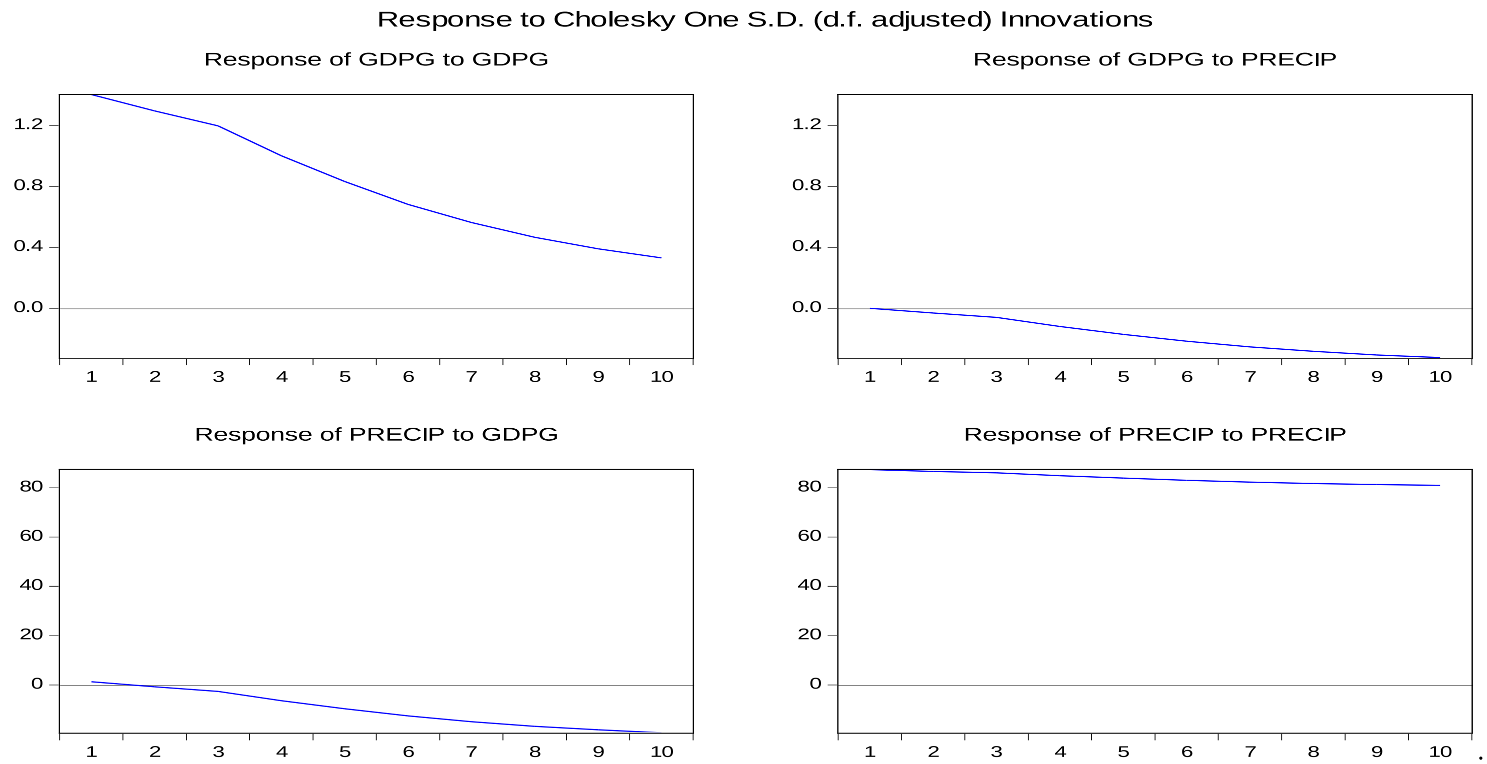
Table A6a: Variance Decomposition Results (Temperature Model)

Period	S.E.	GDPG	TEMP	GE	INF	KS	POP	TO	FDI
1	1.456533	100.0000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2	2.010879	99.23197	0.072289	0.004651	0.158493	0.003729	0.340242	0.187857	0.000764
3	2.423430	97.97543	0.190695	0.012342	0.418261	0.010067	0.895248	0.495843	0.002109
4	2.699983	97.20683	0.569422	0.012539	0.359542	0.009709	1.080551	0.759031	0.002372
5	2.910598	96.26494	1.146231	0.027493	0.312526	0.019769	1.189619	1.036964	0.002458
6	3.084623	95.12813	1.852046	0.053953	0.304575	0.037849	1.283876	1.337024	0.002546
7	3.233723	93.82974	2.664058	0.091778	0.340937	0.063953	1.359898	1.647034	0.002604
8	3.365690	92.40824	3.552867	0.139055	0.418613	0.096773	1.421496	1.960322	0.002638
9	3.485671	90.90667	4.488560	0.193103	0.529113	0.134403	1.473094	2.272396	0.002657
10	3.596908	89.36169	5.447749	0.251778	0.664762	0.175329	1.516816	2.579205	0.002667

Table A6b: Variance Decomposition Results (Precipitation Model)

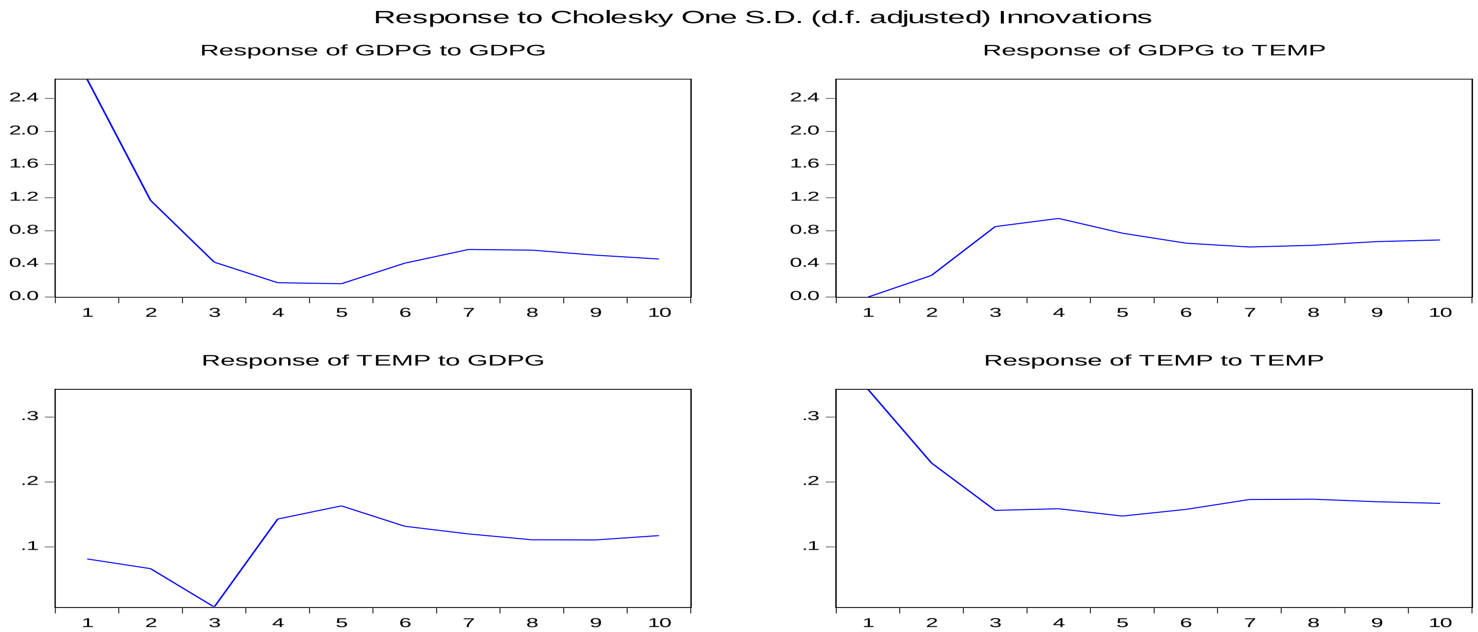
Period	S.E.	GDPG	PRECIP	GE	INF	KS	POP	TO	FDI
1	1.463459	100.0000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2	2.023850	99.36958	0.028229	0.015120	0.148606	0.005017	0.332172	0.101118	0.000154
3	2.440260	98.29519	0.076413	0.041162	0.402779	0.014034	0.895889	0.274180	0.000352
4	2.714530	97.82774	0.204688	0.048688	0.363852	0.014414	1.097288	0.442788	0.000542
5	2.916142	97.35157	0.400420	0.052547	0.315426	0.013458	1.229809	0.635984	0.000789
6	3.075802	96.77690	0.648485	0.055845	0.290842	0.012436	1.356685	0.857700	0.001110
7	3.205664	96.11259	0.945861	0.058408	0.298028	0.011497	1.470366	1.101767	0.001481
8	3.314354	95.36340	1.286665	0.060408	0.339759	0.010762	1.572852	1.364265	0.001892
9	3.407959	94.53886	1.663312	0.062047	0.413460	0.010274	1.667897	1.641817	0.002337
10	3.490500	93.65132	2.068943	0.063412	0.515944	0.010040	1.756710	1.930819	0.002809

Source: Output from Eviews10



Annex 8: Impulse Response of GDP Growth to a Shock in Precipitation

Source: Author's Computations



Annex 9: Impulse Response of GDP Growth to a Shock in Temperature
Source: Author's Computations

Table A7: VEC Normality Tests Results

Component	Skewness	Chi-sq	df	Prob.*		Component	Kurtosis	Chi-sq	df	Prob.
1	0.313186	0.604859	1	0.4367		1	3.190552	0.055978	1	0.8130
2	-0.066094	0.026939	1	0.8696		2	2.664674	0.173351	1	0.6772
3	-0.441632	1.202739	1	0.2728		3	2.731780	0.110910	1	0.7391
4	-0.453714	1.269447	1	0.2599		4	3.209208	0.067475	1	0.7950
5	-0.701914	3.038214	1	0.0813		5	3.510668	0.402039	1	0.5260
6	-0.360097	0.799630	1	0.3712		6	3.737419	0.838337	1	0.3599
7	0.315087	0.612227	1	0.4340		7	2.992328	9.07E-05	1	0.9924
8	0.039646	0.009693	1	0.9216		8	3.081627	0.010272	1	0.9193
Joint		**7.563747**	**8**	**0.4772**		**Joint**		**1.658453**	**8**	**0.9898**

Component	Jarque-Bera	df	Prob.
1	0.660837	2	0.7186
2	0.200289	2	0.9047
3	1.313649	2	0.5185
4	1.336922	2	0.5125
5	3.440253	2	0.1790
6	1.637967	2	0.4409
7	0.612317	2	0.7363
8	0.019965	2	0.9901
Joint	**9.222200**	**16**	**0.9040**

Table A8 11: Lag Selection Criterion

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-581.6905	347.3988	9626.247	31.87516	32.22347	31.99795
1	-387.2510	294.2868	9.033713	24.82438*	27.95914*	25.43151*
2	-323.8789	68.51037*	15.64207	24.85832	30.77953	26.94582
3	-213.6905	71.47355	7.283724*	25.36165	31.06931	25.92953

Key: FPE: Final prediction error; AIC: Akaike information criterion; SC: Schwarz information criterion HQ: Hannan-Quinn information criterion

Note: * indicates lag order selected by the criterion; LR: sequential modified LR test statistic (each test at 5% level).