# Climate Change and Macroeconomic Performance: Evidence from MEFMI Countries

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**Abstract**

Over the last five decades, there has been a considerable rise in average global temperatures, which has led to an increase in the frequency and severity of natural disasters, as well as extreme changes in weather patterns. This study examines the impact of changes in rainfall and temperature on GDP and inflation in MEFMI countries. The study uses a panel ARDL model and a VAR model with local projection spanning 1980 to 2020. Results shows that a one-unit positive deviation in temperature beyond the historical norm, which is the long-term historical average reduces average real GDP in the region by 1.3 percentage points while similar deviations of temperature below the norm appear to have an opposite impact. With respect to precipitation, a one percent positive deviation from the historical norm improves growth by 0.06 percent, while low rainfall reduces growth by 0.03 percent. The results also suggest that positive deviations in temperature have a negative significant effect on inflation while deviations in precipitation in either direction have negative but insignificant effects on inflation. The results, to some extent reflect regional economic dynamics which are largely agro-based, suggesting that productivity in a more intense agro-based region is likely to be positively impacted by better rainfall compared to low-than normal rainfall trends. These findings have several policy implications. The challenge of climate change is quite huge and requires a coordinated and all stakeholder approach. The Ministries of Finance and Planning and the central banks can play a significant role in enhancing resilience to climate shocks through incentivising investments to low carbon technology. In addition, to ensure evidence-based policy making there is need to embed climate change in macroeconomic models. There is also need for training and capacity building in climate data compilation, analysis and macro-model forecasting considering climate related risks. International cooperation and collaboration is also needed in tackling effects of climate change on the macroeconomy.

**Key Words**: Real GDP, Inflation, climate change, temperature, precipitation, Local Projection framework, Panel ARDL

**JEL C33, O40, O44, O51, Q51, Q54**

**List of Abbreviations**

| | |
|---|---|
| ARDL | Autoregressive Distributed Lag |
| CCI | Climate Change Index |
| CPI | Consumer Price Index |
| EKC | Environmental Kuznets Curve |
| GDP | Gross Domestic Product |
| GMM | Generalised Method of Moments |
| IMF | International Monetary Fund |
| IPCC | Intergovernmental Panel on Climate Change |
| LPM | Local Projection Model |
| MENA | Middle East and North Africa |
| MEFMI | Macroeconomic and Financial Management Institute of Eastern and Southern Africa |
| SAPP | Southern African Power Pool |
| SEA | South East Asia |
| SSA | Sub-Saharan Africa |
| USA | United States of America |
| VAR | Vector Autoregression |

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## 1. Introduction

Over the last five (5) decades, there has been a considerable rise in average global temperatures, which has led to an increase in the frequency and severity of natural disasters, as well as extreme changes in weather patterns, characterised by heat waves, droughts, and floods (Intergovernmental Panel on Climate Change, 2021). In the recent past, debate on the implications of such climatic change[1] has gained momentum. The increased focus is driven by, among others, the potential for climate change to amplify global macroeconomic imbalances, scale-up socio-economic uncertainties, undermine the design and implementation of the macroeconomic frameworks and complicate the credibility of policy decisions. While there is a growing concern in literature that climate change has both demand and supply side implications, the magnitude, channels and sectoral effects vary across jurisdictions. For instance, on the magnitude, IMF (2017) posits that the macroeconomic effects of climate change may differ according to different income groups. Other studies such as Maino and Emrullahu (2022) and IMF (2015) find that poor countries disproportionately bear the cost of climate change. IMF (2020) finds that sub-Saharan Africa (SSA), South East Asia (SEA), Middle East and North Africa (MENA) are the most vulnerable to climate change while the United States of America (USA), Europe and China experience moderate climate risks. From the literature, there seems to be considerable correlation between the level of development and vulnerability to climate change.

With regard to transmission, the channels seem to differ for climate dependent agro-based economies, and non-agro based ones. For the former, the transmission is through the agricultural sector (Bosello, Carraro, and De Cian., 2010; World Bank, 2010; Rosenzweig, Elliott, Deryng, Ruane, Müller, Arneth and Jones2014 and Okonjo-Iweala 2020) while for the latter, the situation manifests in low labour productivity. Roson and van der Mensbrugghe (2012) document multiple channels such as a rise in sea level (in SEA); water scarcity (in the MENA region), as well as labour productivity and health (in SSA). The World Tourism Organization -United Nations Environment Programme- World Meteorological Organization (2008) and Andersson, Morgan and Baccianti (2020) find the impact to occur through other climate-sensitive sectors such as tourism, insurance, energy, and transportation. Boehlert, Strzepek, Groves, Hewitson, and Jack (2015) show that the impact channel is through infrastructure, trade and transport corridors. On effects, Chen, Atiqul, Ahmed, Hussain and Ahmed (2021); Adedeji, Reuben and Olatoye (2014) and Dorudola (2019) find a positive link between climate change and food insecurity while Hallegatte, Bangalore, Bonzanigo, Fay, Kane, Narloch, Rozenberg, Treguer and Vogt-Schilb (2015) find climate related shocks to exacerbate poverty levels. Nordhaus and Romer (2018) suggest a bi-directional causality between economic activity and climate change.

[1]Climate change is referred to as a change of climate attributed directly or indirectly to human activity that changes the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods, United Nations Framework Convention on Climate Change (1992).

In Africa, and particularly within the Macroeconomic and Financial Management Institute of Eastern and Southern Africa (MEFMI) region[2], countries have also experienced water and heat stress at varying magnitudes in the recent past. The climate shocks include droughts[3], localised flooding[4], above normal temperatures, seasonal shifts in temperature and wild fires. Idiosyncratic ones include heavy snowfalls (Lesotho); Hurricanes[5] (Mozambique); cyclones[6] (Mozambique, Malawi and Zimbabwe); overflow of large rivers (Mozambique and Uganda); lakeshore stress (Burundi, Tanzania, Kenya and Uganda); sea rise (Angola, Kenya, Mozambique, Namibia and Tanzania) and mountain landslides (Burundi, Kenya, Lesotho, Rwanda and Uganda). The commonality of these shocks is their adverse impact on agricultural productivity, particularly farming activities, which remain a livelihood for most of the population in the region. According to Barnett and Adger (2007); Wheeler and von Braun (2013); Caminade, Kovats, Rocklov, Tompkins, Morse, Colón-González and Lloyd (2014), Pudyastuti and Nugraha (2018) and Tol (2018), these shocks also stress water channels, increase human insecurity, amplify the spread of opportunistic infections and diseases and damage infrastructure. They also divert funds earmarked for other socio-economic developments, weigh on the fiscal positions and in turn, undermine the macroeconomic and financial stability of the region.

Empirically, the available studies on the impact of climate change on the macroeconomy have found mixed results. For example, Barrios, Luisito and Strobl (2010) and Lanzafame (2012) find adverse effects of temperature and rainfall on economic growth while Sandalli (2021) finds no evidence of the negative impact of precipitation on growth. Others like Nordhaus (2017) refute the submission that reducing temperatures beyond a certain level may reduce the impact of climate change. Faccia, Parker and Stracca (2021) and Mukherje and Ouattara (2021) show that increases in temperature result in increased inflation. These contradictions make a stronger case for understanding impact of climate change on the Macroeconomic Performance in the MEFMI region. In addition, the effects of climate change on the macroeconomy of the MEFMI countries, have not been studied. Meanwhile, the region has been getting much hotter and wetter in the recent past. These developments, among others, motivate this study, whose aim is to give guidance on the future of macroeconomic policy management in the MEFMI region, amidst climate shocks. Furthermore, the interconnectedness of the region due to trade and other bi-lateral relations expose the region to contagion effects arising from climate shocks in member countries. This study, therefore, sets out to examine the impact of temperature and precipitation on economic growth and inflation in the MEFMI region.

[2] The MEFMI region comprise of 14 countries in the East and Southern part of the Continent, namely; Angola, Botswana, Burundi, Eswatini, Kenya, Lesotho, Malawi, Mozambique, Namibia, Rwanda, Tanzania, Uganda, Zambia and Zimbabwe.
[3] Examples include 2001-2003 drought; El Nino in 2016 period; The 2001-2003 drought period.
[4] 2007 floods.
[5] Hurricanes Eline and Dineo.
[6] Cyclones Idai and Kenneth in 2019.

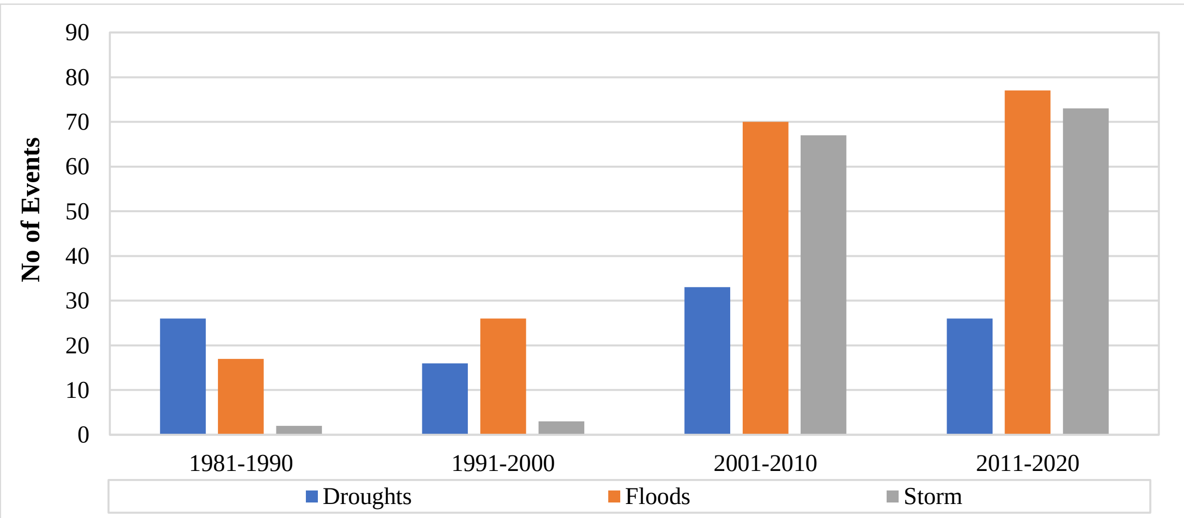
In undertaking the study, a three-pronged empirical strategy is pursued. Firstly, a Panel Autoregressive Distributed Lag (ARDL) model is estimated to establish causal relationships between macroeconomic performance variables, temperature and precipitation. The ARDL approach is chosen due to the fact that it is amenable to long-run analysis even when the underlying variables have different orders of integration. Importantly, de Bandt, Jacolin and Lemaire (2021) and Kahn, Mohaddes, Ng, Pesaran and Raissi, (2019) argue that the ARDL model is robust to omitted variables bias and bi-directional feedback between macroeconomic and climatic variables. Secondly, temperature and precipitation are combined to make a climate change index ($CCI$), which is analysed to determine whether the aggregate measure affects macroeconomic performance differently. Thirdly, we use a local projection model (LPM) framework to analyse the impulse responses for individual countries. The results of the study will assist regional policy makers to better understand the macroeconomic impacts of climate change and design or strengthen policies to deal with climate change effects. For tractability, this study only considers aggregate measures of macroeconomic performance, but further research could disaggregate Gross Domestic Product (GDP) and inflation variables in order to delineate the key channels of transmission of weather shocks.

The rest of the study is structured as follows: Section 2 presents stylised facts, Section 3 discusses literature while Section 4 lays out the methodology. Section 5 discusses the results and Section 6 concludes with policy recommendations.

## 2. Stylised Facts

Climate shocks have become more prevalent and more intense over time in the MEFMI region, as typified by the increased frequency and severity of extreme weather events. Figure 1 shows the prevalence and distribution of natural disasters in the MEFMI region between 1981 and 2020, with floods, storms and drought events being the most common shocks over the period. This has led to an increase in climate related risks to people, infrastructure, and the economies.

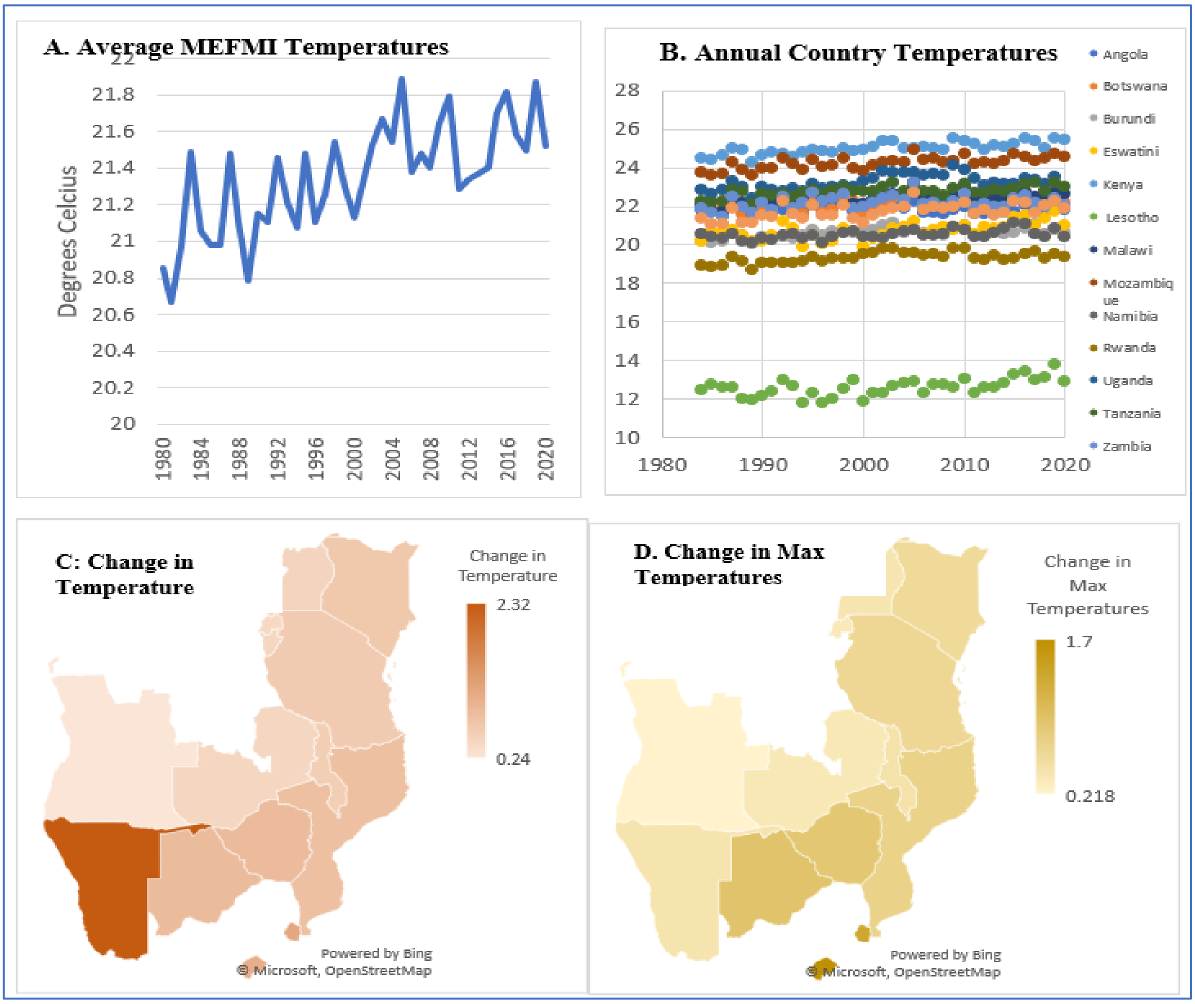
**Figure 1: Climate Events in MEFMI Region**




*Source: Emergency Events Database, 2022*

Climate statistics show that global temperatures have increased by about 1°C compared to the 1880-1910 averages (IMF, 2017). The increase in temperatures has been driven mainly by human activity, particularly through an increase in carbon emissions (IPCC, 2014). The sixth IPCC report estimates that the globe would warm by 1.5°C over the next two decades[7]. Of concern, the MEFMI region, despite contributing less in terms of carbon emissions, is warming in line with these global developments. Since 1980, average temperature in the MEFMI region has increased by 0.67°C from 20.85°C in 1980 to 21.52°C in 2020 (Fig. 2A). The average temperatures, though increasing, have mostly ranged between 18°C and 26°C, except for Lesotho (Fig. 2A). Figure 2C shows that all MEFMI member countries recorded increases in temperature between 1980-2020, particularly when comparing the averages of the first five years (1980-1984) against the average for the last five years (2016-2020) of the study period. The data also shows that Namibia, Lesotho and Eswatini have recorded the most significant changes, having warmed by 2.32°C, 1.14°C and 1.04°C, respectively. Countries such as Zimbabwe, Botswana, Mozambique, Kenya and Tanzania are approaching the 1°C-warming mark with their respective increases in annual average temperature over the period recorded at, 0.86°C; 0.85°C; 0.79°C; 0.68°C; and 0.62°C, respectively.

**Figure 2: Temperature Developments in MEFMI Region**



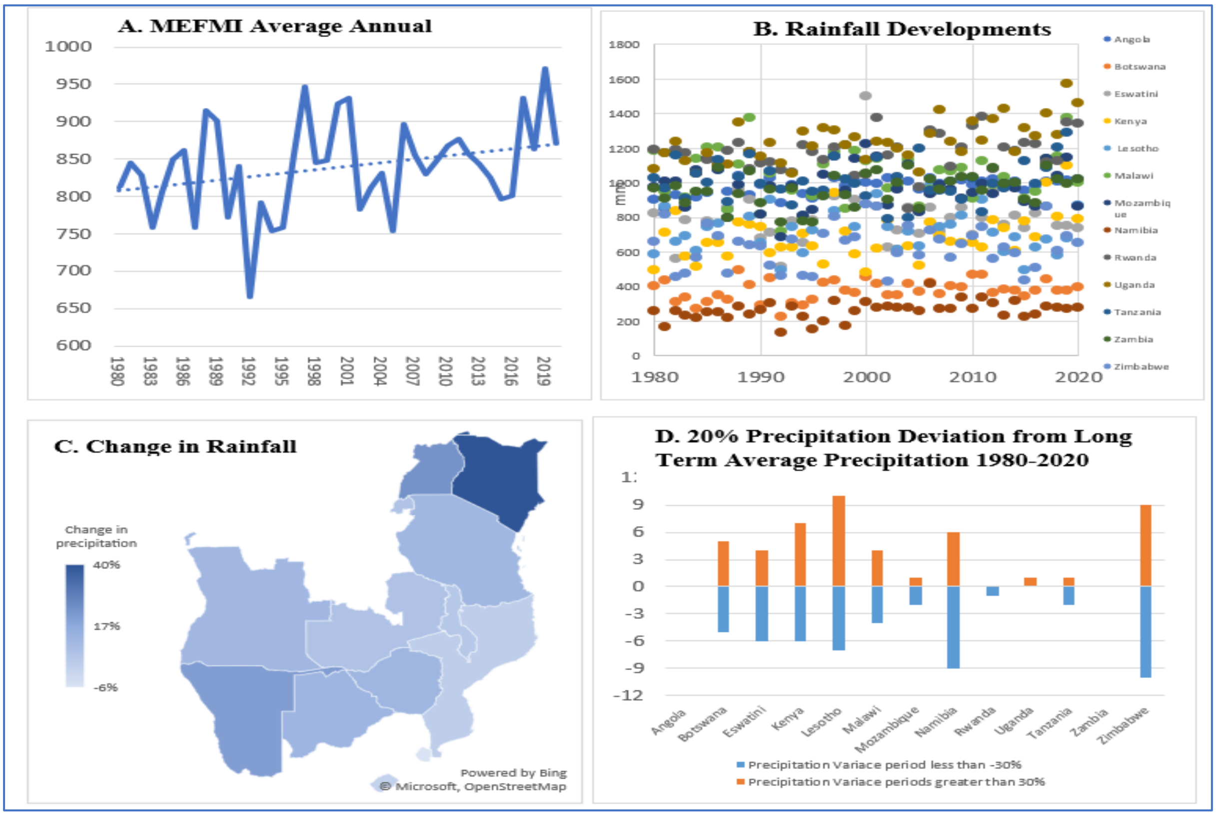

*Source: Authors' computations based on World Bank Climate Portal, 2022*

[7] https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_SummaryForPolicymakers.pdf

Maximum annual temperatures, which signal prevalence of extreme temperatures also exhibit an upward trend. For instance, Lesotho and Eswatini recorded the most significant increase in maximum temperatures when comparing the values for 1980-1984, with the values for 2016-2020, by 1.7℃ and 1.35℃, respectively. The developments in maximum temperatures are an indication of the emergence of more extreme temperature conditions in the MEFMI region and point to heightened climate risks.

In terms of precipitation, annual average rainfall for the MEFMI region increased from 811 millimetres (mm) in 1980 to 870 mm in 2020 (Fig. 3A). Interestingly, when comparing the annual average precipitation for the period 1980-1984 with the period 2016-2020, the data suggests that the MEFMI region is becoming more wet (Fig. 3B). Kenya recorded the largest increase of 39.9 percent from an average of 627.05 mm per annum to 786.08 mm per annum for the sub comparison period (Fig. 3C). There are, however, significant disparities in precipitation trends in the MEFMI region with Eswatini recording a 6.2 percent decrease. (Fig. 3B). Namibia and Botswana have the lowest precipitation levels while Uganda and Rwanda have the highest levels. These disparities may be due, in part, to the semi-arid and desertification differences that appear to be more prevalent in the southern part of the region. Furthermore, these differences also suggest that an equal shock to precipitation patterns in low precipitation member states is likely to have a more significant impact compared to high precipitation member states. In this regard, the analysis on trends in rainfall and temperature in the MEFMI region need to be interpreted with great care, given the multi-year cyclicity in climate and heterogeneity in the region.

**Figure 3: Annual average precipitation Developments**

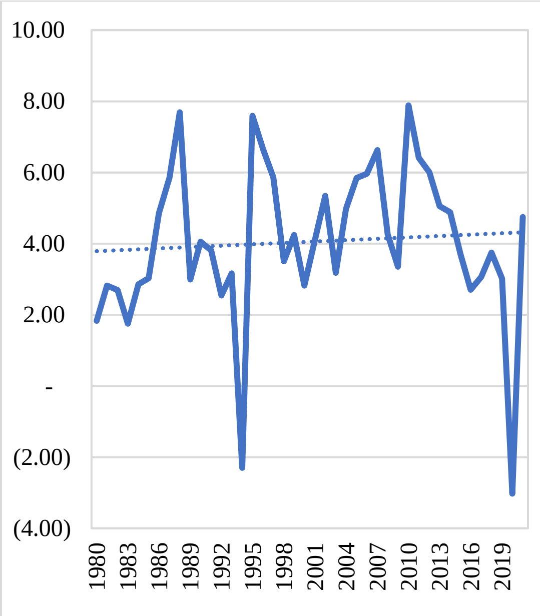



*Source: Author's computations and World Bank climate portal, 2022*

Notwithstanding the general increase in annual precipitation in the MEFMI countries, a cursory analysis shows that actual precipitation in some instances deviated significantly from annual long-term country averages. To show the increased erratic pattern of precipitation, actual annual rainfall for each country is compared to the long-term average of the country for the period 1980 to 2020. On annual basis, the above 20 percent deviation in both directions from this long-term average was computed and the results are presented in Figure 3D. They show that Angola, Rwanda, Uganda, Tanzania and Zambia have the most stable pattern in annual average precipitation. While countries such as Zimbabwe, Lesotho, Namibia, Kenya, Eswatini and Botswana have more significant deviations from annual average precipitation on both the positive and negative sides.

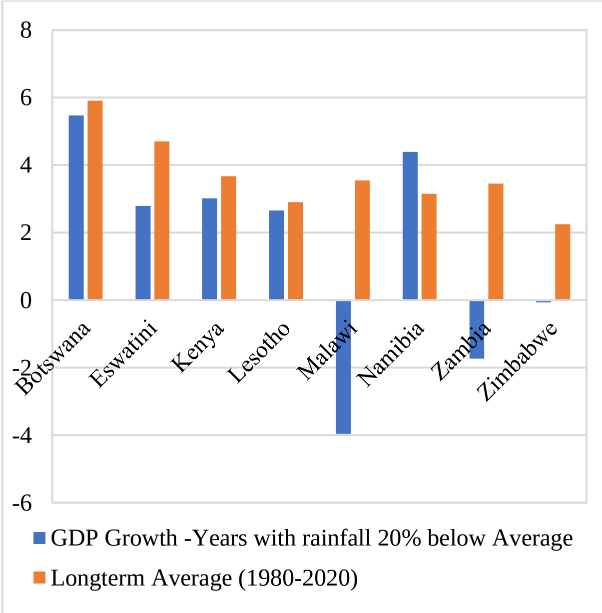
With respect to the macroeconomic statistics, data shows that the annual real GDP growth for the MEFMI region averaged 4 percent from 1980 to 2020 but has been volatile, reflecting impact of various shocks such as weather conditions, other domestic factors, commodity prices and other unprecedented global events such as the 2009 Global Financial Crisis and the 2020 COVID-19 pandemic. The data also shows that real GDP growth tends to be lower than the average in most MEFMI countries during years in which annual rainfall falls below the average by more than 20 percent from the long-term average (Fig. 5). Similarly, real GDP tends to decline following extreme temperatures in the region.

**Figure 4: Annual average GDP growth for the MEFMI Region**



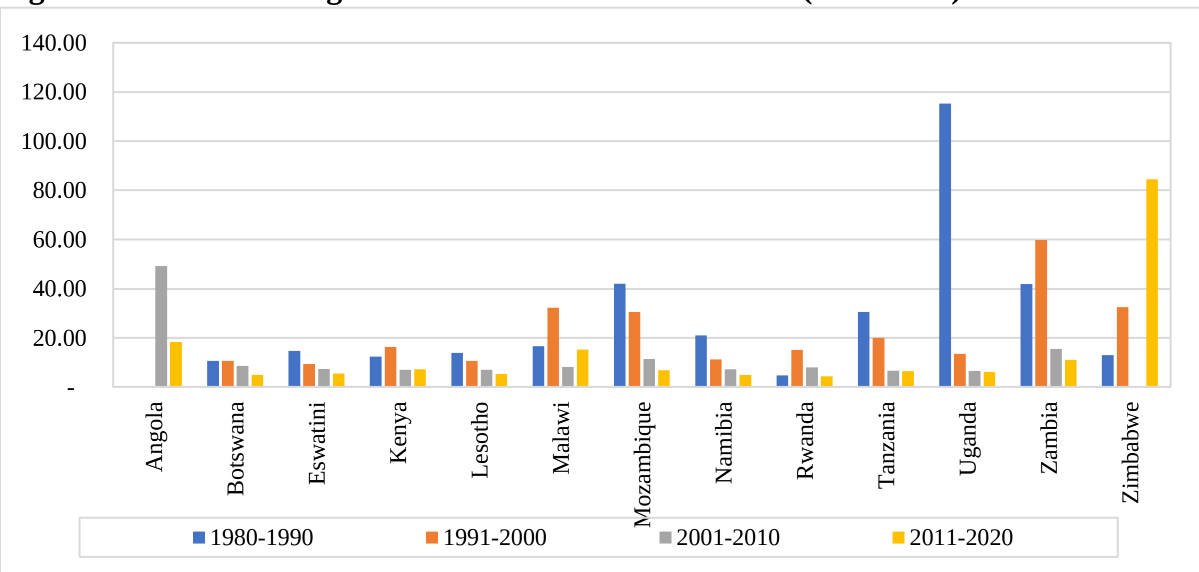

*Source: WEO, April 2022, IMF*

**Figure 5: GDP growth when rainfall is 20%below its long-term Average**




*Source: Own calculation /World Bank climate portal*

**Figure 6: Annual Average inflation for MEFMI Countries (1980-2020)**




*Source: WEO, 2022*

The impact of low rainfall has mainly been pronounced in countries with generally low rainfall and heavily dependent on agriculture which include Malawi, Zambia and Zimbabwe (Figure A1 of the Appendix). Despite greater variabilities across MEFMI member countries, annual inflation in the region has generally been on a declining trend since 1980, reflecting, among others, improved macroeconomic management in the region (Fig. 6).

## 3. Literature Review

### 3.1 Theoretical setting

Theoretically, the discussion on climate change has gained traction in the field of social science. Earlier studies mostly focused on disruptions caused by greenhouse emissions on the environment. The transition of the debate to economics is somewhat new and can be traced to the Environmental Kuznets Curve (EKC). Kuznets (1955) argued that economic growth has positive and negative impact on the environment, suggesting an interdependence between the environment and economic activities. By design therefore, the EKC can be incorporated in various economic growth theories starting from Harrod (1939) and Domar (1946) one sector AK model to the Solow and Swan (1956) neo-classical growth theory; the Mankiw, Romer and Weil (1992) endogenous growth model, as well as the Mundell-Fleming model.

In recent studies, such as Faccia et al. (2021) weather, particularly temperature and precipitation enter the growth models as productivity shocks affecting sectoral developments leading to fluctuations in overall output and inflation. These models are dynamic general equilibrium models with optimising agents and allow for integration of climate change effects into the relevant productivity equations. GIZ (2021) also notes that macro-econometric models extended by environmental aspects that can be designed to evaluate the economic impacts of climate change and these consider three interlinked parts: economy, energy and emissions aspect. Macroecometric models are also important as they can provide estimations on both the short and long-term economic effects of climate change on key economic variables. In addition, the Integrated assessment models (IAM) have been used frequently to study the impact of climate on the economy. They aim to provide policy-relevant insights into global environmental change and sustainable development issues by providing a quantitative description of key processes in the human and earth systems and their interactions. The term assessment is used to refer to generating useful information for decision-making, even in case of large uncertainties.

### 3.2. Empirical literature

The survey of literature focusses on the impact of temperature and rainfall on economic growth and inflation. Dell, Jones and Olken (2012) conduct their study on 120 countries, which constitute rich and poor countries and find that higher temperatures impact negatively on economic growth but the impact was more pronounced on poor countries than rich countries. The transmission occurred through reductions in agriculture and industrial output, as well as heightened political instability. Burke, Hsiang and Miguel (2015(a)) analysed the global economy and found that the relationship between temperature and growth is non-linear, with productivity being at its peak at 13℃ but declined beyond this threshold level. Their results hold for both agriculture and non-agricultural activities. However, different from Dell et al. (2012), their finding is robust to both rich and poor countries. IMF (2017) confirms the non-linear relationship between growth and temperature. They find growth to increase when temperatures rise to the threshold of about 13℃-15℃ and decelerates thereafter. For countries with temperatures above 15℃, the study found the coefficient on temperature to be negative and statistically significant.

Kim, Matthes and Phan (2021) analyse the impact of extreme weather in the USA using the Actuaries Climate Index (ACI) and applying the smooth transition vector autoregressive analysis. Their results show that an increase in the index at later years of the sample reduces the growth rate of industrial production and raises inflation and unemployment. Cantelmo, Melina and Papageorgiou (2019) conduct their study on 129 low- and middle-income countries using a dynamic general equilibrium model and find that weather shocks have large and persistent effects on income convergence path of disaster-prone countries. Results show that disaster prone countries suffer a welfare loss equivalent to 1.6 percent. Their findings show that weather shocks significantly undermine the development process of many low-income countries, particularly through the destruction of private and public capital goods.

Acevedo, Mrkaic, Novta, Pugacheva and Topalovahe (2018) analyse 180 countries across the globe and find that the increase in temperature has uneven macroeconomic effects. Significant effects are realised in countries with hot climates, the majority of which are low-income countries where per capita output decreases in the medium term. This occurs through reduced agricultural output, suppressed productivity of workers exposed to heat, slower investment, and poorer health. Finally, model simulations suggest the projected rise in temperature to the year 2100 would result in a loss of around 9 percent of output for low-income countries with hot climate.

In the SSA region, empirical evidence remains sparse. Notable studies include IMF (2020), Pondi, Mo Choi and Mitra (2022) and Barrios et al. (2010). IMF (2020) notes that the impact of temperature and extreme weather events in SSA is larger and lasts for a longer time than in the rest of the world. Precisely, the study shows that an increase in temperature of 0.5℃ above the 30-year average can result in a decline in economic activity of 1 percent per year. The results also show that the impact in SSA is about 60 percent larger than the average for emerging market and developing countries. The study also finds that natural disasters, particularly droughts have long lasting impact, to the extent that economic growth falls by 1 percentage point with an additional drought.

Another study on Africa was done by Lanzafame (2012) who examines the impact of temperature and rainfall on economic growth using a reduced form ARDL model. The results show that temperature affects economic growth in both the short and long term. The impact of rainfall is, however, statistically insignificant. This finding is echoed by IMF (2017) who use a local projection framework and find an insignificant relationship between rainfall and GDP per capita. Auffhammer, Hsiang, Wolfram and Adam (2011) argue that the apparent lack of the relationship between rainfall and economic growth may reflect the measurement errors in the precipitation variable. This is supported by Barrios et al. (2010), who argues that rainfall has been a critical factor limiting growth in SSA with simulations showing that rainfall patterns could have contributed between 15 percent and 40 percent to the gap witnessed between per capita GDP of Africa and that of other developing countries.

A different strand of literature has focussed on the impact of temperature and rainfall on prices. The available studies also take global and regional focus, but consider the level of development of the economies. For example, Faccia et al. (2021) use panel local projections for 48 countries (both advanced and emerging countries) to investigate the impact of temperature shocks on prices. Their results reveal that hot summers increase food price inflation in emerging market economies in the near-term. The impact of temperature in the medium term, however, tends to be insignificant. The results are non-linear with the impact being more significant for larger shocks and for countries with higher temperatures. Simulations using a two-country model in the same study, however, tend to show that temperatures significantly drive prices even in the medium term.

The importance of temperature on inflation, particularly in developing countries was corroborated by Mukherje and Ouattara (2021) who use panel-VAR method with fixed effects for both developed and developing countries for the period 1961 to 2014. Their results show that increases in temperature lead to higher inflation, with more pronounced and long-lasting effects on developing than developed economies. Corroborating these results is Parker (2016) who investigates the effect of disasters on consumer price inflation and finds negligible effects in advanced countries but long-lasting effects in developing countries. The impact is also different for sub-indices depending on the type of the disasters. In particular, the study shows that storms increase food price inflation in the near term while floods have a short-term impact on inflation. One of the notable studies on the impact of extreme weather events on prices in developing countries is by Heinen, Khadan and Strobl (2018). They look at the impact of hurricane and flood destruction indices on prices in 15 Caribbean Islands. The results suggest large impacts and significant welfare losses.

A few other studies have focussed on Africa. Kunawotor, Bokpin, Asuming and Amoateng (2022) examine the impact of extreme weather events on both headline and food inflation and their effects on monetary policy in Africa. The study uses a two-step dynamic Generalized Method of Moments for the period 1990-2017 and finds that weather-related events result in significant price increases in Africa. Importantly, the research shows that droughts and floods impact negatively on food price inflation. It also notes that agricultural production is the main channel through which extreme weather events affect headline inflation.

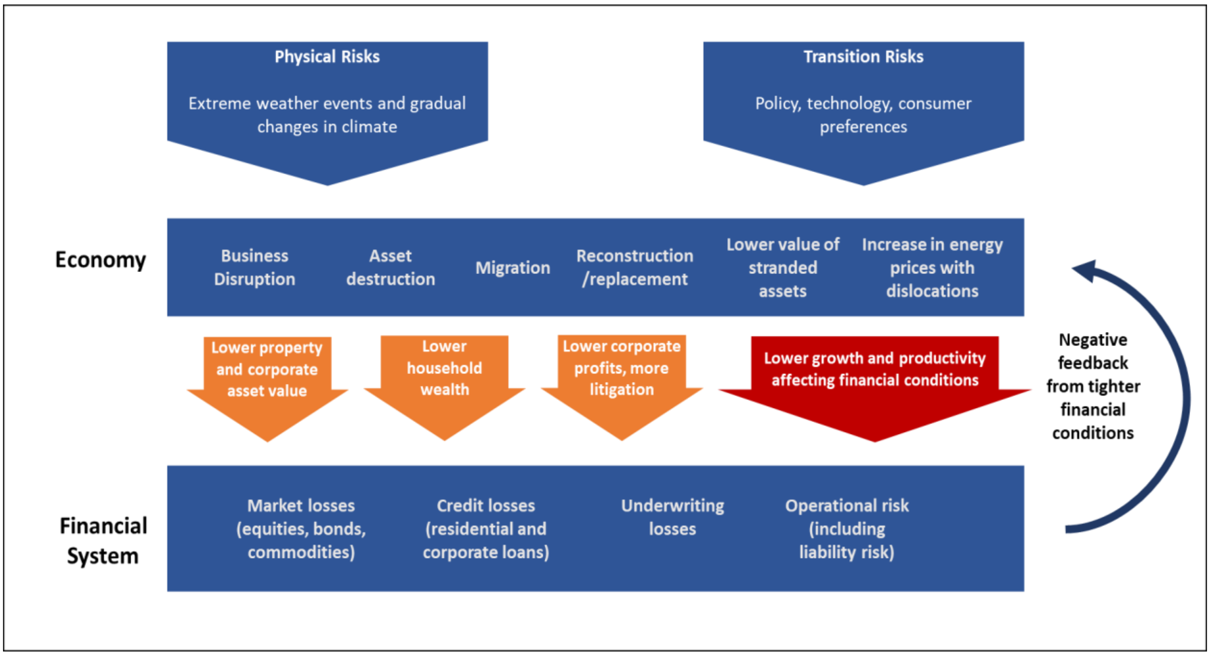
In summary, significant impact of weather on GDP has been established by Dell et al. (2012), Burke et al. (2015(a)), IMF (2017), Kim et al. (2021), Acevedo et al. (2018) with few exceptions finding insignificance of rainfall, IMF (2017) and Lanzame (2012). In terms of effects of temperature, Faccia et al. (2021), Mukherje and Ouattara (2021), Parker (2016) and Heinen et al. (2018) all show adverse effects on inflation. Literature is also skewed towards distinguishing effects of weather on rich and poor countries mainly, finding that weather affects poor and rich countries disproportionately, with more pronounced effects on poor countries than rich countries; Dell et al. (2012), Cantelmo et al. (2019), Acevedo et al. (2018), Faccia et al. (2021), Mukherje and Ouattara (2021) and Parker (2016). In terms of estimation techniques, studies have employed VARs (Kim et al (2021); loMcal projection frameworks-Mukherje and Ouattara (2021)), IMF (2017) and Faccia et al. (2021); ARDL model-Lanzafame (2012); Generalised Method of Moments-Kunawotor et al. (2022) and more complex simulated models-Acevedo et al. (2018).

From the foregoing, literature uses various estimation techniques to find that extreme weather conditions negatively affect macroeconomic developments. The effects appear to be disproportionate with developing economies being more affected than developed economies. They also find that temperatures beyond certain points negatively impact growth and inflation. The findings in literature can be attributed to several factors. Firstly, is the difference in resilience and adaptive mechanisms between developed and underdeveloped countries, leading to disproportionate effects of weather variables on the macroeconomy. Second, is the role that irrigation systems and greenhouses, which are seemingly at advanced stages in developed economies, play in agriculture production. Lastly, is the speed of adjustment to shocks and adaptation to crisis which may be higher in developed economies than in developing economies. Auffhammer et al. (2011) argue that the apparent lack of relationship between rainfall and economic growth in selected developing countries may also reflect the measurement errors in the weather variable. These factors may therefore lead to less pronounced effects of weather in developed economies than in developing economies.

## 4. Transmission of Weather Shocks

To estimate the impact of climate change on the economy, it is necessary to understand the transmission mechanisms of the identified climate shocks. Climate change shocks and meteorological shocks can have an impact on general prices in economies, levels of fiscal expenditure and overall economic growth. These effects will be felt through various transmission channels at the sectoral level such as agriculture and non-agriculture (energy, health and infrastructure), among others (Fig. 7).

**Figure 7: Schematic transmission of weather shocks**




*Source: Authors,2022*

The impact of climate shocks on the macroeconomy, economic growth and inflation largely depends on the size of the shock, geographical characteristics of the country and climate mitigation policies and general macroeconomic policy, Kabundi, Mlachila, and Yao (2022). Precisely, climatic shocks could affect output and prices through physical risks and transition risks. Physical risks manifest directly and indirectly into supply effects. The former can transmit through negative impacts on physical capital including natural resources and the workforce while the latter can occur through short-term and long-term indirect demand side effects (Batten (2018) and Ciccarelli & Marotta (2021). Climate change may also result in demand-side changes. For example, disruption to income, consumption patterns, investments, exports, infrastructures and changes of consumer behaviour, migration and climate awareness may result in either reduced production, depressed labour supply or capital accumulation with a probable impact on inflation and growth. Figure 7 shows that the relationship between climate change and the macroeconomy is complex, given the feedback effects between the financial sector and macroeconomy. For instance, physical risks on the financial sector can materialise directly, through their impact on corporations, households, or indirectly, through the effects of climate change on the wider economy and feedback effects within the financial system.

Other literature from the IMF has shown that the agricultural sector is the most significant transmission channel of climate shocks to the macro-economy in sub-Saharan Africa (IMF, 2017). Agriculture is a key sector in the MEFMI region. Malawi, Mozambique, Rwanda, Uganda and Tanzania have, on average, an agricultural sector that is greater than 20 percent of GDP. Given the sensitivity of agriculture to climate events, these countries may experience larger than expected transmission of climate shocks to the macro-economy. Albeit, countries such as Eswatini, Lesotho and Namibia with smaller agricultural sectors but higher variability in rainfall patterns may also experience pronounced impact on agricultural output. Figure A1 of the appendix shows the size of the agricultural sector for MEFMI countries as a percentage of GDP, and summarised as average size for the periods 2006-2010, 2011-2015 and 2016-2020 (World Bank, 2022).

Risks to the non-agriculture sector vary across regions. However, for the MEFMI region, due to hydro-electricity and coal powered electricity generation, risks to the energy sector may be more pronounced. For instance, prolonged periods of drought or floods may have negative impact on power generation in economies dependent on hydropower. In the MEFMI region, there are two (2) major power pools, namely the Southern African Power Pool (SAPP) and the East African Power Pool (EAPP). Ten (10) out of thirteen MEFMI countries are members of the SAPP. In SAPP, hydroelectricity accounts for 24 percent of total generation as of 2020 after thermal power at 59 percent of total generation.[8] Accordingly, there is a risk that an impact on the capacity of these power plants to generate hydroelectricity emanating from climate shocks may have an adverse effect on economic activity through reduced electrical power availability in the region. Prolonged periods of reduced electricity production may have an overall impact on the price of energy in the consumer basket.

Other non-agriculture, non-energy economic climate induced economic risks can occur in the manufacturing sector due to linkages with the energy and agriculture sector. The largest manufacturing sector in the region is in Eswatini, which represents close to 30 percent of GDP, while countries such as Angola and Botswana have relatively small manufacturing sectors at around 5 percent. The rest of the MEFMI member countries including Kenya, Lesotho, Malawi, Mozambique, Namibia, Rwanda, Uganda, Zambia and Zimbabwe have manufacturing sector that ranges between 8 percent to 19 percent. Despite the relatively smaller manufacturing sector in most MEFMI countries, the transmission through the sector may still be significant for overall inflation and growth. Overall, the IPCC (2021) has summarised the impact of climate change on Africa as follows:

[8] SAAP Annual Report 2021 https://www.sapp.co.zw/sites/default/files/Full%20Report%20SAPP.pdf

i. Extinction of species and reduction / irreversible loss of ecosystems and their services, including freshwater, land and ocean ecosystems;
ii. Risks to food security, risks of malnutrition (micronutrient deficiency), and loss of livelihood due to reduced food production from crops, livestock and fisheries;
iii. Risks to marine ecosystem health and to livelihoods in coastal communities;
iv. Increased human mortality and morbidity due to increased heat and infectious diseases (including vector-borne and diarrhoeal diseases);
v. Reduced economic output and growth, and increased inequality and poverty rates; and
vi. Increased risk to water and energy security due to drought and heat[9].

## 5. Empirical Strategy

Studies have used two (2) different approaches to uncover effects of climate change. The first approach relies on simulations (Costinot, Donaldson, and Smith (2016) and Bosello, Carraro, and De Cian (2013). The second approach relies on an econometric method (Kahn et al. (2019)) to estimate reduced form functions of how climate affects the economy. The econometric models have much lower levels of details but also avoid many adhoc assumptions that are needed in large simulation models. The advantage of econometric models is that they rely on observed behaviour and are amenable to cause-effect analysis and exploiting country specific factors. For these reasons, this study uses the econometric approach. In using the econometric approach, we build on Kahn et al. (2019) ARDL approach to examine the long-term impact of deviation of temperature and precipitation from their historical norms on output growth and inflation across MEFMI countries. This study extends Kahn's analysis by applying three (3) different approaches. In the first approach, we estimate a panel ARDL model specified as follows:

$$\Delta y_{it} = a_i + \varphi_t + \sum_{n=1}^{p} +\sigma_n \Delta y_{i,t-n} + \sum_{n=1}^{p} +\beta'_n \Delta X_{i,t-n} + \varepsilon_{it} \ldots\ldots (1)$$

Alternatively, this is written as

$$\Delta y_{it} = \alpha_i + \varphi_t + \sum_{n=1}^{p} \sigma_n \Delta y_{it-n} + I_{it} \sum_{n=1}^{p} \beta_n^{+} \Delta X_{it-n} + (1 - I_{it}) \sum_{n=1}^{p} \beta_n^{-} \Delta X_{it-n} + \varepsilon_{it}$$
(1`)

Where

$$I_{it} = \begin{cases} 1\ if\ \Delta X_{it} \geq 0 \\ 0\ if\ \Delta X_{it} < 0 \end{cases}$$

Where, $a_i$ are country specific fixed effects, $\varphi_t$ are period specific effects, $y_{it}$ represents our conditioned variables (the log of real GDP and log of the national consumer price index (CPI)) for country $i$ in year $t$, $X_{it} = (C_{it} - C^{*}_{i,t})$

$$C_{it} = (T_{it}, P_{it}) \ldots\ldots (1.1)$$

$$C^{*}_{i,} = T^{*}_{i,}, P^{*}_{i} \ldots\ldots (1.2)$$

[9] Sixth Assessment report page 19

$T_{it}$ and $P_{it}$ are average temperature and precipitation of country *I* in year t while $T^*_{i,t}$ and $P^*_{i,t}$ are historical norms of temperature and precipitation. The historical norms for temperature and rainfall are the historical long-term averages calculated as the moving average over *m* years. It is worth noting that while the sample of the study includes periods of various structural breaks and unprecedented shocks such as significant internal and external conflict, major swings in terms of trade, among others, the effects are orthogonal to climate variation and therefore do not affect the parameters of interest.

The assumption is that annual average temperature ($T_{it}$) and precipitation ($P_{it}$) affect growth and inflation only when they deviate from their historical norms, which are denoted by $T^*_{i,}$ and $P^*_{i}$ , respectively. Thus, if climate variables remain close to their historical norms, they are not expected to have any significant effect on growth and inflation. The deviations of temperature and precipitation (weather variables) from their historical norms takes negative and positive values in order to account for possible asymmetric effect of weather variables on real GDP and inflation. The average long-run effects of these variables are denoted by θ, which will be calculated using Ordinary Least Squares estimates obtained from the short-run equation as follows:

$\theta = \frac{1}{\emptyset}\sum_{n=0}^{p}\beta_n$ and $\emptyset = 1 - \sum_{n=0}^{p}\sigma_n$ ……………………………………………………..(2)

For historical norms, the study uses moving averages of temperature (eq. 7) and precipitation (eq. 8) based on the past *m* years, such that

$T^*_{i,t-1} = \frac{1}{m}\sum_{l=1}^{m} T_{i,t-l}$ ……………………………………………………………….……(3)

$P^*_{i,t-1} = \frac{1}{m}\sum_{l=1}^{m} P_{i,t-l}$ ………………………………………………………………………(4)

Consistent with Vose, Applequist, Squires, Durre, Menne, Williams and Arndt (2014), we set m=30[10]. However, for robustness check of the computed historical norm, we re-estimate by setting m=20 and m=40 and compare the estimates in section 6.4.

Pesaran, Shin and Smith (1999) show that a traditional ARDL model can be used when variables are I(1) or I(0) and the estimates are robust to variable omission as well as bidirectional causality between dependent variables and explanatory variables. The unit root test show that real GDP and CPI are both I(1) while the temperature and precipitation variables are I(0). In addition, the ARDL allows for robustness in the results even in cases of omitted variable bias since the study does not control for other variables which affect GDP growth and inflation. Furthermore, for the panel ARDL, Chudik, Mohaddes, Pesaran, and Raissi (2017) suggests a large number of lags in order to accommodate the possible prolonged effects that the impact of climate change might have on the macroeconomy. For this study, the lag length is based on automatic choice by Akaike information criteria. The lag length varies with the model and are shown in the results tables for each model.

[10]This historical norm for temperature and precipitation is estimated as the historical moving average over 30-year period

In the second approach, temperature and precipitation are combined to form a variable called climate change index ($CCI_t$ ). The $CCI_t$ is a weighted average of temperature and precipitation deviations and is calculated as

$$CCI_t = w_t * normalised\left|\left(T_{it} - T^*_{i,t-1}\right)\right| + (1 - w_t) * normalised||\left(p_{it} - p^*_{i,t-1}\right)| \ldots\ldots\ldots(5)$$

*Set* $w_t$*=50%*

Where $\left|\left(T_{it} - T^*_{i,t-1}\right)\right|$ represents absolute deviations from historical norm.

The $CCI_t$ is a weighted average of deviation of temperature and precipitation from their historical norm in both directions. It attempts to calibrate the average climate conditions from its historical norm. In this case, the further away the temperature and rainfall are from the norm, the higher the index and the worse are the climate conditions. It is derived by first finding the absolute deviations of temperature and rainfall, and then normalising them between zero (0) and one (1). Since the climatic shocks are generated for each country, the normalization aims to bring all of them into proportion with one another. Both negative and positive deviations are normalised in each direction because any deviation from historical norm in either direction is considered a deterioration in climatic conditions. The normalised deviations are such that the new variable increases with severity of the climatic conditions. The closer the CCI is to zero (0) the closer the climatic conditions are to historical norms.

From this equation, the lower the index the better the climate conditions i.e. the climatic conditions are close to historical norm. $w_t$ is the weight assigned to temperature. This treatment accounts for the possibility that although researchers have separated individual effects of temperature and precipitation on macroeconomic developments, the two (2) variables may in fact be correlated. For ease of exposition, $w_t$ is set at 50 percent[11] and the following equation is estimated:

$$\Delta y_{it} = a_i + \varphi_t + \sum_{n=1}^{p} +\sigma_n \Delta y_{i,t-n} + \rho_t \Sigma CCI_{i,t-n} + \mu_{i,t} \ldots\ldots\ldots\ldots(6)$$

The focus in eq. (10) is to estimate parameter $\rho_t$ and compare it with coefficients of temperature and precipitation from the first approach.

Although the panel ARDL model gives us precise estimate of the impact of temperature and precipitation on real GDP and inflation, Stock and Watson (2007) argue that the autoregressive distributed lag specification imposes dynamic restrictions and is not very suited where data exhibits non-linearities. In the third approach, we therefore estimate a Local Projection model (LPM) framework as proposed by Jordà (2005). The LPM is flexible enough, does not constrain the shape of impulse responses and is less sensitive to misspecification (Ginn, 2022).

The local projection impulse response method provides a flexible framework to estimate the dynamic effects of shocks. It allows for the examination of nonlinearities, time-varying effects,

[11]See "An assessment of the economic impact of climate change on the macroeconomy in the Caribbean", Economic Commission for Latin America (2021)

and the potential presence of endogeneity. While VARX may appear handy in this framework, the local projection impulse responses represent a generalisation of impulse responses obtained under VARX. They do provide a more flexible framework for estimating the dynamic effects of a shock. The LPM estimates the impulse response function by imposing the shock on a single equation, typically the equation of the variable of interest. This approach allows for the analysis of the dynamic effects of a shock on a specific variable without explicitly modelling the relationships between all variables in the system.

To estimate the LPM, we first set out a standard Vector Autoregression (VAR) as follows:

$$y_t = \alpha + B(L)y_t + \varepsilon_t \quad \text{.....(7)}$$

Where $y_t$ is a set of endogenous variables (real GDP, inflation, temperature, precipitation and CCI), $\alpha$ is a vector of intercept terms; B(L) is an autoregressive lag polynomial; and $\varepsilon_t$ is a vector of white noise error processes. Multiplying equation 11 by $A_0$ yields a VAR represented in structural form:

$$A_0 y_t = \vartheta + A_0 B(L) y_t + \mu_t \quad \text{.....(8)}$$

Where $\vartheta = A_0\alpha$ and $\mu_t = A_0\varepsilon_t$. Matrix $A_0$ captures the contemporaneous relationship between the variables. To identify $A_0$, a standard Cholesky decomposition is employed imposing lower triangular matrix. Ordinarily, the impulse response function from the above specification are standard ones based on Kilian and Kim (2011) and given as follows:

$$\Phi_h^{VAR} = \sum_{l=1}^{h} \Phi_{h-l}^{VAR} Bl, h \epsilon \{1,2,\dots,H\} \quad \text{.....(9)}$$

and

$$\Phi_h^{VAR} = \Phi_{h-l}^{VAR} \mathrm{A}_0^{-1}, h \epsilon \{1,2,\dots,H\} \quad \text{.....(10)}$$

An alternative approach proposed by Jordà (2005) is to use local projection framework to estimate a reduced form impulse response to fit a liner projection as follows:

$$y_{t+h} = \alpha_h + B_1^h y_t + B_2^h y_{t-1} + \cdots + B_p^h y_t + \epsilon_{t+h} \quad \text{.....(11)}$$

where $\alpha_h$ is an intercept term; $B_i^h$ are autoregressive coefficients for future horizon h=1,…,H and $\epsilon_{t+h}$ is a disturbance term. Due to presence of serial correlation, Newey-West correction will be used for standard errors. The corresponding structural local projection impulse responses are given as:

$$\Theta_h^{LP} = \Phi_{h-l}^{LP} A_0^{-1}, h \epsilon \{1,2, \dots, H\} \text{ ..............................................................(12)}$$

Where $A_0^{-1}$ is recovered from the estimated model. The focus will be to observe the impulse response functions of real GDP and inflation following a one-standard deviation shock to temperature and precipitation.

**5.1 Data**

This study used the following variables: Real GDP, CPI, temperature and precipitation. Real GDP and inflation data have been obtained from the IMF World Economic Outlook and they enter the model in logs. The average annual temperature and precipitation were obtained from the World Bank Climate Knowledge Portal. The historical norms for temperature and precipitation are estimated using annual average data and the treatment follows eq. 5.1 eq. 5.2, eq. 7, eq. 8 and eq.9. The sample spans 1980 to 2020. In addition, data on climate events was sourced from the EM-DAT. However, it suffices to note that the EM-DAT, to some extent, has deficiencies in terms of reporting. Table A1 in the appendix provides the measurement and sources of the variables used in the study.

## 6. Results

This section discusses results, beginning with diagnostic tests results, followed by estimates of the impact of climate change on economic growth and the impact of climate change on inflation, respectively. The section concludes by discussing impulse responses for individual MEFMI countries. For robustness, the study went further to re-estimate the models excluding Angola and Zimbabwe, due to structural challenges experienced in these countries, which largely had inflationary effects over certain segments of the sample. The study focuses mainly on how climate change affects macroeconomic performance in the MEFMI region by recovering long-run estimates. However, given the increased importance of climate change in the MEFMI region, future research should focus on individual country dynamics, including institutional arrangements and effects of current adaptation strategies.

### 6.1. **Unit root test results**

The study conducted unit root tests using the panel tests based on Levin, Lin and Chu, (2002), Im, Pesaran and Shin (2003), Fisher-ADF-Maddala and Wu (1999) and Fisher-PP tests (Choi (2001) test. The results, as presented in Table A2 of the Appendix shows that none of the variables are integrated at order 2 and the dependent variables (i.e. LGDP and LCPI ) are stationary after first difference. The CCI, deviations in temperature and rainfall are found to be 1(0).

6.2 **Lag Length Selection and VAR Stability**

The lag length selection for the ARDL models were done using Akaike information criteria and the optimal lags varied across the models as shown in the results tables indicated ARDL Model. The study, however, focuses on recovering long run coefficients of climatic variables on growth and inflation. With respect to the VAR of the LPM framework, the estimation suggests optimal lag length of 1 while the LM Test for serial correlation shows no serial correlation. Furthermore, all the model diagnostics satisfied the VAR conditions of stability. The results show that the model is stable[12].

**6.3. Impact of Climate Change on Real GDP**

The estimated results for the long run impact of climate change on real GDP in the MEFMI region are presented in Table 1. The results of the first model, which includes both climate variables in the estimation, shows that a unit positive deviation in temperature beyond the norm significantly reduces average real GDP in the region by 1.32 percentage points while deviations of temperature below the norm appear to have an opposite impact. The results are in line with the studies that have shown uneven macroeconomic effects of climate change (Sachs & Warner, 1997), (Jones & Olken, 2010) and Dell et al. (2012). These results suggest that above average temperatures could reduce economic activity and that temperatures below the norm may not hamper labour productivity and in the process positively improve growth prospects. With respect to precipitation, Table 1 shows that one percentage point positive deviation above the historical norm significantly improve growth by 0.06 percent while low rainfall reduces growth by 0.03 percent. The results, to some extent reflect regional economic dynamics, which are largely agro-based. Productivity in a more intense agro-based region will be positively impacted by better rainfall compared to lower-than normal rainfall trends.

For robustness, two (2) more equations are estimated, separating the climate variables. In one model, only temperature deviations from historical norm are included while in the other, only deviations of precipitation from historical norm are included as an explanatory variable. The results from the two (2) models, as presented in Table 1 show no discernible differences from those obtained from the first model which includes both variables in one model. However, the negative percentage deviations of precipitation from the historical norm appear not to be significant this time around. The results of the climate change index as shown in Model 4 of Table 1 are also consistent with those of the other three (3) models. They show that a one-unit improvement in the CCI improves economic growth by 0.59 percentage points, although the results are only significant at 10% level of significance.

[12] To improve paper tractability, these results have not been presented here

**Table 1: Effects of Climate Change on Economic Growth**

| Dependent variable: ΔGDP | | | | |
|---|---|---|---|---|
| | **Model 1** | **Model 2** | **Model 3** | **Model 4 CCI** |
| $\ddot{\theta}_{\Delta(T_{it} - T^*_{i,t-1})}+$ | -1.325*** (0.0043) | -1.645*** (0.0001) | | |
| $\ddot{\theta}_{\Delta(T_{it} - T^*_{i,t-1})}-$ | 2.7677** (0.0310) | 2.532* (0.0606) | | |
| $\ddot{\theta}_{\Delta(p_{it} - p^*_{i,t-1})}+$ | 0.058986*** (0.0018) | | 0.025018** (0.0247) | |
| $\ddot{\theta}_{\Delta(p_{it} - p^*_{i,t-1})}-$ | -0.030527** (0.0174) | | -0.002264 (0.8171) | |
| CC1 | | | | -0.5942* (0.0745) |
| ARDL Model | 2,2,2,2,2 | 2,2,2 | 1,1,1 | 1,1 |

Parentheses are P- Values, *** Significant at 1%, ** Significant at 5%, * Significant at 10%

### 6.4. Results of the Impact of Climate Change on Inflation

Table 2 presents the results of the impact of climate change on inflation in the MEFMI region. The results of the first model show that a unit increase in temperature above the norm has a significant negative (-0.01) impact on inflation while a unit deviation of temperature below the norm appears to be theoretically inconsistent but also insignificant in the MEFMI region.

With respect to deviations of precipitation from historical norm, the results of the first model show that both positive and negative deviations reduce inflation. The impact is more pronounced and significant for negative deviations. Specifically, a 1 percentage point change in precipitation below the norm, reduces inflation by 0.09 percentage points while a 1 percentage point change in precipitation above the norm reduces inflation by 0.004 percentage points.

Table 2 also shows results for the second and third models, which, separately, assess the impact of deviations of temperature (Model 2) and precipitation (model 3) from their respective norms. Specifically, the results from the second model are consistent with those of the first model both in the size and direction of the coefficient, as well as the significance. The results of the climate change index as shown in Model 4 of Table 2 show that worsening of climatic conditions increases inflation although statistically significant at 10% level of significance.

Considering wide swings in inflation and GDP in Angola and Zimbabwe during the sample period, the models were re-estimated excluding the two (2) countries. The results of the impact of climate change on inflation are presented in Table A3 of the Appendix and appear to be broadly in sync with MEFMI-wide findings. Specifically, the first model shows that a 0.01 percentage point positive deviation of temperature from the historical norm significantly lowers inflation by 0.019 percentage points while a negative deviation from the historical norm has contrary impact on inflation. With respect to precipitation, the results show that positive deviations from the norm have an insignificant impact compared to the benchmark model (*i.e. the model inclusive of all MEFMI countries*) while the negative deviations are consistent with the benchmark model. Results for the second and third models do not differ with those of the first in terms of direction of the impact and level of significance but vary in terms of the magnitude of change. Excluding Angola and Zimbabwe, the CCI appears to have inflationary effects in the region.

**Table 2: Long run Effects of Climate Change on Inflation**

| **Dependent variable: ΔLGDP** | | | | |
|---|---|---|---|---|
| | **Model 1** | **Model 2** | **Model 3** | **Model 4 - CCI** |
| $\ddot{\theta}_{\Delta(T_{it} - T^*_{i,t-1})}+$ | -1.793***<br>(0.017) | -1.079<br>(0.3585) | | |
| $\ddot{\theta}_{\Delta(T_{it} - T^*_{i,t-1})}-$ | 2.0531<br>(0.5661) | 3.2545<br>(0.1312) | | |
| $\ddot{\theta}_{\Delta(p_{it} - p^*_{i,t-1})}+$ | -0.004229<br>(0.8872) | | 0.038036<br>(0.1922) | |
| $\ddot{\theta}_{\Delta(p_{it} - p^*_{i,t-1})}-$ | -0.094378***<br>(0.0082) | | -0.009678<br>(0.7338) | |
| CC1 | | | | 2.2675*<br>(0.06389) |
| **ARDL Model** | **1,1,1,1,1,** | **2,2,2** | **1,1,1** | **1,1** |

Parentheses are P- Values, *** Significant at 1%, ** Significant at 5%, * Significant at 10%

### 6.5. Changing the historical Norm

To ensure that the findings are robust and insensitive to the way historical norms are calculated, we re-estimate all models with different computation of historical norms for temperature ($T^*_{i,t-1}$) and precipitation ( $p^*_{i,t-1}$ ) by using 20 year (m=20) and 40 year (m=40) moving averages and compare the results against the benchmark 30 year moving average. The results are presented in Table A4 and A5 of the Appendix. The results for all the models are consistent with those of the benchmark historical norm (m=30). Specially, the estimated coefficients for the impact of the deviations of temperature from their historical norm (m=20) on real GDP range between -0.03 and -0.02 for positive deviations compared to -0.01 and -0.02 in the benchmark model. The estimated coefficients for negative deviations are also in a similar range as those of the benchmark model m=30) as shown in Table 1 and Table 2. A similar observation is also noticed for the estimated coefficients for the impact of the deviations (both positive and negative) of precipitation. Using the historical norm of m=40, the results show that the estimated coefficients for the impact of the positive deviations of precipitation on real GDP range between 0.07 and 0.03, compared to 0.06 and 0.03 in the benchmark model.  Similarly, the estimated coefficients for the impact of the deviations (both positive and negative) of temperature are with similar range of the Benchmark model. A similar trend is largely realized on the impact of climate change on inflation in the MEFMI region for both historical norms of

M=20 and M=40. Overall, these results suggest that the results from the benchmark model are insensitive to specification of historical mean.

### 6.6. Impulse responses

This section discusses the individual local projection impulse responses on the effect of temperature, precipitation and CCI on growth and inflation as shown in Appendix Figure A3 to 5.

#### 6.6.1 Impulse Response of GDP growth

The results suggest that a positive shock to precipitation raises GDP in Botswana, Kenya, Lesotho, Malawi, Mozambique, Zambia and Zimbabwe, but is insignificant in other countries. The results suggest that most countries that depend on agriculture tend to show significant positive effect. Regarding temperature, a positive shock raises output in Angola, Malawi and Tanzania, but reduces output in Uganda and is insignificant in the rest of the countries. Importantly, the results also show that a positive shock to climatic conditions as captured by the broad CCI tend to increase GDP in Botswana, Kenya, Mozambique, Rwanda and Zambia. The same response is observed for Zimbabwe, Malawi and Kenya although initial worsening of GDP is observed.

#### 6.6.2 Impulse responses of inflation

The local projection results suggest that positive shock to precipitation lowers inflation in Botswana, Kenya and Rwanda but raises inflation in Eswatini, Malawi and Namibia. In the rest of the MEFMI countries, impact of precipitation is insignificant. A positive shock is represented by a deviation from the normal rainfall pattern. Normal rainfall pattern in Botswana being the historical average remains relatively low due to its semi-arid condition. Therefore, rainfall patterns above the norm positively affects GDP. In other countries, a positive shock may represent excess rainfall compared to the norm, which is detrimental to agriculture production and hence inflation, which is largely agriculture driven. On the other hand, a positive shock to temperature lowers inflation in Eswatini, Kenya Malawi, Namibia and Zimbabwe. In the rest of the countries, there is no discernible impact. More broadly using the CCI, a positive shock to climate conditions reduces inflation in Angola, Botswana, Malawi, Mozambique, and Zambia but raises inflation in Uganda and Tanzania.

Overall, MEFMI is a region with diverse climate zones and ecosystems, which could be responsible for varied impulse response functions. The MEFMI region includes countries with vastly different levels of annual precipitation, ranging from arid and semi-arid regions (e.g., Namibia, Botswana) to regions with high rainfall (e.g., Tanzania, Mozambique). This has significant implications for agriculture, water availability, and energy production in each country. In terms of temperature, the MEFMI region also includes countries with different temperatures, ranging from the hot and dry deserts of Namibia and Botswana to the cooler highlands of Rwanda and Tanzania. This appears to have significant implications for agricultural productivity, energy demand, and health outcomes which could generate different responses of both inflation and GDP.

Dependence on natural resources may also matter. Many MEFMI countries are highly dependent on natural resources, including forests, fisheries, and agriculture. Climate change impacts on these resources can have significant economic implications but also at varying degree of intensity depending on degree of dependence on each one of them. This can result into differentiated impulse response functions.

Cooler temperatures can help reduce heat stress on crops, increase soil moisture retention, and decrease pest populations, leading to increased agricultural output and, therefore, higher GDP and lower inflation. Cooler temperatures are also attractive to tourists, leading to an increase in tourism-related activity and revenues. Countries like Tanzania and Zimbabwe have significant tourism industries.

Given the vulnerability of the region to climate change, many MEFMI countries have recognised the importance of adapting to and mitigating the impacts of climate change. This has led to a growing emphasis on renewable energy, sustainable agriculture, and climate-smart infrastructure. Therefore, effects of climate change in countries which have progressed in adaptation and mitigation measures might be different from other countries.

Generally, the impact of weather on economies in the MEFMI region is complex and multifaceted, but in general, extreme weather conditions do lead to lower agricultural output, increased energy costs, among others, all of which can contribute to a decrease in GDP and a rise in inflation. The seemingly fewer emphatic results on individual country impulse responses suggest the need for detailed country experiences on the impact of climate in order to capture country peculiarities.

## 7. Conclusion and Recommendations

This study examined the impact of climate change on real GDP and consumer prices in MEFMI region, using the autoregressive distributed lag model, as a core model. Results show that a 1°C positive deviation in temperature beyond the norm significantly reduces average real GDP in the region by 1.3 percentage points while deviations of temperature below the norm appear to have an opposite impact. These findings are similar (Sachs & Warner, 1997), (Jones & Olken, 2010) and Dell et al. (2012). These results suggest that above average temperatures would reduce economic activity. Temperatures below the norm do not hamper labor productivity and in the process, positively improve growth prospects. With respect to precipitation, positive deviations above the historical norm significantly improve growth by 0.06 percent while low rainfall reduces growth by 0.03 percent. The results, to some extent reflect regional economic dynamics, which are largely agro-based suggesting that productivity in a more intense agro-based region is likely to be positively impacted by better rainfall compared to lower-than normal rainfall trends. The results of the climate change index also show that an improvement in the climate conditions by one unit improves economic growth by 0.59 percentage points. With regard to inflation, temperatures above the norm have a disinflationary effect in the long run, similar to deviations in precipitation, both negative and positive.

The findings in this paper have several policy implications. Important to note is that climate change significantly affects economic growth and inflation in the MEFMI region. Climate change, including extreme weather events and mitigatory efforts to low carbon technology, will increasingly affect output and inflation with significant effect on fiscal and monetary policy.

From the fiscal side it is important for governments to strengthen resilience by investing in adaptation, building fiscal buffers, and enhancing insurance systems. This would involve investing in climate resilience and weather proofing economic activities to minimize the business cycle, which includes building of dams to harness water and installation of boreholes for irrigation, installation of solar and wind power to reduce overreliance on hydro and coal powered energy systems. There is also need for prioritising public investments that mitigate climate risks and ensure that these investments address climate change by fully integrating climate risks at each and every stage of the public-investment cycle. It is also important to deliberately put in place fiscal buffers and other ways to pool risks at the national and regional levels, which can be called upon in face of climate related disasters such as floods, drought, etc.

Government can also put in place fiscal incentive structures that encourage private firms to transit to low carbon technologies. This supported, can be supported by environmental tax reforms that align the private cost of energy with its social cost. In this regard, fuel taxes can be considered for countries with large informal sectors such as MEFMI with likely high rates of tax evasion and limited capacity for tax administration.

Central banks can also innovatively use their traditional monetary policy tools such as interest rates, reserve requirements, and open market operations to incentivize investments in the green economy and steer capital towards sustainable initiatives. Thus, central banks can support the development of green bonds in the economy. In addition, central banks can support targeted financing mechanisms to propel smallholder farmers and agricultural enterprises to engage in smart agriculture that mitigate climate change through providing credit facilities and guarantees (partial guarantees). Central banks to also leverage on financial developments (FinTechs) to support climate change related funding.

In addition, the central banks can also issue sustainable banking guidelines to promote sustainable banking practices, which include incorporating environmental and social risk assessments into lending decisions, setting sustainability targets, and encouraging the adoption of sustainable finance principles by commercial banks. In addition, the central banks should use macroprudential tools, including use of Basel capital framework to incentivize banks by giving lower-risk weights to loans to support low carbon transition activities as well as providing framework for financial institutions to provide adequate capital buffers to withstand climate shocks. In addition, central banks can encourage increased use of bancassurance products, which can also go a long way in increasing the resilience of businesses to shocks.

The significant impact of climate change on output and inflation has considerable implications for macroeconomic policy making and macroeconomic management. The increased effects of climate change impact on the conduct o fiscal and monetary policies. In this regard, there is need to embed climate change in the macroeconomic policy making. The macro-fiscal models have to be adapted and modified to take into consideration the channels and impact of climate change. More precisely, there might be need to re-think the current fiscal and monetary policy frameworks. For fiscal policy, this would include incorporating disaster-risk management into fiscal rules, medium-term fiscal frameworks, and debt sustainability analyses while for monetary policy these may entail modifying monetary policy transmissions.

As such, there is need for capacity building in Ministries of Finance and Planning and central banks through training of staff on climate change and its related impact on macroeconomic policy making. In addition, there is also need for training to properly compile and analyse climatic data and embed same in macroeconomic models and forecasting.

In addition, the issues of addressing the effects of climate change on the macroeconomy requires an all stakeholder collaborative approach at the national level, and this involves an Intergovernmental Working Group approach. On an international level, these would entail cooperation with international organisations, development institutions and non-governmental organisations. As a result, a number of central banks have joined the Network for Greening the Financial System (NGFS), which is a platform to share information, experiences and even training on the effects of climate change. International collaboration at continental level between Association of African Central Banks (AACB) and European Central Bank (ECB) has also provided a fruitful platform to share knowledge and experiences on climate change.

Overall, efforts aimed to reducing global warming including such as reduction in fossil fuel energy, reforestation and afforestation, and protection of wetlands should be supported. Broadly, the results emphasise the importance of following an industrial strategy that proactively takes climate change-related risks into account.

Given the rising trade among member countries (both formal and informal) and the finding that climate conditions affect countries with different intensities, it will be important for subsequent research to exploit the extent to which weather shocks in one country affect macroeconomic dynamics in the rest of the countries. For example, a weather shock that destroys power supply may raise import requirements for another country.

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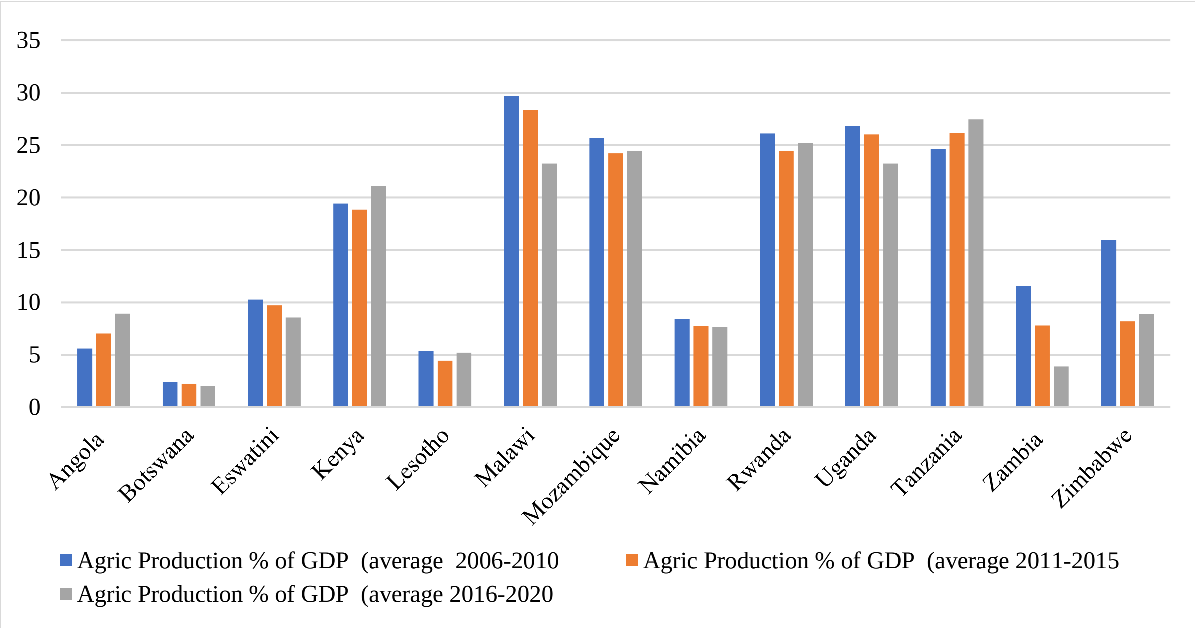
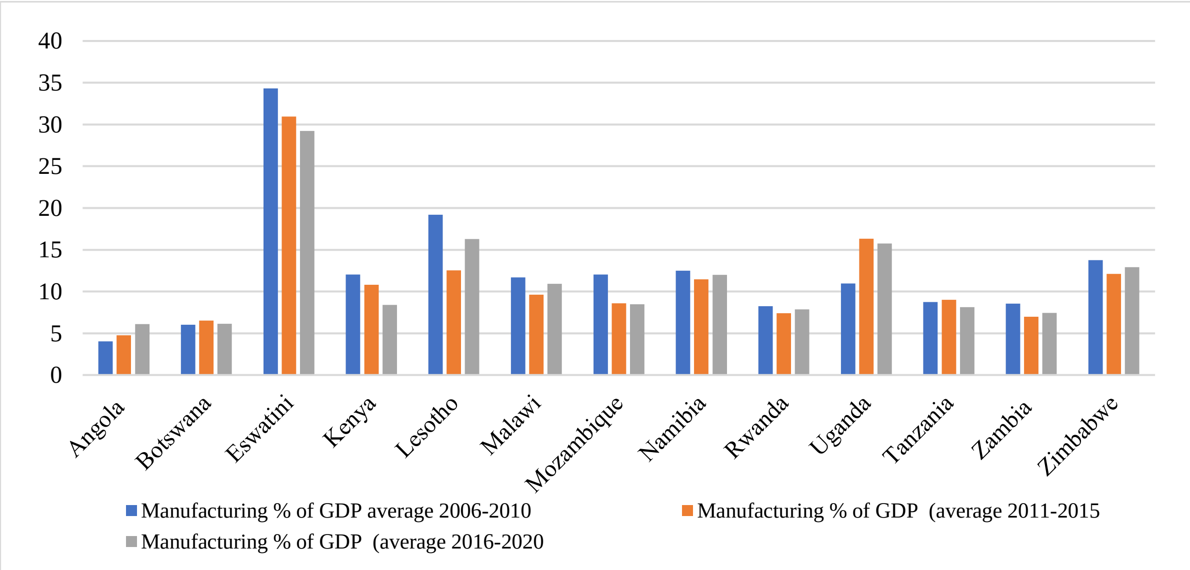
***Figure A 1: Five Year Agriculture Fisheries and Forestry Sector as percentage of GDP by Country***




*Source: WDI, 2022*

**Figure A 2: Five Year Manufacturing Sector as percentage of GDP by Country**




Source: WDI, 2022

***Table A 1: Definition of Variables, Measurement Scales and Data Sources***

| Variable | Definition | Source |
|---|---|---|
| **LGDP** | Log of Real GDP | IMF International Financial Statistics |
| **LCPI** | Log of Consumer Price Index | National Statistical Agencies |
| **Temperature** | Annual Average Temperature | World Bank climate knowledge (2022) |
| **Rainfall** | Annual Average Rainfall | World Bank climate knowledge (2022) |

**Table A 2: Presentation of Panel Stationarity (Unit Root) Tests Results**

| **Variable** | **Levin, Lin & Chu t*** | **Level of Integration** |
|---|---|---|
| LGDP | -0.52783 | - |
| 1st Diff LGDP | -2.13497** | I (1) |
| LCPI | -2.57449** | - |
| 1st Diff LCPI | -2.53270*** | I (1) |
| $\ddot{\theta}_{\Delta(\mathrm{T}_{it} - \mathrm{T}^{*}_{i,t-1})} -$ | -24.2298*** | I (0) |
| $\ddot{\theta}_{\Delta(\mathrm{T}_{it} - \mathrm{T}^{*}_{i,t-1})} +$ | -11.4053*** | I (0) |
| $\ddot{\theta}_{\Delta(\mathrm{p}_{it} - \mathrm{p}^{*}_{i,t-1})} -$ | -8.97154*** | I (0) |
| $\ddot{\theta}_{\Delta(\mathrm{p}_{it} - \mathrm{p}^{*}_{i,t-1})} +$ | -8.62063*** | I (0) |
| CCI | -7.48790*** | I(0) |

***, **, * mean significant at 1%, 5%, and 10%, respectively

**Table A 3: Long run Effects of Climate Change on Economic Growth in the MEFMI Region excluding Angola and Zimbabwe**

| **Dependent variable: ΔLGDP** | | | | |
|---|---|---|---|---|
| | **Model 1** | **Model 2** | **Model 3** | **Model 4 CCI** |
| $\ddot{\Theta}_{\Delta(\mathrm{T}_{it} - \mathrm{T}^{*}_{i,t-1})} +$ | -1.2608*** (0.0027) | -0.5410* (0.0952) | | |
| $\ddot{\Theta}_{\Delta(\mathrm{T}_{it} - \mathrm{T}^{*}_{i,t-1})} -$ | 1.3130 (0.5248) | -0.9284 (0.7181) | | |
| $\ddot{\Theta}_{\Delta(\mathrm{p}_{it} - \mathrm{p}^{*}_{i,t-1})} +$ | 0.00212* (0.092) | | 0.004656*** (0.0029) | |
| $\ddot{\Theta}_{\Delta(\mathrm{p}_{it} - \mathrm{p}^{*}_{i,t-1})} -$ | -0.004091** (0.0118) | | 0.000518 (0.6894) | |
| CC1 | | | | -0.354848 (0.4752) |
| **ARDL Model** | **1,0,0,0,0** | **2,2,2** | **1,1,1** | **2,0** |

**Parentheses are P- Values, *** Significant at 1%, ** Significant at 5%, * Significant at 10%**

**Table A 4: Long run Effects of Climate Change on Inflation in the MEFMI Region excluding Angola and Zimbabwe**

Dependent variable: ΔLCPI

| | Model 1: | Model 2: | Model 3 - | Model 4 - CCI |
|---|---|---|---|---|
| $Ө_{Δ(Ͳ_{it} - Ͳ^{*}_{i,t-1})} +$ | -1.9657*** (0.0006) | -0.9281* (0.0832) | | |
| $Ө_{Δ(Ͳ_{it} - Ͳ^{*}_{i,t-1})} -$ | 2.290 (0.5208) | 4.656 (0.1526) | | |
| $Ө_{Δ(p_{it} - p^{*}_{i,t-1})} +$ | 0.0000915 (0.9761) | | 0.038036 (0.1922) | |
| $Ө_{Δ(p_{it} - p^{*}_{i,t-1})} -$ | -0.012985*** (0.0006) | | -0.009678 (0.7338) | |
| CC1 | | | | 2.287047* (0.615) |
| ARDL | 1,1,1,1,1 | 2,3,1 | 1,1,1 | 2,0 |

Parentheses are P- Values, *** Significant at 1%, ** Significant at 5%, * Significant at 10%

## Robustness Tests

**Table A 5: Effects of Climate Change on Economic Growth - M20**

**Dependent variable: ΔLGDP**

| | Model 1 | Model 2 | Model 3 | Model 4 - CCI |
|---|---|---|---|---|
| $Ө_{Δ(Ͳ_{it} - Ͳ^{*}_{i,t-1})} +$ | -2.979** (0.0162) | -1.6345*** (0.0006) | | |
| $Ө_{Δ(Ͳ_{it} - Ͳ^{*}_{i,t-1})} -$ | 2.7677** (0.0310) | 2.1304* (0.0647) | | |
| $Ө_{Δ(p_{it} - p^{*}_{i,t-1})} +$ | 0.079323** (0.03418) | | 0.028655* (0.0512) | |
| $Ө_{Δ(p_{it} - p^{*}_{i,t-1})} -$ | -0.194041** (0.0174) | | -0.00833 (0.5253) | |
| CC1 | | | | -0.5942* (0.0745) |
| ARDL Model | 2,2,2,2,2 | 2,2,2 | 2,0,0 | 1,1 |

Parentheses are P- Values, *** Significant at 1%, ** Significant at 5%, * Significant at 10%

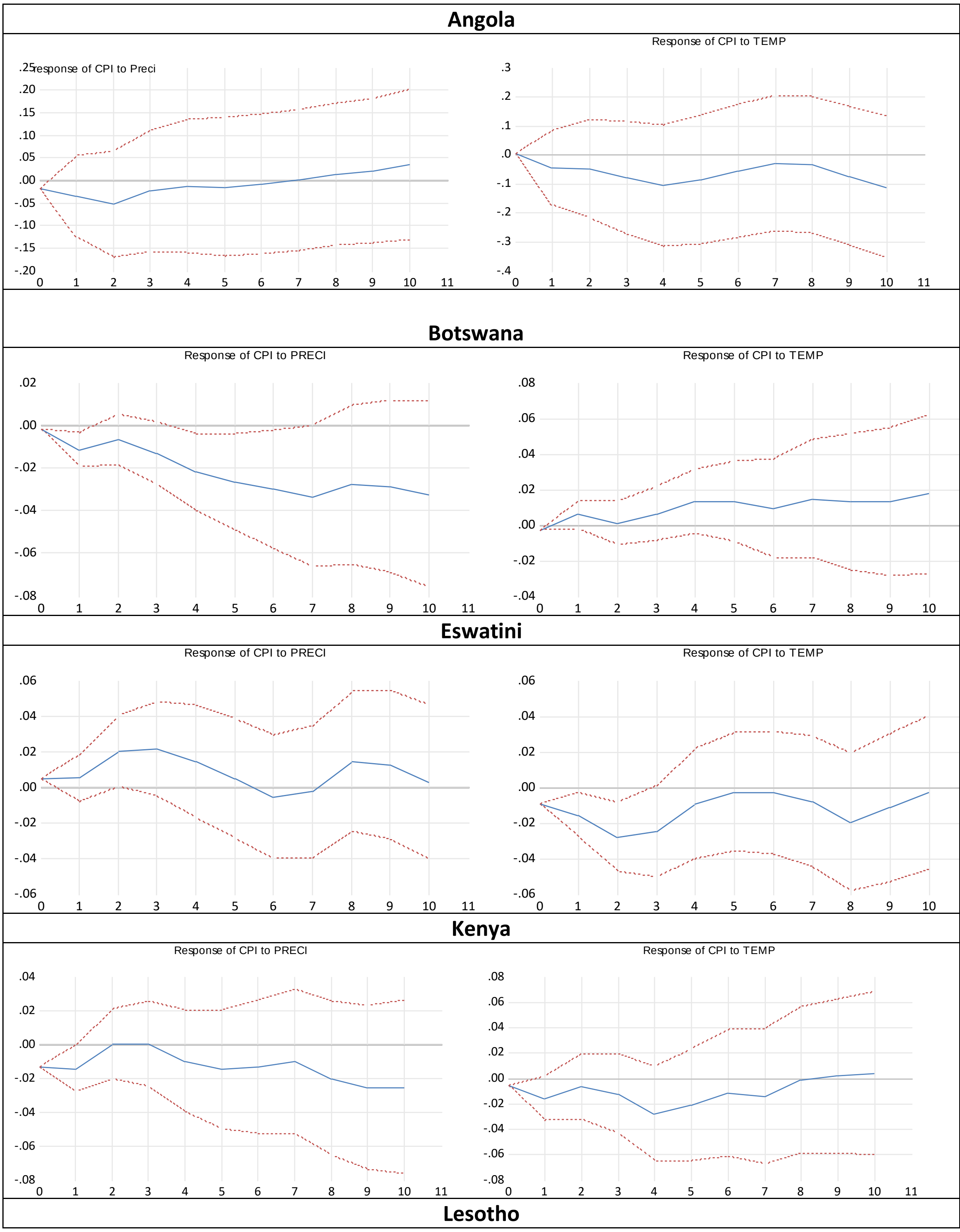
## Table A 6: Effects of Climate Change on Economic Growth - M40

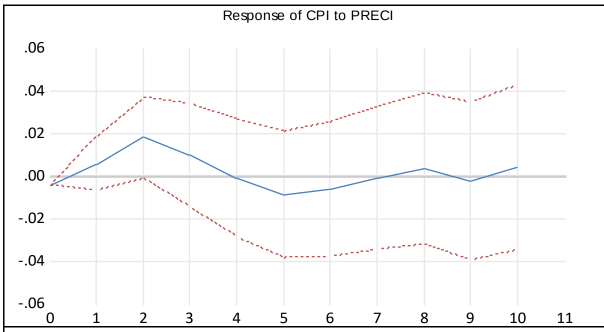
**Dependent variable: ΔLGDP**

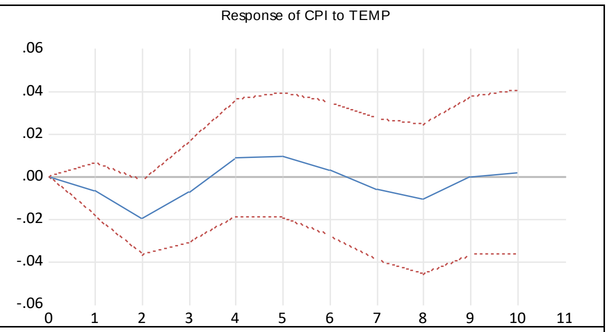
| | **Model 1** | **Model 2** | **Model 3** | **Model 4 - CCI** |
|---|---|---|---|---|
| $\ddot{\Theta}_{\Delta(T_{it} - T^{*}_{i,t-1})}+$ | -0.8267**<br>(0.0235) | -0.813***<br>(0.0023) | | |
| $\ddot{\Theta}_{\Delta(T_{it} - T^{*}_{i,t-1})}-$ | 4.3779**<br>(0.0127) | 1.8788*<br>(0.1337) | | |
| $\ddot{\Theta}_{\Delta(p_{it} - p^{*}_{i,t-1})}+$ | 0.058986***<br>(0.0018) | | 0.019876**<br>(0.0247) | |
| $\ddot{\Theta}_{\Delta(p_{it} - p^{*}_{i,t-1})}-$ | -0.030527**<br>(0.0174) | | -0.002264<br>(0.1332) | |
| CCI | | | | -0.5942*<br>(0.0745) |
| ARDL Model | 1,1,1,1,1 | 1,1,1 | 1,1,1 | 1,1 |

Parentheses are P- Values, *** Significant at 1%, ** Significant at 5%, * Significant at 10%

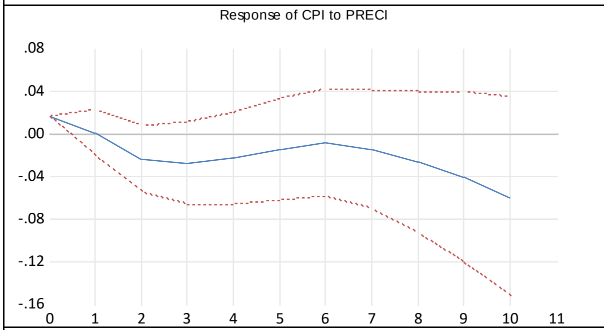
**Figure A 3 Local Projection Impulse Responses of Inflation to Precipitation and Temperature**

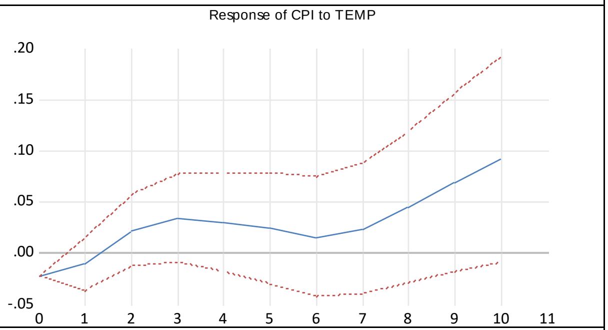




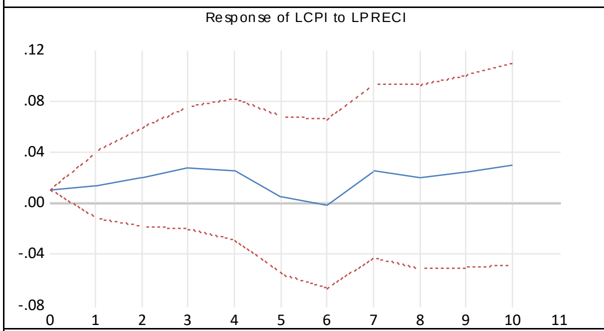



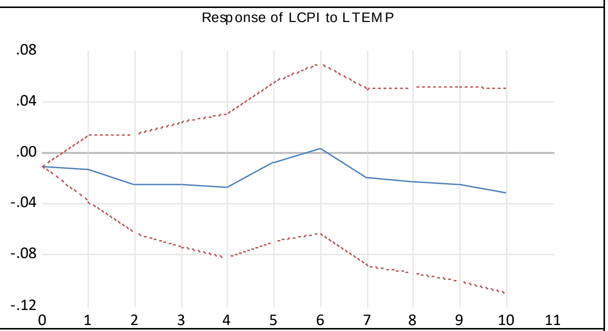

**Malawi**



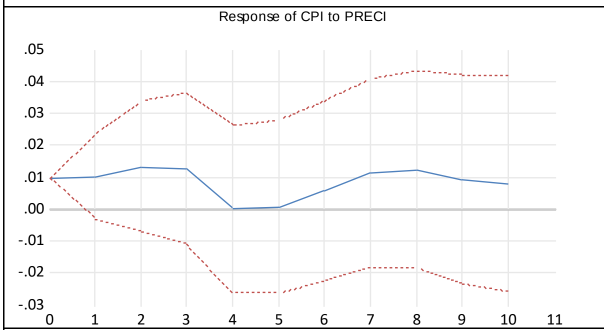



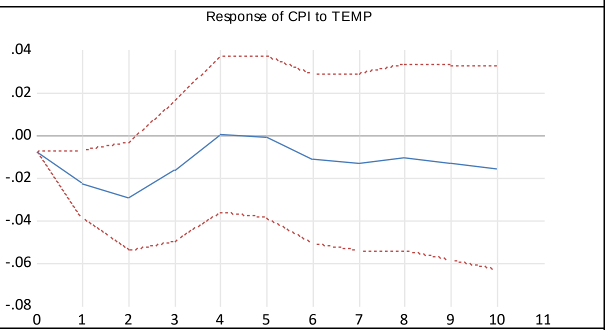

**Mozambique**



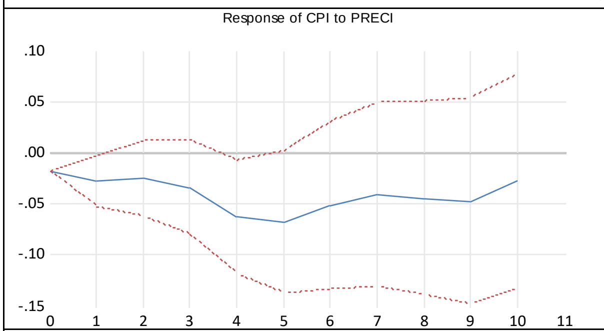



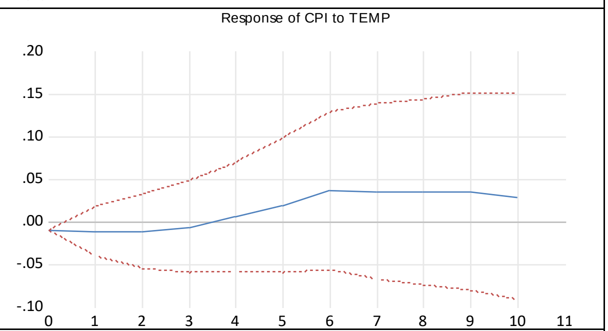

Namibia



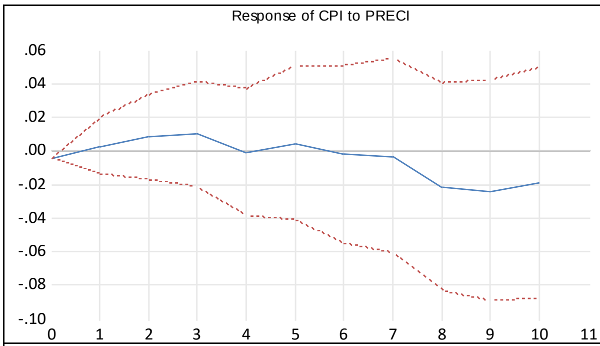



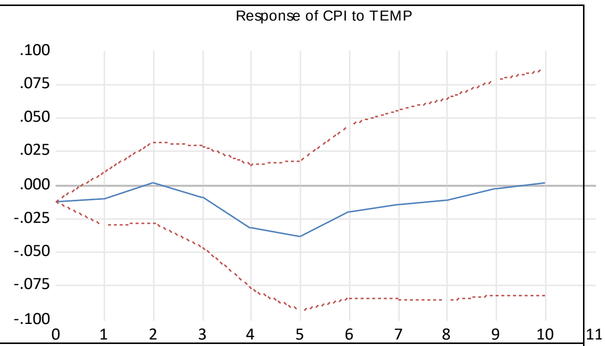

Rwanda




Tanzania




Uganda

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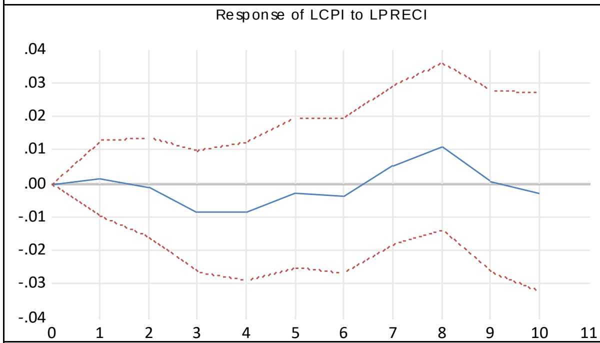
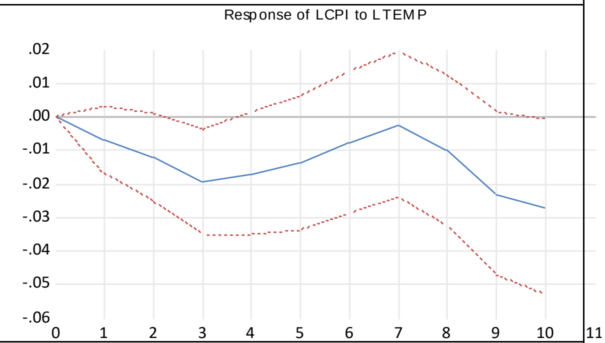
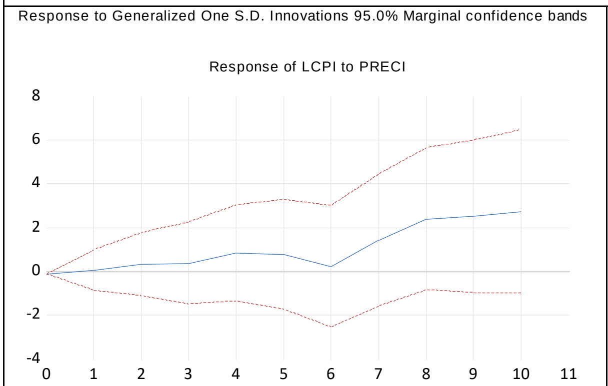
Zambia




**Zimbabwe**



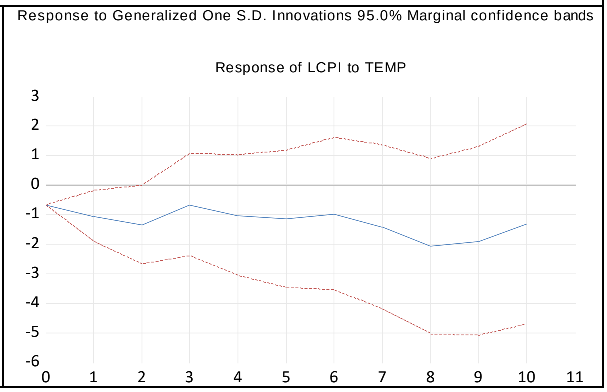
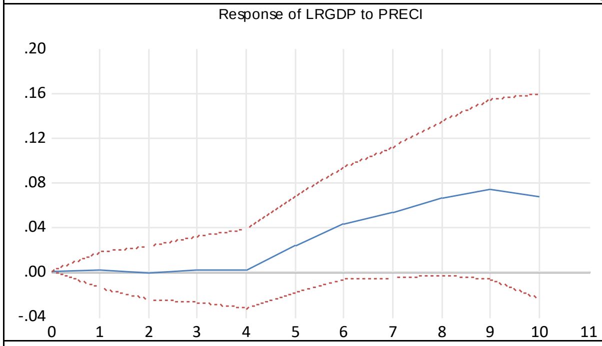
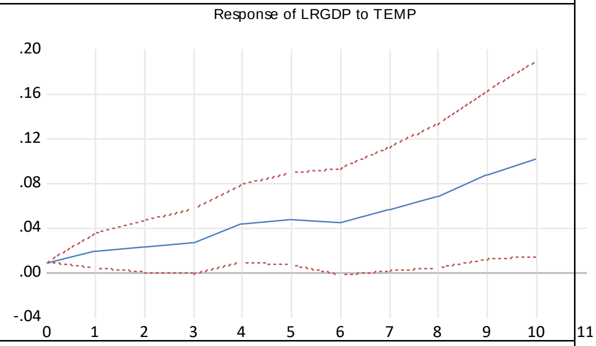



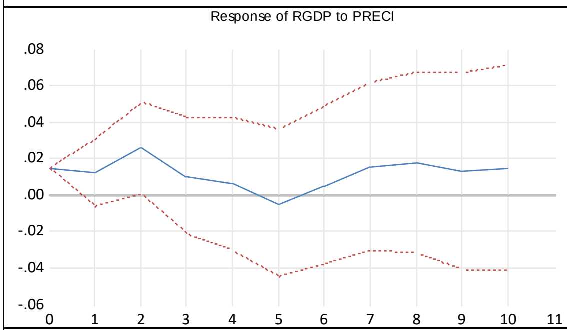
**Figure A 4 Local Projection Impulse Responses of Real GDP to Precipitation and Temperature**

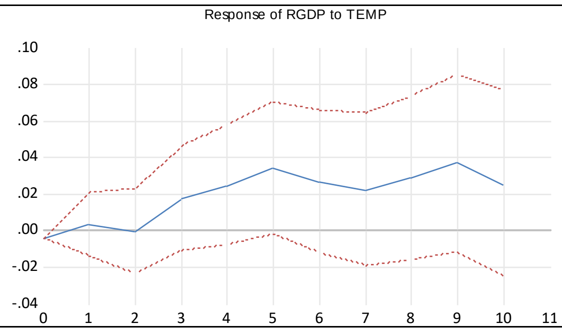
## Angola



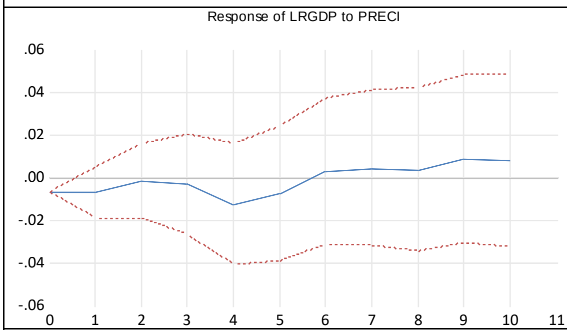



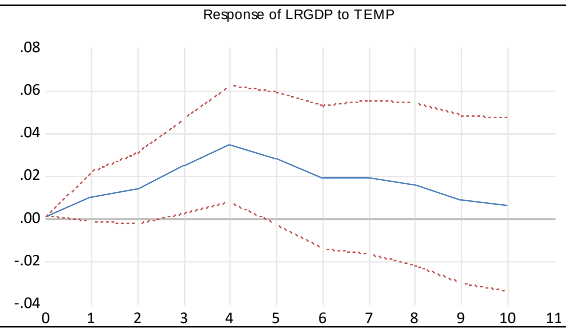

## Botswana



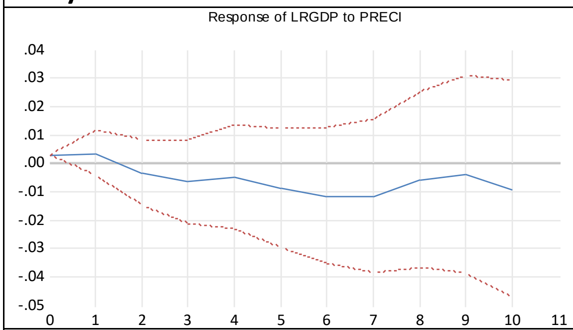



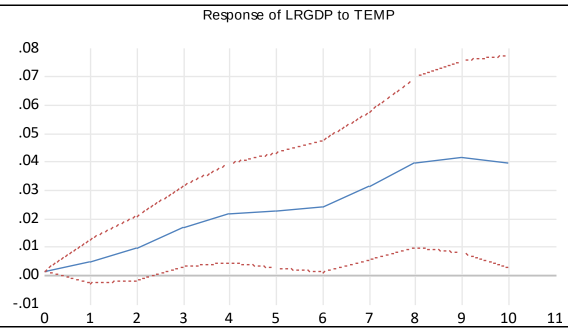

## Eswatini



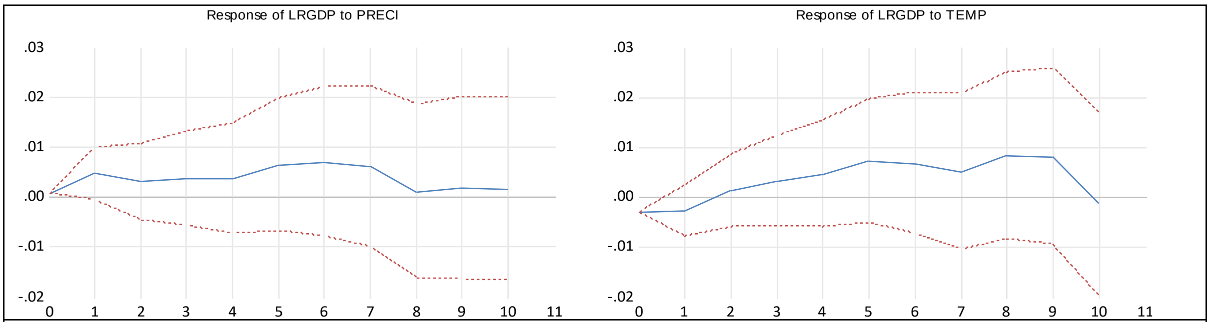




## Kenya

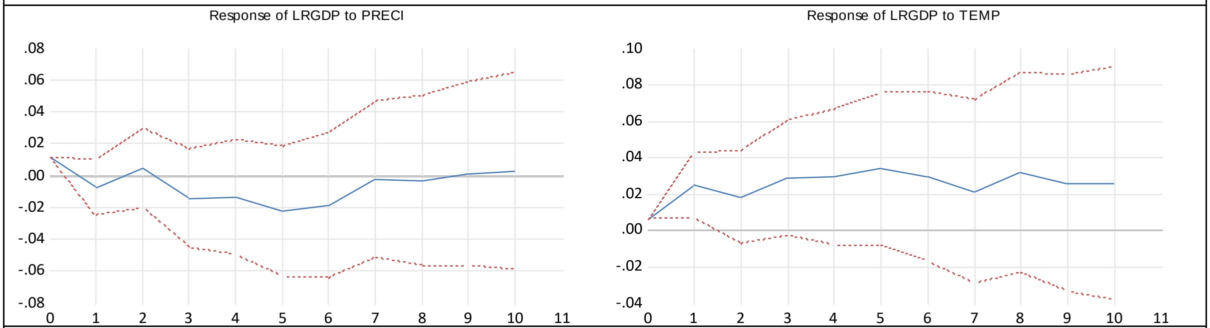


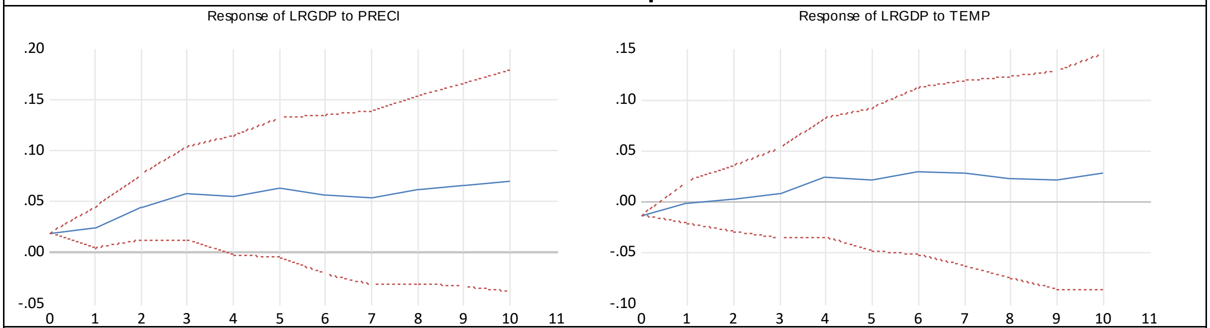

## Lesotho



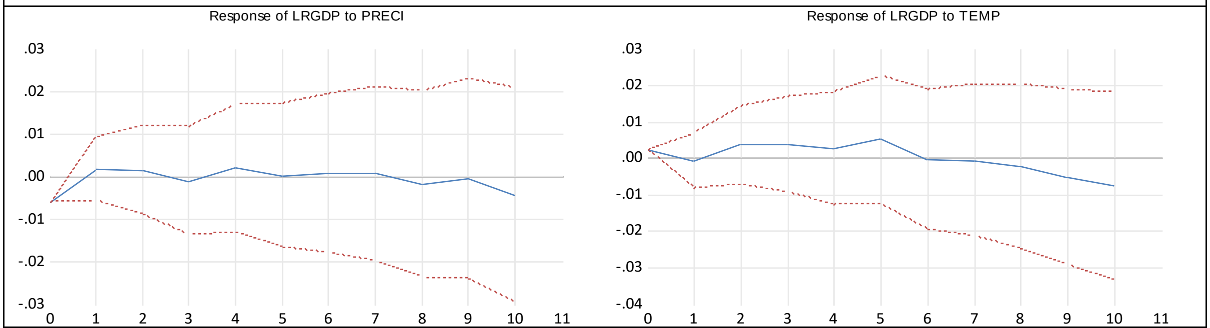

**Malawi**



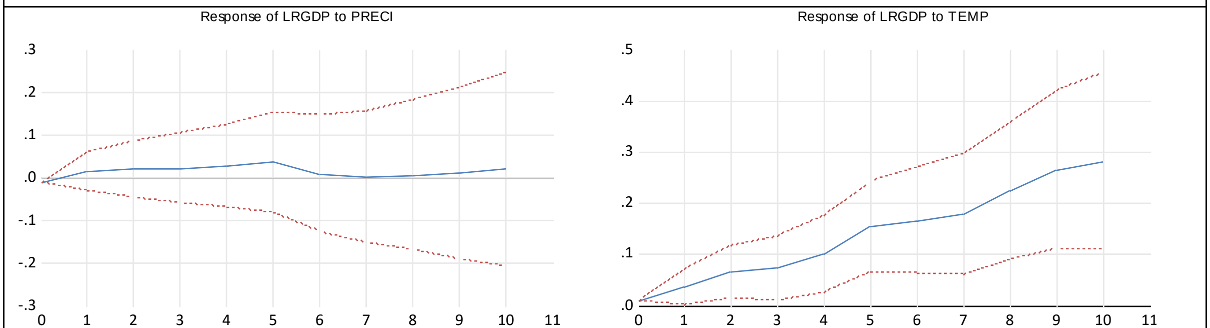

**Mozambique**



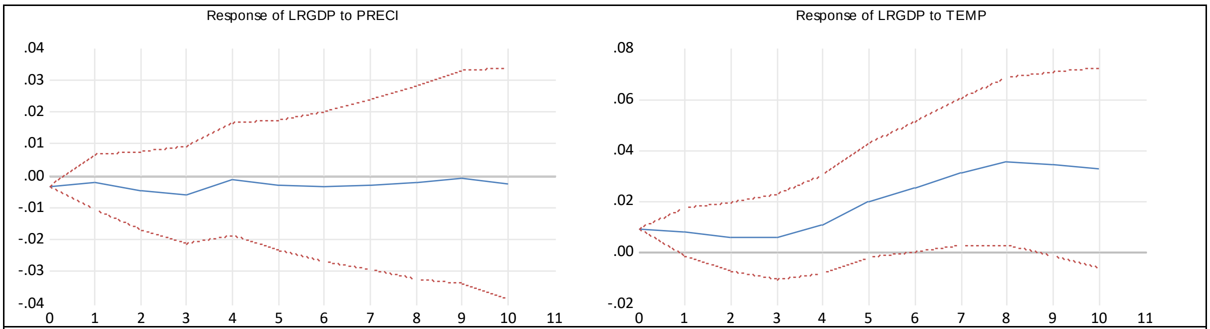

Namibia



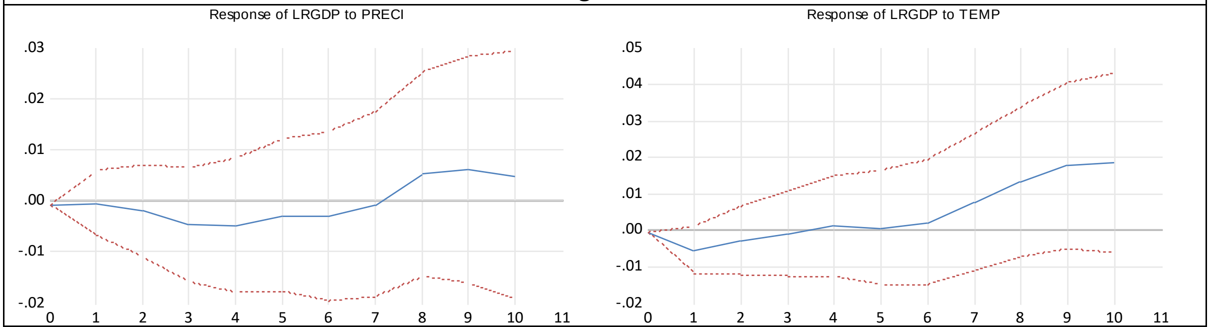

Rwanda



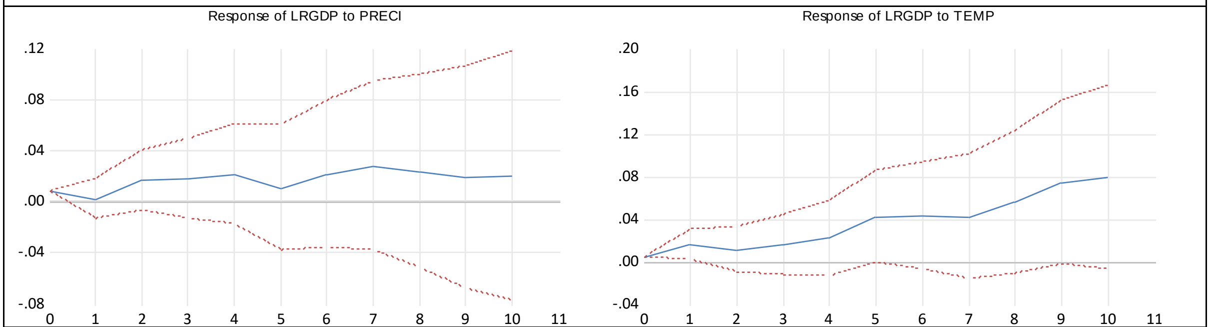

Tanzania




## Uganda




## Zambia




## **Zimbabwe**

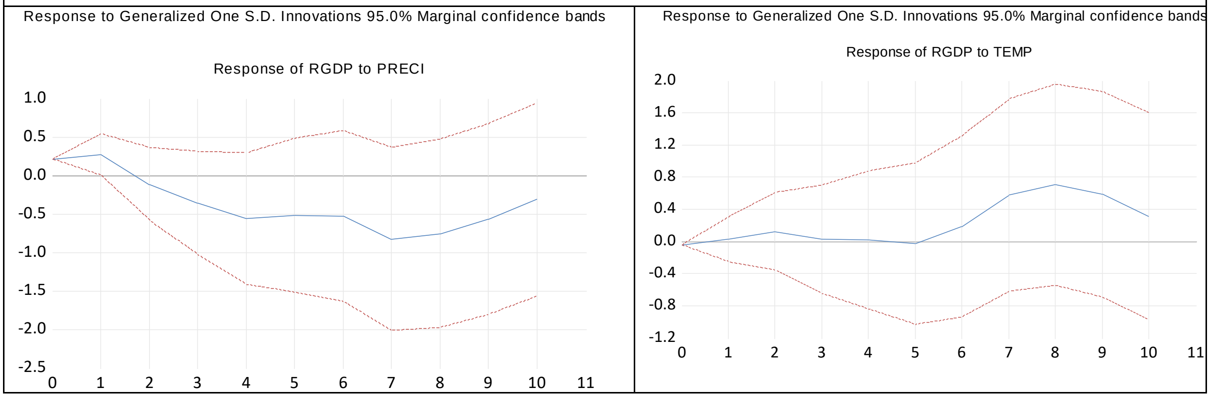
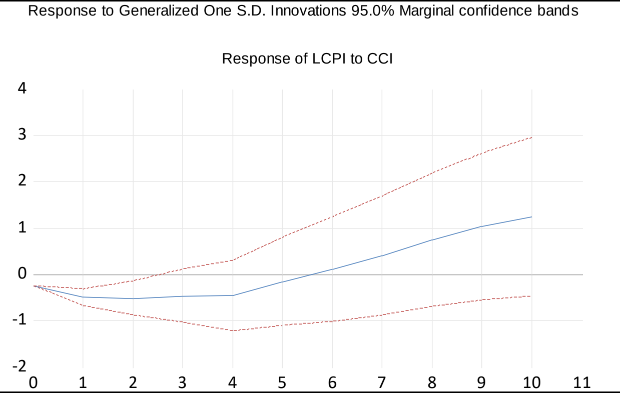
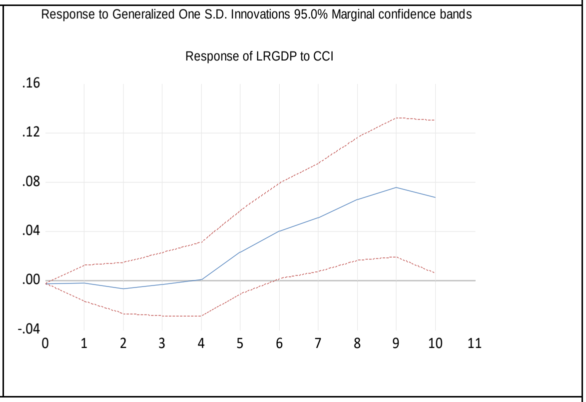


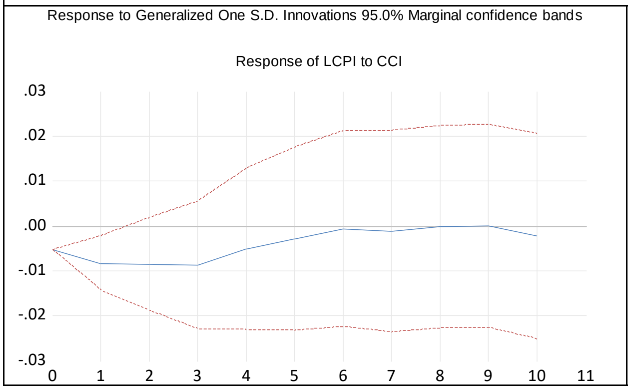
**Figure A5 : Local Projection Impulse Responses of Inflation (left column) and Real GDP(right column)  to Climate Change Index**

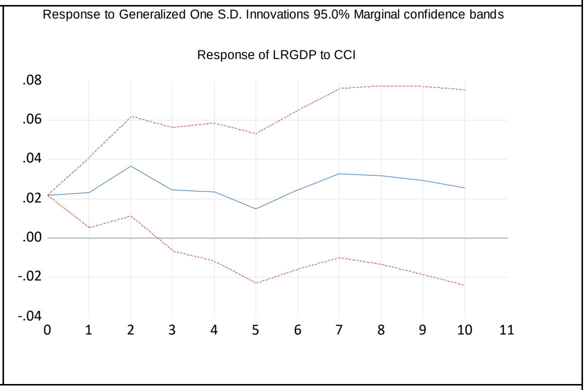
## Angola



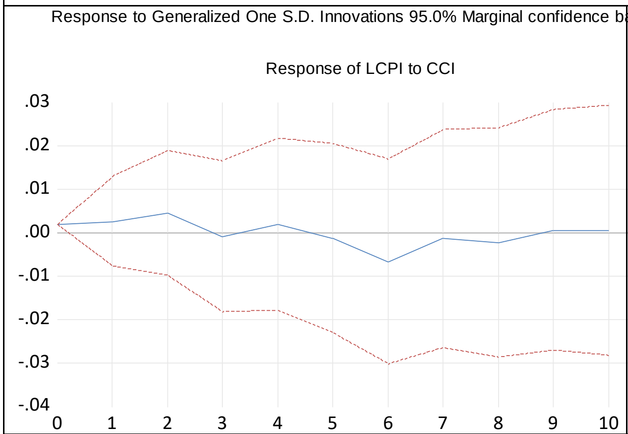



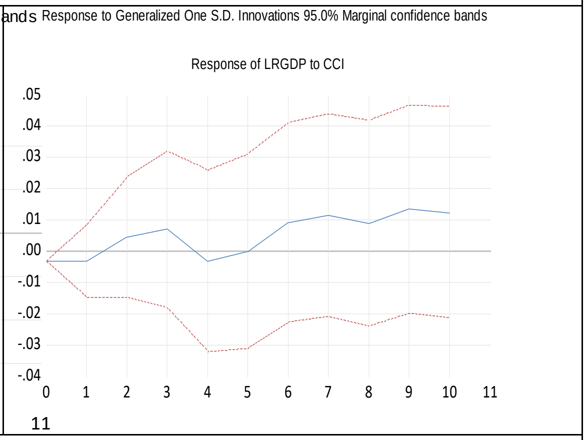

## Botswana



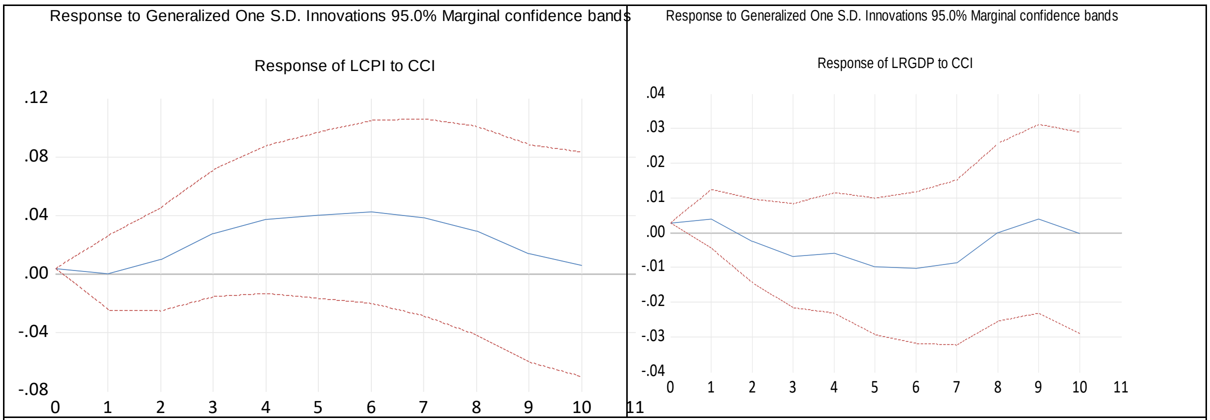




## Eswatini

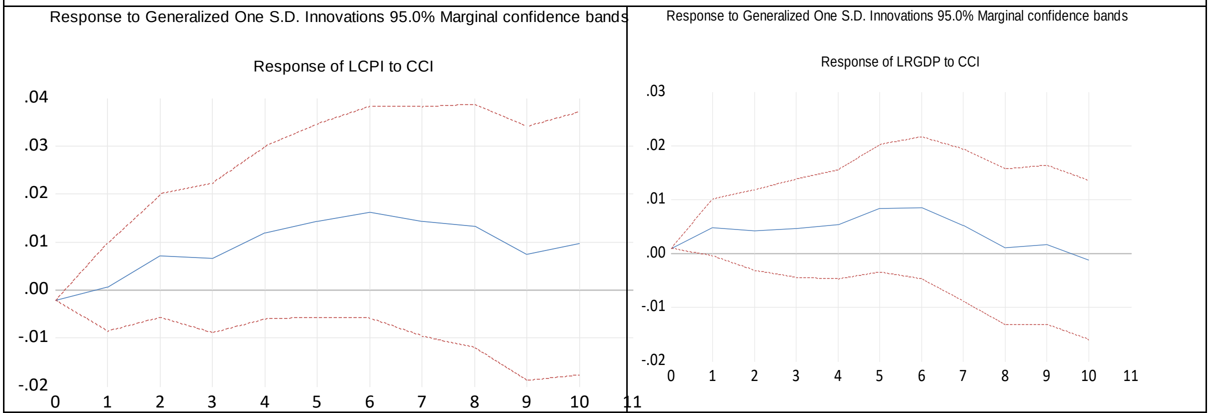


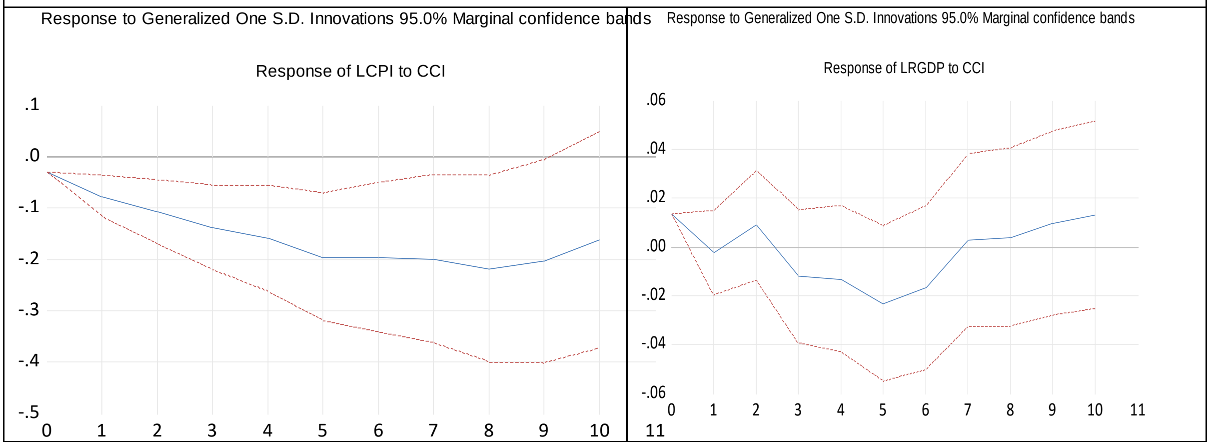

## Kenya



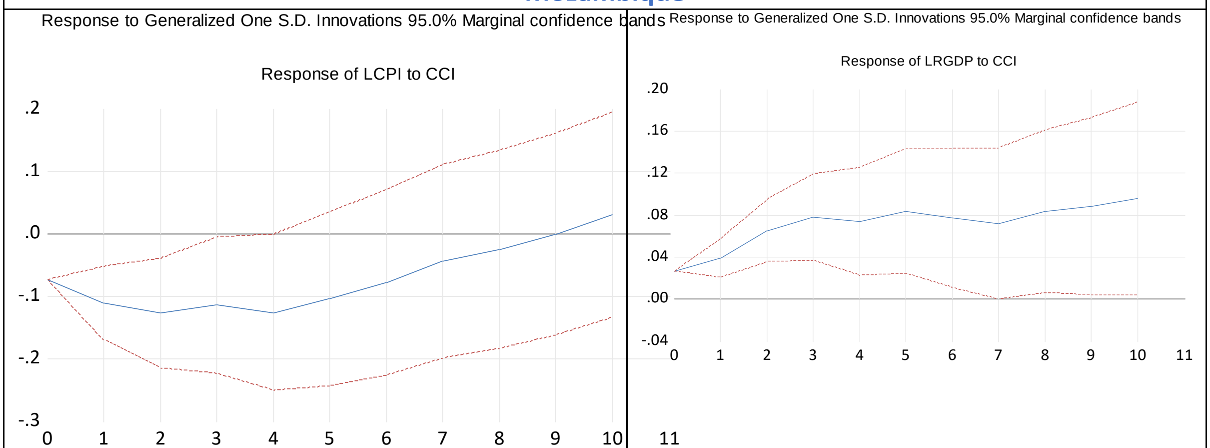

**Lesotho**



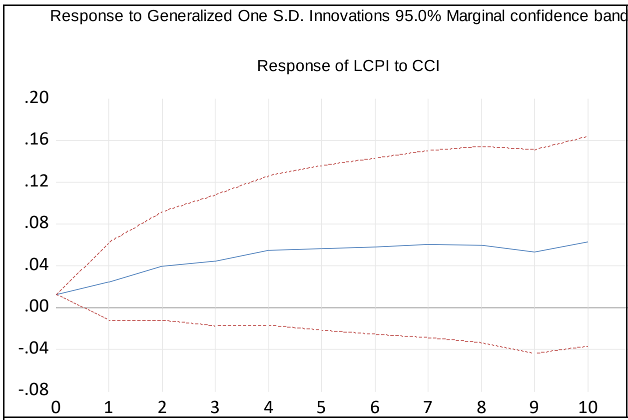

**Malawi**

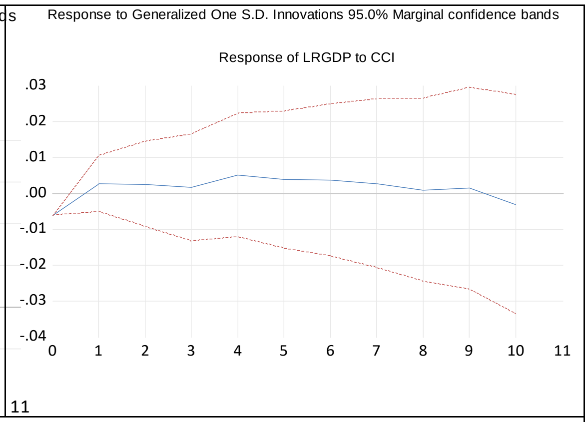



**Mozambique**

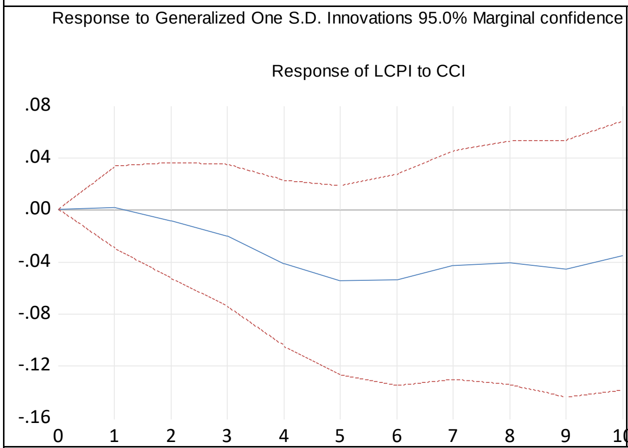


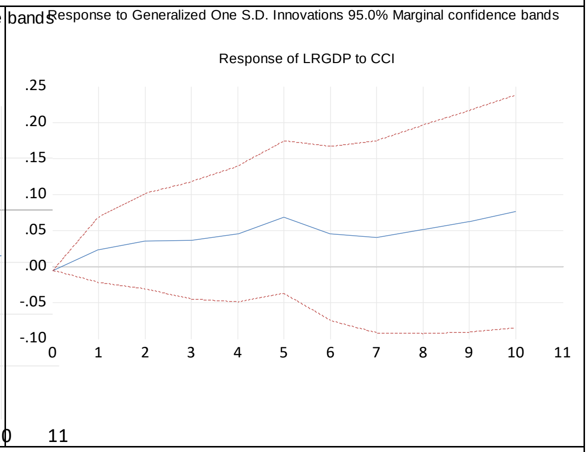

**Namibia**



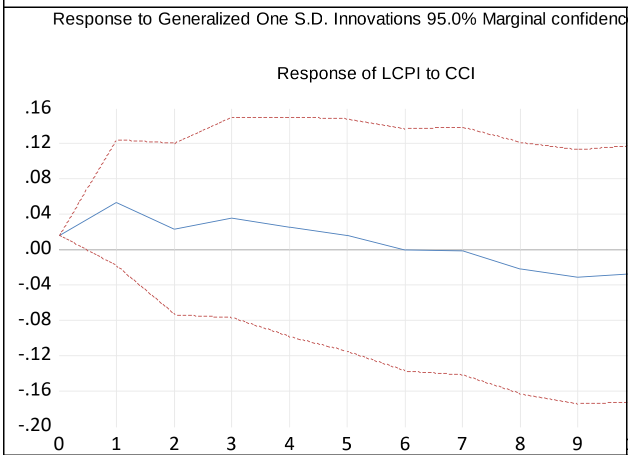



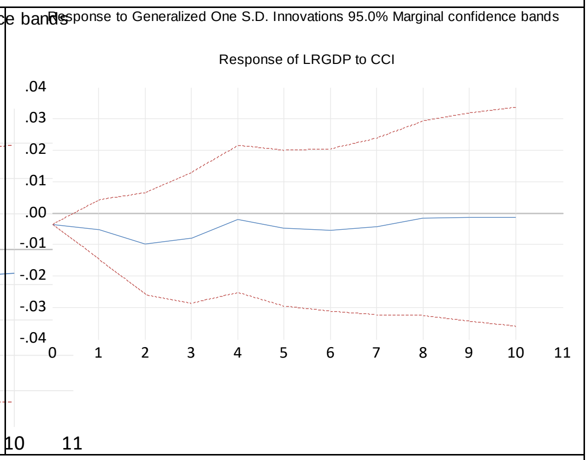

## Rwanda



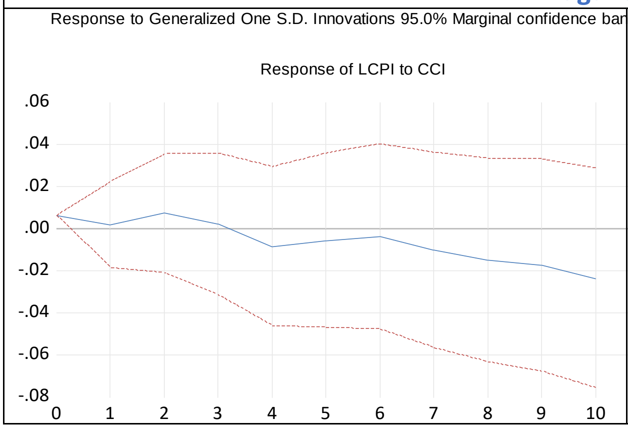



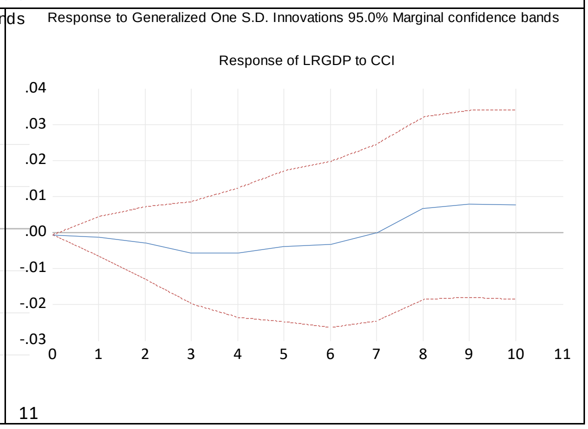

## Tanzania



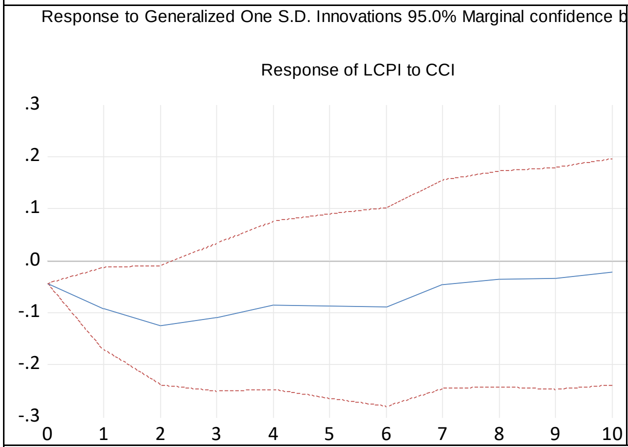



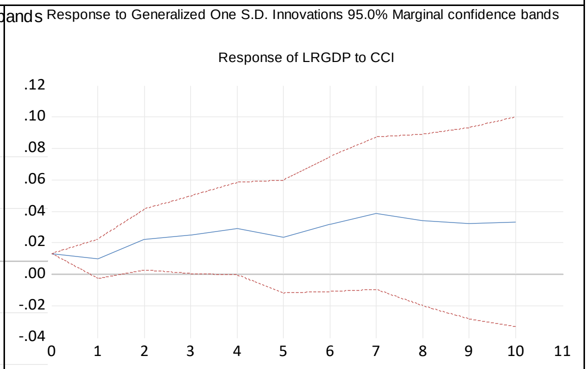

## Uganda



**Zambia**




**Zimbabwe**