



The Impacts of Extreme Weather Events on Inflation and the Implications for Monetary Policy in Africa

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Abstract: Economic debates around mitigating climate change and weather-related events have long centred on fiscal policy tools than those of monetary policy. However, recent discussions point out that monetary policy formulation could also be affected and hence the need to deploy monetary policy tools as well. Our article seeks to investigate the impacts of climate change, particularly extreme weather events, on headline inflation and food price inflation and their apparent implications for monetary policy in Africa over the period 1990–2017. Using a two-step dynamic system Generalized Method of Moments estimation strategy with robust standard errors, we find that weather-related events may need to be large and consequential to cause a significant price hike in Africa. We also find the incidence of droughts and floods to have a bearing on food price inflation. Furthermore, our empirical evidence using mediation analysis, reveals agricultural production to be the critical mechanism whereby extreme weather events affect headline inflation. As central banks are charged with the mandate of ensuring a stable monetary environment, we suggest that

monetary policy authorities consider the short and long run impacts of supply shocks caused by extreme weather events on general price levels in their policy formulation.

Key words: Extreme weather events, floods, droughts, headline inflation, food inflation, Africa

I. Introduction and Literature

The world continues to experience climatic variabilities and these are noticeable through changes in the average weather pattern. The World Meteorological Organisation (WMO) defines climate change as long-term changes in average weather conditions, while the Food and Agricultural Organisation (FAO) defines it comprehensively as encompassing changes in long term averages for all the essential climate variables. Climate change is of global concern due to its linkage with the occurrence of several extreme weather events and natural disasters. Available evidence (see, Kireyev, 2018; Stott, 2016; Stott et al., 2016) indicates that the severity and frequency of extreme weather events is due to climate change or global warming. These extreme weather events have had marked repercussions for global economic activities and have caused damage to properties as well as injuries and deaths of people. An estimate by the World Bank (2013) suggests that extreme weather events have caused about US\$3 trillion worth of damages globally over the last three decades and this is projected to increase in the future. A recent report by FAO (2017) also indicates that between 2008 and 2015, about 27 million people were displaced annually by natural hazards and climate related disasters and this trend keeps rising.

In Africa, according to the emergency events database maintained by the Centre for Research on the Epidemiology of Disasters (CRED), 51,569 people were killed and 412 million people were adversely affected by 1,381 weather events during the period 1990 to 2019. Several studies have gauged the economic implications and consequences of climate change and extreme weather events. While some of these climate change impact studies focus on the consequences of climate change and weather events for economic growth

(Alagidede et al., 2014; Cavallo and Cavallo, 2014; Cavallo and Noy, 2011; Dell et al., 2009, 2012; Klomp and Valckx, 2014), others focus on the implications for fiscal policy (Kunawotor et al., 2020; Lis and Nickel, 2010). A few focus on the implications for income inequality (Dasgupta et al., 2020; Diffebaugh and Burke, 2019; Kunawotor et al., 2020; Otrachshenko and Popova, 2019) and poverty (Brugnach et al., 2017; UNDESA, 2020).

The implications of climate change and extreme weather events for monetary policy have been largely neglected and this is confirmed by Economides and Xepapadeas (2018) and Olovsson (2018). This neglect, they argue, is because climate change mitigation policies follow the classic economic approach of correcting externalities and hence are viewed as best solved through fiscal measures. Also, climate change issues are long term issues while monetary policy principally focuses on price and output stabilization which are short term measures. Therefore, there appears to be a mismatch of interests between climate change concerns and the concerns of monetary policy. However, studies using Neo-Keynesian models (Annicchiarico and Di Dio, 2017; Economides and Xepapadeas, 2018) show that monetary policy and central banks may have a role to play in mitigating the impacts of climate change. Economides and Xepapadeas (2018) particularly argue that although monetary policies are not direct climate policy instruments, the question to be answered is whether monetary policy should take into account the expected impacts of climate change.

Building on the premise above, that extreme weather events are more frequent and severe due to climate change, our study delves into the impacts of climate change-induced weather events on inflation and, by implication, for monetary policy formulation in Africa. Monetary policy in most countries including

Africa largely concentrates on price stability or inflation targeting and so we use inflation as our focal outcome variable. For example, in Ghana and South Africa, the Central Bank and the Ministry of Finance make a public announcement of a specific inflation rate. The set inflation rate is explicitly indicated in the annual budget and then afterwards, the monetary policy committee of the central bank uses the monetary policy rate as a major tool in driving towards this targeted inflation rate. Batten et al. (2020) and McKibbin et al. (2017) affirm that the primary monetary policy objective of most central banks globally is to maintain price stability with the other macro-economic outcomes, such as output stability, being secondary or additional objectives. It is important to gauge the impacts that extreme weather has on inflation because such an understanding, according to Parker (2018),

can provide a guide to monetary policy makers on how to set price levels in the aftermath of a disaster. Understanding the impacts of extreme weather events on inflation particularly in Africa is imperative because, although headline consumer price inflation has been on the decline in the region over the last decade, probably due to an improvement in macro-economic policies, the African continent still has the highest inflation rates relative to other regions of the world as observed in Figure 1.

In addition, Nguyen et al. (2017) argue that the pressures associated with inflation management remain one of the biggest challenges for monetary policy makers in Africa as headline inflation remains very volatile in the sub-region because of the high proportion of food in the consumer price index. Food prices are also very volatile due to unstable agricultural production. That notwithstanding, a

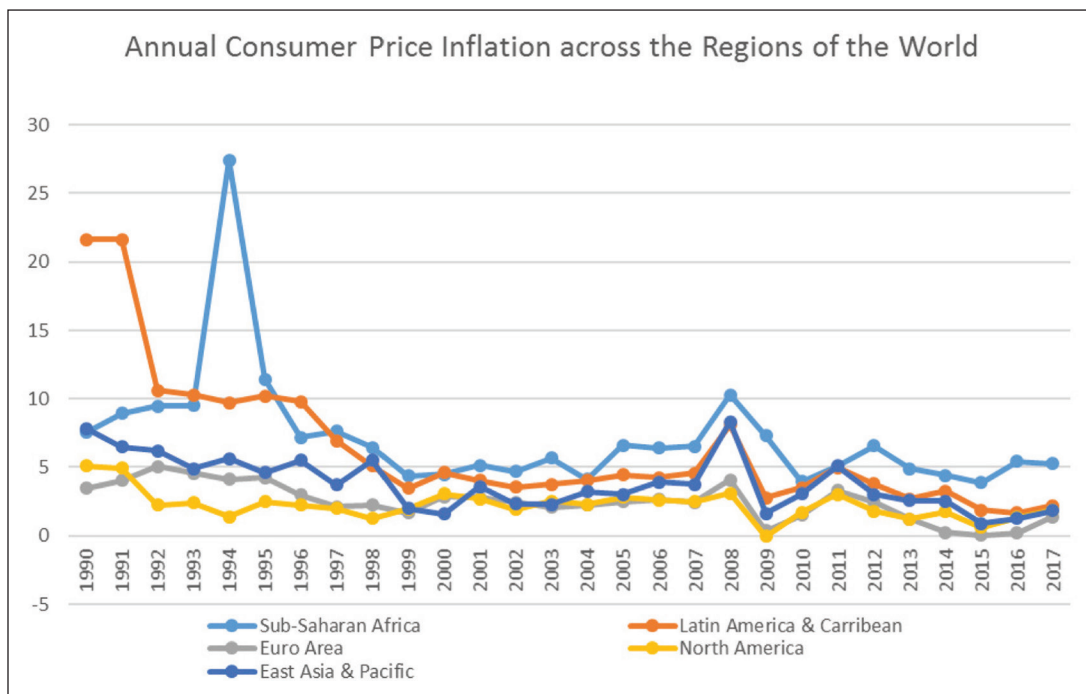


Figure 1. Regional per Annum Distribution of Consumer Price Index Inflation (%) in the World

Source: Authors Construct (2020) from WDI Database

significant proportion of Africans heavily depend on agriculture for livelihood. Recent estimates by the International Labour Organisation (ILO) show that more than half (55%) of the total employment in Sub-Saharan Africa are found in the agricultural sector, while UNDP (2014) estimates also show that, over 70% of the African population are employed in agriculture. Climate change and/or extreme weather events are predicted to jeopardize the welfare of many Africans as the agricultural sector is climate sensitive and the continent is bearing the brunt of climate change impacts (Farid et al., 2016; Lanzafame, 2014; Stern, 2006; World Bank, 2014). A number of studies (FAO, 2017; Hertel et al., 2010; Nelson et al., 2010; Willenbockel, 2011) have projected an increase in the world price of main traded staple crops, as well as price of agricultural products, mainly as a result of climate change, low agricultural productivity and population growth. According to the Food and Agriculture Organisation, climate shocks were one of the leading causes of acute food crisis and malnutrition in 2017, affecting 59 million people in 24 countries in Africa alone. FAO (2017) also projects that climate change could add about 12% to food prices by 2030 in Africa, where food consumption of the poorest households amounts to over 60% of their total spending.

Therefore, in addition to investigating the direct effect of extreme weather events on headline consumer price inflation, our study also investigates the direct effect of extreme weather events on food price inflation. Furthermore, we investigate if the impacts on agricultural production is the main mechanism whereby extreme weather events impact on inflation. Our study differs from the few available climate change impact studies on inflation and monetary policy in many ways. While studies by Olovsson (2018) and Batten et al. (2020) are economic commentaries on the implications of climate change for financial stability and monetary policy, the study

by Mckibbin et al. (2017) goes further by focusing on climate policy frameworks that can make monetary policies more efficient and effective. Others focused on floods and hurricanes in the Caribbean (see Heinen et al., 2018) or on natural disasters in general and their impact on price levels (see Parker, 2018). So far, to the best of our knowledge, there are no studies that focus on the impacts of climate-induced weather events on both headline and food inflation in Africa. To date, there are no empirical studies that investigate the channels whereby extreme weather events impact inflation through agricultural production.

This study is grounded in theoretical literature and it is based on the theory of inflation. Based on this theory, our empirical model captures both supply side factors (factors that cause an increase in cost of production) and demand side factors (factors that cause an increase in money supply) in explaining inflation although our focus is on the supply side sources where inflation is predicted to be driven by supply deficiencies or supply shocks due to climate change and extreme weather events. In terms of the empirical literature, a number of studies (Acevedo et al., 2018; Dell et al., 2012; Firdaus et al., 2019; Hsiang, 2010; Islam & Wong 2017; Loayza et al., 2012; Zhang et al., 2018) have established that climate change (temperature change and precipitation), natural disasters and weather shocks hinder agricultural productivity and industrial output. A few other studies, such as Madito and Odhiambo (2018), Nguyen et al. (2017), Durevall and Sjo (2012), Adu and Marbuah (2011) and Anderson et al. (2009), identified some factors that account for inflation dynamics in various countries. These factors include nominal interest rate, broad money supply, real output, nominal exchange rate, fiscal deficit, inflation expectations, labour cost, government expenditure, domestic agricultural supply shocks, import prices and energy prices. These determinants largely informed our choice of control variables.

II. Methodology

1 Model Specification, Definition and Measurement of Variables and a Priori Expectations

Our main specified models regress inflation (headline inflation and food inflation) on the first period lag of inflation, weather events and a set of control variables as shown below.

1.1 The Effects of Weather Events and Event Types on Headline Inflation

$$\text{Inflation}_{it} = \alpha_1 \text{Inflation}_{it-1} + \alpha_2 \text{Weatherevents}_{it} + \beta' X_{it} + \mu_i + \mu_t + \varepsilon_{it} \quad (1)$$

1.2 The Effects of Weather Events and Event Types on Food Inflation

$$\text{Foodinflation}_{it} = \varphi_1 \text{Foodinflation}_{it-1} + \varphi_2 \text{Weatherevents}_{it} + \beta' X_{it} + \eta_i + \eta_t + \xi_{it} \quad (2)$$

1.3 The Mediating Role of Agricultural Productivity/Production on Inflation

$$\text{Inflation}_{it} = \alpha_1 \text{Inflation}_{it-1} + \alpha_2 \text{Weatherevents}_{it} + \beta' X_{it} + \mu_i + \mu_t + \varepsilon_{it} \quad (3a)$$

$$\text{Agricproductivity}_{it} = \sigma_1 \text{Agricproductivity}_{it-1} + \sigma_2 \text{Weatherevents}_{it} + \beta' X_{it} + \gamma_i + \gamma_t + \varpi_{it} \quad (3b)$$

$$\text{Inflation}_{it} = \theta_1 \text{Inflation}_{it-1} + \theta_2 \text{Weatherevents}_{it} + \theta_3 \text{Agricproductivity}_{it} + \beta' X_{it} + \phi_i + \phi_t + \pi_{it} \quad (3c)$$

Inflation (inflation_{it}) is the main outcome variable in all the models and it is defined as a sustained increase in the general level of prices of goods and services in a country. Inflation is measured by taking the logged difference of headline consumer price index (CPI). However, food inflation ($\text{foodinflation}_{it}$) which is a principal sub-component of headline inflation is introduced in equation (2). It is

measured similarly by taking the natural log of food price inflation. The letters 'i' and 't' represent a given country and year respectively. Inflation is empirically found to show a considerable level of persistence which is also known as inflation inertia. Hence our introduction of the first lag of inflation (inflation_{t-1}). Inflation expectations (first lag of inflation) should therefore positively correlate with current level of inflation.

Our main independent variable is weather events ($\text{Weatherevents}_{it}$). Weather events are measured as count variables based on certain set criteria and decision rule. An event is considered to have occurred if at least one weather event occurs within a given year. Multiple counts are considered within a given year depending on how many times weather events occur.

Three alternative classifications of weather events are considered in our models. Our first classification which we call 'Weather Event 1' follows the criterion which is used by EM-DAT under their disaster sub-group that combines weather events considered to be climatological, hydrological or meteorological. For an event to be considered and entered in EM-DAT, at least one of the following criteria need to be fulfilled; 10 or more people reported killed, 100 or more people reported affected, a declaration of a state of emergency or a call for international assistance.

Secondly, we classify an occurrence as 'Weather Event 2' (Large scale or extreme weather events) if a weather event caused at least one of the following the number of people who died as a result are not less than 1,000, the number of persons affected are more than 100,000, the estimated damage caused by the weather event is at least one billion US dollars. This same classification (extreme weather event) has been used by Lis and Nickel (2010) and Gassebner et al. (2010).

We created a third weather event category and named it 'Weather Event 3' (Medium scale or extreme weather events) as a middle ground between large scale weather event and the basic requirement for an event to be

considered a weather event. Weather Event 3 requires at least one of the following criteria to be fulfilled; the number of people who died as a result are not less than 100, the number of persons affected are more than 1,000, the estimated damage caused by the weather event is at least one million US dollars. It is worth noting that both Weather Event 2 and Weather Event 3 are referred in this study as extreme weather events due to the severity of their impacts. Generally, we expect the occurrence of Weather Event 1, Weather Event 2 and Weather Event 3 to cause an increase in food price inflation as well as headline consumer price inflation either directly or indirectly through a reduction in agricultural productivity/production.

The main types or sub-types of weather events in Africa over our sample period are floods, droughts, storms, landslides, wildfires, extreme temperatures, heat waves, cold waves, land fires, forest fires, tropical cyclones and mudslides. We therefore make an attempt to find out which of these occurrences is likely to directly or indirectly affect inflation. We pay particular attention to floods and droughts as they are the weather event types that are more frequent in Africa. Their effects on inflation are considered in equation (1) and (2). Floods and droughts are also measured as count variables just like 'Weather Event 1' so long as they are considered and entered by EM-DAT.

We expect weather events to have both a direct and indirect effect on inflation. Indirectly, it is our expectation that extreme weather events will cause an agricultural productivity shock and hence an inflationary impact. We address the indirect effect using mediation analysis following the approach proposed by Baron and Kenny (1986). Three main conditions are required to be met in order to establish mediation according to Baron and Kenny (1986). These conditions are: First, the independent variable (Weather events) must affect the dependent variable (inflation) as shown in equation (3a). Secondly, the independent variable (Weather events) must affect the mediator (agricultural productivity/

production) as shown in equation (3b). Thirdly, the mediator (agricultural productivity/production) must affect the dependent variable (inflation) in the presence of the independent variable (Weather events) as shown in equation (3c). Partial mediation is said to occur when the effect of the independent variable (Weather events) on the dependent variable (inflation) is less in equation (3c) than in (3a). Also, perfect or full mediation is said to occur when the independent variable (Weather events) has no significant effect on the dependent variable (inflation) when the mediator (agricultural productivity) is controlled for. In other words, mediation analysis allows us to investigate how far extreme weather events' impacts on inflation are caused by changes in agricultural productivity/production.

Agricultural productivity ($\text{Agric productivity}_{it}$) is measured using the net agricultural production value (2004–2006 constant value) as computed by FAO. Alternative measures used in this study are the net agricultural production index, also computed by FAO, and an index computed using data of crop yields and livestock yields with the aid of principal component analysis. In addition, we use the sub-components of agricultural production value, such as crops net production value, food net production value, and livestock net production value. We expect weather events to impact inflation through the channel of agricultural production. Thus, as weather event is introduced along agricultural production in the same model, we expect agricultural production to become significant with a negative sign while the power of the coefficient of weather events reduces (partial mediation) or it becomes insignificant (full mediation).

A vector is introduced in all the models to represent our set of control variables (X_{it}) that affect inflation. The choice of these control variables are informed by theory or empirical literature. These variables include real GDP, money supply, nominal interest rate, fiscal balance and exchange rate. Fiscal balance is measured as overall budget balance as a

percentage of GDP. Overall balance is computed as the difference between government revenue and government expenditure. A positive balance means a surplus while a negative balance means a deficit. We expect increases in fiscal deficit to translate to higher inflationary rates due to excessive spending.

Real GDP is measured by real GDP. A negative relationship between real GDP and inflation is expected. This is because real GDP is used as a proxy for real income and an increase in real income is expected to lead to an increase in real money demand and hence cause a fall in inflation through a fall in the price of non-tradable goods. Nominal exchange rate is measured by the official exchange rate in the local currency unit to the United States dollars. We expect an increase in the nominal exchange rate (depreciation) to cause an increase in the general price level as prices of tradable goods also increase.

Nominal interest rate is proxied by deposit interest rate, lending interest rate and discount rate. However, deposit rate is mostly used due to data availability as the limited data on lending rate and discount rate reduces the sample size. Deposit rate is defined as the rate paid by commercial or similar banks for demand, time or savings deposits. An increase in interest rate is expected to cause an increase in consumer price inflation due to a resultant increase in the price of non-tradable goods. Money supply is measured by the taking the natural log of broad money. Broad money is defined as: the sum of currency outside banks; demand deposits other than those of the central government; the time, savings, and foreign currency deposits of resident sectors other than the central government; bank and traveller's cheques; and other securities such as certificates of deposit and commercial paper. It is expected that an increase in money supply will increase the general price level through an increase in the price of non-tradable goods. Finally, u_i , η_i and γ_i represent the country fixed effects, u_t , η_t and γ_t represent the time fixed effects. ε_{it} , ξ_{it} , ω_{it} and π_{it} are the idiosyncratic error terms.

2 Sources of Data and Scope of the Study

The study employs panel data over the period 1990–2017 and this includes 52 African countries (see Appendix 1). The data on inflation, deposit interest rate, nominal exchange rate, broad money supply and real GDP are sourced from the World Banks World Development Indicators (WDI). Data on fiscal balance is gleaned from the International Financial Statistics of the International Monetary Fund (IMF) and African Development Bank Socio Economic database. Data on weather events and its types are sourced from the Emergency Events database (EM-DAT) maintained by the CRED at the School of Public Health at the University of Louvain, Brussels, Belgium. This data is originally sourced from United Nations, non-governmental organisation and governmental agencies, research institutes, insurance companies and press agencies. The components of agricultural productivity, net agricultural production value, net agricultural production index and food price inflation are sourced from FAO of the United Nations.

3 Estimation Technique

This article employs the two-step system generalized method of moments (GMM) estimation technique. The choice of a dynamic two step GMM estimation approach with robust standard errors is motivated by five reasons in line with recent GMM-centric literature (Agoba et al., 2019; Asongu et al., 2019; Asongu et al., 2020; Fosu & Abass, 2019; Tchamyou et al., 2019). First, the cross-sectional units (N) are higher than the time series (T). Thus, the number of countries are 52, while the sampled period is 28 years. Second, the dataset is a panel data and the empirical approach accounts for cross country differences in the estimation process. Third, our outcome variable, inflation is known to be persistent or dynamic and shows a great deal of inertia in Africa and hence depends on its lag (see Madito and Odhiambo, 2018; Durevall and Sjo, 2012; Adu and Marbuah, 2011; Ocran, 2007). Fourth, when this dynamic nature of inflation is accounted for, it may result in

possible endogeneity concerns. Accounting for the dynamic nature of inflation requires the introduction of its lag in the model which may result in possible endogeneity concerns. This endogeneity concern can be resolved by identifying an instrumental variable which is correlated with the endogenous independent variable but not the dependent variable. However, identifying a good instrument that has the above qualities and is supported by theory is usually difficult. In view of this, the GMM which generates its own internal instruments is employed to control for the possible endogeneity concerns in this study. Hence, simultaneity is tackled in this study by leveraging on lagged regressors which are employed as instruments. Finally, GMM is preferred as it is excessively time-consuming to identify external instruments and the system GMM estimator works for non-stationary data by employing additional moments conditions. The robustness of GMM is evidenced in several tests. The Hansen test for over identifying restrictions tests for the validity of the moment conditions. Also, the test of the null hypothesis of no second order serial correlation is performed by the Arellano–Bond test for autocorrelation (AR [2]). All these diagnostic tests proved satisfactory in our study.

III. Empirical Results

I Descriptive Statistics, Frequency Distribution and Correlation Matrix

The summary statistics presented in Table 1 show the distributions of the variables used in our regression estimations. Consumer price inflation which is our main outcome variable has a mean of 8.52% which appears quite high in Africa relative to other continents. Regionally, West Africa has the lowest inflation rate (7.6%), followed by North Africa (8.12), East Africa (9.12%) and the highest being Southern Africa (12.6%). With regards to our main explanatory variables, Weather Event 1 has a 93% probability of occurring within a year in an African country. Also, Weather Event 2 and Weather Event 3 on

average have a probability of occurring approximately 30% and 73% of the time respectively. We further tabulate the frequency of occurrence of weather events in Africa in order to get a detailed and perhaps a more meaningful interpretation of the results as shown in Table 2. Out of a total of 1,456 outcomes, Weather Event 1 has occurred 53% of the time for at least once in a year. Out of these occurrences, Weather Event 1 has occurred 82% of the time for at least once or twice in a year and the remaining 18% have occurred between three to nine times. Weather Event 2 has occurred just 25% of the time and this has been the least occurrence of the three classifications of weather events in Africa. Also, Weather Event 3 has occurred 47% of the time with at least one or two counts occurring 88% of the time. In the same vein, flood and drought have 58% and 21% probability of occurring in a year in Africa. There are generally no concerns regarding multicollinearity in the models as shown by the matrix of correlations in Table 3. None of the correlations exceed 0.8.

2 Empirical Results of the Direct Effects of Weather Events on Headline Inflation

The results of the direct effect of weather events on inflation reveal that Weather Event 1 has no statistically significant effect on headline inflation as shown in Model 1. However, Weather Event 2 and Weather Event 3 both have positive and statistically significant effects on headline consumer price inflation. This is shown in Model 2 & Model 3 in Table 4. Thus, the occurrence of Weather Event 2 causes a rise in headline inflation by 0.123 percentage points in Model 2. Similarly, the occurrence of Weather Event 3 causes a rise in headline inflation by 0.0750 percentage points in Model 3. This means that, weather events need to be large enough or severe (extreme weather events) to cause a significant upsurge in headline consumer price inflation in Africa. Thus, the occurrence of extreme weather events (large scale and medium scale weather events) have dire implications for

Table 1. Descriptive Statistics

<i>Variable</i>	<i>Obs</i>	<i>Mean</i>	<i>Std. Dev.</i>	<i>Min</i>	<i>Max</i>
Weather Event 1	1456	.931	1.229	0	9
Weather Event 2	1456	.296	.58	0	5
Weather Event 3	1456	.725	.994	0	8
Drought	1456	.205	.419	0	2
Flood	1456	.581	.913	0	7
Inflation	1233	8.52	11.288	-11.686	98.224
Fiscal balance	1270	-2.522	4.742	-18.073	20.482
Interest rate	1037	9.079	8.932	1.107	147.125
Money supply	1382	34.056	27.33	2.857	251.618
Real GDP	1390	22.877	1.575	18.621	26.864
Agric productivity	1122	.026	1.778	-2.072	9.341
Agric NPV	1393	13.749	1.789	8.401	17.47963

Source: The authors.

Table 2. Weather Events Tabulation from 1990 to 2017

<i>Weather Event 1</i>			<i>Weather Event 2</i>			<i>Weather Event 3</i>		
<i>Variable count</i>	<i>Frequency</i>	<i>Percent</i>	<i>Count</i>	<i>Frequency</i>	<i>Percent</i>	<i>Count</i>	<i>Frequency</i>	<i>Percent</i>
0	689	47.32	0	1,099	75.48	0	774	53.16
1	435	29.88	1	298	20.47	1	438	30.08
2	191	13.12	2	47	3.23	2	162	11.13
3	76	5.22	3	10	0.69	3	52	3.57
4	36	2.47	4	1	0.07	4	17	1.17
5	18	1.24	5	1	0.07	5	11	0.76
6	5	0.34	6	-	-	6	1	0.07
7	2	0.14	7	-	-	7	-	-
8	3	0.21	8	-	-	8	1	0.07
9	1	0.07	9	-	-	9	-	-
Total	1,456	100	Total	1,456	100	Total	1,456	100

Source: Authors construct (2020) from EM-DAT data.

headline consumer price inflation as the general price level may be affected, probably due to the supply shocks they may create. Besides supply shocks, extreme weather events may flood major cities and industrial sites, cause extensive power outage, damage road infrastructure and physical plants, destroy storage

structures, processing plants and electricity grids, destroy food supply chain and increase distribution and marketing cost. These trends may also be inflationary and have economic implications, especially in Africa which has the highest inflationary trends. Monetary policy may also be affected as new prices may need to

Table 3. Correlation Matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Fiscal balance	1.000							
(2) Inflation	-0.086*	1.000						
(3) Interest rate	-0.142*	0.404*	1.000					
(4) Exchange rate	0.097*	-0.239*	-0.162*	1.000				
(5) Real GDP	0.050	0.030	0.007	-0.209*	1.000			
(6) Money supply	-0.205*	-0.140*	-0.168*	-0.352*	0.215*	1.000		
(7) Weath' events	0.017	0.081*	0.084*	0.086*	0.299*	-0.025	1.000	
(8) Agric product'	-0.017	-0.021	-0.161	-0.162*	0.584*	0.529*	0.092*	1.000

Source: The authors.

Note: * $p < .05$

be set in the aftermath of these severe weather events. And this is in line with the assertion by Parker (2018) that an understanding of the impacts of disasters on inflation can provide a guide to monetary policy makers on how to set price levels in the aftermath of a disaster.

The findings also reveal that drought which is one of the types and sub-types of weather events has a positive and statistically significant effect on headline consumer price inflation as shown in Model 4. The occurrence of drought causes headline inflation to increase by 0.140 percentage points. This finding appears plausible as drought causes severe damage to farmlands and agricultural output and hence the possibility of causing a price hike. We however find no statistically significant effect of flood on headline inflation in our sample shown in Model 5. The overall economic implication of these findings is that monetary policy authorities and central bankers in Africa may need to consider the impacts of extreme weather events in their inflation targeting mechanisms as they may tend to have an influence on general price levels. It is worth noting that even if the impact caused by extreme weather events on inflation is short-lived, it may have severe consequences on the welfare of poor households in the affected country as food expenditure forms the bulk of most household budgetary allocations. Willenbockel (2012) lends support to this assertion and argues that temporary

food price hikes caused by extreme weather events may be unpredictable over a longer horizon and that poor households and those in low-income countries struggle to absorb or adjust to sudden shocks easily.

We find the first period lag of inflation to be statistically significant with a positive sign as expected throughout all the Models (Model 1 - 5). Thus, the immediate past headline inflation rate is an unbiased predictor of the current headline inflation rate. This is in line with the findings by Madito and Odhiambo (2018) and Adu and Marbuah (2012). Nominal interest rate is positive and statistically significant in all the models in conformity with theoretical predictions. This means that as interest rate rises, the cost of borrowing goes up and this increases the price of tradable goods and hence the general price levels. We find a negative nexus between exchange rate and inflation and also between money supply and inflation. For the exchange rate, similar results were found by Adu and Marbuah (2012) for Ghana and Ndung'u (1997) for Kenya. Adu and Marbuah (2012) in particular explain that this may be due to exchange rate scarcity resulting in substantial transactions occurring at the parallel exchange rate. However, we find no statistically significant effect of fiscal balance and real income (real GDP) on inflation in our models. All the diagnostic test such as the F-statistics,

Table 4. The Direct Effects of Weather Events on Headline Inflation

<i>Variables</i>	<i>Model 1</i>	<i>Model 2</i>	<i>Model 3</i>	<i>Model 4</i>	<i>Model 5</i>
Lag of inflation	0.132* (0.074)	0.133* (0.073)	0.139* (0.073)	0.128* (0.074)	0.136* (0.073)
Weather Event 1	0.019 (0.029)				
Weather Event 2		0.123** (0.057)			
Weather Event 3			0.075** (0.035)		
Drought				0.140** (0.067)	
Flood					0.036 (0.040)
Interest rate	0.463*** (0.085)	0.459*** (0.086)	0.453*** (0.085)	0.467*** (0.086)	0.464*** (0.085)
Fiscal balance	-0.011 (0.008)	-0.009 (0.007)	-0.011 (0.008)	-0.010 (0.008)	-0.011 (0.008)
Exchange rate	-0.095*** (0.034)	-0.094*** (0.034)	-0.099*** (0.033)	-0.095*** (0.034)	-0.095*** (0.034)
Real GDP	0.060 (0.041)	0.063 (0.039)	0.051 (0.041)	0.066* (0.039)	0.057 (0.041)
Money supply	-0.270* (0.135)	-0.264* (0.136)	-0.269** (0.133)	-0.267* (0.135)	-0.270* (0.134)
Constant	0.436 (1.067)	0.335 (1.014)	0.629 (1.065)	0.286 (1.016)	0.500 (1.060)
Observations	674	674	674	674	674
Number of countries	40	40	40	40	40
Number of Instruments	10	10	10	10	10
Wald test (Prob > F)	0.000	0.000	0.000	0.000	0.000
AR(1):(Pr > z)	-3.95(0.000)	-3.92(0.000)	-3.99(0.000)	-3.93(0.000)	-3.97(0.000)
AR(2):(Pr > z)	0.99(0.321)	0.82(0.411)	1.02(0.306)	1.04(0.298)	1.01(0.314)
Sargan test	1.90(0.386)	2.05(0.359)	1.78(0.411)	1.84 (0.399)	1.86(0.394)
Hansen test	2.38(0.305)	2.67(0.264)	2.24(0.326)	2.24(0.326)	2.32(0.314)

Source: The authors.

Notes: Standard errors in parentheses; *** $p < .01$, ** $p < 0.05$, * $p < 0$; Model 1 addresses the effect of Weather Event 1 on headline inflation. Model 2 and Model 3 address the effects of Weather Event 2 and Weather Event 3 on headline inflation respectively. Model 4 and Model 5 address the effects of drought and flood on headline inflation respectively.

Sargan test and Hansen test proved satisfactorily as shown in the various models and this confirms the reliability and accuracy of the results.

3 Empirical Results of the Direct Effects of Weather Events on Food Price Inflation

Food price hikes are known to be a major contributory factor to headline inflation in

Table 5. The Direct Effects of Weather Events on Food Inflation

<i>Variables</i>	<i>Model 6</i>	<i>Model 7</i>	<i>Model 8</i>	<i>Model 9</i>	<i>Model 10</i>
Lag of food inflation	0.338*** (0.097)	0.331*** (0.097)	0.350*** (0.092)	0.323*** (0.099)	0.352*** (0.097)
Weather Event 1	0.059 (0.043)				
Weather Event 2		0.087 (0.183)			
Weather Event 3			0.103 (0.068)		
Drought				0.253* (0.147)	
Flood					0.103** (0.043)
Interest rate	0.340** (0.139)	0.353** (0.133)	0.317** (0.141)	0.358*** (0.124)	0.346** (0.132)
Fiscal balance	0.003 (0.012)	0.007 (0.013)	0.003 (0.011)	0.007 (0.012)	0.002 (0.012)
Exchange rate	-0.062 (0.047)	-0.063 (0.048)	-0.062 (0.046)	-0.059 (0.047)	-0.064 (0.047)
Real GDP	0.035 (0.044)	0.049 (0.041)	0.031 (0.044)	0.051 (0.042)	0.031 (0.045)
Money supply	-0.472* (0.249)	-0.458* (0.258)	-0.466* (0.247)	-0.449* (0.245)	-0.458* (0.249)
Constant	1.605 (1.455)	1.291 (1.408)	1.673 (1.399)	1.178 (1.376)	1.614 (1.517)
Observations	242	242	242	242	242
Number of countries	37	37	37	37	37
Number of instruments	9	9	9	9	9
Wald test (Prob > F)	0.000	0.000	0.000	0.000	0.000
AR(1):(Pr > z)	-2.33(0.020)	-2.33(0.020)	-2.41(0.016)	-2.39(0.017)	-2.32(0.020)
AR(2):(Pr > z)	-0.46(0.647)	-0.50(0.614)	-0.37(0.713)	-0.38(0.703)	-0.42(0.673)
Sargan test	0.69(0.406)	0.44(0.507)	0.50(0.482)	0.38(0.536)	0.93(0.336)
Hansen test	0.69(0.406)	0.48(0.490)	0.53(0.465)	0.42(0.518)	0.91(0.341)

Source: The authors.

Notes: Standard errors in parentheses; *** $p < .01$, ** $p < .05$, * $p < .1$ Model 6, Model 7 and Model 8 address the effects of Weather Event 1, Weather Event 2 and Weather Event 3 on food inflation respectively. Model 9 and Model 10 address the effects of drought and flood on food inflation respectively.

Africa. This said, Table 5 addresses the direct effects of weather events and event types on food price inflation. We find no statistically significant effect of Weather Event 1, Weather Event 2 & Weather Event 3 on food price inflation as shown in Model 6, Model 7 & Model 8.

However, the findings of the weather event types and sub-types reveal that, drought has a positive and statistically significant effect on food price inflation as shown in Model 9. Flood also has a positive and statistically significant effect on food price inflation as shown in Model

10. Thus, the occurrence of drought causes a rise in food price inflation by about 0.253 percentage points while the occurrence of flood causes a 0.103 percentage point rise in food price inflation. These imply that the frequent incidence of either drought or flood may cause a hike in food prices and this may translate to a rise in the general consumer price inflation. The occurrence of droughts and floods may affect food price inflation through the destruction to farmlands and crops. They may also destroy food storage structures, processing plants, food supply chain and increase the distribution and marketing cost of agricultural commodities. This may lead to a hike in food prices and headline inflation since food price, which is already volatile in Africa, forms a significant part of headline inflation in Africa. As already

mentioned, monetary policy formulation may hence be affected as new prices may need to be set in the aftermath of these severe weather events. This result conforms to the findings by Willenbockel (2012) and the forecasts by FAO (2017) where food prices are projected to rise by 12% by 2030 as a result of climate change. Also, food price inflation is persistent as the lag of food price inflation is statistically significant in all the models (Model 6–Model 10). Thus, past food inflation rate is a predictor of current food inflation rate.

4 Empirical Results of the Indirect Effects of Weather Events on Headline Inflation Through Agricultural Productivity/Production

Weather events may have either a direct or indirect effect on headline inflation.

Table 6. The Indirect Effects of Weather Event 2 on Headline Inflation Through Agriculture

<i>Variables</i>	<i>Model 11</i>	<i>Model 12</i>	<i>Model 13</i>	<i>Model 14</i>	<i>Model 15</i>	<i>Model 16</i>
Lag of inflation	0.133* (0.073)		0.511** (0.243)	0.459* (0.237)	0.466* (0.240)	0.451* (0.246)
Weather Event 2	0.123** (0.057)	0.039** (0.018)	0.127 (0.081)	0.082 (0.084)	0.120 (0.082)	0.116 (0.075)
Lag of Agric product'		0.848*** (0.069)				
Agric production			-0.430** (0.170)			
Crops production				-0.348** (0.148)		
Food production					-0.444** (0.182)	
Livestock production						-0.277** (0.133)
Interest rate	0.459*** (0.086)	0.086** (0.033)	0.444** (0.190)	0.419** (0.205)	0.465** (0.203)	0.391** (0.187)
Fiscal balance	-0.009 (0.008)	-0.003 (0.002)	-0.009 (0.009)	-0.012 (0.009)	-0.011 (0.009)	-0.004 (0.008)
Exchange rate	-0.094*** (0.034)	0.023 (0.014)	0.001 (0.048)	0.011 (0.053)	0.001 (0.048)	-0.042 (0.039)

(Table 6 continued)

(Table 6 continued)

Variables	Model 11	Model 12	Model 13	Model 14	Model 15	Model 16
Real GDP	0.063 (0.039)	0.093 (0.080)	0.642*** (0.228)	0.573** (0.217)	0.660** (0.245)	0.496** (0.186)
Money supply	-0.264* (0.136)	0.019 (0.107)	-0.380** (0.182)	-0.478** (0.199)	-0.415** (0.188)	-0.224 (0.160)
Constant	0.335 (1.014)	-0.333 (0.994)	-7.739** (3.133)	-6.992** (3.080)	-7.798** (3.335)	-6.974** (2.798)
Observations	674	836	648	638	638	638
Number of countries	40	41	40	39	39	39
Number of instruments	10	9	17	17	17	17
Wald test	0.000	0.000	0.000	0.000	0.000	0.000
AR(1):(Pr > z)	(0.000)	(0.000)	(0.005)	(0.005)	(0.006)	(0.005)
AR(2):(Pr > z)	(0.411)	(0.043)	(0.193)	(0.203)	(0.214)	(0.238)
Sargan test	(0.359)	(0.049)	(0.456)	(0.266)	(0.234)	(0.273)
Hansen test	(0.264)	(0.143)	(0.484)	(0.544)	(0.463)	(0.604)

Source: The authors.

Notes: Standard errors in parentheses; *** $p < .01$, ** $p < .05$, * $p < 0.1$; Model 11 shows the effect of Weather Event 2 on headline inflation. Model 12 shows the effect of Weather Event 2 on agriculture production. Model 13 addresses the mediating effect of agriculture production when introduced with Weather Event 2. Models 14, 15 and 16 address the mediating effect of crops production, food production and livestock production respectively when introduced with Weather Event 2 albeit independently.

Table 7. The Indirect Effects of Weather Event 3 on Headline Inflation Through Agriculture

Variables	Model 17	Model 18	Model 19	Model 20	Model 21	Model 22
Lag of inflation	0.139* (0.073)		0.499** (0.239)	0.450* (0.234)	0.454* (0.234)	0.450* (0.238)
Weather Event 3	0.075** (0.035)	0.037** (0.015)	0.059 (0.046)	0.028 (0.047)	0.046 (0.046)	0.033 (0.047)
Lag of Agric product'		0.871*** (0.069)				
Agric production			-0.437** (0.181)			
Crops production				-0.350** (0.153)		
Food production					-0.449** (0.192)	
Livestock production						-0.283* (0.140)

(Table 7 continued)

(Table 7 continued)

Variables	Model 17	Model 18	Model 19	Model 20	Model 21	Model 22
Interest rate	0.453*** (0.085)	0.078** (0.034)	0.448** (0.183)	0.421** (0.200)	0.468** (0.196)	0.385** (0.181)
Fiscal balance	-0.011 (0.007)	-0.003 (0.003)	-0.012 (0.008)	-0.014* (0.008)	-0.014 (0.009)	-0.006 (0.008)
Exchange rate	-0.099*** (0.034)	0.017 (0.012)	-0.007 (0.050)	0.006 (0.056)	-0.006 (0.051)	-0.045 (0.039)
Real GDP	0.051 (0.041)	0.063 (0.083)	0.644** (0.248)	0.574** (0.230)	0.663** (0.263)	0.497** (0.199)
Money supply	-0.269** (0.133)	0.028 (0.111)	-0.402** (0.179)	-0.494** (0.197)	-0.439** (0.188)	-0.247 (0.161)
Constant	0.629 (1.065)	0.038 (1.061)	-7.590** (3.431)	-6.894** (3.310)	-7.675** (3.590)	-6.793** (3.002)
Observations	674	836	648	638	638	638
Number of countries	40	41	40	39	39	39
Number of instruments	10	9	17	17	17	17
Wald test:	0.000	0.000	0.000	0.000	0.000	0.000
AR(1): (Pr > z)	(0.000)	(0.000)	(0.004)	(0.005)	(0.005)	(0.004)
AR(2): (Pr > z)	(0.306)	(0.042)	(0.166)	(0.184)	(0.183)	(0.200)
Sargan test	(0.411)	(0.008)	(0.470)	(0.282)	(0.256)	(0.292)
Hansen test	(0.326)	(0.057)	(0.559)	(0.570)	(0.519)	(0.642)

Source: The authors.

Notes: Standard errors in parentheses; *** $p < .01$, ** $p < .05$, * $p < 0.1$ Model 17 shows the effect of Weather Event 3 on headline inflation. Model 18 shows the effect of Weather Event 3 on agriculture production. Model 19 addresses the mediating effect of agriculture production when introduced with Weather Event 3. Models 20, 21 and 22 address the mediating effect of crops production, food production and livestock production respectively when introduced with Weather Event 3 albeit independently.

The indirect effect of weather events on inflation may be mediated by agricultural productivity. Thus, agricultural productivity/production may experience a setback as a result of weather events and this may lead to an agricultural supply shock which may have an impact on food prices or the general price level. The result of the mediation analysis is presented in Table 6 and Table 7. Weather Event 2 has a positive and statistically significant effect (0.123) on headline inflation as shown in Model 11 when introduced alone. Weather Event 2 also has a statistically significant effect on agricultural production (0.0391) as shown in Model 12. Furthermore and more importantly,

when agricultural production is controlled for, by being introduced in the same model (Model 13) with Weather Event 2, Weather Event 2 loses its statistical significance (0.127) while agricultural production becomes statistically significant with a negative sign (-0.430) as expected. This result means that agricultural production reduces when Weather Event 2 occurs (extreme weather events) and this results in a rise in general prices. Thus, agricultural production serves as a conduit for Weather Event 2 to impact headline inflation. With regards to the components of agricultural production, the findings also reveal that crops production (-0.348), food production (-0.444)

and livestock production (-0.277) reduce at the incidence of Weather Event 2 as shown in Model 14, Model 15 & Model 16 respectively. Thus, extreme weather events cause a negative shock to crop production, food production and livestock production and these lead to a rise in the general price level.

The result for the indirect effects of Weather Event 3 on headline inflation through agricultural production are similar to that of Weather Event 2 and it is presented in Table 7. Weather Event 3 also has a direct and statistically significant effect (0.0750) on consumer price inflation in Model 17. It also has a statistically significant effect (0.0365) on agricultural production in Model 18. It however loses its statistical significance (0.239) in Model 19 when agricultural production (-0.437) is controlled for. This implies that agricultural production serves as a full mediator for Weather Event 3 to affect inflation. Also, crops production (-0.350), food production (-0.449) and livestock production (-0.283) also serve as conduits for Weather Event 3 to affect inflation as shown in Model 20, Model 21 and Model 22 respectively. The economic implication of these findings is that the occurrence of extreme weather events (Weather Event 2 & Weather Event 3) causes a reduction in agricultural production and this tends to affect headline consumer price inflation. Generally, agricultural production is affected through damage to standing crops and stored crops; hikes in waterborne livestock diseases; loss of livestock due to lack of feed and water stress; lower yields in flooded agricultural areas and increased soil erosion which reduces future yields; pollution of water supply for crop irrigation; and, destruction of food supply chain and hence increases in distribution and marketing cost. All these may lead to increase in food prices and general prices.

IV. Conclusion and Recommendations

The empirical literature on climate change impact studies continues to attract a lot of interesting discussion. Typically, climate change mitigating policies are generally

considered fiscal issues, hence best addressed by fiscal policy instruments. However, recent discussions using Neo-Keynesian models argue that monetary policy and central banks may also be affected in some ways. Our study comprehensively investigates the direct effects of extreme weather events and the event sub-types on headline consumer price inflation and food price inflation and the implications for monetary policy formulation in Africa. In addition, we examine the indirect effect of extreme weather events on headline inflation through agricultural production. Our findings reveal that weather-related events need to be large or extreme to cause a price hike in Africa. Moreover, we find droughts to have an impact on both headline inflation and food price inflation. Similarly, floods have the tendency to cause a rise in food price inflation. Also, our findings show that extreme weather events impacts inflation through the channel of agricultural production.

Taking cognisance of the fact that price and output stability are the primary duties of central banks, and being fully aware that even short run impacts of extreme weather events could trigger long term implications for macroeconomic policy in general and also have dire implications for poor households in Africa, we suggest that monetary policy authorities consider the short and long run implications of supply shocks caused by extreme weather events on food price and the general price level. Also, anchoring inflation expectations should be a major objective of policy makers as both headline inflation and food inflation appear persistent in Africa. Additionally, we suggest that a buffer of food stuffs be kept on regular basis to serve as respite in times of weather-related eventualities in order to anchor inflation. It is worth mentioning that this study does not in any way suggest that the solution to climate change should come from monetary policy but rather that monetary policy authorities should consider climate change in their decisions.

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Appendix

Appendix I. List of countries used in the study

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|---------------------------|-------------------|-----------------------|-------------|
| 1. Algeria | 2. Angola | 3. Benin | 4. Botswana |
| 5. Burkina Faso | 6. Burundi | | |
| 7. Cabo Verde | 8. Cameroon | 9. CAR | |
| 10. Chad | 11. Comoros | 12. DRC | |
| 13. Congo Republic | 14. Côte D'Ivoire | | |
| 15. Djibouti | 16. Egypt | 17. Equatorial Guinea | |
| 18. Eritrea | 19. Eswatini | 20. Ethiopia | |
| 21. Gabon | 22. Gambia | 23. Ghana | 24. Guinea |
| 25. Guinea Bissau | 26. Kenya | 27. Lesotho | |
| 28. Liberia | 29. Libya | 30. Madagascar | |
| 31. Malawi | 32. Mali | 33. Mauritania | |
| 34. Mauritius | 35. Morocco | 36. Mozambique | |
| 37. Namibia | 38. Niger | 39. Nigeria | 40. Rwanda |
| 41. Sao Tome and Principe | | | |
| 42. Senegal | 43. Seychelle | 44. Sierra Leone | |
| 45. South Africa | 46. Sudan | 47. Tanzania | |
| 48. Togo | 49. Tunisia | 50. Uganda | |
| 51. Zambia | 52. Zimbabwe | | |
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