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ORIGINAL ARTICLE

Climate change's impact on commodity prices: a new challenge for monetary policy

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Abstract
Climate change is a global issue that is driving up commodity prices such as food, energy and fertiliser. In this light, this study examines the effects of climate change on international commodity prices (food, energy, and fertilisers) from 1961 to 2020. The study employs a Bayesian Vector Autoregression (BVAR) model identified with sign restrictions. First, this study finds that climate change causes an increase in commodity prices, with the effect being greatest for energy, followed by fertilisers, and least for food prices. Second, this study also finds that climate change may have amplified the short-run impact of fertiliser and energy prices on food prices. Third, the estimates suggest that climate change may have a negative impact on global real GDP. Overall, this study's findings of global climate change's positive effects on commodity prices and a negative impact on global real GDP, suggests that monetary authorities may face higher inflation-output trade-off. Hence, this study argues that climate change may be a new challenge to monetary policy strategy, particularly in countries that are net importers of staple foods and have a large share of food items in their consumer price index.

Keywords Climate change · Energy prices · Food prices · Fertiliser prices · Monetary policy

JEL classification E31 · E58 · and R3

1 Background

In recent times, price stability has been recognised as the ultimate goal of central banks' monetary policy (Bofinger et al. 2006; Mukherjee and Ouattara 2021). In this light, any element contributing to inflationary pressure will be viewed as a threat to price stability. However, evidence suggests that climate change fuels price inflation (Heinen et al. 2018; Iliyasu et al. 2023), and thus, a challenge to achieving price

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stability. Climate change is significant changes in global temperature, precipitation, wind patterns, and other climate measures over several decades (UC DAVIS 2022). Climate change has been linked to increased levels of carbon dioxide and other greenhouse gases (nitrous oxide, methane, chlorofluorocarbons) in the atmosphere generated by human activity (Nelson et al. 2010). In the future, the world may continue to face formidable climate change risks if emissions remain non-zero. For example, in terms of global mean annual temperature, the year 2020 set a new high at 1.7 ^{o}C above the climate normal (FAO 2021). The envisaged rise in global mean temperature, amongst others, is the reason that the Paris Agreement targets zero emissions.

On the one hand, climate change amplifies the inflation-output trade-off (Breitenfellner et al. 2019) and instigates structural changes as well as supply-side shocks with strong ramifications for financial stability (SARB 2020; Coelho and Restoy 2022). On the other hand, curtailing climate change risks requires climate protection policies such as carbon emission policies as well as regulatory responses, all of which have been shown to increase production costs and, subsequently, inflation (McKibbin et al. 2017). The different ways of implementing such policies[1] will imply different effects on energy and food prices. This can complicate the monetary policy process if such policies cause a significant increase in prices and, in response, the monetary authorities tighten policy rates to rein in inflation, leading to a fall in domestic GDP, which can counterbalance the net inflation benefits.

However, climate change is most likely to have the greatest effect on agriculture (Batten et al. 2016); hence, food prices can be more susceptible to its adverse effects than non-food prices, except energy prices. Agricultural yields, for example, are weather-sensitive, and if the climate gets increasingly extreme, it may diminish crop yields in areas where food production is critical (Wade and Jennings 2015). This may lead to shortages and soaring commodity prices, which may lead to global food price inflation propagated through trade and other economic links. In this light, this study attempts to examine the effect of climate change on international commodity prices of food, energy, and fertiliser in light of the challenge it presents to monetary policy strategy. This study's focus on international commodity prices is for two reasons. First, there are currently limited empirical estimates to guide policy design (Heinen et al. 2018; Nahoussé 2019; Mukherjee and Ouattara 2021; Faccia et al. 2021; Iliyasu et al. 2023). These studies focus on the response of domestic food and consumer prices, with no consideration of the effect of global climate change on international commodities' prices. Second, this study focuses on international prices of energy, fertilisers, and food due to their sensitivity to climate change risks and their subsequent pass-through to domestic price inflation in the form of global price shocks.

This study's empirical analysis leads to four key findings. First, this study finds that climate change drives an upsurge in commodity prices, and the effect tends to be larger for energy, then fertilisers, and least on food prices. Second, this study also finds that climate change may have amplified the short-run impact of fertilisers and energy prices on food prices. Third, the estimates suggest that climate may have an

[1] These include measures like regulating carbon emissions through a carbon tax, emission trading system (ETS), subsidies, tax credits, guarantees, and provision of infrastructure or technology regulation.

adverse impact (depressed) on global real GDP. The findings also confirm energy and fertiliser prices as viable channels through which climate change affects food prices. Therefore, these findings contribute to the literature on the impact of climate change on price stability. It also justifies the involvement of several central banks in green financing, as well as provides empirical support for the efforts of the Bank of England, the European Central Bank, and the Network for Greening the Financial System (NGFS) of incorporating climate-related risks in their supervision.

The rest of the study is organised as follows. Section two (2) reviews the literature on the impact of climate change risks on inflation. Section three (3) presents and discusses sources of data as well as the methods for evaluating the effects of climate change and input prices on global food prices. Section four (4) presents and discusses the empirical results. Finally, section five (5) concludes the study.

2 Review of literature

There is a growing and still developing body of literature on the economic impact of climate change risks (physical risk and transition risk). Recently, studies have estimated a negative impact of climate change on output (Acevedo et al. 2018; Kahn et al. 2019; Jain et al. 2020), while others found that it fuels inflation (Heinen et al. 2018; Nahoussé 2019; Iliyasu et al. 2023) and complicates the monetary policy process (Economides and Xepapadeas 2018). Theoretically, Wade and Jennings (2015), Mukherjee and Ouattara (2021), and Kramer and Solveen (2021) demonstrate that climate change shocks may contract output supply. Also, evidence shows that hotter temperatures may lower output (Abidoye and Odusola 2015), whereas other evidence suggests that transition risks from climate protection policies and efforts to decarbonise the economy can also affect production costs and subsequently inflation (McKibbin et al. 2017; Kramer and Solveen 2021; Moessner 2022; Konradt and Mauro 2022).

More specifically, studies on the inflationary effects of climate change, particularly on food prices, are meagre. Nonetheless, climate change has been found to have a significant impact on inflation in both developed and developing countries (Heinen et al. 2018; Nahoussé 2019; Mukherjee and Ouattara 2021; Faccia et al. 2021; Iliyasu et al. 2023). These studies have employed panel VAR models (Mukherjee and Ouattara 2021), fixed effects panel models (Heinen et al. 2018), panel local projections (Faccia et al. 2021), and Structural VAR models (Iliyasu et al. 2023) in the estimation of the inflation impact of climate change. For example, Nahoussé (2019) finds that rainfall instability is among the primary drivers of inflation in WAEMU. Similarly, Mukherjee and Ouattara (2021) find that temperature anomalies shocks cause inflationary pressures, albeit the impact is more persistent in developing countries than in developed economies. In South Africa, Nigeria, and Egypt, Iliyasu et al. (2023) observe that climate change has fuelled food and consumer prices. More specifically, Iliyasu et al. (2023) estimated a larger impact on food than overall consumer price inflation. Similarly, temperature shocks have become a more significant effect in explaining food price volatility than rainfall in Uganda (Mawejje 2016).

The evidence from the studies of Mawejje (2016) and Iliyasu et al. (2023) suggests that food prices (international & domestic) may not be insulated from the vagaries of climate change's risk. For example, an earlier study shows that climate change has a positive impact on international food prices. Nelson et al. (2009) prediction shows that by 2050, climate change will increase international rice prices by 32–37%, maize prices by 52–55%, wheat prices by 94–111%, and soybean prices by 11–14%. Later analysis by Nelson et al. (2010) shows that in an optimistic scenario, climate change is likely to cause a 31.2% increase in rice and a 100.7% increase in maize; however, with perfect mitigation, Nelson et al. (2010) shows that increases would be 18.4% for rice and 34.1% for maize. Similarly, using a panel local projection method, Faccia et al. (2021) provide estimates suggesting that temperature anomalies increase consumer prices, food prices, non-food prices, producer prices, and the GDP deflator in a sample of 48 advanced and emerging economies.

Recently, studies such as Hagos (2018) in Ethiopia and Iliyasu et al. (2023) for South Africa, Nigeria, and Egypt, found a positive impact of climate change on food prices. Also, other studies show that climate change raises energy (electricity) prices in Western Europe (Golombek et al. 2012). However, global commodity price shocks can transmit to domestic prices through trade and other economic links; hence, food prices in countries that are net importers of food items may rise as a result. For example, panel studies support a positive impact of international food on domestic food price inflation (Ciccarelli and Mojon 2010; Lee and Park 2013; Furceri et al. 2016; Parker 2018). In this light, Ciccarelli and Mojon (2010) show that global inflation explains 70% of the variance of national inflation rates in OECD countries, and national inflation rates revert it. Similarly, Lee and Park (2013) find a strong co-movement between the lagged value of global food prices and domestic food price inflation in 72 Asia countries. Also, Cachia's (2014) study finds evidence showing the transmission of international commodity prices to food consumer prices in several regions of the world. Specifically, Cachia (2014) estimated the largest spillover for Eastern Africa, the least for North America & Europe, and medium for Asia (South & South-East) as well as Latin America. In addition, Furceri et al. (2016) show that a 10% increase in global food inflation raises domestic inflation by 0.5pp after a year in advanced countries. Also, Parker (2018) finds that global energy and food price have the largest impact on the national inflation rate in 223 countries and territories.

In summary, the reviewed literature suggests three key issues that are relevant to this study. Firstly, the evidence suggests that climate change may fuel inflation in both global and domestic price levels of energy and food (Golombek et al. 2012; Heinen et al. 2018; Nahoussé 2019; Mukherjee and Ouattara 2021; Faccia et al. 2021; Iliyasu et al. 2023). Second, the evidence further suggests that regardless of the trigger, movement in international prices spillover to domestic inflation in the form of global price shocks (Ciccarelli and Mojon 2010; Lee and Park 2013; Cachia 2014; Furceri et al. 2016; Parker 2018). Finally, inferring from the reviewed literature, the impact on domestic inflation of international commodity prices that may be triggered by climate change or input price movement can be a constraint to achieving price stability, especially in net-importer countries and where consumers spend a large fraction of their income on food items. Therefore, this study attempts to estimate the effects of climate change on international commodity prices to draw implications for monetary policy.

2.1 Conceptual framework of climate change's risks transmission to output and inflation

Figure 1 presents the transmission channels of climate change shocks to output and inflation. These effects occur through the two risks associated with climate change – physical[2] and transition[3] risks. Conceptually, both risks introduce supply and demand shocks into the economy. Climate change-related physical risks include, among other things, an increase in the frequency and severity of extreme weather events such as heat waves and typhoons, as well as changes in precipitation patterns, temperatures & sea level rise, floods, droughts, and storms. Figure 1 shows that *supply shocks* induced by physical risks will affect the economy's aggregate supply at given inputs and prices. These effects work through their negative impact on the accumulation of productive capital as well as the supply of effective labour and factor productivity. This will cause upward pressure on the price of existing output due to a decrease in output and productivity, which will affect inflation depending on how long it lasts. On the other hand, physical risk can stimulate innovation (new technologies) via the creation-destruction cycle, resulting in *positive supply shocks*[4]. This boosts output and lowers inflation at the same time. Thus, the net inflation impact of climate change (as a supply shock) will be determined by the relative size of negative and positive shocks.

From Fig. 1, physical risk can cause demand shocks when it impairs firms' balance sheets and household wealth, increase demand for energy, reconstruction, and

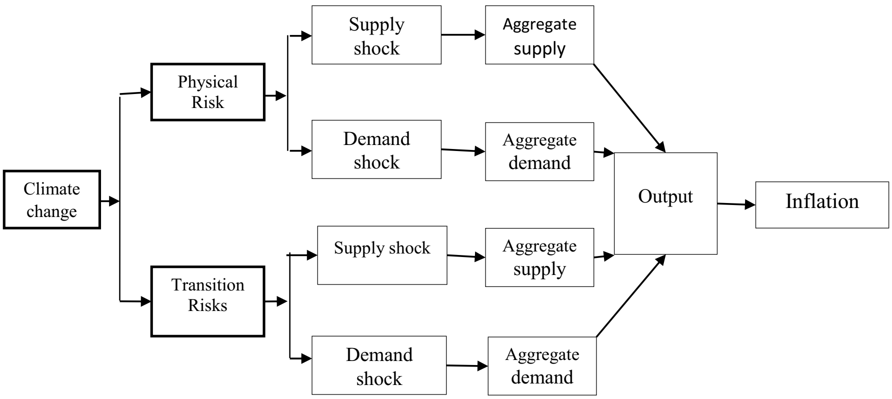


Fig. 1 Conceptual Framework of Climate Change's Risks Transmission to Inflation

[2] Rising temperatures, altered precipitation, decreased oxygen, rising sea levels, extreme events, flooding, drought, increased storms and cyclones, heat waves, acidification and air pollution, and so on.

[3] Among the many measures taken to combat climate change and decarbonise the economy are the following: a carbon tax; subsidies; emission trading system, guarantees; technology regulation; targets and infrastructure; tax credits for renewable energy investment; renewable electricity portfolio standards; and tax credits for residential solar systems, electric vehicles, and weatherisation of both homes and business buildings.

[4] Also, as a result of changes in rainfall patterns or longer growing seasons, some climes can experience positive supply shocks from physical risks.

migration, or decrease lending. These constitute both negative and positive demand shocks. A negative demand shock occurs when climate change leads to the impairment of firms' balance sheets and household wealth, combined with increased migration, leading to a decrease in consumption and investment demand. These would have negative impacts on aggregate demand, output, and inflation. Following a climate-related natural disaster, on the one hand, the increase in energy demand, together with the reconstruction boom will boost consumption and investment. Aggregate consumption and investment will rise, stimulating aggregate demand and output. As a result, inflation will be affected positively. However, the extent of the impact will be determined by the economic agent's perception of the nature of the shock (whether it is transitory or permanent).

The transition risks from climate protection and decarbonisation policies also affect output and inflation through supply and demand channels. The supply shocks manifest in the form of changes in the costs of production induced by changes in carbon taxes, subsidies, guarantees, the emission trading system, technology regulation, targets, and investment tax credits. Each of these aspects of climate protection policies has a different effect on the aggregate supply. For instance, an increase in carbon taxes and prices will affect the cost functions of emissions-intensive industries by increasing their production costs which cause the aggregate supply curve to shift to the left. This shift causes a decrease in output and an increase in prices, hence, inflation (Fig. 1). However, increases in subsidies and guarantees represent positive supply shocks that boost output and lower prices, resulting in lower inflation. In contrast, technology regulation, targets, and permits can disrupt carbon-intensive sectors by stranding carbon-intensive investment and abandoning fossil fuel reserves and coal mines. This reduces aggregate demand by lowering consumption and investment expenditure, resulting in lower output and an increase in inflation.

3 Methodology

The key hypothesis developed in this study, derived from the two sides of the debate reviewed in the previous section, is that while climate change, in itself, has a significant (direct and indirect) positive effect on global inflation through, say, reduced agricultural yields (Nelson et al. 2009; Acevedo et al. 2018; Faccia et al. 2021), the mitigation measures also tend to have significant positive effects on global inflation though, say, increased energy prices[5] (Wade and Jennings 2015; Kramer and Solveen 2021; Konradt and Mauro 2022; Moessner 2022) which, in turn, raises the prices of fertilisers. These two commodities (energy and fertilisers) are key influences on production (agriculture and manufacturing), hence, inflation. For inflation concerns, therefore, a potential dilemma for policymakers would be whether

[5] An increase in the carbon tax or price increases the cost of generating fossil fuels, causing their prices to rise. Because oil is used in the manufacturing and distribution of the vast majority of commodities, an increase in its price raises production costs. Profit margins are stretched when production costs grow, and firms seek to boost prices to maintain markups (Garganas 2006).

the *net inflation benefit*[6] of the climate change mitigation measures is positive and, therefore, justifies the support of monetary authorities through, say, promoting green financing. Admittedly, modelling the causal links between climate change, commodity prices, inflation, and output is complex. For instance, physical risks from climate change have a direct effect on food prices as well as indirect through input prices (i.e., prices of fertilisers and energy). The long-run effects on inflation would also conceptually differ from the short-run effects. Consequently, two dimensions of these complexities are reflected in our modelling and data collection strategies involving the use of a carefully identified Bayesian Vector Autoregressive model (BVAR). The BVAR allow for the use of sign restrictions to reflect the order and directions of the conceptualised complex causal relations amongst the variables. It also allows for the separate estimation of long-run and short-run effects.

3.1 The bayesian VAR model, data and sources

A Bayesian Vector Autoregression (BVAR) model of climate change, global real GDP, and international prices of energy, fertilisers, and food was developed. The choice of a VAR model in this study was motivated by Mukherjee and Ouattara (2021) and Iliyasu et al. (2023) who employed panel VAR and Structural VAR models in their respective studies. Following Kamber et al. (2016), the VAR model is specified as follows:

$$B_0X_t = \sum_{i=1}^{P} B_iX_{t-i} + \varepsilon_t \tag{1}$$

where: $X_t = [cc_t,\ energy_t^p,\ fertilizer_t^p,\ rgdp_t\ food_t^p]'$ is a vector of climate change (cc_t, proxied by temperature and precipitation anomalies), global real GDP ($rgdp_t$), international energy price ($energy_t^p$), international fertiliser price ($fertilizer_t^p$), and international food price ($food_t^p$). The structural shocks ε_t are assumed to be independent of each other. All the variables are in logarithmic form except climate change which is in degrees Fahrenheit (^{o}F) and inches (precipitation anomalies). Two lags were found to be optimal based on these AIC criteria, and a constant was included in the model (see Appendix 1). The model satisfies the stability condition, and there was no evidence of serial correlation in the residuals at lag two (see Appendix 2 and 3). The equation was estimated using a sign restriction identification strategy in the spirit of Uhlig's (2005) rejection method. When compared to the alternative identification strategies, such as Cholesky decomposition and structural VAR (SVAR) identified with only zero restriction, this strategy was chosen because of its flexibility. The estimate based on the Cholesky factorisation identification of shocks is sensitive to the ordering of the variables, whereas SVAR identification with zero restriction is too restrictive.

[6] The net inflation benefit would be the difference between the inflationary effects of unchecked climate change and mitigation measures.

Table 1 Identifying Sign Restrictions

	Temperature anomalies	*Precipitation anomalies*	**Real GDP**	**Energy Price**	**Fertilisers Price**
Temperature anomalies		+		+	+
Precipitation anomalies	+	+		+	+
Real GDP shock	+	+	+	+	+
Energy price shock			-	+	+
Fertilisers price shock			-		+

The model was estimated with annual time series data from 1961 to 2020. Climate change is a long-term phenomenon that often takes at least 30 years to come into effect, hence the 60-year time frame used for this study. This study proxies climate change with temperature and precipitation anomalies[7]. Temperature (precipitation) anomalies indicate how much temperatures (rainfall) in any particular period deviate from the historical average, with the latter corresponding to the average of the 1951–1980 period (Faccia et al. 2021). The data on global temperature anomalies were obtained from the depository of the United Nations Food and Agriculture Organization (FAOSTAT), whereas global precipitation anomalies were collected from The US Environmental Protection Agency (EPA). The international prices of energy, fertiliser, and food were obtained from the World Bank Commodity Price Statistics (The Pink Sheet), and the data on world real GDP was obtained from the World Bank Development Indicators.

3.2 Identification strategy for the BAVR

This study employed the agnostic identification strategy of imposing sign restrictions on impulse response functions developed by Uhlig (2005). This sign restriction approach, also known as Uhlig's (2005) rejection method, was applied to identify the shocks to climate change, energy prices, fertiliser prices, and real GDP. The responses of real GDP and food prices to climate change shocks are not subjected to any sign restrictions; therefore, the study remains agnostic in terms of these two (2) variables. Table 1 shows the identifying restriction on impulse responses. From Table 1, a climate change shock is defined as an unanticipated rise in global temperature anomalies (cc) that raises the prices of energy and fertiliser for two

[7] Climate change is defined in this study as a significant change in the average global average temperatures and precipitation over a long period of time. Four factors influenced the selection of this definition. First, key institutions (EPA, NASA, FAO, NOAA) often report key indicators of climate change, such as temperature and precipitation anomalies. Second, even the Paris Agreement target was set on temperature anomalies. Third, Hansen and Lebede (1987) demonstrate that temperature anomalies, rather than absolute temperatures, are the most appropriate measure of climate change. Fourth, Dell et al. (2012), Acevedo et al. (2018), Mukherjee and Ouattara (2021), Faccia et al. (2021), and Iliyasu et al. (2023) used temperature and precipitation anomalies to proxy climate change in their studies. Thus, using this definition, this study can measure climate change using temperature and precipitation anomalies.

years after the shock[8]. Hence, impulse responses that conform to the right sign were accepted, while those that do not were rejected. In this scenario, the analysis assumes that a sizeable change in climate leads to an increase in the international prices of energy and fertiliser.

Similarly, a real activity (GDP) shock is defined as an unanticipated increase in real activity that raises the international prices of energy and fertiliser for two years (positive demand shock). It is expected that when the level of economic activity (real income) rises, so do the demand and, subsequently, prices of energy and fertilisers. The shock to energy prices is defined as a negative supply shock that reduces real activity and raises fertiliser prices for two years after the shock. Finally, a fertiliser price shock is defined as a negative supply shock that causes a decrease in the level of economic activity two years after the shock. Given that both energy and fertilisers are inputs into the production process, the assumption that real activity drops when prices rise is plausible. As a result, all things being equal, an increase in input prices reduces the supply of the product in consideration. Furthermore, the idea that an increase in energy prices causes a positive increase in fertiliser prices stems from the fact that energy is a key input in fertiliser production. Finally, no restrictions on the response of food prices to any shock were imposed; thus, the study remained agnostic about food price behaviour.

4 Empirical results and discussion

4.1 Dynamic impact of global climate change on commodity prices

Figure 2 presents the median dynamic response of international food prices to a 0.16 °F shock to global temperature anomalies and a 0.59 inch shock to global precipitation anomalies. From Fig. 2, following an unanticipated rise in global temperature and precipitation anomalies, the global prices of food rise persistently for about 4 and 11 years, respectively. This suggests that while climate change may have caused an increase in global food prices, the effect of precipitation anomalies is more persistent. Thus, this finding indicates that climate change manifestations in the form of temperatures and precipitation anomalies have a significant impact on global food prices.

Similarly, Fig. 3 presents the median dynamic response of international energy price to a 0.16 °F shock to global temperature anomalies and a 0.59 inch shock to global precipitation anomalies. However, the international price of energy is constructed to rise in the first two years in response to shocks in global temperature and precipitation anomalies, and the response is unrestricted after then (Table 1). Figure 3 shows that the response of the international price of energy

[8] Evidence suggests that climate change raises energy prices (Golombek et al. 2012; Wade and Jennings 2015), and an increase in energy prices affects the cost of nitrogen fertilisers (urea & ammonium nitrate), which are produced primarily from natural gas (FAO 2022). Also, the direct impact of climate change on fertiliser prices may stem from damages to physical capital.

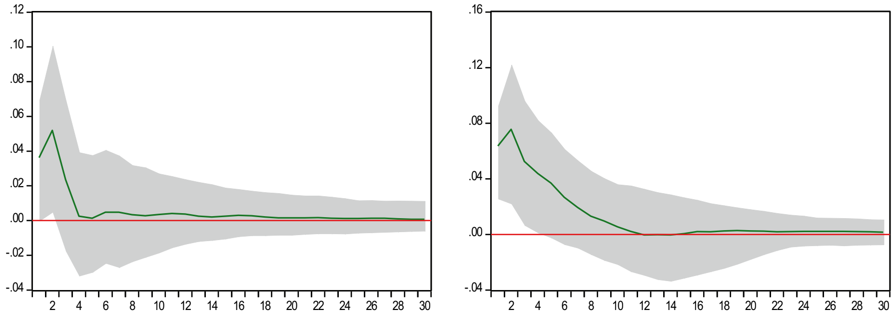


Fig. 2 Dynamic Response of International Food Prices to Shocks in Climate Change

outside the two horizons is positive and persistent, lasting at least ten years. Given that temperature and precipitation anomalies are key indicators of climate change, the findings suggest that climate change may have contributed to an increase in global energy prices. This rise may also pose an additional upside risk to a surge in food and fertiliser price inflation, as energy is a key input in their production and distribution.

Also, Fig. 4 presents the median dynamic response of international fertilisers price to a 0.16 °F shock to global temperature anomalies and a 0.59 inch shock to global precipitation anomalies. From Table 1, the international price of fertilisers is constructed to rise in the first two years in response to shocks in global temperature and precipitation anomalies, and then the response becomes unrestricted. Figure 3 shows a significant increase in the international price of fertilisers as a result of global temperature and precipitation anomalies in the unrestricted horizons. This positive effect appears to be persistent, as the international price of fertilisers takes at least 15 years to fully adjust to the shocks. Thus, these findings imply that global climate change may have a positive long-term impact on fertiliser prices around the world. This may have an impact on food prices because fertilisers are a critical input in the production of agricultural products that are used in food production.

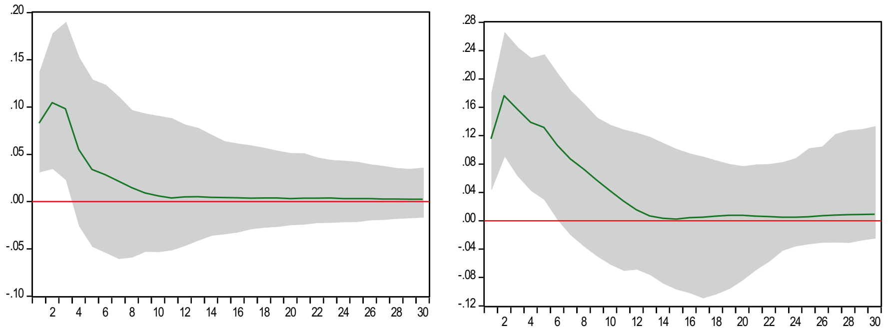


Fig. 3 Dynamic Response of International Energy Prices to Shocks in Climate Change

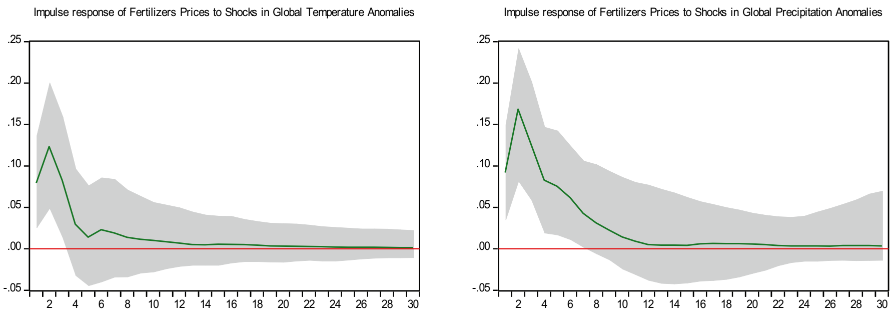


Fig. 4 Dynamic Response of International Food Prices to Shocks in Climate Change

Finally, Fig. 5 displays the median dynamic response of global real GDP to a 0.16 °F shock to global temperature anomalies and a 0.59 inch shock to global precipitation anomalies. On the one hand, Fig. 5 shows that global real GDP has been declining for four years and then increasing following a shock to global temperature anomalies. On the other hand, it demonstrates that global real GDP has been declining significantly and consistently for more than ten years following a shock to global precipitation anomalies. This means that the relative impact of climate change on global real GDP will vary depending on the proxy used, such as temperature and precipitation anomalies.

4.2 Relative impact of global climate change on international commodity prices

Table 2 reports the median dynamic response of international commodity prices as well as global real GDP to a 1 °C shock to global temperature anomalies and a 1-inch shock to global precipitation anomalies. Table 2 shows that a 1 °F increase in global temperature anomalies has a 3.3%, 3.0%, and 1.1% long-run impact on energy, fertiliser, and food prices, respectively. This finding implies that a 1 °F reduction in global temperature anomalies is required to achieve a 3.3%, 3.0%, and

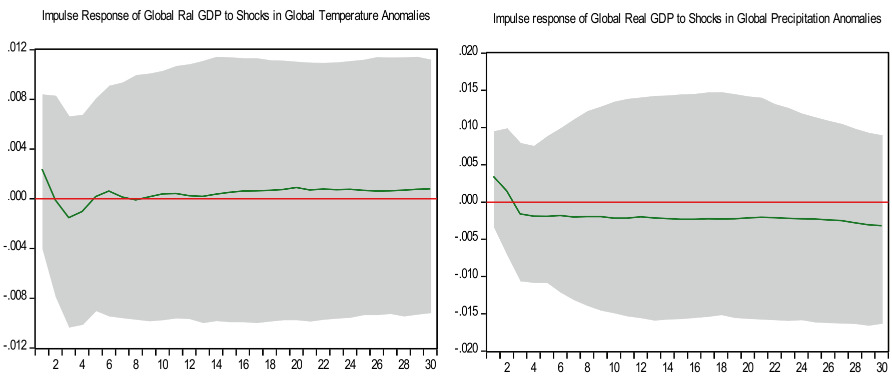


Fig. 5 Dynamic Response of Global Real Gross Domestic Product to Shocks in Climate Change

Table 2 Cumulative Responses of Global Real GDP, International Energy, Fertilizers, and Food Prices to Global Climate Change Shock

Cumulative Response to 1 °F Shock to Temperature Anomalies					**Cumulative Response to 1-inch Shock to Precipitation Anomalies**			
Horizon	Energy Price	Fertilisers Price	RGDP	Food Price	Energy Price	Fertilisers Price	RGDP	Food Price
1	0.5	0.5	0.01	0.2	0.2	0.2	0.01	0.1
2	1.2	1.3	0.01	0.6	0.5	0.4	0.01	0.2
3	1.8	1.8	0.00	0.7	0.8	0.7	0.01	0.3
4	2.1	2.0	0.00	0.7	1.0	0.8	0.00	0.4
5	2.3	2.1	0.00	0.7	1.2	0.9	0.00	0.5
10	2.8	2.5	0.01	0.8	1.8	1.2	-0.02	0.6
15	3.0	2.7	0.02	0.9	1.9	1.3	-0.04	0.6
20	3.1	2.9	0.04	1.0	2.0	1.3	-0.05	0.6
25	3.2	2.9	0.06	1.0	2.0	1.3	-0.07	0.6
26	3.2	3.0	0.07	1.1	2.0	1.3	-0.08	0.6
27	3.2	3.0	0.07	1.1	2.0	1.3	-0.08	0.6
28	3.3	3.0	0.08	1.1	2.1	1.4	-0.09	0.6
29	3.3	3.0	0.08	1.1	2.1	1.4	-0.09	0.6
30	3.3	3.0	0.09	1.1	2.1	1.4	-0.10	0.6

1.1% decrease in energy, fertiliser, and food prices, respectively. Comparatively, results show that energy is most affected, followed by fertilisers, and food prices are the least affected. Similarly, an inch increase in global precipitation anomalies raises energy, fertiliser, and food prices by 2.1%, 1.4%, and 0.6%, respectively (Table 2). Consistent with the findings on temperature anomalies, this result demonstrates that global precipitation anomalies have the greatest impact on energy and fertilisers prices, with the least impact on food prices. This study also discovered that climate change has a negative impact on global real GDP.

Overall, these findings show that climate change has a significant impact on international commodity prices. It also aligns with the evidence that extreme temperatures raise food prices (Nelson et al. 2009, 2010; Parker 2016; Iliyasu et al. 2023) and energy price inflation (Golombek et al. 2012). Consistent with the theory, these results suggest that climate change may have caused an increase in international inputs (energy and fertiliser) and global food prices. Theoretically, this can occur if climate change acts as a negative supply-side shock, causing the output to fall and consequently increase the price. First, the positive response of food prices to climate change shocks can be ascribed to its negative effect on yield (Acevedo et al. 2018), factor productivity (Sheng and Xu 2018), capital accumulation (Fankhauser and Tol 2005), and access to finance (Kling et al. 2021). All of these can result in a decline in output (Wijeratne et al. 2007; Kjellstrom et al. 2009) and supply shortages which can push up food prices. Second, climate change may raise energy demand, influence hydroelectric production supply through a shift in water intake, and lower plant

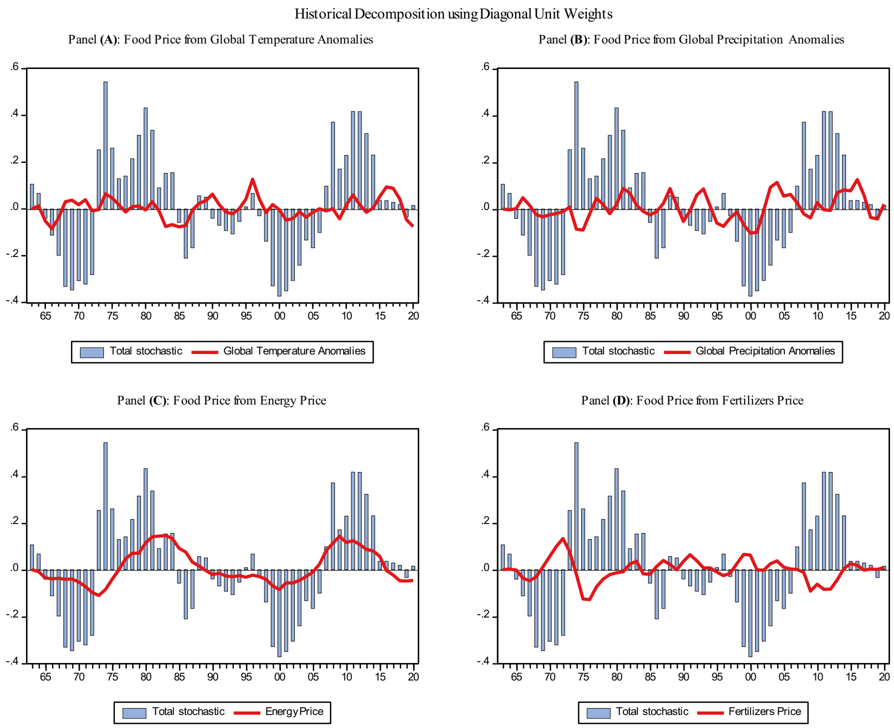


Fig. 6 Historical Drivers of Movement in International Food Price

efficiency for thermal generation (Golombek et al. 2012). Demand pressure, along with a reduction in hydroelectric production and lower thermal generation efficiency, might result in higher prices for available output. Third, rising energy prices would affect the cost of nitrogen fertilisers (urea and ammonium nitrate), which are predominantly made from natural gas (FAO 2022).

4.3 Historical role of global climate change in driving international commodity prices

4.3.1 Historical decomposition of movement in international food price

Figure 6 presents the historical decomposition of movement in the international price of food, indicating the relative contribution of climate change (global temperature and precipitation anomalies) and commodity (energy and fertilisers, i.e., inputs) prices to movement in food prices over the sample period. From Panel (A), global temperature anomalies were found to be significant contributors to surges in food prices during the periods 1972–1982 and 2007–2018 whereas, for the periods 1998–2007 and 2019–2020, they had contributed to its decline

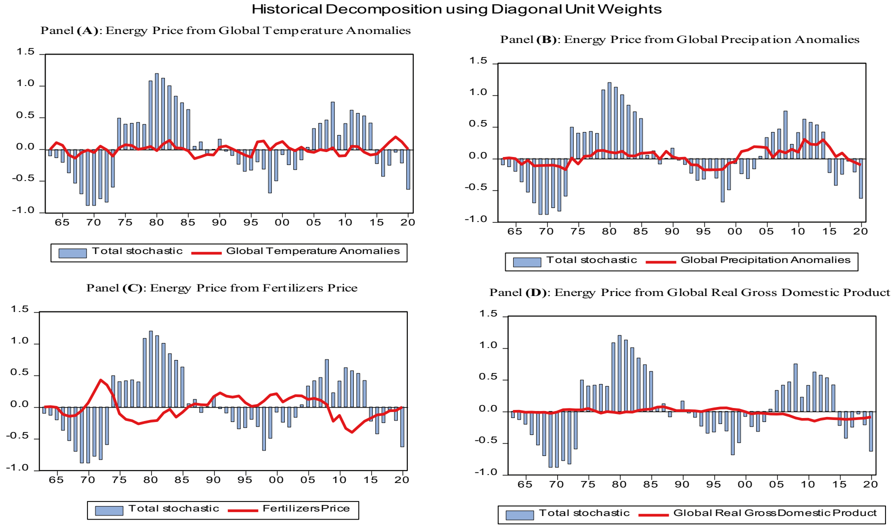


Fig. 7 Historical Drivers of Movement in International Energy Price

significantly. Similarly, Panel (B) shows that global precipitation anomalies contributed significantly to an increase in food prices from 1976 to 1984, 1988 to 1990, and 2010 to 2018. It is also responsible for a significant drop from 1968 to 1973, 1998 to 2002, and 2018–2019. Overall, the results in Panels (A) and (B) indicate that climate change was one of the key drivers of food price increases and decreases during the aforementioned periods.

Furthermore, Panel (C) demonstrates that energy price shocks have been the primary driver of food price movement. More specifically, it was discovered that increases in energy prices contributed significantly to the rise in food prices between 1976 and 1985, as well as between 2007 and 2016. It also resulted in a significant decrease in the years 1964–1972, 1990–2006, and 2019 due to a decrease in energy prices. Similarly, Panel (D) shows that the price of fertilisers has a significant positive influence on food prices in 1973–1974, 1980–1984, 1988–1990, and 2015–2020. However, Panel (D) demonstrates that a decrease in fertiliser prices was one of the factors responsible for the decline in food prices from 1965 to 1969.

Overall, evidence from this historical decomposition of food price movement suggests that climate change (anomalies in global temperature and precipitation) and commodity prices (energy and fertilisers) are significant drivers of food price movements from 1960 to 2020. The findings also suggest that the impact of climate change and input costs (commodity price) on food prices varies over time. Finally, the findings suggest that mitigating the adverse effects of climate change and lowering input prices can help to moderate global food price increases.

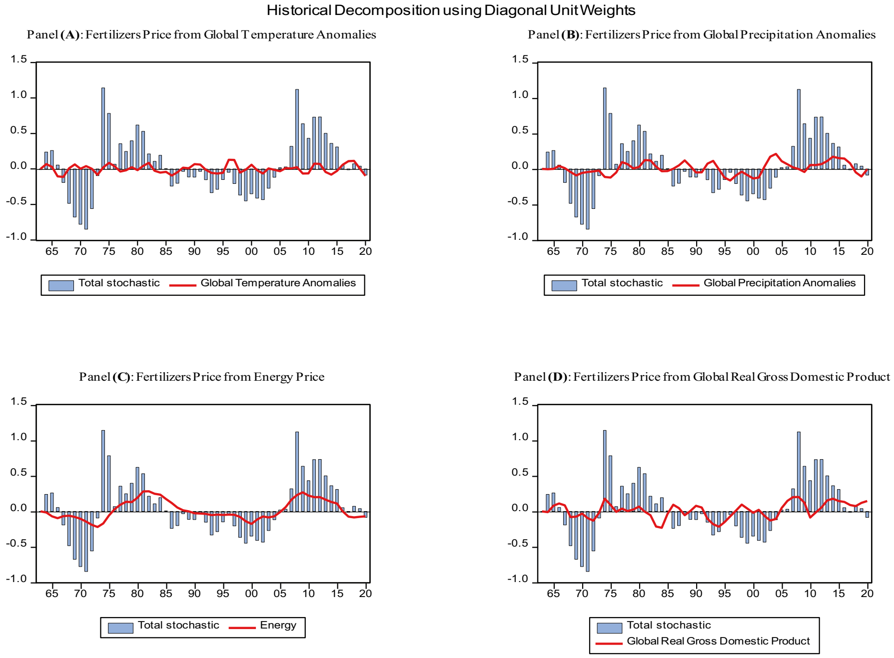


Fig. 8 Historical Drivers of Movement in International Fertilizers Price

4.3.2 Historical decomposition of movement in international energy price

Figure 7 reports the historical decomposition of fluctuation in the international price of energy from 1960 to 2020.

Panel (A) shows that global temperature anomalies contributed significantly to energy price increases in the years 1974–1985 and 2003–2013. Temperature anomalies were also key drivers of the decline in the international price of energy from 1966 to 1973 and 1990 to 1996. Similarly, Panel (B) demonstrates that global precipitation anomalies are one of the contributors to the movement in international energy prices. On the one hand, Panel (B) shows that global precipitation anomalies were among the key drivers of the increase in international energy prices from 1974 to 1988 and 2004 to 2014. Panel (B), on the other hand, demonstrates that global precipitation anomalies drove a significant drop in the international price of energy in the periods 1965–1973, 1991–2000, and 2018–2020. The evidence presented in Panels (A) and (B) shows that climate change was one of the key drivers of increases and decreases in international energy prices, with the impact varying over time.

4.3.3 Historical decomposition of movement in international fertilizer price

Figure 8 displays the historical decomposition of fluctuation in the international price of fertilisers for the period 1960–2020.

From Panel (A), global temperature anomalies were significant among the drivers of increases in the international price of fertilisers in the periods 1973–1983 and 2005–2019, whereas they contributed to a decline in the periods 1972–1974, 1992–1995, and 2020. Furthermore, Panel (B) demonstrates that global precipitation anomalies are one of the contributors to fluctuations in the international price of fertilisers. On the one hand, Panel (B) shows that global precipitation anomalies were among the key drivers of the increase in international fertiliser prices between 1976 and 1986 and 2005 and 2018. Panel (B), on the other hand, shows that global precipitation anomalies drove a significant drop in the international price of fertilisers in the years 1967–1974, 1994–2002, and 2020. The evidence presented in Panels (A) and (B) shows that climate change was one of the key drivers of increases and decreases in international fertiliser and energy prices, with the impact varying over time. Furthermore, Panel (C) shows that increases in the international price of energy contributed significantly to the rise in the international price of fertilisers during the periods 1976–1984 and 2005–2016. From Panel (C), a drop in the international price of energy contributed significantly to a drop in the international price of fertilisers during the periods 1967–1974, 1989–2005, and 2020.

4.4 The role of climate change in propagating the impact of input prices to food price

This section applies ideas from the literature on conditional exchange rate pass-through (CERPT) to quantify the role of global climate change in propagating the impact of input costs (energy & fertilisers) on international food prices. According to the CERPT literature, the magnitude of the ERPT is dependent on the types of exogenous shocks that cause the exchange rate to change (Comunale and Kunovac 2017; Forbes et al. 2020; An et al. 2020; ECB 2020). The CERPT stressed that the type of shocks driving the exchange rate is a significant influence on the impact's transmission (ECB 2020). Relatedly, this suggests that the response of international food prices to changes in input costs may be affected by the shock that causes the movement [9]. Firms, for example, may adjust prices differently in response to cost increases caused by climate change or the implementation of a carbon tax[10].

On the one hand, Column (B) of Table 3 shows that when a 1 °F increase in global temperature anomalies pushes energy prices, its pass-through to international food prices is 0.44 and 0.3 in the short and long run (10 years) [11]. Similarly, Column

[9] Biofuel and fertiliser productions, for example, are emission-intensive and climate-sensitive; hence, climate change or the implementation of a carbon tax can push up energy, fertiliser, and food prices differently.

[10] The natural question is how much of the pass-through of energy and fertiliser prices to food prices may be attributed to climate change shock.

[11] This is known as conditional or shock-dependent pass-through and it is defined as the ratio of the total (cumulative) effect of shock j on price p over the total (cumulative) effect of the same shock on the inputs prices s (ECB 2020, p. 10). For consistency, we replace the exchange rate with input cost in the ECB's definition. The conditional pass-through is computed using the formula: $PT^{\tau}_{n,s} = \frac{\sum_{j=0}^{\tau} \partial \pi_{t+j} / \partial \varepsilon^{s}_{t}}{\sum_{j=0}^{\tau} \partial \Delta e_{t+j} / \partial \varepsilon^{s}_{t}}$, (see; An et al. 2020, p. 18). This metric measures the pass-through of input costs to food price when

Table 3 Conditional Pass-through of Inputs Costs to International Price of Food

A			B		C	
Pass-through to International Food Price of:			*Pass-through to Food Price Conditional on 1°C Increase in Global Temperature Anomalies*		*Pass-through to Food Price Conditional on 1inch Increase in Global Precipitation Anomalies*	
Horizon	Energy Price	Fertilisers Price	Energy Price	Fertilisers Price	Energy Price	Fertilisers Price
1	0.23	0.24	0.44	0.46	0.55	0.69
2	0.47	0.45	0.47	0.44	0.48	0.53
3	0.63	0.54	0.39	0.39	0.43	0.50
4	0.78	0.58	0.34	0.36	0.40	0.50
5	0.92	0.64	0.31	0.35	0.38	0.50
10	1.28	0.74	0.30	0.33	0.32	0.48
15	1.33	0.64	0.31	0.34	0.31	0.47
20	1.30	0.56	0.32	0.35	0.31	0.46
25	1.25	0.51	0.33	0.36	0.31	0.47
26	1.25	0.49	0.33	0.36	0.31	0.47
27	1.24	0.48	0.33	0.36	0.31	0.47
28	1.23	0.47	0.33	0.36	0.31	0.47
29	1.22	0.45	0.33	0.36	0.31	0.47
30	1.21	0.44	0.33	0.36	0.31	0.47

(B) of Table 3 shows that when a 1 °F increase in global temperature anomalies pushes fertilisers prices, its pass-through to international food prices is 0.46 and 0.33 in the short and long run (10 years). On the one hand, Column (C) shows that when global precipitation anomalies triggered movement in energy prices, its pass-through to international food prices is 0.55 and 0.32 in the short and long run (10 years). On the other hand, Column (C) shows that when global precipitation anomalies triggered movement in fertilisers price, its pass-through to international food prices is 0.69 and 0.48 in the short and long run (10 years).

In summary, the inputs pass-through estimates above suggest that increases in prices of energy and fertiliser may have been absorbed by food prices. Although the pass-through was found to be incomplete in the short run, it was more-than-complete (cost-amplifying) in the long run. This implies that increases in input costs (energy & fertiliser) prices are associated with cost amplification in food production, and the market is an imperfect one. In addition, the direct effect of global climate change on food prices was found to be larger than the effect of input prices. Finally, the finding that shocks climate change may have amplified the pass-through of input

Footnote 11 (continued)

movements in energy and fertiliser prices are induced by climate change rather than exogenous movements in input price itself.

Table 4 Accumulated Responses and Dynamic Elasticities of International Energy, Fertilizers, and Food Price to Shocks to Global Temperature Anomalies

	Accumulated (median) Response 0.221 °F Shock to Global Temperature Anomalies			Dynamic Elasticity to 1% Rise in Global Temperature Anomalies		
Horizon	Energy	Fertilisers	Food	Energy	Fertilisers	Food
1	0.11	0.09	0.06	0.72	0.54	0.37
2	0.26	0.27	0.15	1.73	1.57	0.89
3	0.42	0.42	0.23	2.69	2.44	1.29
4	0.56	0.51	0.28	3.52	2.99	1.58
5	0.68	0.58	0.32	4.33	3.46	1.84
6	0.81	0.65	0.35	5.11	3.94	2.10
7	0.92	0.71	0.39	5.84	4.39	2.35
8	1.03	0.77	0.42	6.53	4.81	2.58
9	1.13	0.82	0.45	7.21	5.20	2.78
10	1.23	0.88	0.48	7.84	5.54	2.96

prices to food prices in the short run establishes input prices as viable channels via which climate change affects food prices.

From Column (B), the results imply that conditional on a 1 °F increase in global temperature anomalies, 44% and 30% of any change in energy price tends to be reflected in international food prices after 1 and 10 years, whereas 46% and 33% of fertilisers price change will be reflected. Similarly, Column (C) implies conditional on a 1-inch increase in global precipitation anomalies, 55% and 32% of any change in energy price tend to be reflected in international food prices after 1 and 10 years, whereas 69% and 48% of fertilisers price change will be reflected. Comparatively, these findings suggest that, in the short run, climate change tends to amplify the effect of input price movement on the international price of food. For example, the magnitude of the conditional pass-through of energy and fertilisers are 0.44 and 0.55 compared to 0.23 and 0.24 when the exogenous increase in input price is triggered by itself (Column A), which is about 128%. A similar magnitude was also estimated for the effect of global precipitation anomalies. Therefore, these findings suggest climate change may have amplified the short-run impact of increases in inputs price on the international price of food.

4.5 Robustness

This study performed robustness checks on the estimates by excluding precipitation anomalies from (1). Based on this exclusion, two lags were found to be optimal using traditional criteria, with no constant or time trend included in the model. The estimation was based on the following criteria: (i) sign restriction (Table 4); (ii) traditional BVAR (Table 5); and (iii) Cholesky decomposition ordering (Table 6). All of the estimates from these alternative identification schemes are found to be consistent with the previous results. Climate change was found to have the greatest impact on energy prices, followed by fertiliser prices, and the least impact on food prices, consistent with previous estimates (Table 4). These findings imply that the

Table 5 Estimates from Traditional BVAR

Accumulated Response 1 °F Shock to Global Temperature Anomalies					Dynamic Elasticity to 1% Rise in Global Temperature Anomalies			
Period	D(Rgdp)	Energy	Fertilisers	Food	D(Rgdp)	Energy	Fertilisers	Food
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.12	0.12	0.07	0.00	0.19	0.14	0.09
3	0.00	0.29	0.27	0.15	0.00	0.43	0.30	0.17
4	0.00	0.49	0.41	0.23	0.00	0.68	0.45	0.26
5	0.00	0.70	0.54	0.31	-0.01	0.93	0.59	0.35
6	-0.01	0.90	0.66	0.38	-0.01	1.16	0.72	0.42
7	-0.01	1.10	0.77	0.45	-0.01	1.38	0.83	0.50
8	-0.01	1.28	0.87	0.51	-0.01	1.58	0.94	0.57
9	-0.01	1.45	0.96	0.57	-0.01	1.77	1.04	0.63
10	-0.01	1.62	1.05	0.62	-0.01	1.94	1.13	0.69

estimates in this study are robust to the exclusion of a key variable, estimation technique (Tables 5 and 6), and the number of lags.

In light of the foregoing, Table 4 shows the accumulated (median) responses as well as the dynamic elasticities of international prices of energy, fertilisers, and food to one standard deviation (0.221 °F and 0.167) shock to global temperature anomalies. The results reveal that increases in global temperature anomalies have a positive impact on international prices of energy, fertilisers and food. More specifically, Table 4 suggests that an increase of 1 °F in global temperature anomalies leads to a cumulative increase in global food prices of 0.27, 1.04, and at least 1.81% points in the short, medium, and long run, respectively. Similarly, Table 4 also implies that an increase of 1 °F in global temperature anomalies has a cumulative impact of 0.45,

Table 6 Estimates Based on Cholesky Decomposition

Accumulated Response 1 °F Shock to Global Temperature Anomalies						Dynamic Elasticity to 1% Rise in Global Temperature Anomalies				
Period	CCR	D(RGDP)	Energy	Fertilisers	Food	CCR	D(RGDP)	Energy	Fertilisers	Food
1	1	0	0	0	0	1.00	0.00	0.00	0.00	0.00
2	1.34	-0.01	0.12	0.16	0.12	1.21	0.00	0.17	0.14	0.12
3	1.84	-0.01	0.38	0.38	0.23	1.69	-0.01	0.47	0.38	0.21
4	2.15	-0.01	0.64	0.59	0.35	1.90	-0.01	0.74	0.56	0.29
5	2.49	-0.01	0.93	0.79	0.45	2.18	-0.01	1.03	0.74	0.36
6	2.76	-0.01	1.23	1.00	0.56	2.37	-0.01	1.32	0.92	0.45
7	3.04	-0.01	1.53	1.20	0.67	2.56	-0.01	1.61	1.11	0.53
8	3.28	-0.02	1.83	1.40	0.77	2.72	-0.01	1.88	1.29	0.61
9	3.52	-0.02	2.13	1.59	0.88	2.87	-0.01	2.16	1.46	0.69
10	3.73	-0.02	2.42	1.78	0.98	2.99	-0.01	2.42	1.63	0.77

1.90, and 5.67% points on international energy prices in the short, medium, and long run, respectively. Finally, the results in Table 4 suggest that an increase of 1 °F in global temperature anomalies has a cumulative impact on global fertiliser prices of 0.41, 1.90 and 3.98% points in the short, medium, and long run, respectively. Consistent with findings in Table 2, these results suggest that higher global temperature anomalies have the largest impact on energy prices, followed by fertiliser prices, and the least on global food prices.

4.6 Implication of finding for monetary policy

Three major findings emerge from this study. First, this study finds that climate change drives an upsurge in commodity prices and the effect tends to be larger for energy, then fertilisers, and least on food prices. Second, this study also finds that climate change may have amplified the short-run impact of fertilisers and energy prices on food prices. Third, the findings show that climate change reduce global output. The evidence presented here that climate change drives commodity price increases have implications for monetary policy, despite the argument that central banks should never respond to commodity price shocks because they are transitory (Rosengren 2011). However, the finding that the positive effect of climate change on commodity prices is significant and persistent has important implications for the effectiveness of monetary policy strategy and for effective anchoring of inflation expectations.

The positive effects of climate change on commodity prices may make traditional monetary policy instruments less effective in addressing inflationary pressures. On the one hand, the traditional monetary policy instruments are intended to combat demand-induced inflation by adjusting the policy rate to alter liquidity so as to achieve low and stable inflation. Climate change's effect on commodity prices, on the other hand, is a supply-side-induced inflationary pressure that conventional monetary policy instruments may be unable to accommodate. Raising policy rates, for example, will not reduce emissions or mitigate climate change (the sources of price increases) but can depress output even further. This, along with the third finding that global climate change has a negative impact on global real GDP, suggests that traditional monetary policy tightening can rein in inflation only at even a significantly higher cost of output. Thus, climate change may amplify inflation-output trade-off measured by the sacrifice ratio (output cost of disinflation). This suggests that central banks may have to sacrifice more output in trying to rein in inflation that is predominantly caused by climate change. This can complicate monetary policy if, on the one hand, a central bank prioritises output and lowers policy rates to stimulate growth, resulting in a significant increase in prices, and, on the other hand, the Bank tightens policy rates to rein in inflation, resulting in a fall in domestic GDP, which can offset the net inflation benefits.

Another implication of climate change's positive effects on commodity prices is an increase in economic agents' inflation expectations. It has been demonstrated that sustained increases in commodity prices are associated with the de-anchoring of economic agents' inflation expectations, particularly when they have second-round effects on core inflation (Evans 2011). The anchoring of economic agents' inflation is critical for monetary policy's effectiveness in achieving its predetermined inflation target. In this regard, monetary policy may find it more difficult to anchor inflation when economic agents' inflation expectations are not anchored due to climate change's positive effects on commodity prices and thus may be less effective in achieving the inflation target. This can be more pronounced in countries that are net importers of foods, given the ample empirical evidence linking global commodity price shocks to domestic inflation (Ciccarelli and Mojon 2010; Lee and Park 2013; Cachia 2014; Furceri et al. 2016; Parker 2018). This also implies that climate change can be a threat to domestic price stability, particularly in economies where food items account for a large share of the consumer basket. In such economies, the impact of climate change on international energy, fertiliser, and food prices can cause domestic food price inflation, posing a challenge to monetary policy. Agriculture and food's high share of total output, consumption, employment, trade, and government revenues are all macroeconomic channels through which global food price shocks are transmitted to domestic prices (SF: Special Focus 2019).

Overall, this study's findings provide some empirical support for the involvement of many central banks in "green finance" as a means of mitigating the impact of climate change concerns on inflation. It also implies that central banks should support global efforts to mitigate climate change risk. In recent years, the Bank of England, the European Central Bank, and the Network for Greening the Financial System (NGFS) have recognised the necessity of incorporating climate change risks into their operations. However, because climate change may have an asymmetric impact on global prices of energy, fertiliser, and food, our findings should be interpreted with some caution. Empirical evidence suggests that global warming has a non-linear impact on prices (Faccia et al. 2021). Furthermore, while this study aims to derive monetary policy implications from international evidence, monetary policy is mostly implemented at the national level. As a result, our findings should be viewed in light of these limitations.

5 Conclusion

This study employs a BVAR model with sign restrictions to examine the effects of global climate change on commodity prices from 1961 to 2020. Three major findings emerge from this study. First, this study finds that climate change drives an upsurge in commodity prices, and the effect tends to be larger for energy, then fertilisers, and least on food prices. Second, this study also finds that climate change may have amplified the short-run impact of fertilisers and energy prices on food prices. Third, the estimates suggest that climate may have an adverse impact (depressed) on global real GDP. The findings also confirm energy and fertiliser prices as viable channels through which climate change affects food prices. In this light, this study argues that climate change presents a new challenge to monetary policy strategy and, thus, can be an obstacle to price stability, especially in countries that are net importers of staple foods and where food items account for a large share of consumers' consumption basket. Therefore, this study provides some empirical justification in support of central bank's involvement in green financing. It also provided empirical support for the efforts of some major central banks, including the Bank of England, the European Central Bank, and the Network for Greening the Financial System (NGFS), to incorporate climate change risk into their financial and price stability monitoring.

Appendix 1. VAR Model Lag Selection Results

VAR Lag Order Selection Criteria
Endogenous variables: GTA_C GPA_INCH ENERGY FERTILIZERS RGDP FOOD
Exogenous variables: C
Date: 04/04/23 Time: 15:04
Sample: 1961 2020
Included observations: 57

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-86.46569	NA	1.03e-06	3.244410	3.459468	3.327989
1	240.8738	574.2798	3.78e-11	-6.978028	-5.472621*	-6.392975*
2	280.2355	60.76900*	3.50e-11*	-7.095983*	-4.300229	-6.009458
3	302.7128	29.96975	6.29e-11	-6.621503	-2.535400	-5.033504

The maximum lag was set at 3, given the long-term nature of the phenomenon under investigation. We reckon that it is reasonable to expect climate change event to have up to three years lag effect

LR sequential modified LR test statistic (each test at 5% level)

*indicates lag order selected by the criterion

Appendix 2. VAR Model Stability Results

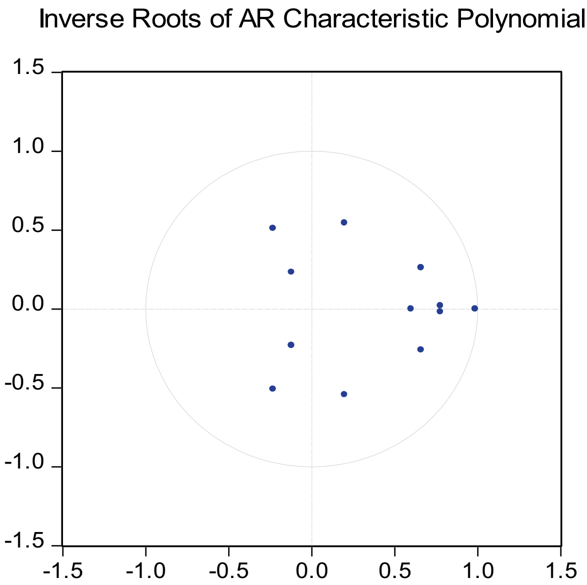
Roots of Characteristic Polynomial
Endogenous variables: GTA_C GPA_INCH
ENERGY FERTILISERS RGDP FOOD
Exogenous variables: C
Lag specification: 1 2
Date: 04/04/23 Time: 15:03

Root	Modulus
0.986579	0.986579
0.776757–0.019825i	0.777010
0.776757 + 0.019825i	0.777010
0.660536–0.261053i	0.710251
0.660536 + 0.261053i	0.710251
0.600075	0.600075

Root	Modulus
0.199654–0.543936i	0.579421
0.199654 + 0.543936i	0.579421
-0.232399–0.509161i	0.559691
-0.232399 + 0.509161i	0.559691
-0.121174–0.231209i	0.261038
-0.121174 + 0.231209i	0.261038

No root lies outside the unit circle

VAR satisfies the stability condition



Appendix 3. VAR Residual Serial Correlation LM Tests Results

VAR Residual Serial Correlation LM Tests
Date: 04/04/23 Time: 15:04
Sample: 1961 2020
Included observations: 58

Null hypothesis: No serial correlation at lag h						
Lag	LRE* stat	df	Prob.	Rao F-stat	df	Prob.
1	27.71792	36	0.8371	0.752525	(36, 152.1)	0.8402
2	37.25727	36	0.4110	1.041396	(36, 152.1)	0.4173
3	24.68876	36	0.9229	0.664154	(36, 152.1)	0.9246
Null hypothesis: No serial correlation at lags 1 to h						
Lag	LRE* stat	df	Prob.	Rao F-stat	df	Prob.
1	27.71792	36	0.8371	0.752525	(36, 152.1)	0.8402
2	70.22028	72	0.5374	0.963025	(72, 158.1)	0.5641
3	111.8822	108	0.3797	1.015927	(108, 133.3)	0.4631

*Edgeworth expansion corrected likelihood ratio statistic

Author contributions Aliyu Rafindadi Sanusi conceptualised the approach, interpreted and discussed the empirical findings, reviewed the text in its entirety, and contributed to the writing of the introduction. Jamilu Iliyasu conducted the estimation and wrote the initial drafts of the introduction, literature review, identification of the VAR model, and the conclusion section.

Data availability The data that supports the findings of this study are available in United Nations Food and Agriculture Organization (FAOSTAT), World Bank Commodity Price Statistics (The Pink Sheet), and United States Environmental Protection Agency (EPA) Repositories.

Declarations

Competing interests We have no conflict of interest to declare.

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