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Macroeconomic Consequences of Climate Change in Africa & Policy Implications

JOHN ASAFU-ADJAYE, NJUGUNA NDUNG'U AND ABEBE SHIMELES[1]

ABSTRACT

The objectives of this study are two-fold. First, we analyze the effect of climate shocks (proxied by temperature) on inflation and real output. Second, we investigate the broader macroeconomic impacts of climate change on African economies. The results of the first investigation show that temperature shocks are inflationary and cause significant decline in real output. On the basis of this finding, we argue that central banks should pay attention to climate-induced supply shocks to come up with the appropriate policy response. The second investigation focuses on agriculture given its importance in the economies of African countries. The results indicate that a climate-induced decline in agricultural productivity causes a fall in household income resulting in massive reductions in welfare. With the decline in agricultural output, food demand outstrips supply, putting upward pressure on domestic prices and inflation. To satisfy food demand, more crop land is brought into production, which results in increased loss of land cover with adverse implications for carbon

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emissions. We also investigate the impacts of the African Continental Free Trade Area. We find that, given the effects of climate change in a business-as-usual scenario, the gains from increased intra-African trade are limited. We show that the adverse impacts of climate change could be mitigated by African countries leveraging technological innovations such as climate-smart agriculture (CSA) to increase agricultural productivity. To promote the diffusion of CSA, African governments should strengthen national agricultural research and extension systems to provide information on localized CSA practices to farmers. There is also the need to build the requisite infrastructure and ecosystems to support adoption of digital agricultural technology.

Keywords: Africa, Climate change, Agricultural productivity, Temperature shocks, Inflation

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INTRODUCTION

The COVID-19 pandemic has taken a heavy toll on countries around the world, and Africa is no exception. Prior to the pandemic, in 2019, Africa had already begun to experience a slowdown in economic growth. Although a few countries such as Rwanda, Côte d'Ivoire and Ethiopia had shown high growth rates of more than 7 percent, the average growth rate for the region was 3.6 percent (World Bank 2021). This growth rate was not high enough to speed up economic and social progress. On a per capita basis, average growth was only about 0.7 percent per year, and the pace of job creation has not kept up with the 29 million young people entering the job market every year (AUC/OECD 2018). Now, we know that COVID-19 will worsen these adverse trends.

The measures taken to address the pandemic—lockdowns, quarantines, social distancing, travel bans and restrictions—have severely disrupted economies. It has been estimated that Africa's gross domestic product (GDP) shrank by 2.1 percent in 2020, and it is forecast to recover at a moderate average pace of 3.4 percent in 2021 (AfDB 2021). Growth is expected to recover further to 4.6 percent in 2022, underpinned by an expected rebound in commodity prices, resumption of tourism, a rollback of pandemic-induced restrictions and rollout of COVID-19 vaccinations. Among Africa's sub-regions, the hardest hit in terms of economic growth is South Africa, whose growth is estimated to have declined by 7 percent in 2020. It is followed by Central Africa (-2.7 percent), West Africa (-1.5 percent) and North Africa (-1.2 percent). East Africa, which is least dependent on natural resources, managed to achieve an estimated growth of 0.7 percent in 2020 (Anyanwu and Salami 2021).

African governments have responded with a range of measures to address the COVID-19 pandemic including fiscal (e.g., budget support for the health sector), expansionary monetary and macro-financial policies, as well support for vulnerable communities, small and medium scale enterprises and the agricultural sector. International financial institutions including the World Bank, International Monetary Fund (IMF), multilaterals and bilaterals have collectively mobilized a global response package of $230 billion to be spent between

2020 and 2021 to aid the global response (Anyanwu and Salami 2021). The African Development Bank (AfDB) has also created a $10 billion COVID-19 Rapid Response facility and launched a $3 billion 'Fight COVID-19 Social Bond.'

The pandemic struck at a time that Africa was making slow and uneven progress towards achieving the Sustainable Development Goals (SDGs). For example, 600 million people (about 50 percent of the population) currently do not have access to electricity, and 90 percent of extreme poverty is likely to be concentrated in Africa by 2030 (World Bank 2019). The COVID-19 pandemic has exacerbated Africa's developmental challenges. It is estimated that an additional 23 million people could be pushed into extreme poverty, and 20 million jobs could disappear, costing up to $500 billion in revenue (World Bank 2020). Climate change and broader environmental degradation will further compound Africa's recovery efforts. The continent is already under various forms of climate-related stress such as floods, droughts and locust invasions that have worsened food security in various areas. And the situation is likely to worsen in a business-as-usual scenario.

The purpose of this study is to analyze the macroeconomic impacts of climate change and to discuss the implications for policy. We argue that, although the outlook looks grim, the COVID-19 pandemic can be an opportunity for Africa to launch a green innovation-led recovery that would not only speed up growth, but also simultaneously address climate change and other environmental issues that threaten Africa's future. Using empirical modeling tools, we show that climate change will have a devastating impact on African economies. The increase in temperatures will fuel inflation, with negative implications for food security and poverty. We also show that the African Continental Free Trade Area (AfCFTA) has the potential to boost Africa's growth through the lowering tariffs on intra-African trade. However, under current trends, this will worsen environmental degradation, such as the loss of land cover, leading to increased carbon dioxide (CO_2) emissions that will feed into more global warming. However, by leveraging technological innovations, such as climate-smart agriculture (CSA), to increase agricultural productivity, the continent can reap a win-win dividend of boosting economic growth and mitigating the effects of climate change.

The remainder of the paper is structured as follows. The next section undertakes a brief review of the theoretical and empirical literature on the effects of climate change on macroeconomic variables with a focus on agriculture. Section 3 discusses the analytical framework employed in the study. The penultimate section presents and discusses the study's findings, while Section 5 concludes with the policy implications.

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LITERATURE REVIEW

The Impact of Climate Change on Output and Prices

Climate change affects economies through multiple supply and demand channels. Bolton et al. (2020) have argued that unlike other supply-side shocks, climate change shocks are expected to be persistent, with frequently irreversible effects. It is expected that climate change will impact labor supply, capital accumulation and productivity. For example, higher temperatures are expected to increase mortality and morbidity, thereby reducing the skill

base. In places such as Africa that are already warm, climate change will reduce labor productivity (Fankhauser and Tol 2005). Human capital is expected to be adversely affected by climate-induced responses such as mass migration, crime and social unrest (Dell, Jones, and Olken 2014). The Intergovernmental Panel on Climate Change (IPCC) has projected that across the African continent, all regions will very likely experience warming greater than 3°C by the end of this century, except Central Africa where warming is very likely to be under 2.5°C. This will result in a substantial increase in heatwave magnitude and frequency across the continent, leading to increase in mortality, heat stress and deadly temperatures (IPCC 2021). Research suggests that this is likely to damage capital and land and increase the depreciation rate of capital with long-term impacts on income and output (Fankhauser and Tol 2005; Stern 2013). Kahn et al. (2019) estimate that by 2100, a 0.04°C increase in temperatures will likely result in a 7 percent reduction in GDP per capita. Climate-related natural disasters will also disrupt transportation and distribution networks and adversely affect productivity and global trade.

Climate change will affect all sectors of the economy; however, agriculture, water supply, energy resources (particularly those dependent on hydro resources), transport and infrastructure will be particularly vulnerable. African agriculture is the most vulnerable because it is mainly rain-fed. We review the impacts on agriculture in more detail below. The higher temperatures, coupled with reduced and/or variable rainfall, will lead to reduced agricultural output, which will be transmitted to prices and inflation. This can happen in a number of ways. First, the negative impact on agricultural productivity will contribute to food shortages, causing food prices to rise when there is an excess of demand over supply.

Second, climate shocks could translate into higher prices through trade. For example, it has been shown that the reduction in productivity due to higher temperatures (e.g., see Deryugina and Hsiang 2014) can result in a reduction in the quantity of goods exported, particularly by poor countries (e.g., see Gassebner et al. 2010; and Jones and Olken 2010) which could potentially affect market prices. Temperature shocks can also lead to higher prices when there is an increased demand for energy. Nelson et al. (2010) estimate that inflation-adjusted prices of the world's three most important staple grains (maize, rice and wheat) will increase by 31 to 106 percent by 2050 due to climate change. On the issue of energy, as temperatures rise, there will potentially be an increased demand for energy. Temperature shocks can also affect energy supply by reducing the productive efficiency of the infrastructure used to produce the energy. Therefore, given an increase in demand and a reduced supply of energy, there would be a rise in prices and increase in inflation. Climate change will also adversely affect livestock (Rojas-Downing et al. 2017) and fish stocks (FAO 2018a), which can again drive up prices.

The Impact of Climate Change on African Agriculture

A number of studies predict negative impacts of climate change on Africa's economy and, in particular, agriculture. Using the dynamic Global Trade Analysis Project (GTAP) model, Asafu-Adjaye (2014) estimates that climate change will negatively impact all economies across Africa. Southern Africa will be the hardest hit, with the decline in agricultural productivity reducing growth by 6 percentage points per year by 2050, followed by North Africa (-1.4

percentage points) and East Africa (-0.6 percentage points). Fischer et al. (2005)—using the Food and Agriculture Organization (FAO)/International Institute for Applied Systems Analysis (IIASA) Agro-Ecological Zones model and climate variables from five different global climate models (GCMs) under four emissions scenarios—have projected that by the 2080s, climate change will cause a significant reduction in suitable rain-fed land, thereby reducing the production potential for cereals. The study shows that wheat production is likely to disappear from Africa by the 2080s. Local level assessments also indicate substantial crop losses for various countries. Stige et al. (2006) have projected significant reductions in maize production in southern Africa under possible increased El Niño-Southern Oscillation (ENSO) conditions, assuming no adaption. In Egypt, climate change could decrease national production of many crops (ranging from –11 percent for rice to –28 percent for soybeans) by 2050, compared with their production under current climate conditions (Abou-Hadid 2006). Schlenker and Lobell (2010) have estimated that by 2050, maize, sorghum and millet production on the continent could decline by 22 percent, 17 percent and 17 percent, respectively. More recent work indicates that even at low (+2°C) levels of warming, agricultural productivity is likely to decline across the globe but particularly across tropical areas (Challinor et al. 2014). Thornton et al. (2011) estimates that, with 4°C of warming, crop seasons in most of Sub-Saharan Africa could shrink by 20 percent or more. In the cocoa and coffee growing areas in the tropics, temperature shifts are likely to change the distribution and reduce the productivity of the crops (Schroth et al. 2016).

Livestock is an important component of African agriculture, and approximately 80 percent of the potential cropland is also used for grazing. The impact of climate change on livestock farming in Africa has been examined by Seo and Mendelsohn (2007). They considered various scenarios including a uniform increase in temperature of 2.5 and 5.0 and a uniform change in rainfall of 215 percent and +15 percent across all of Africa. Their model predicts a 32 percent loss in expected net revenue with a 2.5 warming, and a 70 percent loss with a 5C warming. Rainfall effects were found to be relatively smaller. For example, a 15 percent increase in rainfall leads to a loss of 1 percent in expected net revenue per household from livestock and a 15 percent decrease in rainfall leads to a gain of 2 percent. In more recent work, Rojas-Downing et al. (2017) conclude that livestock production will be limited by climate change because animal water consumption is expected to increase by a factor of three, while demand for crop land, which accounts for a significant share of livestock feed, will increase due to increased food demand.

Cline (2007) conducted one of the most comprehensive analyses of the impacts of climate change on global agriculture through the 2080s. Using a Ricardian model, he predicts declines in agricultural output for all the African countries in the sample. The losses are reduced to some extent in countries with a significant share of cropland under irrigation. The weighted average crop losses for a Business-As-Usual (BAU) scenario without carbon fertilization range from 84 percent (Senegal) to 2.5 percent (Uganda), with a mean decline of 27.8 percent for the sample. Countries such as Sudan, Senegal, Niger and Mali, which have low proportions of irrigated land are projected to suffer declines of 100 percent, while losses of 50 percent or more are reported for countries such as South Africa and Zambia. Cline also used crop model forecasts, which showed similar trends as the Ricardian model forecasts. He estimates that BAU climate change by the 2080s will reduce agricultural production by about 28 percent on average without carbon fertilization. With carbon fertilization, the crop losses are lower, with productivity declining by 18 percent on average.

More recent work by Hertel et al. (2010) confirms the devastating effect of climate change on African agriculture. Based on a synthesis of the literature on regional crop yield responses to climate changes, they estimate the productivity decline in the production of selected food crops to range from 10 to 22 percent for a number of African countries under various scenarios. Climate change is estimated to impact more severely on South Africa where decline in the production of coarse grains is projected to decline from 25 to 42 percent (Hertel et al. 2010).

The Contributions of This Paper

Although the economic impact of climate change has been widely studied and reported, the literature on the impact on individual Africa countries is sparse. In general, African countries tend to be presented in such studies as an aggregate¾Sub-Saharan Africa. In a recent paper, Mukherjee and Ouattara (2021) analyzed the effect of temperature shocks on inflationary pressures using a global sample, including a few African countries. They found that temperature shocks tend to be inflationary and that, for developing countries, these tend to persist after several years. Asafu-Adjaye (2014) was one of the few papers to focus on the macroeconomic impacts of climate change on various sub-regions of Africa. The current paper makes two key contributions. First, we investigate the effects of temperature shocks on output and inflation for a large number of African countries using a panel vector-auto-regression model. Second, we employ a computable general equilibrium model to examine the macroeconomic and sectoral impacts of climate-induced decline in agricultural productivity on African countries. We address the policy implications of both analyses.

ANALYTICAL FRAMEWORK

The study employed two modelling strategies—a partial equilibrium (econometric) analysis to investigate the response of real output and inflation to temperature shocks and a computable general equilibrium (CGE) model to address the economywide impacts of climate change. Both approaches are briefly discussed below.

Panel Vector-auto-regression Model and Data

MODEL SPECIFICATION In order analyze the impact of temperature shocks on output and inflation, we use the following reduced-form panel vector-auto-regression (VAR) model.

$$y_{i,t} = \emptyset_0 + B(L)y_{i,t-j} + \eta_i + \zeta_t + \varepsilon_{i,t} \quad (1)$$

where $y_{i,t}$ is a k−dimensional vector representing a vector of endogenous variables, $B(L)$ is the lag polynomial, $\emptyset_0$ is a vector of constant, η_i captures country-specific fixed-effects, ζ_t are time specific trends, and $\varepsilon_{i,t}$ is a k−dimensional vector of reduced-form disturbances with $E[\varepsilon_{i,t}] = 0$. We also assume that $E[\varepsilon_{i,t}, \varepsilon'_{i,s}] = 0$ and $E[\varepsilon_{i,t}, \varepsilon'_{i,s}] = \sum\varepsilon$. Finally, i and t represent, respectively, country and time subscripts.

Given that that the reduced-form disturbances will be generally correlated, we need to transform Equation (1) into a structural model. We do this by pre-multiplying Equation (1) by a (k × k) matrix B_0 as follows:

$$B_0 y_{i,t} = B_0 B(L) y_{i,t-j} + B_0 \eta_i + B_0 \zeta_t + A_0 \mu_{i,t} \tag{2}$$

where $A_0\mu_{i,t} = B_0\varepsilon_{i,t}$ describes the relationship between the structural disturbance $\mu_{i,t}$ and the reduced-form disturbances $\varepsilon_{i,t}$. The structural disturbances are assumed to be uncorrelated with each other, thus implying that the variance-covariance matrix of the structural disturbances $\sum\mu$ is diagonal. The contemporaneous relation among the variables in the vector of endogenous variables is captured by matrix B_0.

Following Christiano et al. (2005) and Mallick and Sousa (2013), we specify a 6-variable VAR model (in logs) comprising temperature (LTemp), real GDP (LrealGDP), government spending represented by real gross national government expenditure (LGNE), money supply (LM2), consumer price index (LCPI) and terms of trade (LToT). All the variables are assumed to be endogenous. We assume that temperature is not contemporaneously affected by all the other variables in the model but responds to shocks to these variables with a lag effect. Recent studies such as Stern (2016), Kahn et al. (2019), Schultz and Mankin (2019), Castle and Hendry (2020) and Petris (2021) have shown that climate-related variables such as temperature may not be strictly exogenous as previously assumed. Thus, modeling temperature shocks as endogenous, as we have done here, would be reasonable.

DATA We use annual data for a panel of 48 African countries over the period 1990 to 2020. The variables on inflation (CPI), real GDP, government spending (GNE) and money supply (M2) were taken from the World Bank's World Development Indicators Database (World Bank 2021). For the temperature variable, we obtained data from the Climate database of the Food and Agricultural Organization (FAO 2018b).

UNIT ROOT AND LAG SELECTION Due to missing values, we conducted the unit root tests using only the Fisher-type and Im-Pesaran-Shin (IPS) tests. The results show that real GDP, GNE and M2 were not stationary in levels but at difference (see Table A1). Next, we selected the lag structure of the VAR. Following past practice for annual data, we set the maximum lag to 2. The results indicate that the optimal lag order to consider in this estimation is 1 (see Table A2).

ESTIMATION OF THE PANEL VAR MODEL We estimated the panel VAR model using two methods—first difference transformation (*fd*) and the Helmert transformation (*fod*). Both *fod* and *fd* specify how the panel-specific fixed effects will be removed. *fod* specifies that the panel-specific fixed effects be removed using forward orthogonal deviation or Helmert transformation. By default, the first lags of the transformed dependent variable list in the model are instrumented by the same lags in levels (that is, untransformed). *fod* is the default option, while *fd* specifies that the panel-specific fixed effects be removed using first difference instead of forward orthogonal deviations.

The GTAP-AEZ Model

To analyze the impact of climate change on African economies, we use a well-documented global trade model—the GTAP CGE model (Hertel et al., 1997) and its accompanying database. The GTAP model is a widely used, comparative static CGE model, which comprehensively tracks bilateral trade flows between all countries/regions in the world, and explicitly models the consumption and production for all commodities of each national economy. Producers are assumed to maximize profits, while consumers maximize utility. Factor market clearing requires that supply equal demand for agricultural and non-agricultural skilled and unskilled labor and capital, natural resources and agricultural land, and adjustments in each of these markets in response to the climate change shocks determines the resulting wage and rental rate impacts. Firms sell their output to the other firms (as intermediate inputs), to private households, government and to the global market. They export tradable commodities and import intermediate inputs from the other regions. Following the Armington assumption (Armington 1969), goods are differentiated by their country of origin. In this study, we use the standard GTAP model closure.[2] In this closure prices, wages, quantities of all non-endowment commodities and regional incomes are set endogenous. Conversely, population, technical change variables, labor supply, policy variables and all endowments are set exogenous.

The version of the GTAP model we use in this study is the GTAP–agro-ecological zone (AEZ) model, which facilitates more comprehensive analyses of the trade-offs due to climate change, alternative land use and land-based mitigation strategies in an economy-wide framework (e.g., see Hertel et al. 2009). It also considers land rent effects and the impacts on land use via factor market effects. The land-use database disaggregates land endowment and the three land-use activities (cropland, grazing land and forest) into 18 global AEZs based on six different lengths of growing periods (6 x 60-day intervals), and three climatic zones (tropical, temperate and boreal) (Monfreda et al. 2009). Given the large number of AEZs, the model is simplified by having a single national production function with multiple AEZ inputs.

Land mobility within each AEZ is modeled through a nested constant elasticity of transformation (CET) frontier, with a two-tier structure that determines optimal behaviour. That is, first, the rent-maximizing landowner decides the allocation of land among the three land-use activities based on the relative returns to land, and secondly, she/he decides the allocation of cropland between different crops according to the relative returns in the crop sectors. Following Ahmed et al. (2008), we use the CET parameter among three land-use activities (Ω_1) of -0.5 to reflect the flexibility of land conversion over the 25-year time horizon considered in this study. Also, the parameter value for the elasticity of transformation of cropland among different crops (Ω_2) is set to one, reflecting the higher flexibility of this conversion than Ω_1. Based on the historical patterns of bilateral trade, and the specified Armington assumption, the model determines the countries in which agricultural area expansion or contraction takes place.

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[2] The model closure determines which variables are exogenous and which variables are endogenous.

For this analysis, we used the land-use augmented version of the latest GTAP 10 database. We combined the original 141 GTAP regions into 21 regions including 14 African countries, China, India, North America, Latin America, the EU 28 and the rest of the world (see Table A3 in the appendix). Additionally, the original 65 GTAP commodity sectors were aggregated into 13 sectors to facilitate the analysis (Table A3).

The experimental design involved analyzing three climate change scenarios. Scenario 1 investigates the impacts of climate on African economies with a focus on agriculture, Scenario 2 superimposes on Scenario 1, the effects of the AfCFTA, while Scenario 3 examines the two scenarios coupled with an innovation-led green recovery. Each of these are briefly explained below.

SCENARIO 1: IMPACTS OF CLIMATE CHANGE ON AGRICULTURE This scenario was implemented by imposing climate-induced negative technical change shocks on the crop sector over the period 2020 to 2050. We used productivity shocks estimated by Hertel et al. (2010) for various countries and regions in the world. Hertel et al.'s projections assume a global warming of approximately 1°C by 2030. They present two climate scenarios, the "most likely" case which they refer to as the "medium crop productivity" scenario and an "extreme case" referred to as the "low crop productivity" scenario. The IPCC Sixth Assessment Report (AR6) predicts that across the African continent, all regions will likely experience warming greater than 3°C by the end of this century (IPCC 2021). Based on this prediction, we modified Hertel et al.'s (2010) extreme case (lower crop productivity) estimates for the African countries. The technical change shocks used can be found in Table A4.

SCENARIO 2: IMPACTS OF CLIMATE AND THE AFCFTA Trading under the AfCFTA began on January 1, 2021 for trade in goods. Under Phase 1 of the Agreement, tariffs on 97 percent of tariff lines are to be eliminated. Non-Least Developed Countries will liberalize tariffs of non-sensitive goods over 5 years and Least Developed Countries (LDCs) over 10 years. Seven percent of tariff lines can be sensitive goods. Non-LDCs remove tariffs on such goods over 10 years and LDCs over 13 years. Three percent of tariff lines are exempted from liberalization. To implement this scenario, we removed tariffs on 97 percent of goods traded among the African countries.

SCENARIO 3: IMPACTS OF CLIMATE, AFCFTA AND AN INNOVATION-LED GREEN RECOVERY This scenario incorporates scenarios 1 and 2, and in addition, we assume that African countries implement innovation-led green recovery plans. For modeling purposes, we focus on two key areas relating to climate change adaptation and mitigation in Africa—agriculture and energy. In agriculture, we assume that African countries invest in and promote climate-smart agricultural technologies. These include implementing agricultural intensification practices, distributing temperature-tolerant and drought-resistant seed and crop varieties, using chemical and organic fertilizers and applying environmentally friendly pest and weed control measures. Based on Dissanayake et al. (2017), we estimate that applying these measures could close Africa's crop yield gap by at least 50 percent and increase total factor productivity (TFP) by at least 30 percent in Sub-Saharan Africa's crop sector. We further assume that applying additional climate-smart measures such as solar irrigation systems, investing in satellite imagery to improve weather forecasting and investing in agricultural research and development (R&D) could raise TFP by a further 10 percent. The final TFP shocks applied are net of the shocks in Scenario 1.

RESULTS AND DISCUSSION

This section first reports the results for the effects of temperature shocks on inflation and real output using the panel VAR model. This is then followed by the wider macroeconomic impacts using the CGE model.

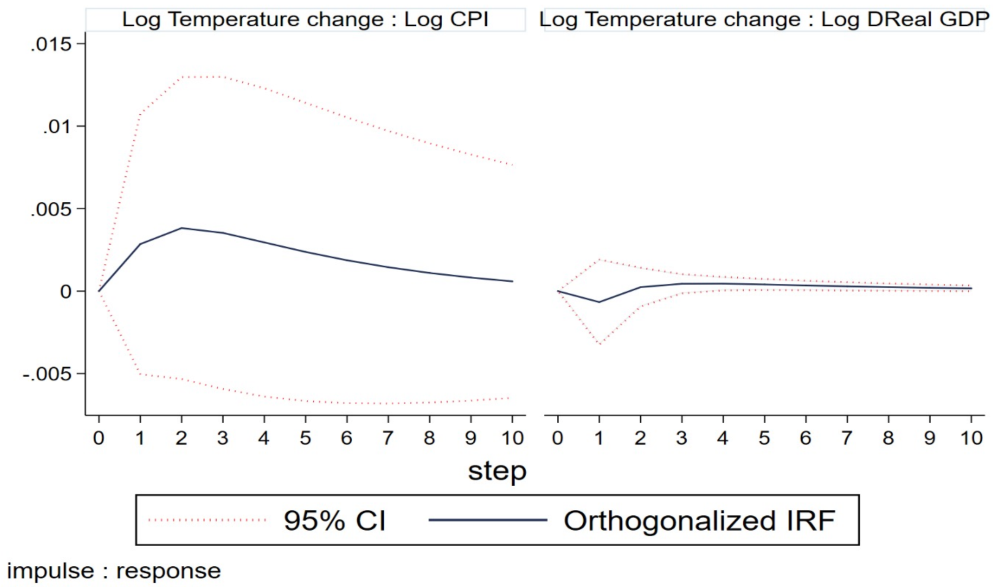
Dynamic Response of Inflation and Real Output to Temperature Shocks

We present the mean response of inflation and real output to temperature shocks over a 10-year time horizon. Figure 1 presents the impulse response functions (IRFs) for inflation and real output using the Helmert transformation (*fod*) and the first difference transformation (*fd*). The y-axis represents the mean responses, while the red dotted lines represent the 95 percent confidence interval bands. It can be seen from the IRFs that the mean response of inflation to a temperature shock (Panel A, left-hand chart) is positive over the first two years. Although the effect diminishes thereafter, they remain statistically significant up to 10 years after the initial impact (see Table A5). For real output (Panel A, right-hand chart), the IRF shows that a temperature shock reduces output over the first year. Although there is a recovery, the effect persists and remains significant up to the next 8 years. Panel B shows results using the first difference transformation (*fd*). The instantaneous impact of a temperature shock in a decline in the CPI, but the price level rises thereafter and remain significant 10 years after the initial shock. Regarding real output, the negative impact is observed in year 2 and the effects remain significant by year 10. Overall, these results show that temperature shocks result in increases in inflation and reduce real output.

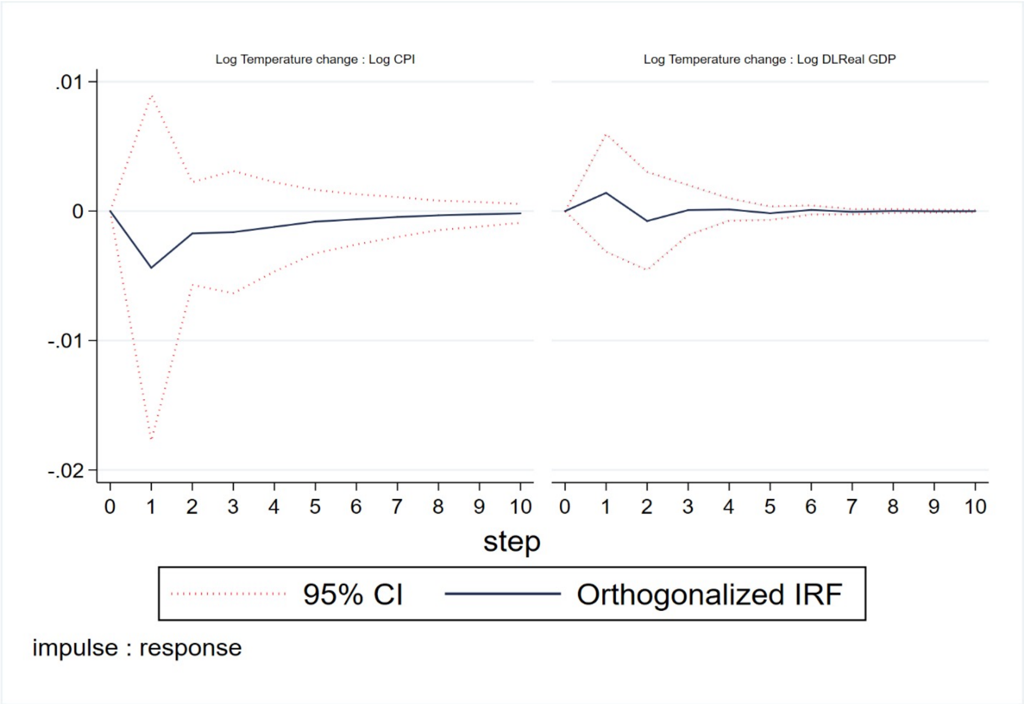
Supply shocks, such as temperature shocks from climate change, present a challenge for the conduct of monetary policy because they tend to pull prices and output in opposite directions, as shown here. This presents a trade-off between achieving price stability and output stability. In this situation, attempts to focus on pure inflation targeting could further reduce output. Our results suggest that central banks need to pay attention to temperature-induced supply shocks in order to come up with the right stabilization response. In particular, it would be prudent for central banks to consider temperature-related shocks when forecasting inflation and other macroeconomic variables.

FIGURE 1 Impulse response functions (IRFs)

Panel A: IRFs using forward orthogonal deviation (Helmert transformation, fod)



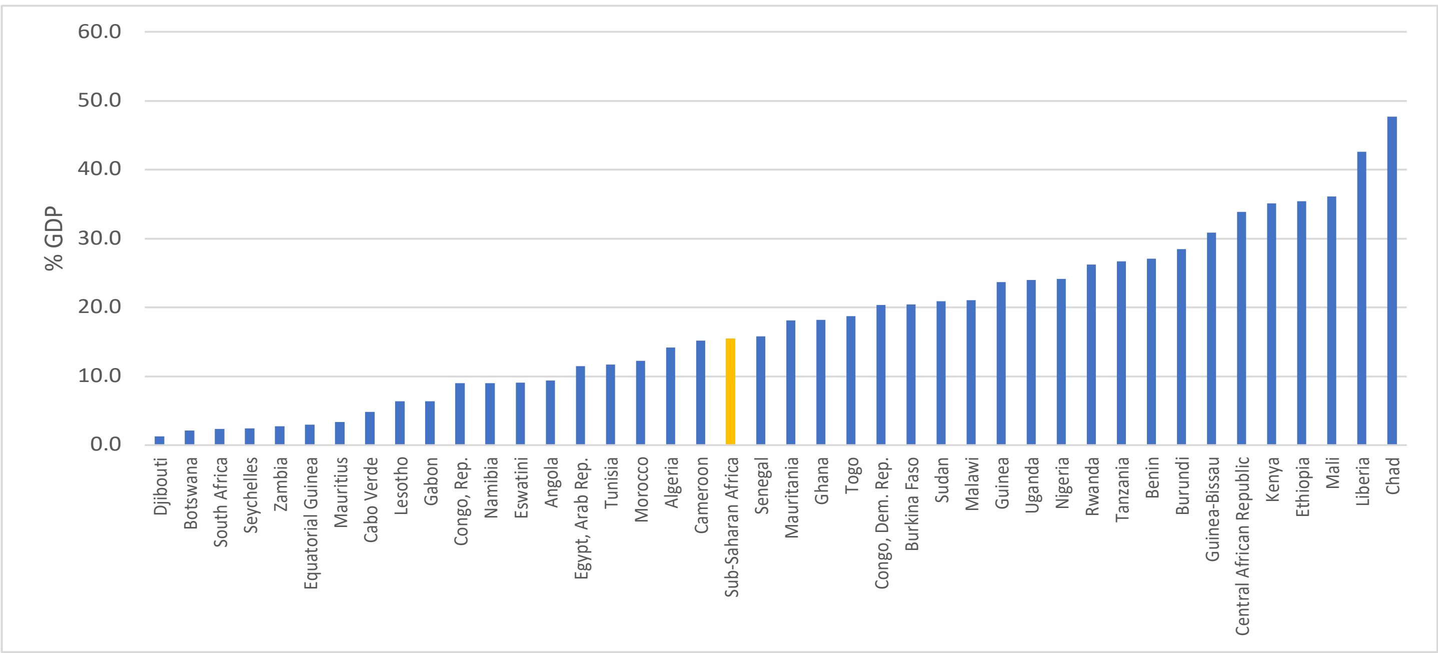
Panel B: IRFs using first difference transformation (fd)



Macroeconomic Impacts of Climate Change

Although agriculture represents only about 3 percent of global GDP, its share is much larger in African countries averaging 15 percent of GDP in 2021 (see Figure 2) but with a range of 1 percent (Djibouti) to 61 percent (Sierra Leone). In terms of employment, agriculture accounts for an average of 54 percent of the working population in Africa (ILO 2021). And in countries such as Burundi, Somalia and Malawi, more that 70 percent of the labor force works in agriculture.

FIGURE 2 Share of agriculture, forestry and fishing in value added (% GDP) in Africa, 2020

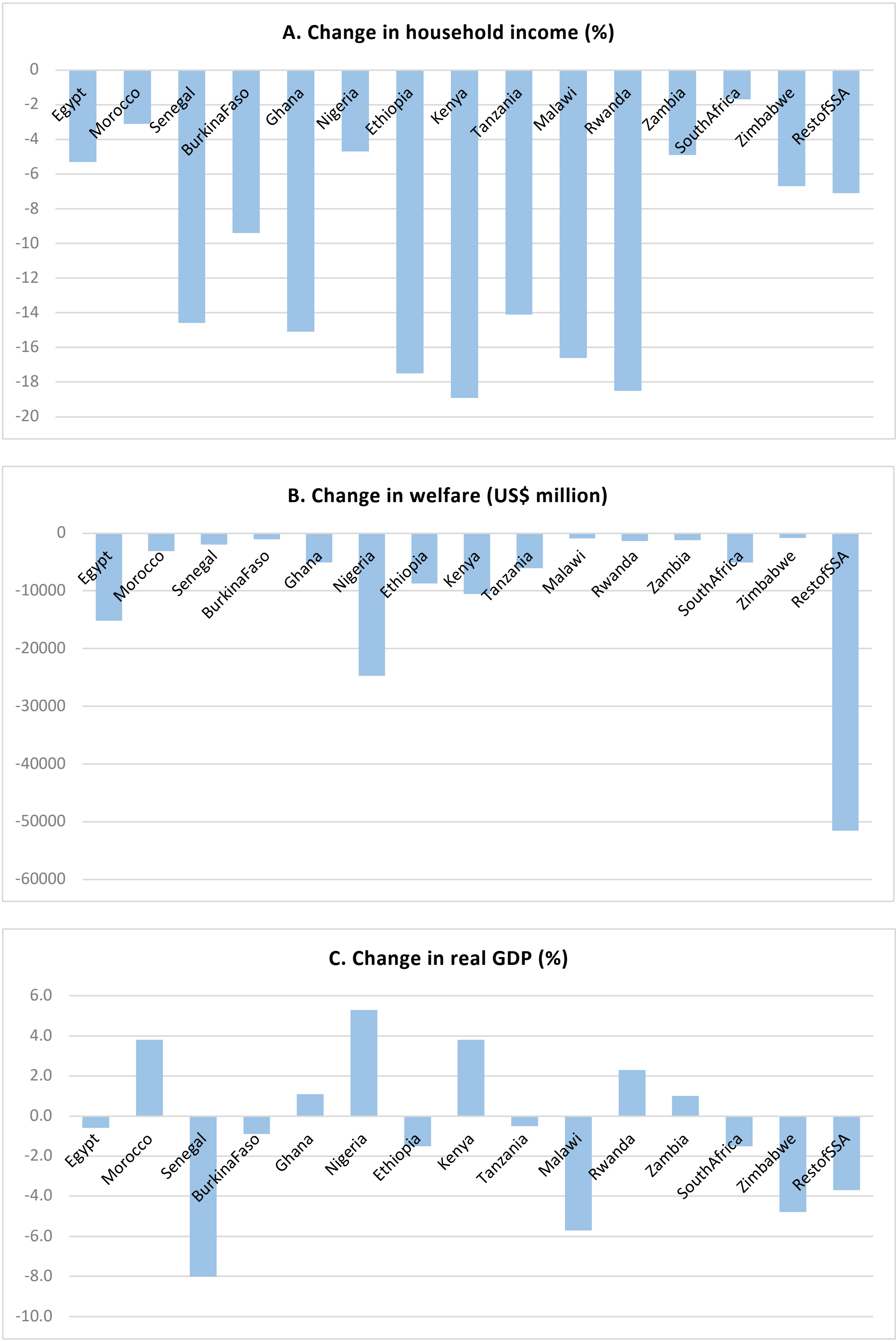


Source: World Bank (2021)

Given the important role of agriculture in the broader economic performance of Africa as well as other developing countries, the potential macroeconomic impact of climate change on agricultural production has important policy implications.

The remaining sections discuss the impacts of climate-induced productivity decline in agricultural productivity on African economies. As can be expected, because most African agriculture is rain-fed, this sector and related sectors such as food processing experience significant decline as a result of climate change. For example, the decline in the production of grains and crops ranges from –6.6 percent (Morocco) to –35.9 percent (Burkina Faso). Given that most Africans rely on agriculture for their income and sustenance, the fall in output leads to a fall in household incomes across the continent (Panel A, Figure 3). Agriculture-dependent countries such as Ghana, Malawi, Ethiopia and Rwanda experience decline of 15 percent or more in household income. Consequently, there is a fall in welfare of about \$9.2 billion on average (Panel B, Figure 3) with a range \$831 million (Zimbabwe) to \$24.6

FIGURE 3 Macroeconomic impacts of climate change



Source: GTAP-AEZ model simulations

billion (Nigeria).[3] The fall in agricultural output results in the majority of African countries becoming net food importers. Because food generally has inelastic demand, the decline in agricultural output leads to increases in the prices of food commodities, some of which increase by more than 50 percent (Table A6). The increase in food prices puts upward pressure on inflation (as confirmed by rises in the GDP deflator) and increases food insecurity. This, coupled with the decline in household income, will increase the incidence of poverty particularly amongst the vulnerable and low-income groups.

The decline in agricultural productivity as a result of climate change reduces the net returns in this sector and therefore, resources such as capital and labor are re-directed into sectors with higher rates of return such as extraction and manufacturing. Real GDP declines by 0.7 percent (Panel C, Figure 3) on average. As can be expected, the falls are higher for agriculture-dependent countries. Resource-rich countries (e.g., Nigeria and Zambia) and more diversified economies such as Morocco and Kenya show increases in GDP.

The climate-induced decline in agricultural productivity leads to additional land being brought into production. Our simulation results show that the area under crops increases across the continent with increases ranging from 1 to 8 percent (Table 1). As a result, there is a significant loss in forest cover, especially for the agriculture-dependent countries. These results are consistent with earlier studies that found that, between 2000 and 2010, agricultural expansion in Africa accounted for approximately 70 percent of forest loss in the region (African Progress Panel 2015).

TABLE 1 Changes in land cover from climate change (%)

Country	Forest	Cropland
Egypt	-3.1	0.1
Senegal	-6.7	4.2
Burkina Faso	-13.5	7.8
Ghana	-1.7	2.4
Nigeria	-18.8	2.6
Ethiopia	-21.4	5.1
Kenya	-11.1	2.2
Tanzania	-5.4	7.9
Malawi	-4.0	3.8
Rwanda	-33.1	5.2
Zambia	-6.5	7.5
South Africa	-9.8	2.5
Zimbabwe	-11.1	0.8
Rest of SSA	-1.9	5.6

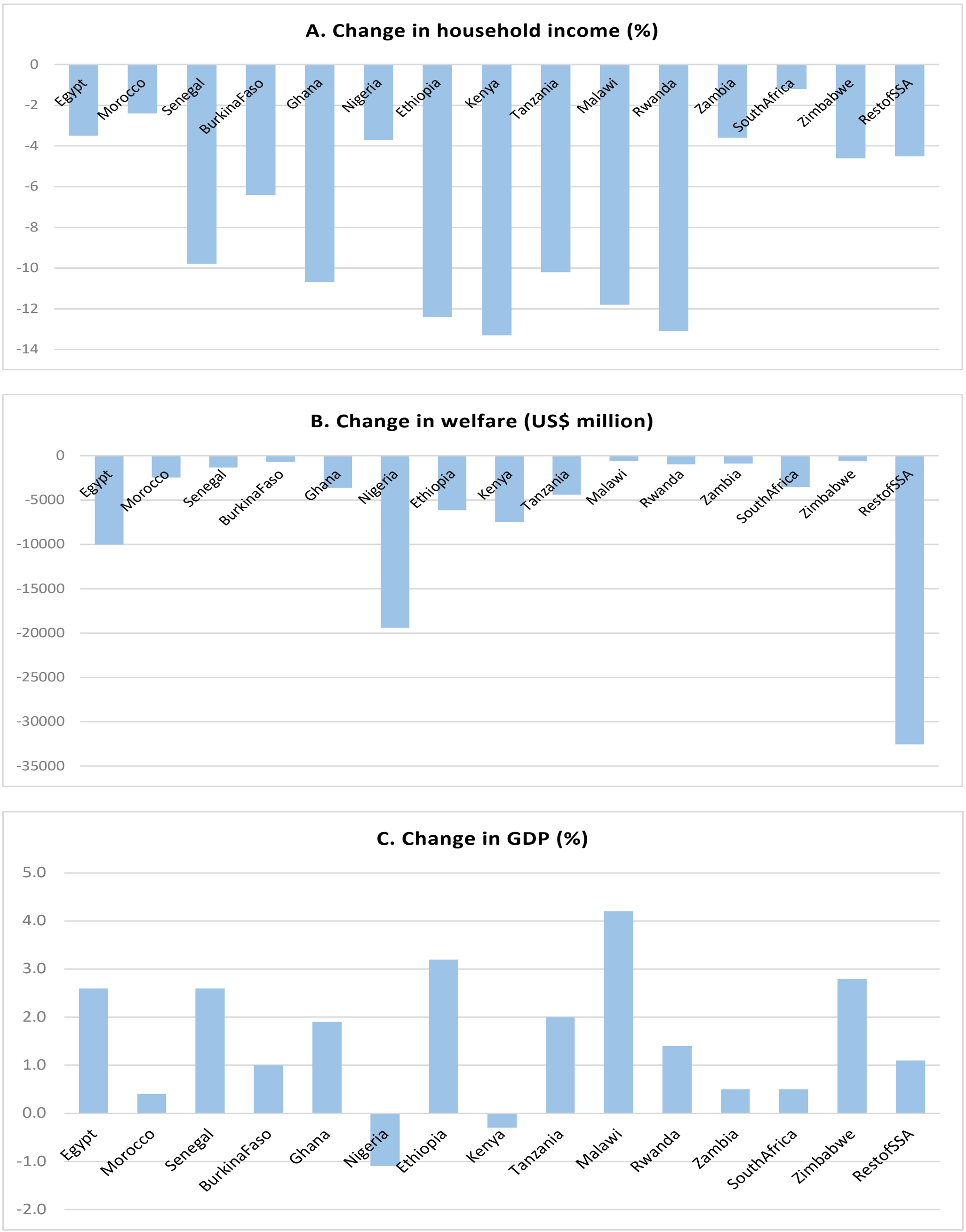
Source: GTAP-AEZ simulations

[3] In the GTAP model, welfare changes are measured by equivalent variation (EV). EV is a money metric measure that compares the cost of pre- and post-shock levels of consumer utility, both valued at base year prices.

Impacts of Climate Change and the AfCFTA

Implementation of the AfCFTA to some extent mitigates the adverse impacts of climate change. While the overall effects on household incomes are still negative, average real GDP growth is now -7.4 percent compared to -10.5 percent before the AfCFTA. This implies that intra-African trade reduces the loss of household incomes by about 3 percentage points (Panel A, Figure 4). The household income decline now ranges from -1.2 percent (South

FIGURE 4 Impact of Climate Change and the AfCFTA



Source: GTAP-AEZ Model Simulations

Africa) to -13 percent (Rwanda). As a result of this, the welfare losses are also less than in the previous scenario as shown in Panel B of Figure 4. For example, welfare losses across the continent now range from $566 million (Zimbabwe) to $19.4 billion (Nigeria), with an average of $6.4 billion compared to an average of $9.2 billion in the previous scenario.

The effects of increased intra-African trade on real GDP in the presence of climate change are mixed (Panel C, Figure 4). In general, diversified economies, such as South Africa and Morocco, and resource-rich countries, such as Nigeria, show better growth outcomes. On the other hand, agriculture-dependent countries do not show any marked growth improvements as a result of increased trade. This suggests that the lifting of trade barriers in and of itself will not necessarily lead to increased growth gains for African countries without accompanying improvements in agricultural productivity to address the adverse effects of climate change.

Our simulation results indicate that free trade has a deleterious environmental impact in terms of loss of forest cover (Table 2). In this scenario, forest cover declines on average by 17.2 percent, while cropland increased by 5.1 percent. This compares with an average of forest cover loss of 10.1 percent and increase in cropland of 4.1 percent in the previous scenario. Countries such as Rwanda and Malawi experience forest cover loss of 74.4 percent and 27.6 percent, respectively, as a result of large increases in the area under crops.

TABLE 2 Changes in land cover from the AfCFTA (%)

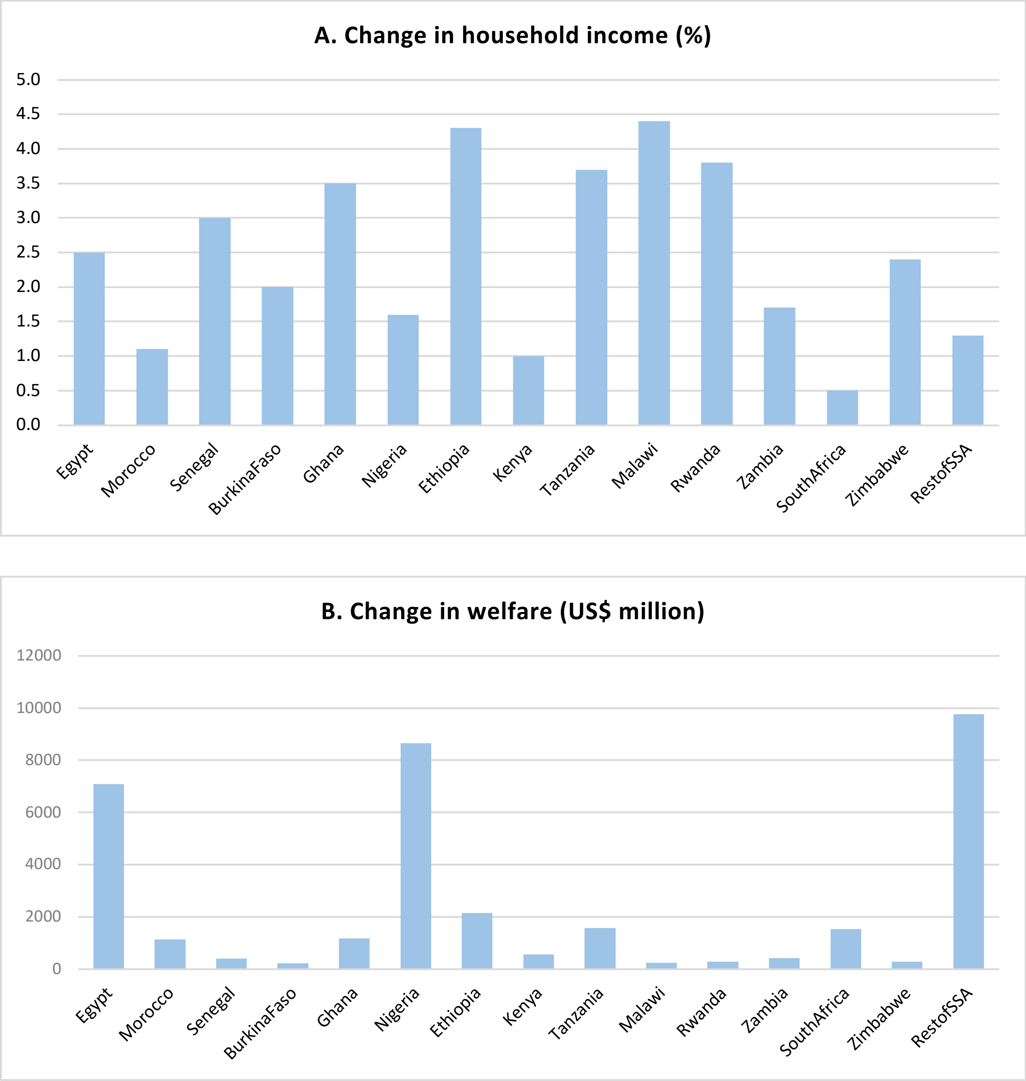
Country	Forest	Cropland
Egypt	-4.7	0.3
Morocco	-5.1	5.3
Senegal	-8.7	4.7
Burkina Faso	-10.7	4.4
Ghana	-2.8	2.8
Nigeria	-11.7	0.5
Ethiopia	-24	6.5
Kenya	-17.9	5.3
Tanzania	-8.1	9.9
Malawi	-27.6	8.0
Rwanda	-74.4	8.1
Zambia	-7.8	9.9
South Africa	-9.6	2.8
Zimbabwe	-12	1.3
Rest of SSA	-2.4	6.4

Source: GTAP-AEZ simulations

Impacts of an Innovation-Led Green Recovery

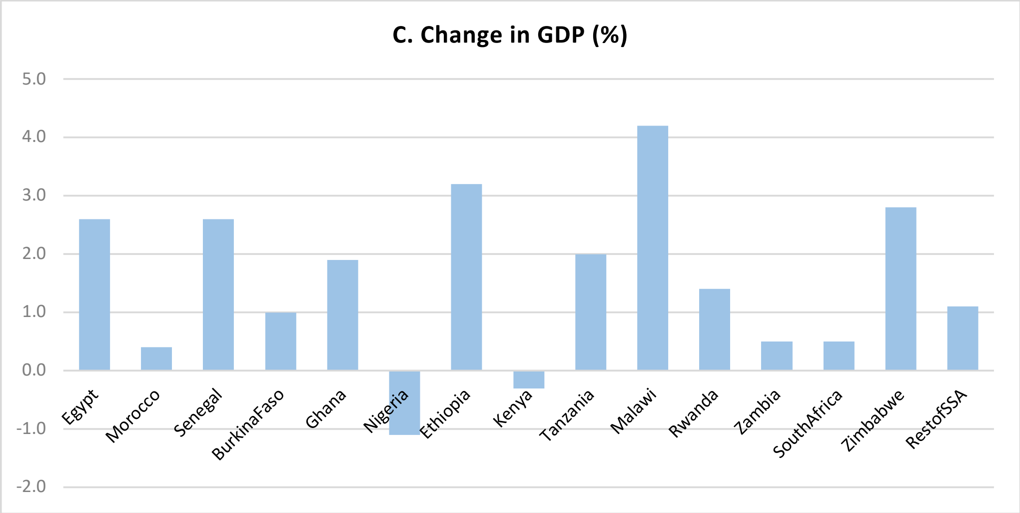
The results in this scenario show that technological innovations such as climate-smart agriculture that improve agricultural productivity and improvements in infrastructure have the potential to enhance the benefits of intra-African trade and at the same time mitigate the negative effects of climate change. The productivity improvement reverses the decline in output we saw in the previous scenarios. Increased agricultural output puts downward pressure on domestic prices, which decline faster than the price of imports (Table A7). Consequently, we observe improvements in household incomes which increase across the continent, with an average rise of 2.5 percent (Panel A, Figure 5).

FIGURE 5 Impacts of an innovation-led green recovery



Source: GTAP-AEZ model simulations

FIGURE 5 *Continued*



Source: GTAP-AEZ model simulations

As can be expected, the income increases are much larger for the agriculture-dependent countries. In turn, the increase in household income leads to improvements in welfare across the board, ranging from $223 million (Burkina Faso) to $8.6 billion (Nigeria). There are also increases in GDP for most African countries, with the largest gains being observed for agriculture-dependent countries such as Senegal, Ghana, Ethiopia, Malawi and Zimbabwe (Panel C, Figure 5).

The productivity improvements also lead to less land being brought under cultivation. Thus, we observe an increase in forest cover, which increases by 4.3 percent on average (see Table 3) with a range of 1.2 percent (Egypt) to 23.6 percent (Rwanda)

TABLE 3 Changes in land cover from innovation-led recovery (%)

Country	Forest	Cropland
Egypt	1.2	-0.1
Morocco	3.1	-0.2
Senegal	3.4	0.1
Burkina Faso	2.3	1.9
Ghana	-0.2	0.5
Nigeria	4.9	-0.5
Ethiopia	4.2	-0.6
Kenya	4.7	-0.2
Tanzania	2.1	-0.8
Malawi	5.9	-1.5

Country	Forest	Cropland
Rwanda	23.6	-1.4
Zambia	3.1	-2.3
South Africa	1.2	1.4
Zimbabwe	4.5	-0.2
Rest of SSA	0.4	0.6

Source: GTAP-AEZ simulations

CONCLUSION AND POLICY IMPLICATIONS

This paper provides empirical support for the widely accepted view that climate change will have a devastating impact on Africa's economy, resulting in large welfare losses. Given that the majority of Africans depend on the agricultural sector for their livelihoods, a climate-induced decline in agricultural productivity leads to significant decline in household income and therefore, a massive fall in welfare. With the decline in agricultural output, food demand outstrips supply and puts upward pressure on prices and, hence, inflation. Most African countries become net importers of food commodities. While we do not measure poverty and food insecurity in this study, we infer from the results that both will be exacerbated by climate change particularly for the vulnerable and low-income groups for whom food forms a large part of their budget. Our study also shows that a climate-induced decline in agricultural productivity could result in more crop land being brought under production to satisfy food demand. This will accelerate the loss in landcover as more forest land is converted into crop land, resulting in increased CO_2 emissions, which will feed into more climate variability.

The AfCFTA, effective as of January 1, 2021, provides an opportunity for African countries to kickstart their economic recovery given the devastating impacts of COVID-19. Our modeling results, however, indicate that the expected growth and welfare effects may not materialize. Given the effects of climate change and in a BAU scenario, increased intra-African trade could produce limited economic and welfare gains. Furthermore, free trade across Africa could worsen environmental impacts as more crop land is brought into production with an accompanying increase in forest cover loss. Our results, however, show that the adverse impacts could be reversed by African countries investing in technological innovations such as climate-smart agriculture to increase agricultural productivity. In this regard, the AfCFTA could be a tool to stage a green innovation-led economic recovery.

Climate-smart agriculture (CSA) leverages digital technological innovations and improved farming practices to increase productivity and profitability on farms. Examples include the use of new crop varieties that tolerate heat and soil salinity and resist floods and drought. Other examples include conservation agriculture, crop diversification and integrated pest management to improve soil and water quality. By making more effective use of land and agricultural inputs, CSA helps to reduce the amount of additional land needed for production, thereby helping to conserve land cover and reduce CO_2 emissions. African farmers face numerous challenges in adopting CSA. Key among them are access to information about CSA practices, access to credit and access to insurance services. CSA is a knowledge-intensive practice, but public extension systems in Sub-Saharan Africa have too few resources to serve highly scattered and heterogeneous smallholder farmers who have little formal education. To promote the diffusion of CSA, African governments should strengthen national agricultural research and extension systems to provide information to localized CSA practices to farmers. In their 2014 Malabo Declaration, African leaders reaffirmed their commitment to earmark at least 10 percent of their annual budgets to agriculture. To date, only a handful of countries have kept that promise, resulting in weak national agricultural research systems.

African governments should also build the requisite infrastructure and ecosystems to support adoption of digital agricultural technology. There is a need to address both the supply-side and demand-side barriers to digital technology access. Measures to ease supply-side barriers include improving low rural network coverage and increasing farmers' access to digital applications. The demand-side measures include improving farmers' skills and knowledge. Governments should also take measures to end the gender disparity in agriculture. In both female- and male-headed households, women constitute a major portion of the African farming community. Yet, studies indicate that female-managed plots are less likely than male-managed plots to adopt improved agricultural practices, mainly because female farmers have limited access to resources, technology and institutions.

Our finding that climate change is inflationary and reduces real output has important implications for central banks. It suggests that central banks should pay attention to climate-induced supply shocks to come up with the appropriate policy response. In particular, there would be a need to consider temperature-related shocks when forecasting inflation and other macroeconomic variables. Finally, considering these findings, central banks should consider approaches such as green climate financing and green quantitative easing to help address the impacts of climate change.

To conclude, we briefly discuss the study's limitations and possible future work in this area. The econometric analysis used temperature as a proxy for the effects of climate change on inflation and real output. Further work could also consider the impacts of precipitation. The general equilibrium analysis was based on the GTAP model, which currently is only capable of analyzing impacts on the real side of the economy. This implies that the model cannot say anything about how climate change will affect financial sector stability. There are prospects for developing future models that incorporate the financial sector to assist the work of central banks, the private sector and the public sector, particularly Ministries of Finance and Economic Planning.

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APPENDIX TABLES

TABLE A1 Panel unit root tests

Variables	Unit root tests at level			Unit root tests at Difference		
	Fisher-type		Im-Pesaran-Shin	Fisher-type		Im-Pesaran-Shin
	ADF	PP	IPS	ADF	PP	IPS
	Chi-squared ***(P)***	*Chi-squared* ***(P)***	W-t-bar	*Chi-squared* ***(P)***	*Chi-squared* ***(P)***	W-t-bar
LRealGDP	106.61	117.73	2.42	404.16*	894.36*	-8.92*
LGNE	78.74	97.1	1.26	422.66*	868.80*	-11.59*
LM2	88.96	74.63	1.07	387.22*	777.13*	-11.28*
LCPI	196.46*	127.56**	-1.74**	419.86*	508.80*	-10.68*
LToT	*125.82***	*131.89**	-1.98**	718.08*	1169.81*	-19.59*
Ltemp	*620.98**	*1133.70**	-16.41*	1880.51*	2261.38*	-41.59*

TABLE A2 Optimal lags

Selection order criteria				No. of obs	=	859
Sample: 1990 - 2019				No. of panels	=	46
				Ave. no. of T	=	18.674
lag	CD	J	J pvalue	MBIC	MAIC	MQIC
1	1	106.625	0.005021	-379.79	-37.375	-168.472
2	1	43.1043	0.19346	-200.103	-28.8957	-94.4443
3	1	.	.	.	.	.

TABLE A3 Regional and sectoral aggregation

Region/Country	Sectors	Commodities included in sector
Egypt	Grains/Crops	Paddy rice; wheat; coarse grains; vegetables, fruits and nuts; other crops
Morocco	Meat and livestock	Bovine cattle, sheep and goats, horses, Raw milk, Wool, silk-worm cocoons.
Senegal	Ruminants	
Burkina Faso	Non-ruminants	
Ghana	Forest	
Nigeria	Extraction	Fishing, coal, oil, gas, other minerals
Ethiopia	Processed food	Bovine meat products, other meat products, dairy products, processed rice, sugar, other food products , beverages and tobacco products.
Kenya	Textiles and apparel	Textiles, wearing apparel
Tanzania	Light manufacturing	Leather products, wood products, paper products, publishing
Malawi	Heavy manufacturing	Petroleum, coal products, Mineral products nec, Ferrous metals, Metals nec, Metal products, Motor vehicles and parts, Transport equipment nec, Electronic equipment, Machinery and equipment nec, Manufactures nec.
Rwanda	Utilities & construction	Electricity; gas manufacture, distribution; water; construction,
Zambia	Transport & communications	Trade, transport nec, water transport, air transport, communication
SouthAfrica	Other services	Financial and insurance services, recreational and other services, public admin., defense, education, health, dwellings
Zimbabwe		
Rest of Sub-Saharan Africa		
China		
India		
North America		
Latin America		
EU_28		
Rest of the World		

Note: “nec” stands for not elsewhere classified.

Source: Author’s aggregation using the GTAP 10 database version

TABLE A4 Prescribed productivity shocks

Region/Country	Shock to GrainsCrops sector (%)
Egypt	-12
Morocco	-12
Senegal	-35
Burkina Faso	-35
Ghana	-35
Nigeria	-35
Ethiopia	-35
Kenya	-32
Tanzania	-32
Malawi	-32
Rwanda	-32
Zambia	-32
SouthAfrica	-42
Zimbabwe	-32
Rest of SSA	-32
China	-10
India	-10
North America	-3
Latin America	-3
EU_28	-5
RestofWorld	-17

Source: Modified from Hertel el al. (2010).

TABLE A5 Variance decompositions for the dynamic response of inflation and real output to temperature shocks (fod)

Step	Response variable	Impulsive variable	fevd	se	p5	p95
1	DLRealGDP	LTemp	0	0	0	0
2	DLRealGDP	LTemp	0.000217	0.001533	1.57E-06	0.004023
3	DLRealGDP	LTemp	0.000241	0.001657	6.51E-05	0.004102
4	DLRealGDP	LTemp	0.000333	0.00164	0.000127	0.00403
5	DLRealGDP	LTemp	0.000427	0.001625	0.000161	0.004007
6	DLRealGDP	LTemp	0.000501	0.001623	0.000182	0.004131
7	DLRealGDP	LTemp	0.000555	0.001625	0.000209	0.004311
8	DLRealGDP	LTemp	0.000592	0.001629	0.000218	0.004449
9	DLRealGDP	LTemp	0.000619	0.001632	0.000224	0.004556
10	DLRealGDP	LTemp	0.000637	0.001635	0.000229	0.004638
Step	**Response variable**	**Impulsive variable**	**fevd**	**se**	**p5**	**p95**
1	LCPI	LTemp	0	0	0	0
2	LCPI	LTemp	0.000372	0.001434	2.92E-06	0.003966
3	LCPI	LTemp	0.000689	0.002333	2.63E-05	0.006157
4	LCPI	LTemp	0.000817	0.002878	4.62E-05	0.007826
5	LCPI	LTemp	0.000846	0.003216	6.39E-05	0.008745
6	LCPI	LTemp	0.000834	0.003432	7.38E-05	0.009376
7	LCPI	LTemp	0.000805	0.003573	7.04E-05	0.009783
8	LCPI	LTemp	0.000771	0.003669	7.97E-05	0.010054
9	LCPI	LTemp	0.000739	0.003735	9.42E-05	0.010238
10	LCPI	LTemp	0.00071	0.003783	0.000101	0.010365

TABLE A6 Scenario 1: Impact of climate change on domestic prices

Commodity	Egypt	Morocco	Senegal	Burkina Faso	Ghana	Nigeria	Ethiopia	Kenya	Tanzania	Malawi	Rwanda	Zambia	South Africa	Zimba-bwe	Rest of SSA
Grains & Crops	8.2	4.3	25.6	22.5	24.1	-20.8	38.0	34.6	23.8	20.5	32.4	-1.7	21.0	6.8	22.4
Meat & Livestock	6.2	-1.3	-10.8	16.0	-6.4	20.5	-5.8	-16.2	8.8	-14.7	7.6	3.2	10.9	-4.7	-2.3
Ruminants	71.5	28.5	10.4	17.9	21.5	62.9	11.0	8.8	12.5	-7.0	22.5	16.0	20.1	21.2	21.7
Non-ruminants	64.5	18.3	2.4	29.1	49.5	52.0	7.0	22.6	9.0	25.9	5.5	40.9	16.7	1.2	18.0
Forest	3.5	22.8	-13.2	-15.8	6.8	-14.2	-31.5	0.1	10.3	24.4	-13.4	-2.5	-10.3	9.6	2.1
Extraction	-0.1	-0.1	-3.0	0.3	-0.9	-0.4	-16.1	-5.8	-0.8	-0.9	1.5	-0.4	0.1	-1.0	-0.2
Processed Food	8.1	7.5	-2.8	5.6	15.8	-1.3	-8.9	-12.8	19.6	11.0	15.5	10.6	-3.1	2.1	8.6
Textiles & Clothing	-2.9	0.3	-7.2	-3.7	2.4	2.3	-5.2	-6.9	9.8	-4.7	-8.9	5.2	-1.7	13.2	-1.7
Light Manufacturing	-2.8	-1.1	-8.1	-3.0	0.5	-0.9	-8.0	-6.2	-3.0	-12.5	-6.6	4.0	-0.5	0.8	-2.0
Heavy Manufacturing	-2.8	-0.5	-5.3	-1.2	-3.6	-1.1	-8.0	-5.6	-5.5	-13.4	-5.3	-1.3	-0.2	-5.7	-2.2
Utilities & Construction	-4.2	-0.6	-6.0	-2.6	-4.2	-2.5	-8.2	-7.6	-6.9	-14.9	-9.1	-0.9	1.9	-5.5	-3.3
Transport & Comms	-6.0	-1.3	-8.3	2.9	-5.1	0.5	-9.8	-10.2	-4.7	-20.9	-8.0	-3.0	-0.6	-6.5	-3.9
Other Services	-3.9	0.5	-10.0	-3.8	-3.9	-0.3	-5.9	-8.4	-8.7	-22.8	-7.2	-4.1	-0.7	-8.9	-5.3

Source: GTAP-AEZ model simulations

TABLE A7 Scenario 3: Impact of an innovation-led green recovery on domestic prices

Commodity	Egypt	Morocco	Senegal	Burkina Faso	Ghana	Nigeria	Ethiopia	Kenya	Tanzania	Malawi	Rwanda	Zambia	South Africa	Zimba-bwe	Rest of SSA
Grains & Crops	-13.1	-4	-7.4	-3.9	-6.3	-4.8	-8.2	-0.8	-7.9	-2.7	-8.4	-5.9	-5.2	-5.4	-7.3
Meat & Livestock	-1.8	-0.5	-0.3	-5.3	1.5	-3.3	3	0.6	-1.3	3.5	-1.7	-1.3	-4.2	2.1	-0.8
Ruminants	-22	-11.9	-9.7	-7.1	-5.7	-8.4	-7.8	-9.8	-6.6	-3.5	-10.7	-7.2	-6.9	-6.7	-8
Non-ruminants	-18	-9.9	-7.5	-9.4	-12.3	-9.3	-4.6	-8.3	-5.1	-4.6	-6.9	-12.7	-6.7	-1	-8.4
Forest	-2.1	-0.7	4.3	4.3	0.4	-1.3	9.4	-2.3	-0.3	-3.6	2.5	-0.8	1.2	-0.8	1.2
Extraction	0.2	0.1	0.8	-0.1	0.3	0.1	4.6	0.2	0.5	0.4	0	0.2	0	0.4	-0.9
Processed Food	-1.2	-1.2	0.8	-0.2	-1.2	-1.5	2.1	0.7	-2.2	0.5	-1.5	-2.8	0.1	0.2	-1
Textiles & Clothing	2	0.1	1.8	0.6	0.7	-0.7	2	0.2	-0.1	2.3	1.8	-1.1	0.3	-0.9	0.6
Light Manufacturing	1.7	0.4	2.1	0.6	1	0.4	2.1	0.1	1.7	3.7	1.7	-0.1	0.3	1.1	0.7
Heavy Manufacturing	1.6	0.3	1.3	0.4	1.1	0.5	2.3	0.1	1.7	3.3	1.5	0.4	0.2	1.9	0.6
Utilities & Construction	2.2	0.3	1.5	0.8	1.3	0.8	3.1	0.2	2	3.7	2.1	0.5	-0.3	2	0.8
Transport & Comms	3.1	0.5	2.1	0	1.5	0.4	2.6	0.3	1.8	5.3	1.8	0.6	0.3	2.4	0.9
Other Services	2.8	0.3	2.5	0.9	1.5	0.6	2.3	0.3	2.8	5.9	2.2	1	0.3	3.2	1.2

Source: GTAP-AEZ model simulations


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