Climate Change and Agricultural Trade in Sub-Saharan Africa

By

Godfrey Mahofa

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Climate Change and Agricultural Trade in Sub-Saharan Africa

By

Godfrey Mahofa
Carnegie Postdoctoral Research Fellow in Economics
University of Cape Town, South Africa

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Abstract

Climate change is a threat to the agricultural sector and food security of many countries in sub-Saharan Africa (SSA). However, changes in climate across the continent are not expected to be consistent as some countries will experience huge declines in rainfall and increases in temperature. This implies that changes in agricultural productivity due to climate change will not be uniform and this is likely to affect trade patterns on the continent. Using a combination of climate change scenarios from the Food and Agriculture Organization of the United Nations' Global Agro-Ecological Zones (FAO-GAEZ), cereals production data from the Food and Agriculture Organization of the United Nation's FAOSTAT, and trade data from the United Nation's UN Comtrade database, this study explores the impact of climate change on agricultural trade, particularly trade in major cereals, within SSA. Results show that by the 2050s, climate change will lead to a majority of countries experiencing an increase in their need to import cereals. However, some countries such as Burundi, Tanzania and Zambia could have the potential to increase their exports. This suggests that trade flows are likely to be important in strengthening the resilience of African food systems from shocks emanating from climate change. For example, countries in East Africa such as Tanzania could export maize to countries in Southern Africa that could experience maize deficits. Delivering food from surplus to deficit areas is likely to be important in the future, hence the need to improve the movement of food products across borders. Policies to be adopted may include improving trade facilitation, reducing intra-SSA tariffs, avoiding trade policy uncertainty, removing export bans, and encouraging the production of cereal crops where countries have gained a comparative advantage.

JEL codes: Q170, Q540
Key words: Climate change, comparative advantage, cereals trade

1. Introduction

The climate is changing, and it is a threat to the agricultural sector and food security of many countries in sub-Saharan Africa (SSA) (Lobell and Schlenker, 2010). By 2050, mean temperatures in SSA are expected to increase by 1.6 degrees Celsius and rainfall is expected to decrease by 10%, on average, especially in Southern Africa (IPCC, 2007). Increases in temperature and reduced rainfall levels are expected to lower agricultural productivity in many parts of the continent. This is likely to have detrimental effects on food security, poverty, nutrition outcomes, and the prevalence of infectious diseases (Serdeczny et al, 2015). However, the impacts of climate change will not be uniform, and the regions are expected to experience different patterns of climate change. For example, Southern Africa is likely to experience a decline in precipitation levels, whereas in Eastern Africa precipitation is expected to increase (Serdeczny et al, 2015). This, in turn, will have a differential impact on agricultural productivity across regions in SSA, where some regions will become more productive and others will be less productive in the future (Seo et al, 2009).

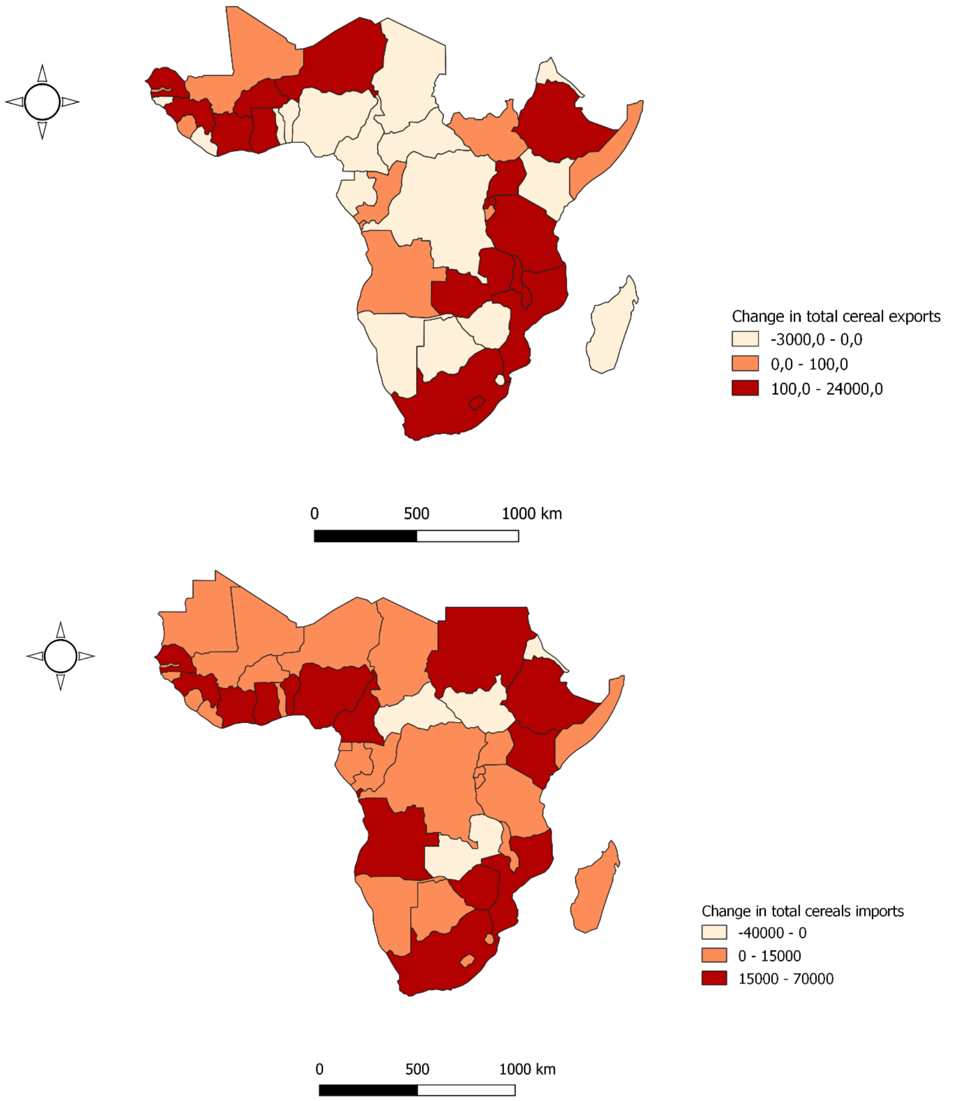
These changes in productivity levels will affect agricultural trade flows in SSA through changes in comparative advantage, where changes in temperature and rainfall levels affect agricultural comparative advantage (Nelson et al, 2009; Costinot et al, 2016). The assumption is that climate change may affect comparative advantage in the agricultural sector and, therefore, result in changes in the composition of trade flows as producers respond to new conditions. In particular, trade in five major cereals in SSA is likely to be affected by climate change as production patterns change. The production of maize, rice, millet, wheat and sorghum has declined since 1980 because of global warming and it is expected that it could decline by as much as 20% by the middle of this century (Lobell and Schlenker, 2010; Lobell et al, 2011). Understanding the impacts of climate change on cereals trade flows is important for several reasons. First, cereals trade is of critical importance for many countries in SSA. For most of the population in the region, cereal production and trade is an important part of the food system, as cereals are a major staple food. Therefore, access to regional and international cereal markets is an important pathway out of grinding poverty and food insecurity.

Second, the ability of the agricultural sector and food security systems to respond to climatic shocks also depends on trade in cereal products. Empirical evidence has shown that the negative impacts of climate change are dampened when trade patterns adjust (Costinot et al, 2016). Intra-African and international cereals trade is important, because trade has the potential to help reduce the effect of climate change by delivering food from surplus areas to countries experiencing food productivity declines (Govereh, 2007; Duchin and Juliá, 2007). To achieve this, there is a need to promote and facilitate freer movement of cereals. Free trade allows nations to fully exploit their comparative advantage and the existence of barriers to trade exacerbate climate change effects by reducing the responsiveness of consumers and producers to incentives. This points to the importance of trade policies in SSA if they are to respond effectively to changes in climate, among other adaptation strategies that include irrigation and the adoption of improved varieties. Recent empirical evidence has shown that trade costs are high in SSA and have a negative effect on food prices, agricultural income and welfare (Porteous, 2016).

Although recently there has been some considerable interest in studying the linkages between climate change and international trade, little is known in SSA about the impact of future climate change on intra-SSA cereals trade. This paper addresses this issue by simulating the impacts of climate change on bilateral exports and imports in SSA by combining estimates from a historical relationship between production and cereals trade, and post-climate change in cereals productivity estimates for each country and crop in the region. To restrict the number of agricultural products in the analysis, the study focuses on cereals trade as it forms the major share of food consumption goods and is the focus of climate change estimates. Documenting the impacts of climate change on cereals trade flows and the potential role of trade as an adaptation strategy is critical for improving food security policy design. The output from this research will be of great use to national governments, and international and regional development organizations that are presently seeking ways to reduce food insecurity and undernutrition through facilitating the access of farmers to markets in the face of adverse shocks.

Figure 1 shows the distribution of the average 2000–2016 change in cereals trade across SSA countries. The first map shows that the change in cereals exports varies across countries, with countries such as South Africa, Zambia and Niger experiencing a large increase in exports. The majority of countries experienced a small change in cereal exports, while others experienced a decline. The second map in Figure 1 also shows that there is a wide variation in change in cereal imports, with the countries observed to be experiencing increased exports also importing more cereal products. The study relies on this historical variation across time and countries to estimate a relationship between production and trade for each country and major cereal crop.

Figure 1: Distribution of average 2000–2016 change in cereals trade (US$'000) in sub-Saharan African countries



Source: Author using data from FAOSTAT(2018) and openAfrica (2018).

To further highlight the relative importance of cereals trade in SSA, Table 1 shows the shares of major cereals trade in total trade for SSA countries. The analysis in this paper draws on five major cereal crops whose aggregate share in total trade is presented in Table 1. Between 2000 and 2016, the share of cereals exports in total trade was low for the majority of countries in SSA. In West Africa, countries such as

Benin, Burkina Faso and Senegal had the highest share of cereal exports. The share of cereal exports had been increasing in Benin and Senegal. In Benin, the share of cereal exports increased to 42% in 2010 and then declined to 0.01% in 2016, whereas in Senegal the share increased from 0.01% in 2000 to 6% in 2005, and dropped to 4% in 2016. In other West African countries such as Cameroon, Côte d'Ivoire, Nigeria, Niger, Togo and Ghana the share of cereal exports in total trade was very low over the 2000–2016 period. Uganda, Tanzania and Ethiopia had the highest shares of cereal exports in the East African region, while countries such as Rwanda, Kenya, Burundi and Eritrea had low shares of cereal exports. The share of cereal exports was above 5% for Uganda in 2001, 2005, 2006, 2012, 2015 and 2016. In Tanzania, the share of cereal exports reached 21% in 2002 and declined to 1.4% in 2016. Ethiopia had the highest share of cereal exports at 13% in 2012 and had the lowest share in 2009. Southern Africa is one of the major producers of cereals in SSA as is reflected in their relative importance in cereals trade. Malawi has the largest share of cereal exports in the region. In 2007, the share of cereal exports in Malawi was about 32%, which was lowest in 2006. In Zambia, the share of cereal exports had been increasing over the 2000–2016 period, increasing to 14% in 2012. Other countries in the region recorded low shares of cereal exports over the period. These statistics that show the variation in the changes in the share of cereal exports in total trade across countries and time reveal that there are differences in the relative importance of cereals trade across countries in SSA. The relative importance may be altered as a result of climate change as production specializations change.

Table 1: Share of value of cereals exports in total trade 2000–2016 (trade values in US$'000)

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Benin	0.01	0.03		0.00	0.01		0.02	3.68	7.11	15.68	41.98	13.20	15.68	13.22	5.13	0.11	0.01
Botswana	0.39	0.60	0.69	0.51	0.87	0.64	0.75	0.08	0.10	0.36	0.12	0.13	0.12	1.45	0.04	0.03	0.06
Burkina Faso	5.42	7.53	2.42	0.13	1.73	0.82		4.32	2.35	4.29	3.38	1.59	0.98	2.16	2.40	3.55	1.50
Burundi			1.79		0.51		0.12	0.92	1.12	0.44	0.95	0.68		0.00	0.35	0.03	0.00
Cameroon	0.00	0.00	0.00	0.13	0.01	0.00	0.00			0.00	0.20	0.18	0.06	0.17	0.65	1.44	1.95
Cape Verde						5.02						0.00	8.24	0.00			
Congo. Rep.										0.01	0.01				0.00		
Côte d'Ivoire	0.01	0.13	0.09	0.05	0.23	0.15	0.06	0.02	0.34	0.47	0.16	0.37	0.43	0.33	0.48	0.42	0.42
Djibouti										0.95							
Eritrea	0.17	0.00	0.00	0.65													
Ethiopia*	0.97	2.52	4.18	0.83	4.45	4.44	0.39	0.14	0.04	0.00	2.88	0.89	12.66	0.23	0.85	0.16	
Fmr Sudan									0.00	0.00		0.93					
Gabon	0.06	0.15	0.09	0.00	0.07	0.01	0.00	0.00	0.00								
The Gambia										0.19	0.00	0.00	0.00	1.61	15.54	0.15	0.45
Ghana	0.06	0.24		0.17	0.01	0.00	0.00	0.09	0.00	0.00	0.36	0.00	0.00	0.01			0.01
Guinea	0.41		3.40		0.00	0.01	0.08		15.76					0.00	0.01	0.04	
Guinea-Bissau					18.84												
Kenya	0.18	0.12	0.98	0.26	0.35	0.25	0.28	0.26	0.32	0.37	0.52			0.41			
Lesotho	0.98	2.94	1.43	2.83	1.18				2.31	0.34	0.23	0.10	0.06	0.03	0.06	0.04	
Madagascar	0.33	1.37	1.77	0.14	0.34	0.01	0.32	0.44	0.01	0.02	0.00	0.00	0.08	0.03	0.00	0.05	0.01
Malawi	8.40	1.43	1.51	13.30	1.16	0.30	2.68	31.79	7.17	4.87	2.02	17.38	0.94	1.30	0.90	0.63	1.23
Mali	0.72	1.06	0.49	0.11	0.63	0.36	0.75	0.04	0.13		0.17	0.30	0.04				0.00
Mauritius	0.02	0.01	0.04	0.04	0.06	0.00	0.08	0.10	0.14	0.28	0.00	0.07	0.00	0.00	0.00	0.00	0.00
Mozambique		1.06	3.37	0.82	1.25	0.88	1.06	0.64	1.05	1.29	0.73	0.84	0.21	0.05	1.15		0.10
Namibia	0.14	0.06	0.13	0.19	0.06	0.06	0.02	0.03	0.05	0.04	0.02	0.04	0.01	0.01	0.01	0.01	0.00
Niger	0.05	0.02	0.03	0.08	0.00	0.14	0.57	0.05	0.01	0.00	0.01	0.36	0.00	0.00	0.03	0.00	0.06
Nigeria	0.01	0.00		0.02								0.00		0.21			
Rwanda		0.00		0.00		0.00	0.64	1.93	0.07	0.01	0.42	0.24	0.59	0.61	0.09	0.43	2.12
Senegal	0.01	0.00	0.25	1.91	4.29	5.87	0.36	3.38	1.24	5.20	1.95	3.57	3.31	3.17	3.12	3.15	3.81
Seychelles	0.00	0.00		0.00	0.00			0.00									0.04
South Africa	1.26	1.20	3.65	2.97	2.19	3.41	1.86	0.37	4.88	4.64	1.76	1.45	1.48	1.79	1.84	1.61	2.11
Sudan													42.82			0.27	
Swaziland	0.07	0.04	0.06	0.13	0.09	0.13	0.09	0.13						0.05	0.04	0.01	0.02
Tanzania	2.04	5.64	20.63	10.34	3.31	2.85	1.59	1.74	1.86	0.54	1.23	1.30	3.24	1.97	6.22	1.07	1.39
Togo	0.67	0.56	0.58	0.11	0.11	0.02		0.40	0.01	0.00	1.42	0.09	2.78	0.00	0.31	0.08	0.01
Uganda	0.73	8.72	2.50	2.93	3.81	5.67	6.99	2.95	1.81	2.13	4.47	3.63	9.16	3.10	2.87	6.59	6.12

Notes: *Ethiopia excludes Eritrea Source: UN COMTRADE (2018)

Agricultural trade is of critical importance for many SSA countries. Improvements in agricultural trade in the region is likely to be associated with economic growth and poverty reduction, as most poor people in the region are dependent on agricultural production for income generation and food security. SSA countries are known for being chronically food insecure and highly dependent on food aid. However, less is known about SSA's highly productive and food surplus regions (Govereh, 2007). Agricultural trade is important for linking food surplus zones with food deficit regions, thereby increasing food security in deficit regions through food availability and accessibility. This will be particularly important in the face of extreme events such as frequent occurrences of droughts and flooding as a result of climate change. In addition to increasing the resilience of food security systems to cater for changes in climate through delivering food to deficit regions, agricultural trade will also reduce price volatility, improve producer incentives and increase agricultural growth (Govereh, 2007). Other studies have noted that improvements in world trade is an important adjustment mechanism for negative shocks arising from climate change (Duchin and Juliá, 2007; Baldos and Hertel, 2015).

Agricultural trade has been an engine for economic growth and structural transformation in developed regions (Porteous, 2016). In Organisation for Economic Coordination and Development (OECD) countries, agricultural trade has expanded faster, as compared to other regions and has been a vehicle for raising the standard of living (Aksoy and Beghin, 2004 Aksoy and Ng, 2010). Aksoy and Beghin (2004) report that during the period 1980/1981 to 2000/2001 intra-European Union (EU) agricultural imports increased from 51% of total agricultural imports to 66%, and intra-NAFTA imports rose from 29% to 44% during the same period. The growth in intra-regional trade in OECD countries has been attributed to successful trade policy reforms. The value of world agricultural trade increased between 2000 and 2016, exhibiting an average annual growth rate of 6%, and emerging economies have been increasing in importance in world agricultural markets (FAO, 2018). South Africa was the only country from SSA in the top 20 agricultural exporters between 2000 and 2016. An important feature of the increased participation of emerging economies in world agricultural trade has been the rapid growth of South-South trade, that is, agricultural trade within middle and low-income countries (FAO, 2018).

However, in SSA the situation has been different. Agricultural trade within SSA countries, and between SSA countries and the rest of the world has been low (Rakotoarisoa et al, 2012). Patterns of agricultural trade documented in the literature show that the share of food and agricultural exports is declining in SSA, contributing 33% to total merchandise exports in 1990, from a level as high as 56% in 1980, while there are increasing levels of agricultural imports (Aksoy and Beghin, 2004). As a share of world agricultural trade, African trade was less than 5% between 2005 and 2007 (Rakotoarisoa et al, 2012). SSA has increasingly become a net importer of food and agricultural products in the past two decades, with agricultural imports growing at an annual average rate of about 13% (Rakotoarisoa et al, 2012; USDA-FAS, 2015). These constituted mainly imports of cereals and livestock products, which are important for improving food security and the nutritional status of individuals. Climate shocks may affect the importation of these products, as they are likely to be associated with the potential of countries to increase their import of food through changes in comparative advantage and income.

About 30% of agricultural imports into SSA come from other developing regions such as Asia, with Thailand, Malaysia, India and Indonesia being the top countries (USDA-FAS, 2015). European Union countries contributed about 25% of the imports. Intra-regional trade in food and agriculture products has been relatively low, accounting for about 17% of total merchandise exports. However, intra-regional trade has been growing over the years but at a slower rate compared to international trade (USDA-FAS, 2015). Cereals trade account for only about 5% of total trade.[1] In SSA, regional production patterns determine trade flows within the continent. SSA has traditional areas of food surplus and food deficit, for example, the Horn of Africa and the Sahel are drought-prone areas and usually suffer from food shortages, while the food surplus areas constitute those areas that are highly productive with favourable and reliable rainfall (World Bank, 2012). As a result, Southern Mali exports surplus sorghum to Niger and coastal West Africa, and other “staple-food-basket zones” with climates that support the production of different cereals such as Northern Zambia, Eastern Uganda, Northern Mozambique, most of Tanzania and South Africa. In West Africa, Nigeria is a major producer of food crops such as rice and exports millet, sorghum and yam to neighbouring countries. Most of the rice imported by West African nations such as Senegal and Côte d’Ivoire is sourced from Thailand.

The poor performance of intra-regional trade can be attributed to several factors, most importantly trade policies, complex transit procedures, poor institutional environments and high transport costs. Josling (2008) and Porteous (2016) note that SSA countries face much higher trade-related costs than other countries in getting their products to international markets. This is likely to exacerbate the impact of climate shocks. For example, high trade costs have been shown to reduce the adoption of agricultural technologies that may be important for adapting to climate change shocks (Porteous, 2016).

To shed light on the role of climate change on agricultural trade patterns and the potential role of trade as a mechanism to reduce the impact of climate shocks, this study adds to the literature by simulating the impacts of climate change on bilateral trade in cereals.

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[1] It should be noted that a significant portion of cereals trade in SSA is informal.

2. Literature review

The economic impact of climate change on the agricultural sector has recently received a great deal of attention in the literature. Most studies on the impact of climate change on agricultural production show that there will be a negative effect on yields in vulnerable African countries. Kurukulasuriya and Mendelsohn (2008) studied the impact of climate change on African agriculture. Using cross-section farm survey data collected from 11 countries, they regress annual net revenues on climate variables and conclude that current climate had an effect on farm revenues. Findings from the study reveal that net revenues are lower in areas with higher temperatures, and in terms of precipitation, farms in Africa are less responsive to changes in rainfall as compared to changes in temperature.

Agricultural production in most SSA countries is rain-fed, hence climate shocks affecting agriculture are likely to have economy-wide effects, with food security and income declining in some countries (Arndt et al, 2012). Recent evidence has shown that future changes in climate will negatively affect SSA's growth and development prospects in the absence of adaptation and mitigation (Simbanegavi and Arndt, 2014). Gross domestic product (GDP) is expected to decline by 4%, with agriculture the main impact channel because of the dependency of SSA's economies on rain-fed agriculture. Using a dynamic global computable general equilibrium (CGE) model (GTAP-Dyn) also shows that SSA will experience a decline in agricultural productivity as a result of climate change (Asafu-Adjaye, 2014). Similarly, Calzadilla et al. (2013) show that by the 2050s crop harvest area and production in SSA will decline by 0.72% and 1.55%, respectively, as a result of climate change. Ward, Florax and Flores-Lagunes (2014) also show that the cereal yield across SSA is expected to decline by an average of 36% by the end of the century as a result of climate change.

Country-specific studies have also shown that climate change will have negative effects on agricultural productivity. Molua (2008) analysed the impact of changing climate variables on agricultural production in Cameroon. Results from the study show that climate change will affect agricultural production in the country. The value of the projected agricultural output in 2050 will decrease by 41% compared to the 1961–2001 mean value. In Malawi, rain-fed maize production may decrease by 14% by the middle of the century, and by 33% by the end of the century as a result of climate change (Msowoya et al, 2016). Similar evidence shows that in South Africa, climate change may decrease crop area and production by 5% and 10%, respectively, which in turn will lead to GDP declining by 0.6% (Calzadilla et al, 2014).

Given these findings of the effects of climate change on agricultural production, it is crucial to see how the trade in cereals responds to changes in climate given the heterogeneity of African countries in terms of climate. The IPCC (2000) simulated the global impact of climate change on cereals trade. They predict a growing dependence on net cereal imports by developing countries by 2080. They conclude that the comparative advantage of producing cereals is likely to shift to developed countries and that developing countries' net imports will increase by 25%. Nelson et al. (2009), analysed the effects of climate change on agricultural trade flows and the potential role of using agricultural trade flows as an adaptation strategy. Results from the study show that developing countries' imports of grains will increase with changing climate. They also conclude that changing trade flows are important as a mechanism to partially cushion negative productivity shocks resulting from climate change. Lee (2009) examined the impact of climate-change-induced crop yield change using the global trade analysis project (GTAP) model and finds that developing countries are more adversely affected by climate change than developed countries. In another study, Ahmed et al. (2010) looked at how climate volatility affects agricultural production and the potential role of international trade to reduce the impact of climate-induced food production variability in Tanzania. Using the GTAP model, a CGE model, the study finds that climate variability has a negative effect on agricultural production and poverty in the 21st Century. Recently, Ahmed et al. (2012) showed that Tanzania has the potential to gain from climate change as trade opportunities in the maize sector are likely to increase.

Most current studies on the impacts of climate change rely on CGE models that simulate the change in future climate scenarios. This study complements these studies by combining econometric and simulation methods. First, the study uses econometric modelling to estimate parameters that relate to production and trade, and then simulates the impact of climate change using productivity estimates as a result of climate change, obtained from the literature. In doing so, the study first identifies either the increased need for imports or increased capacity to export, and second the implications for regional trade partners; whether the partner can meet demand for exports or whether their demand for imports can be satisfied by the exporting partner.

3. Conceptual framework and methodology

The main goal of this study is to examine the impact of climate change on cereals trade. The literature shows that to examine the effects of climate change on agricultural markets and trade, the main channel is through changing patterns of production as a result of changing comparative advantage (Nelson et al, 2009; Costinot et al, 2016). Increases in temperature and declines in rainfall are expected to affect the productivity of agricultural products, especially cereals, and this will in turn affect the comparative advantage of different countries, which will have implications for patterns of trade. The distribution of agricultural production will change as countries generate surpluses and deficits in different agricultural commodities over time due to changes in comparative advantage. A well-functioning international trade system will help countries adapt to the changing climate as food will be shipped from surplus to deficit countries.

Arndt et al. (2012) propose a different channel, stressing the role of infrastructure, for example, roads. Climate change may lead to a deterioration of road infrastructure through increases in temperature and increased frequency of extreme events such as flooding. If climate change affects the quality of road infrastructure, it may lead to logistical challenges which may affect trade. Conversely, poor road quality may affect total factor productivity, and this may affect comparative advantage in the agricultural sector.

This study focuses on the channel that affects agricultural production patterns directly, starting with modelling the relationship between production and cereals trade in SSA. Estimates from this relationship are then combined with post-climate change estimates of agricultural productivity obtained from the literature to simulate the impact of climate change on cereals trade.

Empirical approach

To simulate the impacts of climate change on the composition of cereals trade, we first specify a basic regression model where exports and imports in a country are expressed as a function of cereals production and the price that is fetched in the export and domestic market, respectively:

$$X_{ijt} = \beta_0 + \beta_1 Q_{it} + \beta_2 P_{jt} + \varepsilon_{ijt} X_{ijt} = \beta_0 + \beta_1 Q_{it} + \beta_2 P_{jt} + \varepsilon_{ijt} \tag{1}$$

$$M_{ijt} = \alpha_0 + \alpha_1 Q_{it} + \alpha_2 P_{it} + \epsilon_{ijt} M_{ijt} = \alpha_0 + \alpha_1 Q_{it} + \alpha_2 P_{it} + \epsilon_{ijt} \tag{2}$$

where X_{ijt} is exports of cereals from country i to j in year t, M_{ijt} is imports of country i from j in year t, Q_{it} is production of cereals in country i and year t. P_{jt} is the export price and P_{it} is the import price. All variables were transformed to natural logarithms. β_1 and α_1, the regression estimates measuring the percentage change in exports/imports as a result of a percentage change in production, are then combined with predictions about the impact of climate change on crop yields in the 2050s. Let post-climate-change crop productivity for any country i and crop k in the simulations be $(A_i^k)'$ and denote baseline crop productivity as A_i^k. $(A_i^k)'$ estimates are based on agronomic predictions from the United Nations' Global Agro-Ecological Zones (GAEZ) project, which is based on various scenarios of the future. Because of the uncertainties surrounding the estimates (Burke et al, 2011), this paper chooses a baseline scenario and also presents simulations based on estimates of other scenarios as a robustness check. The GAEZ project has post-climate-change estimates of productivity for about 11 scenarios, but this study selects one as a baseline and the other 10 scenarios are presented as a sensitivity analysis.

Another important concern is that countries may implement adaptation strategies that can ensure production, for example, irrigation, planting more resilient varieties and crop substitution, which may dampen the climate-trade linkages. Results in this paper are based on a farming system that uses high input from the GAEZ model, where production is based on improved or high yielding varieties, fully mechanized with low labour intensity and optimal use of chemicals and pesticides. Thus, the analysis in this paper predicts climate change impacts under current technology and farm management practices, and does not take into account the possibilities of additional adaptation. There is little evidence of past climate adaptation by farmers in SSA. For example, there are low levels of irrigation and the growth in irrigation is slow in the region. In addition, it is not clear how the so-called "adaptation" would change production and trade patterns. It is noted in the literature that some of the adaptations are not really climate adaptation, but good farming practices that will boost productivity equally in current and future climate scenarios, thus including them in a future climate impact analysis is likely to be misleading and also difficult to model at country level (Hertel, 2018).

To simulate the impact of climate change on exports and imports, this study follows a number of steps after estimating Equations 1 and 2 for each cereal crop. First, for each country and cereal crop, the paper calculates percentage changes in crop productivity as a result of climate change using the expression:

$$\Delta A_i^k = \left[(A_i^k)' - A_i^k\right] / A_i^k$$

Second, we combine the percentage changes in crop productivity with regression estimates (elasticities) to calculate predicted percentage changes in exports or imports in the 2050s using the following expression:

$\beta_1 * (\Delta A_i^k)$ for exports and
$\alpha_1 * (\Delta A_i^k)$ for imports

The predicted percentage changes in trade flows are then used to calculate the actual change in trade values as a result of climate change in the 2050s.[2]

Data

We use annual data from 2000 to 2015 on exports, imports and value of agricultural production for about 42 sub-Saharan African countries.[3] Data on exports and imports were obtained from UN Comtrade (UN Comtrade, 2018). Export and import prices were estimated by dividing the export or import value by export or import quantity, respectively. The study considers trade in five major cereal crops (maize, millet, rice, sorghum and wheat). The value of agricultural production for each country and crop was obtained from FAOSTAT (FAOSTAT, 2018). A dataset of exports, imports and production was created, consisting of data for 42 SSA countries from 2000 to 2015. Table A6 in the Appendix shows the list of SSA countries included in the sample. As not all SSA countries export or import a particular crop in a given year, the sample used in estimating Equations 1 and 2 is only for those countries that exported or imported a cereal crop within the sample period. In essence, the analysis in this paper does not include any zero and missing trade flows and this effectively assumes that if a country does not buy or sell a particular crop from or to a given country, then it will not buy or sell from that country in the future.

Post-climate-change estimates of productivity changes were obtained from the GAEZ project implemented by the FAO (FAO-GAEZ, 2019). The estimates from the GAEZ project are based on agronomic models predicting how each crop will perform in growing conditions available at a particular location. The agronomic models are based on three inputs that include growing characteristics of a particular location (soil type and conditions, elevation, average land gradient) and climate variables such as rainfall, temperature, wind speed and sun exposure. The other input is crop-specific parameters that govern the relationship between a set of growing characteristics and yield of that specific crop. An aggregation of such parameters found in the agronomic literature is used. The last input into the model is assumptions about the use of complementary inputs such as irrigation, fertilizers, machinery and labour

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[2] We use the average trade flow for each country over the study period to calculate changes in value of exports.

[3] Only countries that have data for all variables are considered.

to the growing of a crop at each location. Different sets of productivity predictions are estimated for different scenarios of the application of complementary inputs. The analysis in this study is based on a ‘high-inputs’ scenario, where production is based on high yielding varieties and fully mechanized with low labour intensity and rain-fed water supply.

Future estimates are available for the 2020s, 2050s and 2080s. This paper uses scenarios for the 2050s as this period is examined in a number of studies (Ahmed et al, 2010; Arndt, Farmer et al, 2012; Arndt, Chinowsky et al, 2012; Costinot et al, 2016). This will allow us to compare results from this study with similar studies. Also, the effect of climate change is expected to be severe by mid-century. The productivity estimates are calculated at a grid cell and also at country level thus allowing heterogeneity within countries. For some data not at the country level, spatial resolution allows the calculation of data at the country level by aggregating the cell estimates using geographic information system (GIS) software. The GAEZ estimates are based on an average of 30-year periods and use the predicted future daily weather. The estimates of predicted future daily weather are obtained from average runs of general circulation models (GCM) under different emission scenarios as outlined in the “Special report on emission scenarios” (SRES) from the Intergovernmental Panel on Climate Change (IPCC, 2000). There are various scenarios corresponding to different assumptions about the economy and population growth, and the GAEZ estimates are based on around 11 GCM-SRES pairs. This study follows Costinot et al (2016) who base projections on a Hadley CM3 A1FI model. However, sensitivity tests are carried out for the remaining 10 scenarios. Pre-climate-change estimates of productivity for each country and crop are also obtained from the GAEZ database and are based on average crop yields for the period 1961–1990.

4. Results

Table 2 describes average projected changes in cereals productivity due to climate change in SSA using the baseline climate scenario and implies that opportunities for more intra-SSA trade in cereals are likely to exist as changes in productivity vary across regions. Overall, average cereals productivity in the whole SSA is expected to decrease by 2.32%, with wheat, maize and rice productivity decreasing by 22.7%, 11.7% and 3.9%, respectively, whereas productivity of crops such as millet and sorghum is likely to increase. This is because millet and sorghum are drought-resistant crops and are likely to grow well in dry and high temperature conditions that are a result of climate change. Across regions within SSA, Southern Africa is expected to experience large declines in maize, wheat and rice productivity of about 18.5%, 27.6%, and 17.4%, respectively, whereas Eastern Africa is likely to experience lower decreases in maize and wheat productivity, and in fact, rice productivity in the region is set to increase by 28.4%. This suggests that the comparative advantage of maize, wheat and rice production will shift to Eastern African countries. However, Central and Southern Africa are expected to gain a comparative advantage in millet production as productivity is likely to increase by 134.7% and 83.8%, respectively.

Table 2: Average projected changes in cereals productivity due to climate change in 2050s

	Yield change (t/ha)	Percentage change in yield
SSA		
All cereals	-0.10	-2.33
Maize	-0.93	-11.69
Wheat	-0.53	-22.65
Rice	-0.15	-3.92
Sorghum	0.08	1.39
Millet	1.02	58.68
Southern Africa		
Maize	-1.63	-18.52
Wheat	-0.89	-27.63
Rice	-0.51	-17.43
Sorghum	0.19	2.79
Millet	1.53	83.83
East Africa		
Maize	-0.36	-4.70
Wheat	-0.25	-5.76
Rice	0.72	28.40
Sorghum	0.17	2.94
Millet	0.92	56.13
Central Africa		
Maize	-0.53	-8.33
Wheat	-0.61	-31.56
Rice	-0.08	-1.39
Sorghum	0.16	4.24
Millet	1.11	134.66
West Africa		
Maize	-0.85	-10.66
Wheat	-0.39	-62.13
Rice	-0.39	-8.71
Sorghum	-0.07	-1.22
Millet	0.67	33.25

Source: Author’s computation based on data from FAO-GAEZ

Notes: In all cases, the post-climate-change estimates are based on GCM-SRES scenario obtained from Hadley CM3 A1FI model. Baseline scenario is average yield attainable in the period 1961–1990

Table 3 describes in detail the projected maize productivity changes in the 2050s as a result of climate change for each country and for all climate scenarios available in the GAEZ database. Table A2 to A5 in the Appendix show projected percentage changes in productivity for wheat, rice, millet and sorghum. There is a degree of uncertainty regarding future agricultural productivity. Of the major maize producers in SSA, South Africa is likely to experience large declines in productivity in almost all climate scenarios except for the MPI ECHAM4 B2 scenario, ranging from 14.5% to 79.3%. Other major producers such as Malawi, Tanzania and Zambia are likely to experience increases in maize productivity in the 2050s. These variations in productivity changes are expected to change trade patterns as countries will be able to export more of the crop where they have gained a comparative advantage, and import more of the crop where they have lost comparative advantage due to climate change.

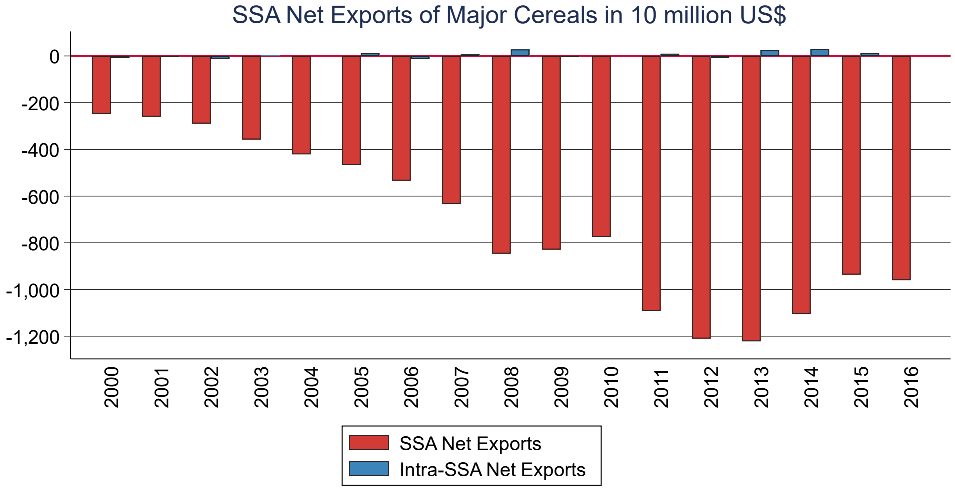
Table 3: Projected percentage changes in maize productivity by 2050s

	GCM-SRES combinations										
Country	HadleyCM3 A1F1	HadleyCM3 B1	CSIRO Mk2 A2	CSIRO Mk2 B2	HadleyCM3 B2	CSIRO Mk2 B1	MPI ECHAM4 A2	CCCma CGCM2 A2	CCCma CGCM2 B2	HadleyCM3 A2	MPI ECHAM4 B2
Angola	-13.20	-6.13	8.74	6.40	-6.49	1.04	-3.43	8.94	3.77	-4.75	24.04
Burundi	8.90	5.64	2.35	-0.39	2.60	-1.68	-0.45	5.73	1.13	8.60	-3.27
Benin	-1.30	-2.85	0.03	-3.79	-6.95	-3.67	-1.65	-1.45	-6.91	-1.07	-7.47
Burkina Faso	-2.85	-4.97	-11.20	-10.92	-0.27	-10.65	-1.09	-1.31	-3.84	-0.40	12.50
Botswana	-84.25	-78.55	-72.50	-74.96	-73.82	-66.16	-47.89	-33.46	-29.47	-25.04	87.72
Central African Republic	-0.04	6.41	3.94	3.29	-2.88	2.06	-2.76	1.73	-0.15	-2.17	-0.45
Côte d'Ivoire	1.57	-12.50	4.97	-10.44	-12.55	-10.54	4.18				
Cameroon	1.25	4.45	0.04	-0.42	-0.78	-0.91	1.77	-0.27	-3.39	-1.69	2.45
Democratic Republic of the Congo	9.44	6.25	1.93	-0.93	1.29	-2.52	3.24	0.04	-4.17	7.80	2.46
Congo. Rep.	12.50	8.30	0.82	0.15	4.42	0.53	-0.29	-1.93	-1.52	8.41	-0.99
Eritrea	-42.58	-52.46	-79.85	-69.14	-51.89	-74.80	-49.10	2.44	0.72	9.84	401.70
Ethiopia	-13.57	-21.69	-19.75	-21.76	-19.57	-22.24	-12.19	1.90	-2.72	1.48	44.40
Gabon	4.08	2.74	2.17	1.56	1.84	1.53	0.69	-2.34	-1.66	2.75	-1.27
Ghana	4.25	-7.83	5.38	-11.34	-9.07	-11.27	3.48	-1.54	-9.09	-2.34	-8.85
Guinea	0.68	-15.19	0.61	-8.70	-13.03	-10.31	1.47	-3.82	-25.67	-1.03	-3.66
Gambia	-4.22	-2.79	-1.23	-1.47	-1.22	-1.22	-2.07	-2.09	-2.21	-6.26	6.14
Guinea-Bissau	-1.04	-19.86	0.14	-24.96	-33.89	-26.23	-2.36	-2.08	-30.36	-0.66	-18.42
Equatorial Guinea	5.04	3.15	0.54	0.90	-0.99	-0.30	0.40	-1.12	-2.30	3.40	-1.54
Kenya	-4.89	-16.32	-1.63	-10.21	-14.48	-7.05	-6.75	5.35	2.55	-0.25	60.16
Liberia	-6.49	-3.84	0.01	-0.99	-3.05	-0.66	-1.57	-2.94	-3.50	-6.14	-0.82
Lesotho	-48.23	-59.53	-51.42	-52.38	-52.09	-52.82	-36.39	-39.83	-35.36	-33.57	4.06
Madagascar	7.51	-9.06	0.93	-8.39	-0.98	-6.53	7.38	1.56	-5.82	6.63	4.28
Mali	-69.34	-69.54	-69.54	-68.94	-66.76	-69.04	-64.87	3.24	3.79	-9.67	39.98
Mozambique	-3.98	-3.69	-6.02	-13.09	-2.53	-12.88	-1.47	-0.95	-5.51	0.68	8.21
Mauritania	-97.84	-97.15	-95.16	-93.79	-93.47	-94.55	-89.70	18.27	28.08	-14.08	373.02
Malawi	11.29	9.42	5.55	-4.06	8.74	-3.38	7.11	5.84	3.89	10.51	23.57
Namibia	-91.17	-82.85	-58.23	-62.25	-81.49	-68.87	-76.49	-1.27	-5.31	-29.51	120.05
Niger	-65.44	-71.84	-79.03	-77.37	-66.87	-79.77	-60.92	-6.21	-11.26	3.00	258.68
Nigeria	-0.36	-0.63	-2.99	-3.45	-0.30	-3.65	4.29	-0.01	-2.68	-1.55	11.28
Rwanda	1.10	-19.36	-0.48	-15.96	-21.47	-19.16	-6.28	2.47	-15.28	2.92	-21.05
South Sudan	-1.98	-4.21	-1.83	-6.99	-6.59	-6.91	-3.30	-1.61	-6.43	-1.86	-1.38
Senegal	-30.35	-30.24	-13.54	-11.03	-15.15	-11.10	-11.92	-0.82	-0.03	-7.51	39.74
Sierra Leone	-0.24	-4.15	1.65	0.61	-11.70	-1.37	7.42	-11.49	-11.53	-6.25	7.10
Somalia	-98.67	-98.46	-90.00	-93.97	-97.07	-92.38	-93.87	-2.28	16.51	-22.46	345.74
Swaziland	12.82	-0.35	1.66	2.05	9.02	5.19	14.40	11.42	-0.22	7.59	21.71
Chad	-49.54	-52.29	-56.68	-55.50	-49.45	-56.15	-46.17	-4.90	-1.54	-5.16	70.99
Togo	0.23	-6.66	2.54	-7.46	-12.79	-8.04	-0.45	-1.04	-14.22	-2.04	-11.34
Tanzania	7.11	1.17	1.73	-5.29	2.17	-6.61	4.02	4.07	-2.70	6.23	12.66
Uganda	4.62	-29.40	-2.92	-24.91	-30.84	-26.77	-5.92	5.89	-25.94	8.20	-23.89
South Africa	-78.19	-79.28	-74.46	-76.59	-71.57	-72.66	-55.13	-14.52	-25.54	-20.85	83.54
Zambia	8.63	7.85	8.26	4.37	6.70	3.47	7.14	5.22	3.20	8.68	18.11
Zimbabwe	-8.86	-3.06	5.81	1.01	6.47	4.13	12.38	0.25	5.28	2.29	38.04

Source: Author's computation based on data from FAO-GAEZ (2019)

For example, countries in Southern Africa will likely gain from producing drought-resistant crops such as millet and export them to countries in Eastern and West Africa that have experienced a low increase in millet productivity. Figure 2 shows overall trends in net exports of major cereals in SSA over the period 2000–2016, and the results show that SSA countries are net importers of cereals. Generally, imports of cereals had been increasing and peaked in 2012 and 2013, while they were lowest in 2000. The results also show that intra-SSA trade in cereals is low and there were positive intra-SSA net exports in years 2005, 2008, 2013 and 2014.

Figure 2: Overall SSA trade in major cereals

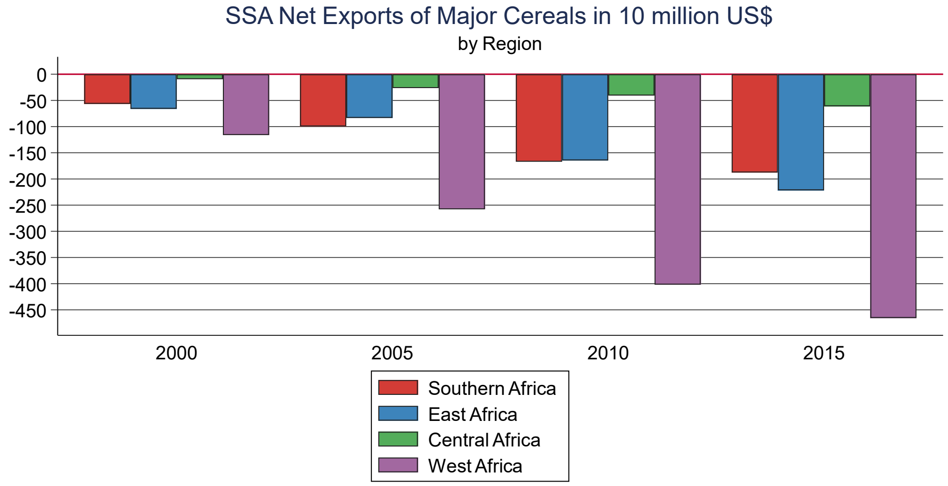


Source: UN Comtrade(2018)

Looking at trade patterns within SSA by region, Figure 3 shows that West Africa is the largest net importer of cereals over the study period, followed by Eastern and Southern Africa, with Central Africa the smallest net importer of cereals. These results suggest that SSA is heavily dependent on imports of cereals and that there is variation across regions, with West Africa more dependent on imports.

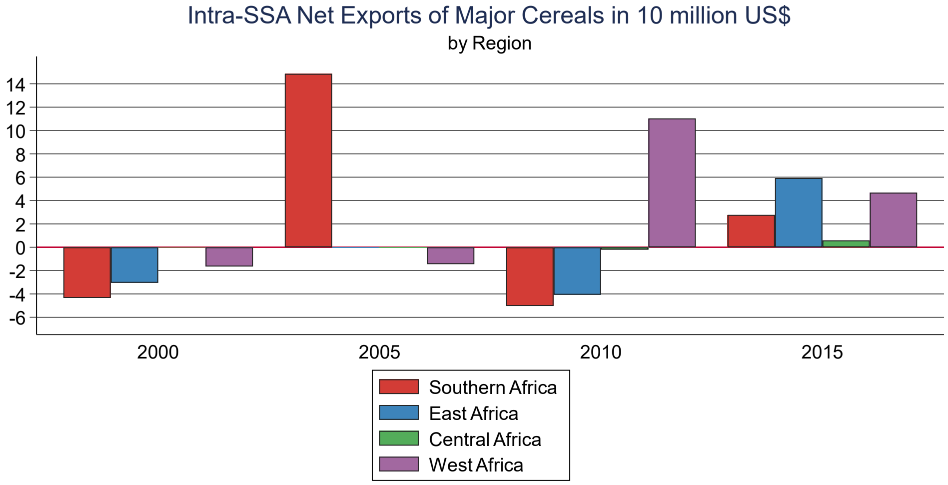
Changes in the climate may affect these current trade patterns as Southern Africa may become a bigger importer of cereals whereas Eastern Africa will shift to become an exporter of cereals. When looking at intra-SSA net exports, the results in Figure 4 show that trade patterns vary across regions and time. In 2000 West Africa was importing less from SSA countries, whereas Southern African imports from SSA were relatively large. In 2005, trade patterns shifted with Southern Africa becoming an exporter of cereals to SSA and West Africa importing from SSA countries. Trade patterns shifted again in 2010 with West Africa becoming an exporter, and Southern and Eastern African countries net importers of cereals. In 2015 all regions were net exporters of cereals to SSA countries, with Eastern Africa the largest exporter. These findings are consistent with anecdotal evidence highlighting that trade patterns in SSA are changing across regions, which is a reflection of the current production shocks that specific regions are facing. These production shocks are likely to be driven mainly by weather shocks.

Figure 3: Overall SSA net exports of major cereals by region



Source: UN Comtrade (2018)

Figure 4: Intra-SSA net exports of major cereals by region



Source: UN Comtrade (2018)

To shed more light on what may be driving these trade patterns in SSA and whether production shocks driven by weather shocks are likely to be important, Table 4 compares the characteristics of net importers and exporters. The intra-SSA imports and exports of net exporters are significantly higher than those of net importers. The gross value of cereals production is significantly higher for net exporters than for net importers, suggesting that exporters produce more and importers produce less, highlighting the positive relationship between production and exporting.

Table 4: Country characteristics for intra-SSA trade (average for 2000–2015)

Variables	Net importer	Net exporter	Difference	T-statistics
Exports (value in US$'000)	369.8364	10671.67	-10301.84***	-3.099
Imports (value in US$'000)	3540.75	1473.574	1977.23	0.9149
Output (gross production value in current millions of US$)	355.1637	1901.744	-1546.581**	-2.5166

Source: Author's computation based on FAOSTAT (2018) and UN Comtrade data(2018)
Notes: ***p<0.01, **p<0.05 and *p<0.1

This paper estimates the relationship between exports/imports and production as specified in Equations 1 and 2 for each crop using data from 2000 to 2015 to obtain estimates to use in simulating the impact of climate change on trade within SSA. Results of the estimates are presented in Table 5, which shows that the relationship between production and cereal exports is positive and statistically significant for all crops. The estimated coefficients of the import demand function also show the expected negative relationship between production of cereals crops and imports of cereals, with the exception of millet. These results suggest that as production increases, the demand for imports decreases and the supply of exports increases. The coefficients for export and import prices are also as expected, as the increase in export prices will increase export supply and the increase in import price will decrease import demand.

Table 5: Production and bilateral trade in SSA, 2000–2015 (pooled OLS)

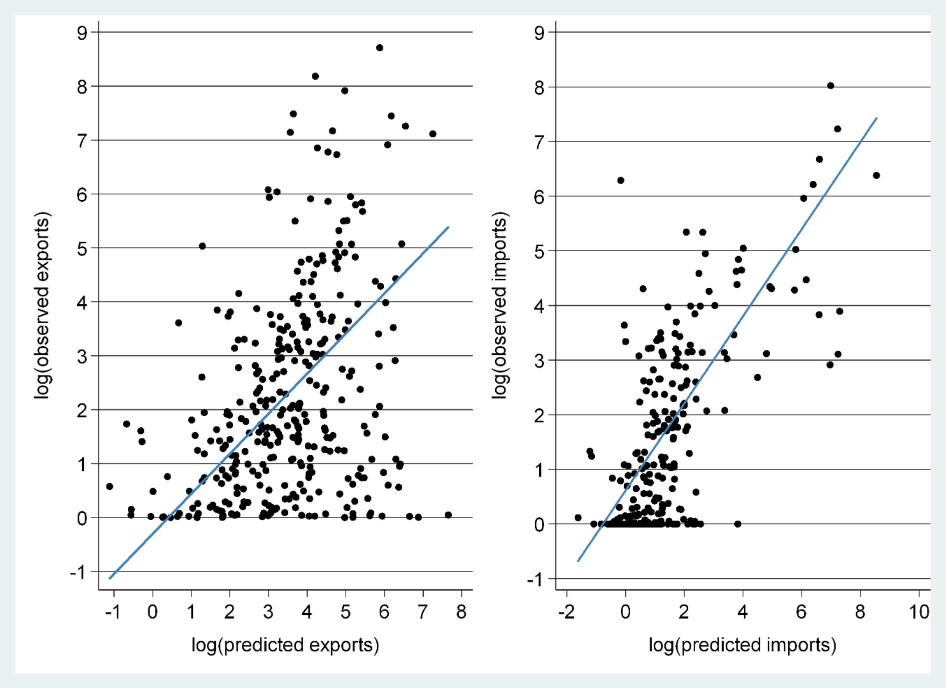
	Exports					Imports				
	Maize	Millet	Rice	Sorghum	Wheat	Maize	Millet	Rice	Sorghum	Wheat
ln output value	0.205***	0.242***	0.219***	0.229***	0.179***	-0.173***	0.151***	-0.0569*	-0.311***	-0.310***
	(0.0296)	(0.0535)	(0.0355)	(0.0488)	(0.0550)	(0.0343)	(0.0526)	(0.0300)	(0.0632)	(0.0458)
ln export price	0.569	77.91***	136.8	37.32*	1.108***					
	(2.017)	(16.05)	(89.60)	(20.79)	(0.269)					
ln import price						-0.463***	-2.402	1.278***	-6.191***	-0.791***
						(0.118)	(1.940)	(0.389)	(1.451)	(0.208)
N	1553	331	1239	482	450	1553	331	1239	482	450
R-squared	0.0325	0.0728	0.0375	0.0431	0.0274	0.0195	0.0537	0.00517	0.0560	0.0865
F-stats	24.16	24.90	20.32	14.08	12.98	21.16	8.89	7.05	16.67	26.43

Notes: Dependent variable is the natural logarithm of export and import value of each crop. Standard errors in parentheses (* p<0.10, ** p<0.05, *** p<0.010)

Before proceeding with using the estimated relationship to simulate the impact of changes in agricultural productivity as a result of climate change on bilateral exports and imports, it is advisable to describe how the model fits the data in the sample. Figure 5 plots observed bilateral exports/imports and predicted bilateral exports/

imports, across all exporters i and importers j and crops k in the case of exports, and across all importers i and exporters j and crops k in the case of imports. There seems to be no perfect match between predicted values and observed data for both exports and imports, as one would expect all the observations to be around the 45-degree line. A regression of predicted exports on observed export flows yields a coefficient estimate of 0.74 with a clustered standard error of 0.12 and an R-squared of 0.30, whereas a regression of predicted imports on observed import flows yields a coefficient estimate of 0.80 with a clustered standard error of 0.05, and an R-squared of 0.68.

Figure 5: Observed vs predicted bilateral exports/imports across exporters I, importers j and crops k for exports, and importers I, exporters j and crops k for imports



Simulations: Climate change impacts on trade

Table 6 shows aggregate changes in trade volumes in SSA as a result of climate change. The results show that the capacity of the region to export maize and wheat may decline in the 2050s, and there is going to be a need to increase imports of maize and wheat. Conversely, the region’s capacity to increase exports of millet, wheat and rice is likely to increase.

Table 6: Average projected change in cereals trade in SSA in 2050s

	Exports (%)	Imports (%)
Maize	-4.46	3.75
Millet	121.13	75.36
Rice	15.53	-4.04
Wheat	-3.53	6.10
Sorghum	0.20	-0.27

Source: Author's computations

Table 7 shows percentage changes in trade flows in the 2050s for major cereal crops and for each country in SSA. The results show that the potential of most SSA countries to export maize will decline, with Southern African countries such as Namibia, Botswana and South Africa experiencing the largest declines of 19%, 17% and 16%, respectively. In West Africa, the potential export of maize will decline by 14% in Mali, 13% in Niger and 6% in Senegal. Countries with the potential to experience slight declines in exports include Nigeria (0.07%), Benin (0.27%) and Burkina Faso (0.58%). Some countries will have the potential to increase maize exports: Malawi (2.3%), Burundi (1.8%), Zambia (1.8%), Madagascar (1.5%), Tanzania (1.5%), Uganda (1%), Ghana (0.9%), Cameroon (0.3%), Côte d'Ivoire (0.3%), Rwanda (0.2%), Guinea (0.1%), and Togo (0.05%). Simulation results of other crops show that all countries that exported millet will have the potential to increase exports, with the highest projected increases in South Africa (463%), Rwanda (138%), Niger (47%) and Mali (40%), and the lowest increases in Burkina Faso (0.3%) and Senegal (1.17%). Of the countries that exported rice, less than half will have the potential to increase exports in future as a result of changing climate. Countries that are likely to experience relatively large declines in rice exports in the 2050s include Zimbabwe (9.2%), Senegal (8.9%), The Gambia (8.8%), and Mozambique (7%). Countries with the potential to increase exports of rice include South Africa (83.3%), Rwanda (60.9%) and Kenya (28.1%). Wheat exports are expected to decline for most of the countries that are currently exporting wheat, with both Botswana and Guinea experiencing the largest decline of 18%. Some countries such as Uganda and Nigeria have the potential to increase exports by 4.2% and 2.4% respectively. Fewer countries were exporting sorghum in the baseline, and of these countries, more than half will have the potential to increase exports of sorghum to SSA countries.

Table 7: Percent change in SSA trade in 2050s

Country	Maize (%)		Millet (%)		Rice (%)		Wheat (%)		Sorghum (%)	
	X	M	X	M	X	M	X	M	X	M
Benin	-0.27	0.22			-1.27	0.33				
Botswana	-17.30	14.57	28.51	17.74			-17.92	30.95	-2.52	3.41
Burkina Faso	-0.58	0.49	0.30	0.19	-2.40	0.62			-0.27	0.36
Burundi	1.83	-1.54			13.49	-3.51	-2.81	4.86	3.01	-4.09
Cameroon	0.26	-0.22	38.59	24.01	0.06	-0.01	0.17	-0.29		
Congo. Rep.					-1.48	0.39				
Côte d'Ivoire	0.32	-0.27	15.44	9.60	-2.40	0.62			1.74	-2.36
Eritrea									1.68	-2.28
Ethiopia(excludes Eritrea)	-2.79	2.35	12.81	7.97	10.44	-2.71	-0.85	1.47	0.03	-0.04
Gabon					-0.26	0.07				
Gambia. The					-8.80	2.29			-0.28	0.38
Ghana	0.87	-0.73	5.43	3.38	-1.95	0.51			1.62	-2.20
Guinea	0.14	-0.12			-1.46	0.38	-17.92	30.95	1.04	-1.41
Guinea-Bissau					-2.58	0.67				
Kenya	-1.00	0.85	6.65	4.14	28.11	-7.31	-1.68	2.89	0.23	-0.32
Lesotho	-9.90	8.34					-0.22	0.39	-11.79	15.99
Madagascar	1.54	-1.30			-2.72	0.71				
Malawi	2.32	-1.95	10.23	6.36	-3.25	0.84	-5.79	10.00	3.59	-4.88
Mali	-14.24	11.99	40.33	25.09	-5.76	1.50			-2.67	3.62
Mozambique	-0.82	0.69			-6.96	1.81	-4.85	8.38	2.39	-3.24
Namibia	-18.72	15.77	37.08	23.07			-2.10	3.63	-2.56	3.48
Niger	-13.44	11.32	46.89	29.17	18.79	-4.88			-0.65	0.88
Nigeria	-0.07	0.06			-0.60	0.16	2.38	-4.12		
Rwanda	0.23	-0.19	138.63	86.25	60.89	-15.82	-0.88	1.52	2.15	-2.92
Senegal	-6.23	5.25	1.19	0.74	-8.85	2.30			-0.82	1.12
South Africa	-16.05	13.52	463.10	288.11	83.25	-21.63	-2.51	4.33	-3.55	4.82
Tanzania	1.46	-1.23	6.54	4.07	2.48	-0.64	-1.82	3.14	2.25	-3.06
Togo	0.05	-0.04			-1.88	0.49			0.44	-0.59
Uganda	0.95	-0.80	5.50	3.42	-1.10	0.29	4.17	-7.20	1.59	-2.16
Zambia	1.77	-1.49	5.18	3.23	-4.09	1.06	-9.65	16.67	2.35	-3.18
Zimbabwe	-1.82	1.53	12.87	8.01	-9.19	2.39	-6.31	10.89	5.14	-6.98

Notes: X represents exports and M represents imports
Source: Author's computation

Table 7 also shows the expected percentage changes in overall imports in the 2050s for major cereal crops and importing countries in SSA. The results show that countries in the region are likely to need to increase their imports of maize from fellow SSA countries. From the countries that are currently importing maize from SSA countries, Namibia, Botswana, South Africa, Mali and Niger are likely to increase their need for maize imports by 15.8%, 14.6%, 13.5%, 12% and 11.3%, respectively. Countries such as Malawi, Burundi, Zambia, Tanzania, Madagascar, Rwanda, Cameroon, Ghana and Guinea are expected to decrease their need for maize imports from the region. Of the countries currently importing rice from SSA, the majority are likely to increase their imports from SSA and only a few countries will reduce their need for imports of rice. For example, South Africa, Rwanda, Kenya and Niger are likely to reduce their need for rice imports by 21.6%, 15.8%, 7.3% and 4.9%, respectively. Most of the countries importing wheat are likely to need to increase their imports in future. Botswana and Guinea are likely to increase their need for imports of wheat in future by a higher magnitude of 31%, followed by Zambia (16.7%) and Zimbabwe (11%). Countries such as Uganda, Nigeria and Cameroon are likely to reduce imports of wheat by 7.2%, 4.1% and 0.3%, respectively.

The need for sorghum imports for most SSA countries is likely to decline, particularly for Southern African countries such as Zimbabwe (7%), Malawi (5%) and Zambia (3%). As most Southern African countries are going to get warmer in future as a result of climate change, these countries are likely to gain a comparative advantage in growing sorghum, explaining the need to reduce imports in the region. Earlier results on exports show that these countries have the potential to increase exports of sorghum, thereby suggesting that some countries will potentially export those crops where they have gained comparative advantage and import those where they have lost comparative advantage.

These results suggest there are going to be changes in intra-SSA exports and imports as a result of changes in production patterns. However, it is also interesting to look at the effect on the partner country if they can meet the demand for exports or whether their demand for imports can be satisfied. In essence, can an increase in export supply as a result of climate change from country i be met by a corresponding increase in demand for imports by country j? To answer this, the study presents results in the Appendix showing the impact of climate change on bilateral trade balances. Table A6 shows results for those countries that are currently trading in maize. In Burundi, demand for maize imports from Tanzania and Uganda may be about US$2.5 million and US$13 million, respectively, but Tanzania and Uganda's maize exports to Burundi may only be US$1.1 million and US$1.6 million, respectively. Similarly, Botswana's demand for maize imports from South Africa, Zambia and Zimbabwe is likely to be US$25.8 million, US$251,000 and US$171,000 respectively, while export supply by South Africa, Zambia and Zimbabwe may be US$36.8 million, US$1.6 million and US$226,000, respectively. Kenya's demand for maize imports from Tanzania, Uganda and South Africa may be US$840,000, US$2.5 million and US$71 million, respectively, but the supply of maize exports from Tanzania, Uganda and South Africa is likely to be

US$8.7 million, US$8.6 million and US$25 million, respectively. The findings also show that Malawi is likely to demand maize imports of about US$2.8 million and US$3.8 million from South Africa and Zambia, respectively, while export supply by South Africa and Zambia may be US$2.5 million and US$6.3 million. Zimbabwe's import demand for maize from Malawi may be US$8 million, but export supply from Malawi to Zimbabwe is likely to be US$11.5 million. Namibia's maize import demand from South Africa and Zambia may be US$20.3 million and US$160,000, respectively, while export supply from South Africa and Zambia is likely to be US$26.4 million and US$8 million. This finding highlights the fact that export supply of maize in most countries in the region is not demanded by countries in the region.

For countries currently trading in millet, a similar trend is evident (Table A7). For example, the import demand of millet for Kenya from Tanzania and Uganda may be US$900,000 and US$1.9 million, respectively, but export supply of millet to Kenya from Tanzania and Uganda is likely to be US$245,000 and US$194,000, respectively. Table A7 shows that most countries are likely to be exporters of millet in the 2050s. However, there is a mismatch in export supply and import demand. With regards to rice trading (Table A8), Benin's demand of imports of rice from Tanzania and Rwanda may be US$2.7 million and US$122,000, respectively, but Tanzania and Rwanda's export supply is likely to be US$55,000 and US$29,000, respectively. Benin's exports to Burkina Faso may be US$21,000, but import demand is likely to be US$47,000. Côte d'Ivoire's export supply to Burkina Faso, Ghana and Mali may be US$2.5 million, US$2.8 million and US$975,000, respectively, while import demand from these countries is likely to be US$3.4 million, US$166,000 and US$78,000. Ghana may demand about US$7.4 million of rice from Niger, while Niger is likely to be able to supply about US$2.3 million worth of exports to Ghana. Kenya's import demand of rice may be about US$1.4 million from Tanzania, and Tanzania's export supply is likely to be US$1.4 million. This suggest a match in terms of import demand and export supply between Kenya and Tanzania. Kenya's exports to Uganda may be US$239,000, but Uganda is likely to need to import about US$465,000 worth of rice. Mali may import US$2 million worth of rice from Senegal whilst Senegal's export supply is likely to be US$19.5 million. Rice exports to Zimbabwe from Mozambique may be US$1.4 million, while the import demand in Zimbabwe of Mozambican rice is likely to be US$2.4 million. Mozambique may import US$0.8 million of rice from South Africa and South Africa's export supply is likely to be US$0.8 million. Zimbabwe's import demand of maize from South Africa may be US$17.8 million, but South Africa will have capacity to export US$16.2 million.

Table A9 show the results of likely wheat trade in the 2050s as a result of climate change. Burundi's import demand of wheat from Kenya may be about US$7,000, but Kenya's exports are likely to be less than a thousand dollars. Botswana's import demand of wheat from South Africa may be worth about US$24.7 million, but South Africa is likely to have the capacity to supply about US$28.3 million of wheat. Kenya may have the capacity to export wheat worth about US$537,000 and US$619,000, respectively, to Rwanda and Uganda, but Rwanda and Uganda are likely to only demand imports of wheat worth US$398,000 and US$510,000, respectively. South

Africa may have the capacity to export US$22.8 million worth of wheat to Lesotho, but Lesotho is likely to demand only US$5.8 million in wheat imports. Productivity changes as a result of climate change in the 2050s are likely to make most countries in the region exporters of sorghum. However, it should be noted there are some bilateral mismatches as import demand by some countries may not be met by the export capacity of the partner country. For example, Botswana's import demand of sorghum may be US$11.7 million from South Africa, but South Africa is likely to have the capacity to supply US$10.5 million worth of exports of sorghum to Botswana. These results also highlight that there may be unallocated export potential and or unmet import needs, as the arrangement of the data implies that any change in import need or export potential can only be allocated among existing trade partners. This may emanate from data quality issues, as the study uses export and import data reported by countries, but this may not be the same with the data reported by the partner country. In addition, a huge portion of trade in cereals in SSA is informal cross-border trade, which is not recorded and may affect the reported trade amounts between countries.

Robustness checks: Future climate scenarios

The analysis in the paper is based on the predictions of the Hadley CM3 A1FI model for post-climate-change productivity estimates. Previous studies have noted that there is a high level of uncertainty regarding future changes in rainfall and temperature and, consequently, future productivity estimates (Burke et al, 2011). The future estimates are also guided by the assumptions about how the economy will evolve and emission scenarios. The aim of this section is to explore the sensitivity of the simulation results to alternative future climate scenarios.

In the GAEZ model there are 10 additional GCM-SRES combinations that are based on general circulation models, which were developed by an independent team of climatologists from several countries, and then combined with emission scenarios from the IPCC program (Costinot et al, 2016). The Hadley CM3 model under scenarios A1, A2, B1 and B2 was developed at the Hadley Centre, UK Meteorology Office; the MPI ECHAM4 under scenarios A2 and B2 was developed at the Max-Planck-Institute for Meteorology in Germany; the CSIRO Mk2 under scenarios A2, B1 and B2 was developed at Australia's Commonwealth Scientific and Industrial Research Organisation and the CCCma CGCM2 under scenarios A2 and B2 was developed by the Canadian General Circulation Model.

Tables 8 and 9 report changes in exports and imports of maize in the 2050s under alternative climate scenarios. As expected, the uncertainties in productivity estimates as a result of climate change will also lead to different results for predicted changes in exports and imports. Tables 8 and 9 make it clear that there is much uncertainty over how predicted productivity changes as a result of climate change will affect exports and imports of maize. As can be seen from the tables, most countries have the potential to increase their exports under the MPI ECHAM4 B2 scenario, and the largest declines in maize exports is under the Hadley CM3 B1 scenario. By contrast, the need to increase maize imports for most countries in SSA occurs under the Hadley CM3 B1 scenario, whereas maize imports will decrease by the largest magnitude under MPI ECHAM4 B2.

Table 8: Change in SSA maize exports in 2050s under alternative future climate scenarios (%)

Country	Hadley CM3 B1	CSIRO Mk2 A2	CSIRO Mk2 B2	Hadley CM3 B2	CSIRO Mk2 B1	MPI ECHAM4 A2	CCCma CGCM2 A2	CCCma CGCM2 B2	Hadley CM3 A2	MPI ECHAM4 B2
Benin	-0.58	0.01	-0.78	-1.43	-0.75	-0.34	-0.30	-1.42	-0.22	-1.53
Botswana	-16.13	-14.89	-15.39	-15.16	-13.59	-9.83	-6.87	-6.05	-5.14	18.01
Burkina Faso	-1.02	-2.30	-2.24	-0.06	-2.19	-0.22	-0.27	-0.79	-0.08	2.57
Burundi	1.16	0.48	-0.08	0.53	-0.34	-0.09	1.18	0.23	1.77	-0.67
Cameroon	0.91	0.01	-0.09	-0.16	-0.19	0.36	-0.06	-0.70	-0.35	0.50
Côte d'Ivoire	-2.57	1.02	-2.14	-2.58	-2.16	0.86				
Ethiopia (excludes Eritrea)	-4.45	-4.06	-4.47	-4.02	-4.57	-2.50	0.39	-0.56	0.30	9.12
Ghana	-1.61	1.11	-2.33	-1.86	-2.31	0.71	-0.32	-1.87	-0.48	-1.82
Guinea	-3.12	0.12	-1.79	-2.67	-2.12	0.30	-0.79	-5.27	-0.21	-0.75
Kenya	-3.35	-0.33	-2.10	-2.97	-1.45	-1.39	1.10	0.52	-0.05	12.35
Lesotho	-12.22	-10.56	-10.75	-10.70	-10.85	-7.47	-8.18	-7.26	-6.89	0.83
Madagascar	-1.86	0.19	-1.72	-0.20	-1.34	1.52	0.32	-1.20	1.36	0.88
Malawi	1.93	1.14	-0.83	1.79	-0.69	1.46	1.20	0.80	2.16	4.84
Mali	-14.28	-14.28	-14.16	-13.71	-14.18	-13.32	0.67	0.78	-1.99	8.21
Mozambique	-0.76	-1.24	-2.69	-0.52	-2.64	-0.30	-0.19	-1.13	0.14	1.69
Namibia	-17.01	-11.96	-12.78	-16.73	-14.14	-15.71	-0.26	-1.09	-6.06	24.65
Niger	-14.75	-16.23	-15.89	-13.73	-16.38	-12.51	-1.27	-2.31	0.62	53.11
Nigeria	-0.13	-0.61	-0.71	-0.06	-0.75	0.88	0.00	-0.55	-0.32	2.32
Rwanda	-3.98	-0.10	-3.28	-4.41	-3.93	-1.29	0.51	-3.14	0.60	-4.32
Senegal	-6.21	-2.78	-2.26	-3.11	-2.28	-2.45	-0.17	-0.01	-1.54	8.16
South Africa	-16.28	-15.29	-15.73	-14.70	-14.92	-11.32	-2.98	-5.24	-4.28	17.15
Tanzania	0.24	0.35	-1.09	0.45	-1.36	0.83	0.84	-0.55	1.28	2.60
Togo	-1.37	0.52	-1.53	-2.63	-1.65	-0.09	-0.21	-2.92	-0.42	-2.33
Uganda	-6.04	-0.60	-5.11	-6.33	-5.50	-1.21	1.21	-5.33	1.68	-4.91
Zambia	1.61	1.70	0.90	1.38	0.71	1.47	1.07	0.66	1.78	3.72
Zimbabwe	-0.63	1.19	0.21	1.33	0.85	2.54	0.05	1.08	0.47	7.81

Source: Author’s computation

Table 9: Change in SSA maize imports in 2050s under alternative future climate scenarios (%)

Country	Hadley CM3 B1	CSIRO Mk2 A2	CSIRO Mk2 B2	Hadley CM3 B2	CSIRO Mk2 B1	MPI ECHAM4 A2	CCCma CGCM2 A2	CCCma CGCM2 B2	Hadley CM3 A2	MPI ECHAM4 B2
Benin	0.49	-0.01	0.66	1.20	0.64	0.29	0.25	1.20	0.19	1.29
Botswana	13.58	12.54	12.96	12.76	11.44	8.28	5.79	5.10	4.33	-15.17
Burkina Faso	0.86	1.94	1.89	0.05	1.84	0.19	0.23	0.66	0.07	-2.16
Burundi	-0.97	-0.41	0.07	-0.45	0.29	0.08	-0.99	-0.20	-1.49	0.57
Cameroon	-0.77	-0.01	0.07	0.13	0.16	-0.31	0.05	0.59	0.29	-0.42
Côte d'Ivoire	2.16	-0.86	1.80	2.17	1.82	-0.72				
Ethiopia (excludes Eritrea)	3.75	3.42	3.76	3.38	3.85	2.11	-0.33	0.47	-0.26	-7.68
Ghana	1.35	-0.93	1.96	1.57	1.95	-0.60	0.27	1.57	0.40	1.53
Guinea	2.63	-0.10	1.50	2.25	1.78	-0.25	0.66	4.44	0.18	0.63
Kenya	2.82	0.28	1.76	2.50	1.22	1.17	-0.92	-0.44	0.04	-10.40
Lesotho	10.29	8.89	9.06	9.01	9.13	6.29	6.89	6.11	5.80	-0.70
Madagascar	1.57	-0.16	1.45	0.17	1.13	-1.28	-0.27	1.01	-1.15	-0.74
Malawi	-1.63	-0.96	0.70	-1.51	0.58	-1.23	-1.01	-0.67	-1.82	-4.08
Mali	12.02	12.02	11.92	11.54	11.94	11.22	-0.56	-0.66	1.67	-6.91
Mozambique	0.64	1.04	2.26	0.44	2.23	0.25	0.16	0.95	-0.12	-1.42
Namibia	14.33	10.07	10.76	14.09	11.91	13.23	0.22	0.92	5.10	-20.76
Niger	12.42	13.67	13.38	11.56	13.79	10.53	1.07	1.95	-0.52	-44.73
Nigeria	0.11	0.52	0.60	0.05	0.63	-0.74	0.00	0.46	0.27	-1.95
Rwanda	3.35	0.08	2.76	3.71	3.31	1.09	-0.43	2.64	-0.51	3.64
Senegal	5.23	2.34	1.91	2.62	1.92	2.06	0.14	0.01	1.30	-6.87
South Africa	13.71	12.88	13.24	12.38	12.56	9.53	2.51	4.42	3.60	-14.44
Tanzania	-0.20	-0.30	0.92	-0.38	1.14	-0.70	-0.70	0.47	-1.08	-2.19
Togo	1.15	-0.44	1.29	2.21	1.39	0.08	0.18	2.46	0.35	1.96
Uganda	5.08	0.50	4.31	5.33	4.63	1.02	-1.02	4.48	-1.42	4.13
Zambia	-1.36	-1.43	-0.76	-1.16	-0.60	-1.23	-0.90	-0.55	-1.50	-3.13
Zimbabwe	0.53	-1.01	-0.17	-1.12	-0.71	-2.14	-0.04	-0.91	-0.40	-6.58

Source: Author’s computation

5. Conclusion and policy recommendations

The climate is changing and its impact on agricultural production in SSA countries is likely to be negative, which may have implications for food security and poverty for the majority of the population in the region. However, although there are challenges associated with a changing climate, there are also opportunities as countries can take advantage of changing comparative advantages to explore new trade potentials within the region. As climate is an important input in agricultural production, differential changes in rainfall and temperature across countries is likely to affect productivity. Some countries are expected to experience an increase in rainfall, which may result in increased productivity for those countries. Consequently, climate change is expected to affect patterns of production differently across countries in SSA, and may have implications for patterns of trade.

Using a combination of climate change scenarios data from FAO-GAEZ, production data from FAOSTAT and trade data from UN Comtrade, this study explored the impact of climate change on agricultural trade, particularly trade in major cereals, within sub-Saharan Africa. The empirical results show that by the 2050s, climate change may lead to the region increasing its need to import maize and wheat, and also increasing its potential to export millet, sorghum and rice. Few countries in the region will have the potential to increase their exports to fellow SSA countries. For example, maize exports are likely to decline for the majority of SSA countries, but countries such as Burundi, Cameroon, Côte d'Ivoire, Ghana, Guinea, Madagascar, Malawi, Rwanda, Tanzania, Togo, Uganda and Zambia are likely to have the potential to increase maize exports. The results suggest different countries gaining comparative advantages in different cereal crops, pointing to the importance of trade as a country can export a crop where they have gained a comparative advantage and import a crop where they have experienced a decline in comparative advantage.

The empirical results showing the effect on bilateral trade, that is, if the partner country can meet the demand for exports or if their demand for imports can be satisfied, suggest that there may not be export capacity to meet the demand for cereal imports from within the continent, and in other instances, export supply of cereal crops in some countries in the region may not be demanded by countries in the region as the change in import demand is low compared to the change in exports. This mismatch suggests that there is a need to diversify sources of imports and destination of exports to create a balance, which may be achieved by deeply integrating regional and international cereal markets.

To mitigate the adverse effects of climate change on food security, the results from this study suggest that trade flows are likely to be important in strengthening the resilience of African food systems in the face of shocks emanating from climate change. Delivering food from surplus areas to deficit areas is likely to be important for improving availability and reducing food price volatility from climate shocks, hence the need to improve the movement of food products across borders. Policies to be adopted may include improving trade facilitation by removing complex regulatory environments and improving transportation infrastructure, reducing intra-SSA tariffs, avoiding trade policy uncertainty and removing export and import bans. The results of the study have implications for improving food security in the face of climate shocks, as the physical availability of food through trade is also an important component of food security. In addition, as climate change will alter specialization patterns, countries are encouraged to concentrate on producing those cereal crops where they have gained comparative advantage as a result of climate change instead of traditional crops they have been used to growing.

This study did not tease out the general equilibrium effects of climate change; it is expected that changes in climate are likely to have an effect on the whole economy through linkages between the agricultural sector and other sectors of the economy. This is likely to underestimate or overestimate the effects of climate change reported in this study. Future studies should consider incorporating these general equilibrium effects in examining whether climate change will affect trade patterns. Another important concern is that the study did not address discrepancies in bilateral data, especially as informal trade in grains is common. Future studies could consider using a linear programming approach to allocating the increases in export potential across the countries with increasing import needs.

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Appendix

Table A1: SSA countries in the sample

Angola
Benin
Botswana
Burkina Faso
Burundi
Cameroon
Cape Verde
Central African Republic
Chad
Comoros
Congo
Côte d’Ivoire
Djibouti
Eritrea
Eswatini
Ethiopia
Gabon
Ghana
Guinea
Kenya
Lesotho
Liberia
Madagascar
Malawi
Mali
Mauritania
Mauritius
Mozambique
Namibia
Niger
Nigeria
Rwanda
Sierra Leone
Somalia
South Africa
Togo
Uganda
United Republic of Tanzania
Zambia
Zimbabwe

Table A2: Projected percentage changes in wheat productivity by 2050s

	GCM-SRES combinations										
Country	Hadley CM3 A1F1	Hadley CM3 B1	CSIRO Mk2 A2	CSIRO Mk2 B2	Hadley CM3 B2	CSIRO Mk2 B1	MPI ECHAM4 A2	CCCma CGCM2 A2	CCCma CGCM2 B2	Hadley CM3 A2	MPI ECHAM4 B2
Angola	-52.10	-68.57	-71.09	-36.76	-34.82	-47.66	-41.86	-37.66	-32.09	-26.81	-23.04
Burundi	-15.71	-77.78	-78.28	-8.00	-8.54	-14.00	-9.44	-8.82	-3.94	-7.25	-10.29
Botswana	-100.00	-96.91	-98.37	-21.78	-21.67	-35.07	-28.55	-32.34	-16.38	-23.73	-29.76
Cameroon	0.93	-98.76	-98.86	-3.64	3.13	-1.21	-0.03	3.08	-1.78	-3.70	-4.32
Democratic Republic of the Congo	-34.78	-95.41	-95.51	-16.39	-17.69	-31.04	-27.84	-23.74	-6.49	-13.89	-13.28
Congo. Rep.	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00
Eritrea	-6.92	-97.13	-97.90	-3.36	-10.71	-16.50	-12.22	-4.54	-20.34	1.38	0.81
Ethiopia	-4.75	-78.50	-78.88	-1.90	-4.83	-6.27	-6.58	-3.23	-6.17	-0.72	2.02
Guinea	-100.00	-99.97	-99.97	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00
Equatorial Guinea	-23.40	-100.00	-100.00	-19.73	-15.13	-26.19	-19.23	-15.53	-26.91	-28.75	-31.97
Kenya	-9.35	-87.15	-86.90	-7.29	-4.02	-12.19	-10.64	-8.72	-4.21	-3.64	-3.04
Lesotho	-1.25	-22.43	-21.54	12.05	17.15	5.36	6.83	-0.48	2.70	8.23	0.59
Madagascar	-8.66	-62.85	-64.11	0.23	-0.51	-5.38	-4.01	-4.91	-6.35	-3.93	-1.94
Mozambique	-27.09	-88.48	-90.11	-21.70	1.32	-24.18	-13.79	-18.55	1.08	-12.02	6.66
Malawi	-32.30	-49.96	-50.70	-22.22	-20.57	-36.68	-30.37	-32.03	-5.51	-12.70	-13.23
Namibia	-11.74	-83.37	-83.60	-16.68	-25.82	-18.21	-18.52	-12.16	-21.43	-6.39	-5.71
Nigeria	13.30	-99.99	-99.99	10.04	20.28	13.42	11.95	15.29	17.44	9.44	13.53
Rwanda	-4.91	-53.49	-52.72	-5.89	-10.88	-4.54	-3.36	-1.33	-0.72	-4.03	-3.01
South Sudan	3.72	-99.93	-99.93	-9.26	5.54	-6.12	-5.19	-6.86	-7.47	-3.53	-4.62
Swaziland	-38.61	-20.12	-20.94	-17.80	-24.52	-35.54	-38.80	-39.76	-28.96	-35.00	-31.42
Tanzania	-10.15	-82.68	-83.13	1.59	-3.68	-15.64	-8.56	-5.42	8.45	-1.36	1.12
Uganda	23.27	-96.72	-96.70	16.63	7.79	22.87	17.30	17.66	18.30	5.86	15.90
South Africa	-13.99	-67.67	-65.13	-11.13	-22.79	-16.90	-16.08	-11.69	-13.05	-13.90	-18.20
Zambia	-53.86	-45.10	-47.94	-33.75	-27.52	-51.93	-43.31	-42.30	-18.08	-26.57	-27.34
Zimbabwe	-35.18	-48.55	-47.02	-19.70	-10.43	-31.45	-18.07	-31.91	-10.25	-13.99	-10.36

Source: Author's computation based on data from FAO-GAEZ

Table A3: Projected percentage changes in rice productivity by 2050s

	GCM-SRES combinations										
Country	**Hadley CM3 A1F1**	**Hadley CM3 B1**	**CSIRO Mk2 A2**	**CSIRO Mk2 B2**	**Hadley CM3 B2**	**CSIRO Mk2 B1**	**MPI ECHAM4 A2**	**CCCma CGCM2 A2**	**CCCma CGCM2 B2**	**Hadley CM3 A2**	**MPI ECHAM4 B2**
Angola	-50.06	-5.53	-36.25	-27.76	-35.76	-39.65	11.97	14.39	11.97	27.32	8.29
Burundi	61.59	62.64	54.66	46.20	43.80	54.90	48.99	47.25	44.45	43.42	54.94
Benin	-5.80	7.88	-0.47	8.22	-6.91	0.00	-15.14	-12.74	-5.14	-0.91	-18.21
Burkina Faso	-10.97	14.99	-4.50	11.79	-22.99	3.26	-41.83	-40.67	-2.79	6.32	-40.84
Central African Republic	-3.51	-1.18	-0.55	-0.70	-4.80	-2.26	-5.93	-4.95	-5.93	-7.34	-5.65
Côte d'Ivoire	-10.95	1.12	-10.40	2.98	-2.10	-1.98	-9.59	-9.74	5.97	-1.31	-14.24
Cameroon	0.25	1.77	0.89	1.46	-1.16	0.71	0.15	0.40	-0.52	-1.50	0.20
Democratic Republic of the Congo	-5.72	-0.50	-3.39	-0.54	-2.80	-3.86	0.61	1.34	0.55	-1.58	-0.34
Congo. Rep.	-6.77	-3.05	-3.39	-1.88	-2.21	-3.70	-1.85	-1.61	-2.21	-2.69	-1.63
Ethiopia	47.65	55.83	52.65	47.47	16.45	57.85	35.97	34.88	21.27	19.06	32.98
Gabon	-1.17	-2.67	-2.02	-0.68	-0.37	-0.96	-1.04	-0.89	-2.46	-2.79	-0.82
Ghana	-8.91	0.91	-8.14	2.30	-4.61	-1.51	-9.82	-9.73	0.00	-1.64	-15.92
Guinea	-6.67	1.74	-9.64	7.15	5.13	-3.37	1.35	1.29	11.54	-0.25	-4.27
Gambia	-40.14	-14.56	4.00	12.49	-35.28	-42.40	-7.09	-3.75	23.49	20.27	-19.21
Guinea-Bissau	-11.76	19.71	-3.97	29.42	16.43	-14.97	23.65	25.83	33.47	0.38	-6.37
Equatorial Guinea	7.07	-4.38	2.03	0.76	5.80	2.85	3.50	2.00	-3.03	-4.23	2.87
Kenya	128.30	103.01	122.48	25.04	26.40	7.96	95.56	138.74	64.23	41.96	144.58
Liberia	-5.20	-3.26	-3.23	-3.04	-3.20	-5.03	-1.95	-1.77	-2.99	-3.44	-1.64
Madagascar	-12.43	10.50	5.14	-0.24	-0.85	7.09	15.38	14.95	3.04	0.82	14.36
Mali	-26.30	3.43	-0.16	-7.75	-22.96	-23.97	-27.49	-25.18	25.46	20.59	-27.97
Mozambique	-31.75	2.24	5.56	-11.67	-27.73	-23.42	19.66	19.49	-1.78	-1.35	17.91
Malawi	-14.83	2.46	11.25	-7.33	-13.36	-16.27	36.40	34.07	6.95	3.20	25.84
Niger	85.75	402.16	274.95	424.47	-100.00	369.60	-100.00	-100.00	-93.08	-4.54	-100.00

Continued

Table A3 Contd.

Country	GCM-SRES- combinations										
	Hadley CM3 A1F1	Hadley CM3 B1	CSIRO Mk2 A2	CSIRO Mk2 B2	Hadley CM3 B2	CSIRO Mk2 B1	MPI ECHAM4 A2	CCCma CGCM2 A2	CCCma CGCM2 B2	Hadley CM3 A2	MPI ECHAM4 B2
Rwanda	277.87	340.67	315.68	317.38	194.34	170.69	281.40	286.94	286.81	98.80	334.78
South Sudan	-15.25	16.13	6.76	-8.60	-21.27	-19.72	-25.02	-22.49	-4.58	-21.15	-26.35
Senegal	-40.37	-9.31	-7.31	-0.68	-26.92	-39.25	-14.48	-13.01	22.53	16.35	-25.96
Sierra Leone	-4.07	-4.03	-5.01	-2.18	-2.52	-2.91	-1.98	-1.79	-1.88	-2.25	-1.79
Swaziland	50.67	286.40	330.97	27.54	-77.16	0.67	-45.17	69.73	-8.96	180.58	-22.64
Chad	-12.29	14.52	44.12	6.60	-17.63	-5.79	-20.59	-21.16	-22.43	-20.47	-22.41
Togo	-8.60	4.75	-5.66	5.89	-4.81	-1.09	-12.78	-11.92	0.68	-2.33	-19.68
Tanzania	11.33	0.57	17.30	5.71	4.10	-5.26	43.65	49.40	12.92	4.92	53.70
Uganda	-5.04	23.26	4.23	-7.53	-15.55	-20.48	6.42	9.27	8.36	-12.90	3.52
South Africa	379.91	511.81	630.92	149.09	-28.06	15.24	-57.84	8.41	-37.48	210.65	-49.38
Zambia	-18.65	2.60	3.49	-3.33	-11.08	-16.46	9.41	14.64	0.38	-7.11	4.32
Zimbabwe	-41.94	59.88	114.23	-3.96	-51.31	-38.72	51.00	70.30	2.87	-20.33	80.88

Source: Author’s computation based on data from FAO-GAEZ

Table A4: Projected percentage changes in millet productivity by 2050s

	GCM-SRES combinations										
Country	**Hadley CM3 A1F1**	**Hadley CM3 B1**	**CSIRO Mk2 A2**	**CSIRO Mk2 B2**	**Hadley CM3 B2**	**CSIRO Mk2 B1**	**MPI ECHAM4 A2**	**CCCma CGCM2 A2**	**CCCma CGCM2 B2**	**Hadley CM3 A2**	**MPI ECHAM4 B2**
Angola	38.29	36.52	26.28	22.77	37.16	31.83	18.43	20.92	28.67	32.06	35.96
Burundi	97.31	48.28	36.94	27.81	88.05	47.28	40.22	65.20	53.42	110.13	111.39
Benin	1.83	0.42	1.93	0.77	1.04	7.49	-9.42	-1.17	-11.51	-8.39	-0.93
Burkina Faso	1.25	0.77	-2.99	-2.51	0.36	-2.99	-2.82	-0.56	-1.09	-0.20	0.51
Botswana	117.64	54.80	-34.65	-12.53	-4.66	-30.78	25.88	42.67	123.27	125.76	126.78
Central African Republic	51.64	-1.32	17.31	11.22	-2.70	18.80	4.15	10.31	46.45	48.25	50.57
Côte d'Ivoire	63.69	26.05	-22.75	-24.97	-1.51	25.86	-57.34	-2.23			
Cameroon	159.20	9.83	3.95	1.22	-3.16	7.62	-5.10	6.16	181.89	198.04	154.66
Democratic Republic of the Congo	200.36	29.42	-1.47	-10.47	48.39	13.35	-16.21	4.19	160.27	159.89	170.16
Congo. Rep.	16091.17	461.49	250.28	281.70	2384.12	309.31	-10.00	-35.35			
Eritrea	133.94	30.95	-5.33	-27.36	26.72	-38.18	48.16	49.58	143.97	130.16	127.73
Ethiopia	52.84	21.10	0.75	0.04	27.79	7.81	-1.55	6.25	47.28	50.60	51.22
Ghana	22.39	13.66	-19.52	-20.60	-3.28	21.66	-20.26	-1.36	9.85	8.26	32.42
Guinea	30.23	13.72	-21.58	-25.82	1.18	3.91	-64.88	-4.94	0.20	-6.19	4.65
Gambia	0.83	-0.03	0.13	0.37	0.85	1.18	-1.25	-1.05	-1.32	-0.47	1.03
Guinea-Bissau	3.56	3.20	-61.67	-64.21	4.25	3.79	-70.22	0.33	-46.79	-52.57	-32.79
Kenya	27.42	-3.99	0.86	-0.92	18.65	9.43	-3.01	-0.92	32.80	29.70	26.55
Madagascar	93.96	22.88	-24.94	-19.90	22.20	1.52	-11.18	13.06	48.77	63.47	48.32
Mali	166.40	1.45	-8.30	-9.23	-5.49	-8.80	-5.84	1.05	164.81	178.12	165.59
Mozambique	31.49	7.24	-21.34	-21.95	22.08	-7.94	-7.85	4.22	5.39	14.59	22.90
Mauritania	674.00	-7.27	-45.71	-53.11	-67.79	-56.92	-28.02	-2.52	671.49	738.75	675.00
Malawi	42.20	18.74	-20.28	-18.36	39.22	5.00	9.98	17.45	26.25	31.41	35.15
Namibia	152.99	-20.97	16.46	-1.68	-23.63	28.70	9.63	20.45	196.08	155.40	177.55
Niger	193.43	18.67	-18.59	-29.56	5.25	-19.63	4.77	16.25	217.30	197.67	177.83
Nigeria	12.44	3.36	1.36	0.37	-0.83	2.29	-1.19	1.53	13.77	14.41	13.72
Rwanda	571.94	184.54	1.65	-51.78	336.59	234.50	21.73	271.93	337.38	264.07	290.16

Continued

Country	GCM-SRES combinations										
	Hadley CM3 A1F1	**Hadley CM3 B1**	**CSIRO Mk2 A2**	**CSIRO Mk2 B2**	**Hadley CM3 B2**	**CSIRO Mk2 B1**	**MPI ECHAM4 A2**	**CCCma CGCM2 A2**	**CCCma CGCM2 B2**	**Hadley CM3 A2**	**MPI ECHAM4 B2**
South Sudan	6.26	-8.04	-5.79	-7.13	2.95	2.79	-9.87	2.22	-10.81	-0.75	6.17
Senegal	4.90	-3.34	-3.55	-3.71	-16.51	-3.83	-3.13	5.71	-0.94	1.26	5.10
Sierra Leone	105.11	37.07	3.81	-11.17	-27.56	6.13	-58.06	-54.70	101.37	55.81	98.35
Somalia	295.90	66.86	-47.44	24.32	173.77	2.58	-8.25	24.56	423.16	321.19	300.52
Swaziland	158.53	68.95	74.42	60.60	111.64	74.80	66.69	70.80	128.04	164.27	166.70
Chad	86.35	7.99	-4.35	-4.97	4.83	-5.82	-1.11	3.67	79.44	84.83	83.78
Togo	5.94	3.31	-6.06	-8.52	-2.05	14.58	-26.94	-0.03	-13.90	-16.34	-5.15
Tanzania	27.00	14.67	-11.67	-16.52	27.47	-0.77	-2.56	11.12	23.40	23.57	21.04
Uganda	22.70	-5.49	-61.16	-66.10	28.92	0.21	-65.83	20.89	-12.01	27.97	28.85
South Africa	1910.58	494.37	76.89	96.35	220.38	92.94	135.55	244.27	1821.27	1880.19	1733.55
Zambia	21.39	10.73	-0.07	-3.12	19.85	12.94	2.03	10.12	6.52	8.09	13.51
Zimbabwe	53.11	44.07	33.92	35.02	47.35	37.05	36.16	42.40	47.70	49.90	50.78

Source: Author's computation based on data from FAO-GAEZ (2019)

Table A5: Projected percentage changes in sorghum productivity by 2050s

	GCM-SRES combinations										
Country	**Hadley CM3 A1F1**	**Hadley CM3 B1**	**CSIRO Mk2 A2**	**CSIRO Mk2 B2**	**Hadley CM3 B2**	**CSIRO Mk2 B1**	**MPI ECHAM4 A2**	**CCCma CGCM2 A2**	**CCCma CGCM2 B2**	**Hadley CM3 A2**	**MPI ECHAM4 B2**
Angola	7.96	6.73	9.76	10.84	11.11	7.18	16.49	11.61	7.75	9.81	
Burundi	13.14	3.35	16.86	-17.28	-1.53	-1.90	1.69	11.12	10.70	13.39	0.92
Benin	-0.95	-8.87	-0.74	-12.72	-1.35	-4.10	1.87	-1.60	-10.01	-3.67	-3.87
Burkina Faso	-1.16	-4.43	-1.41	-0.86	-1.49	-5.02	-5.10	-2.06	-0.53	-1.96	-5.37
Botswana	-10.98	-47.63	-60.26	-2.12	-18.04	-0.10	5.52	-15.56	-4.17	-4.90	0.97
Central African Republic	2.13	-0.95	-3.69	-8.64	-3.53	4.21	8.05	3.82	-3.99	10.46	6.93
Côte d'Ivoire	7.60	-34.99	-6.81								
Cameroon	4.79	-14.51	-9.09	-5.34	1.53	-0.36	1.43	3.53	-0.68	9.75	0.33
Democratic Republic of the Congo	20.69	-8.89	15.91	-6.07	7.28	-4.55	5.84	0.21	3.21	14.52	-0.71
Congo. Rep.	39.66	-29.74	18.00	5.31	5.73	3.16	4.32	1.04	13.00	25.77	3.05
Eritrea	7.33	-28.92	-38.53	16.62	6.51	-2.51	-2.05	5.73	7.49	2.95	-2.68
Ethiopia	0.11	-16.83	-1.79	-3.39	4.28	2.63	9.14	9.15	-8.42	-5.13	3.14
Gabon	5.96	-68.57	-40.90	-0.39	4.40	3.63	3.27	0.44	3.19	-0.44	0.85
Ghana	7.09	-13.19	-3.23	-14.09	6.60	-13.39	11.36	-1.78	-12.88	-9.85	-13.17
Guinea	4.54	-40.65	-1.47	-17.73	6.61	-16.03	0.94	-5.56	-23.81	-23.65	-13.66
Gambia	-1.21	-2.28	-0.70	-2.63	-2.30	-1.10	-0.60	-2.25	-1.31	-0.47	-1.33
Guinea-Bissau	-1.13	-49.03	-0.60	-43.99	-2.50	-43.18	0.05	-2.04	-52.96	-32.10	-41.45
Equatorial Guinea	0.39	-100.00	-100.00	-0.89	20.14	-9.57	-8.03	-10.33	1.09	11.62	-9.34
Kenya	1.02	-13.32	-3.14	-4.94	3.95	-4.52	2.13	4.16	-7.31	-8.27	-5.65
Liberia	-9.00	-62.33	-75.12	-4.58	8.00	-2.55	1.63	-4.57	-4.86	-9.42	1.18
Lesotho	-51.43	-62.58	-59.63	-48.51	-41.69	-50.78	-51.64	-52.50	-52.64	-53.82	-54.01
Madagascar	19.69	-21.50	-1.91	-7.03	8.61	-9.75	4.19	7.72	-2.78	-11.91	-13.42
Mali	-11.65	-66.32	-68.02	-4.11	-2.94	-2.00	-3.81	0.33	-3.36	-10.21	-3.65
Mozambique	10.42	-10.69	6.45	-2.12	-0.54	-16.45	-7.26	0.04	3.56	7.78	-15.71
Mauritania	-14.88	-91.41	-96.37	-6.12	-1.31	1.92	-2.75	8.73	-5.17	-13.43	-1.56
Malawi	15.68	3.58	14.91	10.82	8.66	-12.67	3.44	7.27	12.28	13.24	-14.19
Namibia	-11.19	-57.43	-72.42	0.35	-6.49	3.29	9.48	8.51	-13.48	-3.91	6.96

Continued

Table A 5 Continued.

	GCM-SRES combinations										
Country	**Hadley CM3 A1F1**	**Hadley CM3 B1**	**CSIRO Mk2 A2**	**CSIRO Mk2 B2**	**Hadley CM3 B2**	**CSIRO Mk2 B1**	**MPI ECHAM4 A2**	**CCCma CGCM2 A2**	**CCCma CGCM2 B2**	**Hadley CM3 A2**	**MPI ECHAM4 B2**
Niger	-2.84	-68.88	-67.87	8.59	3.88	-6.78	-10.45	-5.66	0.72	-5.83	-8.47
Nigeria	0.45	-2.28	-1.85	-2.26	3.00	-2.90	-1.96	0.45	-1.56	1.14	-2.56
Rwanda	9.39	-19.85	10.58	-33.65	-8.94	-28.83	2.05	10.73	-31.57	-29.38	-23.31
South Sudan	-0.23	-9.60	-1.29	-10.82	-4.77	-8.78	-0.91	-0.46	-8.20	-2.99	-8.35
Senegal	-3.60	-6.49	-23.92	-6.23	-5.62	-2.92	-2.55	-1.44	-2.13	-1.51	-3.14
Sierra Leone	-4.46	-18.40	-9.00	0.32	13.19	-4.00	2.20	-18.16	-18.27	-8.19	0.68
Somalia	-31.71	-82.00	-50.80	-4.49	-6.77	-5.75	0.18	4.26	-24.93	-29.22	2.26
Swaziland	20.84	0.36	13.27	10.14	14.42	7.83	8.77	11.75	14.49	7.47	7.65
Chad	-4.90	-48.78	-47.36	-5.94	-1.88	-5.01	-3.46	-5.80	-3.48	-4.98	-3.92
Togo	1.90	-19.23	-3.29	-19.15	1.01	-7.88	9.52	-0.74	-18.91	-8.88	-6.64
Tanzania	9.83	-4.53	10.25	3.48	5.16	-12.69	-2.44	4.65	3.59	1.96	-10.29
Uganda	6.94	-37.84	13.33	-35.13	-7.46	-37.76	-3.02	10.15	-42.86	-40.94	-35.02
South Africa	-15.49	-62.71	-65.54	-14.37	-19.89	-20.12	-22.22	-13.86	-16.48	-21.99	-23.45
Zambia	10.24	-0.34	10.08	4.51	7.55	-1.35	8.44	5.96	4.70	7.43	0.32
Zimbabwe											
	22.44	13.48	20.07	24.36	25.18	20.25	24.15	17.55	23.46	21.61	20.16

Source: Author's computation based on data from FAO-GAEZ (2019)

Table A6: Maize trade flow matrix in 2050s (US$'000)

	AGO	BDI	BEN	BFA	BWA	CAF	CIV	CMR	COG	COM	CPV	DJI	ERI	ETH	GAB	GHA	GIN	GMB	GNB	KEN	LSO	MDG	MLI	MOZ	MRT	MUS	MWI	NAM	NER	NGA	RWA	SDN	SEN	SLE	SUD	SWZ	SYC	TCD	TGO	TZA	UGA	ZAF	ZMB	ZWE
BDI																															190									-2498	-12951			
BEN								8	2						2														6579										145					
BFA			84				79	136	58							275							79						3459				11	109					339					
BWA	100																							15		3		-3								5					0	-25791	-251	-171
CIV			35	53					1						2	180	19						108		13				193				603						7					
CMR						0			14					2	2																							856						
COG																																												
ERI																																												
ETH												88								17		373										1780								860				
GAB																																												
GHA				296			-43		44			6						0											1477	2				0					22					
GIN																														2														
GMB																																												
GNB																																												
KEN		19						3		1			209	30												0	240				742	583					0			-840	-2475	-70635	2377	4
LSO																					0																					-15818		
MDG										32																18											228							
MLI				-116			10								2	5	27								124				202				-183						3					
MOZ	316				43			31	20											1543		4					1211	2				614				1				287		-15625	24	1915
MWI	136				388			387	24											5005				-2809						0				0						-192	391	-2732	-3817	11491
NAM	228				4				9																																	-20288	-159	0
NER				53												-145														-309														
NGA																																						0				-2900		
RWA		366																		-1327																				-698	-9291			
SEN				9			0		4		1067					9	37	11	14				202		8																			
TGO	3		-130			677	10								14	1306													3117															
TZA		1119						1	9	4										8670		124		-11			1863				576				410		140				-3487	-1258	1098	1537
UGA		1569							18				14							8581							64				1593	1315	4		7148					704		-221	5215	
ZAF	2825	0	570	22	36836	98	441	706	53	8	755	23	7	455	14	917	504	9		25308	26552	842	81	14977	1415	167	2486	26424	15	49	1	76	654	8	1	21834	148	119	196	1796	16		3012	53815
ZMB	169	873			1572			291	7							10				6625	115	97		1464		10	6293	7954		2	2885		0	0		699				4281	-454	-634		52857
ZWE	72		0		226			37	0				0	19		0				-710	15		0	-3041		6	-7957	0		12					1	132				18	18	-35031	-56946	

Source: Author's computation

Notes: Values represent net trade balances (positive values indicate exports, negative values indicate imports)

Table A7: Millet trade flow matrix in 2050s (US$'000)

	AGO	BDI	BEN	BFA	BWA	CAF	CIV	CMR	COG	COM	CPV	DJI	ERI	ETH	GAB	GHA	GIN	GMB	GNB	KEN	LSO	MDG	MLI	MOZ	MRT	MUS	MWI	NAM	NER	NGA	RWA	SDN	SEN	SLE	SUD	SWZ	SYC	TCD	TGO	TZA	UGA	ZAF	ZMB	ZWE
BDI																																												
BEN																																												
BFA							15																						365	84														
BWA																												0														7	18	8
CIV				9					2						13	55																												
CMR									3						1																													
COG																																												
ERI																																												
ETH												57								185																								
GAB																																												
GHA							47																																0			1		
GIN																																												
GMB																																												
GNB																																												
KEN													104																		0	2								-9	-1955	74		
LSO																																												
MDG																																												
MLI	2			1011			630								3	10									1327				847				29						2					
MOZ																																												
MWI																				6																				14				
NAM	3																																									5	0	
NER							11									23														-1923														
NGA																																												
RWA		-1																																										
SEN							58									105		14																										
TGO																																												
TZA		7																		194							1				14										-2295	88		
UGA		2																		245											1	10			38					-15				
ZAF	679				107			45	3							1				0	154	0		25		2	16	325	656			1	54			4	2			-664			11	288
ZMB		0			0															18								3												1				
ZWE	16				8															0				5																		47		

Source: Author's computation

Notes: Values represent net trade balances (positive values indicate exports, negative values indicate imports)

Table A8: Rice trade flow matrix in 2050s (US$'000)

	AGO	BDI	BEN	BFA	BWA	CAF	CIV	CMR	COG	COM	CPV	DJI	ERI	ETH	GAB	GHA	GIN	GMB	GNB	KEN	LSO	MDG	MLI	MOZ	MRT	MUS	MWI	NAM	NER	NGA	RWA	SDN	SEN	SLE	SUD	SWZ	SYC	TCD	TGO	TZA	UGA	ZAF	ZMB	ZWE
BDI																															122									-2709				
BEN				21					122						6	-83													19	18026				1762				1887	-1044					
BFA			-47				-3404		54							3							87						215	545	0		1656	1677										
BWA																																												
CIV			98	2520				317	3		627				1	2792	51						975						236	31	0		139						85					0
CMR						817			221						114															551	0							1206						
COG	110																																											
ERI																																												
ETH												6																																
GAB			0			7	3	62																															0					
GHA			8	11	0		-166																						-7384	0				1					-646			-16		0
GIN	0																																42	127										
GMB																			11				59																					
GNB																																	-5061											
KEN		0							3	8		222	8	8										73			8	48		1439	15	109					6			-1407	239		0	1
LSO																																												
MDG	3									16																-331																		
MLI				-85			-78										111	14							27				410				-2007											
MOZ	19								67																		49													0		-754	200	1359
MWI	19				0				15					1						20				11								0	0			0				22		454	402	320
NAM																																												
NER			-1376													12							3							-178									-8					
NGA																2364																							369			181		
RWA		29																																						-5683	-1089			
SEN				47			1209	0	39		116				222		532	760	3609				19454		1288					1				3264								0	0	
TGO			194	139			18		50		125				36	-103	142						714		40				65	55				62										
TZA	1	55			0			22	839	550										1419				7			89			0	2175	15			1						1376	-5	122	3
UGA		1075							44											-465							0				1007	906	25		1927								8	
ZAF	878	0	1	0	41754		7	0	44	13		4	2	7	0	26	25	11		64	10305	93	-2	881	0	3	110	9219		597	0	0	1	1	2	27197	11	0	1	29	15		2512	16153
ZMB	20	84			6				19									1									-315													115		-790		-54
ZWE					0																			-2391			7															-17778	145	

Source: Author's computation

Notes: Values represent net trade balances (positive values indicate exports, negative values indicate imports)

Table A9: Wheat trade flow matrix 2050s (US$'000)

	AGO	BDI	BEN	BFA	BWA	CAF	CIV	CMR	COG	COM	CPV	DJI	ERI	ETH	GAB	GHA	GIN	GMB	GNB	KEN	LSO	MDG	MLI	MOZ	MRT	MUS	MWI	NAM	NER	NGA	RWA	SDN	SEN	SLE	SUD	SWZ	SYC	TCD	TGO	TZA	UGA	ZAF	ZMB	ZWE
BDI																				-7											85													
BEN																																												
BFA																																												
BWA																												0														-24691	0	10
CIV																																												
CMR						1									0																													
COG																																												
ERI																																												
ETH												-517											0									5			35940									
GAB																																												
GHA																																												
GIN																							1562											0										
GMB																																												
GNB																																												
KEN		0											31																		537	9								-119	619	5		
LSO																																										-5706		
MDG																																												
MLI																																												
MOZ																											1732									334				0		-1883	392	386
MWI																																										235	20	132
NAM	3				2																																					-6048	86	
NER																																												
NGA	0															17116																										4030		
RWA		1																		-398																					-323			
SEN																																												
TGO																																												
TZA		464							4551	15		5								-5			32	0			465				1073						13593				5117		63	61
UGA		233							6											-510											401	48								-8				
ZAF	3	443	0		28268			0	1							0	0			790	22770		0	952		277	826	6885		0	0			0	73	8233	8			1	1		11617	7837
ZMB	7				47															4						8	17	1														-8662		1150
ZWE	2																							-3961			1113																1246	

Source: Author's computation

Notes: Values represent net trade balances (positive values indicate exports, negative values indicate imports)

Table A10: Sorghum trade flow matrix in 2050s (US$'000)

	AGO	BDI	BEN	BFA	BWA	CAF	CIV	CMR	COG	COM	CPV	DJI	ERI	ETH	GAB	GHA	GIN	GMB	GNB	KEN	LSO	MDG	MLI	MOZ	MRT	MUS	MWI	NAM	NER	NGA	RWA	SDN	SEN	SLE	SUD	SWZ	SYC	TCD	TGO	TZA	UGA	ZAF	ZMB	ZWE
BDI																															8									-40				
BEN																																												
BFA			1				37									14							1467						693	83			8					245						
BWA																0								84				-2												195		-11646	57	341
CIV				2											7	2							-480						0															
CMR																																												
COG																																												
ERI																																-971												
ETH												120																	17			135			1509									
GAB																																												
GHA							5																																					
GIN								1																																				
GMB																																	24											
GNB																																												
KEN												13	18	25								182					1				106	488								-211	-313	6		
LSO																																										-357		
MDG																																												
MLI							7																		13				351				1						0					
MOZ																											0															41		104
MWI					24																			1										0		0						45	14	159
NAM	10																																									-107		
NER																						1								-800														
NGA																																												
RWA		-20																																						-91	-1912			
SEN							14																																					
TGO															10															0														
TZA										0										407											43										127		9	
UGA		3											66							-121											56	232			76					-59		-469		
ZAF	87				10502			12								0				110	138	0		54		0	3	53	212	40		141			134	1002	0			221	194		13	254
ZMB	2				98															71							37	9												30		-448		10
ZWE	11				60																			-3			104	5							0					72		-4954	399	

Source: Author's computation

Notes: Values represent net trade balances (positive values indicate exports, negative values indicate imports)

Table A11: Change in SSA exports of cereals in 2050s (%)

Country	Maize	Millet	Rice	Wheat	Sorghum
Benin	-0.15		-1.12		
Botswana	-9.98	28.79		-10.16	-2.73
Burkina Faso	-0.34	0.31	-2.11		-0.29
Burundi	1.05		11.86	-1.60	3.26
Cameroon	0.15	38.97	0.05	0.09	
Congo. Rep.			-1.30		
Côte d'Ivoire	0.19	15.59	-2.11		1.89
Eritrea					1.82
Ethiopia (excludes Eritrea)	-1.61	12.93	9.18	-0.48	0.03
Gabon			-0.22		
The Gambia			-7.73		-0.30
Ghana	0.50	5.48	-1.72		1.76
Guinea	0.08		-1.29	-10.16	1.13
Guinea-Bissau			-2.27		
Kenya	-0.58	6.71	24.71	-0.95	0.25
Lesotho	-5.71			-0.13	-12.77
Madagascar	0.89		-2.39		
Malawi	1.34	10.33	-2.86	-3.28	3.89
Mali	-8.21	40.73	-5.07		-2.89
Mozambique	-0.47		-6.12	-2.75	2.59
Namibia	-10.80	37.45		-1.19	-2.78
Niger	-7.75	47.35	16.52		-0.70
Nigeria	-0.04		-0.53	1.35	
Rwanda	0.13	139.99	53.52	-0.50	2.33
Senegal	-3.59	1.20	-7.78		-0.89
South Africa	-9.26	467.66	73.18	-1.42	-3.85
Tanzania	0.84	6.61	2.18	-1.03	2.44
Togo	0.03		-1.66		0.47
Uganda	0.55	5.56	-0.97	2.36	1.72
Zambia	1.02	5.24	-3.59	-5.47	2.54
Zimbabwe	-1.05	13.00	-8.08	-3.57	5.57

Source: Author's computation

Table A12: Change in SSA imports of cereals in 2050s (%)

Country	Maize	Millet	Rice	Wheat	Sorghum
Benin	0.14		0.38		
Botswana	9.17	15.09		32.08	3.64
Burkina Faso	0.31	0.16	0.71		0.39
Burundi	-0.97		-4.00	5.04	-4.36
Cameroon	-0.14	20.42	-0.02	-0.30	
Congo. Rep.			0.44		
Côte d'Ivoire	-0.17	8.17	0.71		-2.52
Eritrea					-2.43
Ethiopia(excludes Eritrea)	1.48	6.78	-3.09	1.52	-0.04
Gabon			0.08		
The Gambia			2.61		0.40
Ghana	-0.46	2.87	0.58		-2.35
Guinea	-0.07		0.43	32.08	-1.51
Guinea-Bissau			0.76		
Kenya	0.53	3.52	-8.33	3.00	-0.34
Lesotho	5.25			0.40	17.07
Madagascar	-0.82		0.81		
Malawi	-1.23	5.41	0.96	10.36	-5.20
Mali	7.55	21.35	1.71		3.87
Mozambique	0.43		2.06	8.69	-3.46
Namibia	9.92	19.63		3.77	3.71
Niger	7.12	24.81	-5.57		0.94
Nigeria	0.04		0.18	-4.27	
Rwanda	-0.12	73.37	-18.05	1.57	-3.12
Senegal	3.30	0.63	2.62		1.19
South Africa	8.51	245.10	-24.67	4.49	5.14
Tanzania	-0.77	3.46	-0.74	3.25	-3.26
Togo	-0.03		0.56		-0.63
Uganda	-0.50	2.91	0.33	-7.47	-2.30
Zambia	-0.94	2.74	1.21	17.28	-3.40
Zimbabwe	0.96	6.81	2.72	11.29	-7.45

Source: Author’s computation

Mission

To strengthen local capacity for conducting independent, rigorous inquiry into the problems facing the management of economies in sub-Saharan Africa.

The mission rests on two basic premises: that development is more likely to occur where there is sustained sound management of the economy, and that such management is more likely to happen where there is an active, well-informed group of locally based professional economists to conduct policy-relevant research.

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Middle East Bank Towers,
3rd Floor, Jakaya Kikwete Road
Nairobi 00200, Kenya
Tel: +254 (0) 20 273 4150
communications@aercafrica.org