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Impact of Climate Change and Agricultural Policy on Household Welfare and Trade in East Africa Community

Richard Mulwa

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The KENYA INSTITUTE for PUBLIC POLICY RESEARCH and ANALYSIS

ECA

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Foreword

Climate change and climate change variability is a threat to food production patterns, thus exacerbating food and nutrition insecurity across Africa. Therefore, tackling poverty, hunger and food security is a priority for the Africa Union Agenda 2063 which underscores the right of Africans to live healthy and productive lifes. Further, the African Union has set a target to eliminate hunger and food insecurity by 2025 towards achieving the Sustainable Development Goal (SDG) 2 on ending hunger, achieving food security and improving nutrition. Unfortunately, Africa is not on track in meeting these targets mainly because the region is not producing enough food due to climate change and low adoption of technology. However, climate change has variable impacts on food production, with both production losses and gains across the region. As a result, regional trade is critical for facilitating the distribution of agricultural products to enhance food security in the region.

The East Africa Community (EAC) region is particularly vulnerable to climate change. The region is already experiencing increased climate change impacts, including extreme weather conditions, persistent drought, floods, and landslides and rising sea level which threaten food security and efforts to eradicate poverty. Despite the huge potential to produce enough food, the agricultural production system in the region is mainly rainfed, which consequently leads to high food and nutrition insecurity.

Finding solutions to perennial food security challenges in the EAC is crucial and urgent as climate change impacts intensify in frequency and severity. Looking beyond just agricultural production systems is thus critical in tackling this peril. Thus, there is need to apply other approaches such as the nexus approach which allows for evaluating integrative systems where, for instance, trade facilitates food security in a changing climate environment. Although agriculture production is vulnerable to climate change, food security is not necessary a result of low production but a combination of other factors such as poor food distribution caused by perverse subsidies and other trade barriers. The EAC has been able to attain a common market status, which could facilitate trade in the region and thus mitigate food shortages.

Despite the various measures and programmes adopted in EAC, some parts of the region continue to face food deficits due to restrictive trade policies and barriers to trade. Opportunities exist for adopting existing policy frameworks by member countries to address food security needs.

Preface

The project on Regional Assessment of Climate Change, Agricultural Production, Trade in Agricultural Production and Food Security in East African Community (EAC) was carried with support from the ACPC-CLIMDEV Work Programme. The ClimDev-Africa Programme is an initiative of the African Union Commission (AUC), the United Nations Economic Commission for Africa (UNECA) and the African Development Bank (AfDB). It is mandated at the highest level by African leaders (AU Summit of Heads of State and Government). The Programme was established to create a solid foundation for Africa's response to climate change and works closely with other African and non-African institutions and partners specialized in climate and development.

Over the last few years, our understanding and certainty about how climate is changing and the possible impacts this could have has grown immensely. This notwithstanding, agricultural production systems in the EAC region are highly vulnerable to climate change, consequently affecting food and nutrition security. The region is the most developed regional economic community (REC) in Africa, and cross border trade plays a critical role in facilitating food security. In response, the United Nations Economic Commission for Africa–African Climate Policy Centre (ACPC) is increasing its efforts to improve the capacity of EAC member states for mainstreaming climate change impacts in development policies, frameworks and plans.

The three-year project was launched in May 2014 covering Burundi, Kenya, Rwanda, Tanzania and Uganda. The activities carried in this study were linked to the ClimDev-Africa Programme work stream II, which focuses on solid policy analysis for decision support, and was spearheaded by the Kenya Institute for Public Policy Research Analysis (KIPPRA). The overall objective of the project was to assess whether or not agricultural production systems and trade policies in EAC can be adjusted to alleviate the impact of climate change on food security, and promote sustainable development. The project outputs include pre-project report, country scoping studies, indepth EAC studies on climate change, crop production model, economic policy and trade and finally a comprehensive regional report.

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The study was conducted as a part of the activities of the Climate Change and Development in Africa (ClimDev-Africa) Programme supported by the UK Department for International Development (DfID), European Union Commission, Norway, Sweden, France, Nordic Development Fund, and the United States Agency for International Development (USAID).

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The regional Partner Institutions included Economic Policy Research Centre (EPRC)–Uganda team lead by Dr Isaac Shinyekwa, Sokoine University–Tanzania team led by Prof. Siza Tumbo, University of Burundi team led by Dr Alex Ndayiragije, and Kigali Independent University team led by Mr Paul Muzungu. The participation of the stakeholders in various stages of the preparation of the report was highly valuable in enriching the report.

The Economic Commission for Africa and KIPPRA would like to express their appreciation to all the government Ministries, State Departments and Agencies in Burundi, Kenya, Rwanda, Tanzania and Uganda for their active participation and providing the data and information used in preparing the report.

Executive Summary

The East Africa Community (EAC) was established to widen and deepen co-operation among the EAC Partner States in, among others, political, economic and social fields for their mutual benefit. One of the ways of reaping the economic and social benefits is intra-regional trade between Partner States which is expected to yield economic benefits by availing commodities at reduced prices and boost social welfare by reducing poverty through increased incomes. Using a spatial equilibrium multi-market model, we modelled the impact of agricultural policy, trade policy, and climate change on the welfare of people in individual EAC Partner States and the region as a whole. We estimated the base model and three different scenarios to determine how changes in different variables influence welfare and trade flows in the EAC. The base scenario represents the prevailing conditions projected into the future (year 2045) with the assumptions that the current growth rates of demand side and supply side shifters remain as they are. In this scenario, we also assumed the prevailing common external tariffs (CETs). Results show a mean welfare change of US$ 7.94 per person for the baseline. This, however, varies from country to country. In the second scenario, we introduced agricultural policy (the Maputo and Malabo declarations) which aims to increase investment in agriculture GDP by 10 per cent by year 2045. This policy is expected to increase both demand and supply sides of grains production and trade. We also extended the assumption of the prevailing CETs in this scenario. Results show that agricultural policy will increase welfare per person to a mean of US$ 11.73. In the third scenario, we maintained the agricultural policy but increased the CETs. This policy has the impact of reducing the trade between EAC and the rest of the world. Limiting trade with the rest of the world reduces the welfare to US$ 4.88, indicating trade with the rest of the world is very critical to EAC. It also shows that with increased CETS and trade policy, EAC will not produce enough to satisfy local consumption and depress the prices so as to increase welfare. In this case the CETs are counter-productive and do not achieve their goal. Finally, we introduced climate change to the model with agricultural and trade policy. The results from this scenario show further depression in the welfare to US$ 4.86 per person, indicating that the impact of climate change will have adverse effects on production. It is important to note that only maize was considered in climate change estimations as the impact of climate change on other crops could not be estimated. If the estimates for the other crops were available, the welfare would be much lower than estimated. The changes in welfare in the different scenarios were also accompanied by a re-alignment in trade flows both at the intra-EAC level and also with the rest of the world.

Abbreviations and Acronyms

AGRA	Alliance for Green Revolution in Africa
ARDP	Agricultural Rural Development Policy
ARDS	Agricultural Rural Development Policy
ASARECA	Association for Strengthening Agricultural Research in East and Central Africa
CAADP	Comprehensive African Agricultural Development Programme
CET	Common External Tariff
CM	Common Market
CSFS	Common Strategy for Food Security
DFIs	Development Finance Institutions
DRM	Disaster Risk Management
EAC	East African Community
EACCCP	East African Communioty Climate Change Policy
ENSO	El Nino Southern Oscillation
FAO	Food and Agriculture Organization
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
GMOs	Genetically Modified Organisms
IAASTD	International Assessment of Agricultural Knowledge, Science and Technology for Development
IFPRI	International Food Policy Research Institute
IPCC	Intergovernmental Panel on Climate Change
LDCs	Least Developed Countries
MT	Metric Tonnes
NAAIAP	National Accelerated Agricultural Inputs Access Programme
NAPAS	National Adaptation Programme of Action
NBFs	National Biosafety Frameworks
NCCAP	National Climate Change Action Plan
NCCRS	National Climate Change Response Strategy
NCCRS	National Climate Change Response Strategy

NTBs	Non-Tariff Barriers
RoW	Rest of the World
SEM	Spartial Equilibrium Model
SPS	Sanitary and Phytosanitary
SSTS	Sea Surface Temperatures
UNDP	United Nations Development Programmes
UNEP	United Nations Environment Programmes
UNFCCC	United Nations Framework Convention on Climate Change
WTO	World Trade Organizations
WWF	World Wide Fund

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1. Introduction

1.1 Climate Change, Agricultural Production and Trade

Anthropogenic climate change will, over the coming decades, cause dramatic transformations in the biophysical systems that will affect human settlements, ecosystem services, water resources and food production, all of which are closely linked to human livelihoods (UNFCCC, 2005; IPCC, 2001; 2007; O'Brien and Leichenko, 2007; Mearns and Norton, 2010). These transformations are likely to have widespread implications for individuals, communities, regions and nations. In particular, poor, natural resource-dependent rural households will bear a disproportionate burden of the adverse impacts (Adger, 2001, 2003; Burton et al., 2006). The extent to which these impacts will be felt depends in large part on the extent of local and national adaptations and adaptive capacities (Shah et al., 2008; Yesuf et al., 2008; Mearns and Norton, 2010).

Although there is a considerable scientific uncertainty about the future trajectory of climate change, its impacts are already discernible and will increasingly affect the basic elements of life for people around the world (IPCC, 2007). Such impacts include those on numerous agricultural regimes, and human health including infectious disease vectors (Adger et al., 2007). While climate change is a global phenomenon, potential effects are not expected to be uniform; rather they are unevenly distributed both between and within countries (Hunter et al., 1998; O'Brien and Leichenko, 2009). Moreover, the differential impacts on the livelihoods of human population vary and are largely determined by the location of settlement and levels of income, education and awareness (Hunter et al., 1998). Africa is expected to experience adverse impacts from climate change mainly due to the interactions of multiple stressors, including extreme poverty, over-dependence on rain-fed agriculture, HIV/AIDS prevalence, insufficient public spending on rural infrastructure, poor data availability and quality, and knowledge gaps (UNEP, 2005; IPCC, 2007). These stressors contribute to a weak overall adaptive capacity and thus may compound poverty for vulnerable groups.

The projections of future climate change are uncertain especially in relation to scenarios of future rainfall, floods and droughts. However, temperature projections are generally more reliable. A warming throughout sub-Saharan Africa is projected to be larger than the global annual average (IPCC, 2007). As regards rainfall, some model predictions indicate that East Africa region is going to have increased rainfall events (IPCC, 2007; SEI, 2009; Seitz and Nyangena, 2009) while other recent research suggests that local circulation will result in depressed precipitation instead (Funk et al., 2008). Nonetheless, the climate is changing already and consensus is that the future climate is unlikely to be the same as at present. Thus, there is need to apply precautionary principle on the grounds that the costs of not acting are likely to be incalculably high.

Vulnerability to climate change is a function not just of geography and dependence on natural resources but also of socio-political and institutional factors that influence how climate change ramifications unfold (Adger, 2003). The most vulnerable are often the poor, politically disenfranchised and marginalized communities, who are among the first to experience the impacts and least equipped to diversify their livelihoods (Eriksen et al., 2008; Mannke, 2011). As a result, low income populations dependent on subsistence farming will increasingly face severe hardships because they have little flexibility to buffer potentially large shifts in their production bases (FAO, 2008; Ribot, 2010). Climate stresses will push these populations over an all-too-low threshold into insecurity and poverty that violates their basic human rights (Moser and Norton, 2001).

The nexus between agriculture, trade and climate change should be appreciated from different fronts. On one hand, the agricultural value chain, and land use change, including deforestation account for 30% of the total global GHG emissions while, on the other hand, the adverse impacts of climate change are leading to land degradation, and food insecurity (IPCC, 2007; Celso et al., 2012). And yet, agriculture has the potential to be part of the solution through integrated approaches of food security, adaptation and mitigation (World Bank, 2011; 2012). Spatial and temporal variation of precipitation and increased temperatures are the main climate change related drivers which impact agricultural production (ODI, 2009). Increased temperature levels will cause additional soil moisture deficits, crop damage and crop diseases; unpredictable and more intense rainfall; and higher frequency and severity of extreme climatic events (Boruru et al., 2011). Similarly, the drivers of climate change have the potential of altering plant growth and harvestable yield through carbon dioxide fertilization effects (UNDP, 2012).

The geography of a people's location relative to other people may position them more acutely in harm's way when climate change ramifications unfold (Boruru et al., 2011). In mid to high latitude regions, moderate local increases in temperature can have small beneficial impacts on crop yields while in low latitude regions such moderate temperature increases are likely to have negative yield effects (Iglesias, 2006; Aydinalp and Cresser, 2008; IAASTD, 2009). This will significantly increase yield variability in many regions of the world and result into polarization of effects with substantial increases in prices and risk of hunger amongst poorer nations (Iglesias, 2006; UNDP, 2012). However, through advance preparation and careful management of agricultural systems, these risks could be substantially reduced. Recent studies show that for each 1°C rise in average temperature, dryland farm profits in Africa will drop by nearly 10 per cent (FAO, 2008). Similarly, yields from rain-fed crops could be halved by 2020, and net revenue from crops could fall by 90 per cent by 2100 in some countries in Africa (UNFCCC, 2007).

Extreme climatic events of drought and floods are a threat to the agricultural system and could bring about both chronic and transitory food insecurity. This is because many crops have annual cycles and yields that fluctuate with climate variability, particularly rainfall and temperature (FAO, 2008). As a consequence of climate change, rural areas that depend on rain-fed agriculture will become more vulnerable to food insecurity. Climate change may also alter the nature and location of agriculture production and processing, resource extraction, manufacturing and other sectors (KEPSA, 2014). This will have implications for pattern and volume of international trade flows. It may alter the comparative advantage of countries and lead to shifts in the pattern of international trade. This effect will be stronger in those countries whose comparative advantage stems from climatic or geophysical sources. Moreover, climate change can also increase the vulnerability of the supply, transport and supply chains upon which international trade depends. Any disruptions to these chains will raise the costs of engaging in international trade (WTO-UNEP, 2009).

1.2 The East Africa Community Economies

The East African Community (EAC) comprises five Partner States namely Kenya, Uganda, Tanzania, Rwanda and Burundi. The region has a total area (including water) of 1.82 million square kilometers and is located 5°3°”N & 12°S latitude, and 28°45”E & 41°5°” E longitudes. It has a population of 149.7 million people, a combined Gross Domestic Product (GDP at current prices) of US$ 145.86 billion and a GDP per capita of US$ 974 (EAC, 2016). The Treaty establishing the EAC came into force in July 2000 following the signature by three Heads of State, namely Kenya, Uganda and Tanzania. The Protocol establishing the EAC Customs Union was signed in March 2004 and commenced on 1st January 2005. The Republic of Rwanda and the Republic of Burundi acceded to the Customs Union in June and July, 2007, respectively.

The EAC Common Market (CM) protocol was signed in November 2009 and ratified by the EAC Partner States in July 2010. Subsequently, the EAC Monetary Union was signed in November, 2013 and is expected to adopt a common currency in the year 2023. The aim of the East Africa Community (EAC) is to widen and deepen cooperation among the Partner States in, among others, political, economic and social fields for their mutual benefit. The ultimate goal of the region is a political federation which started as EAC Customs Union in 2005 and became fully effective on January 2010. Partner States have adopted the Common Market

(CM) Protocol. The CM will be followed by the establishment of a Monetary Union and finally a Political Federation. Poverty reduction and improved welfare of the people was a key agenda behind EAC establishment. Given the prevailing per capita incomes, poverty is still a big challenge in the region. Table 1a and 1b show EAC's GDP in million US$ and GDP per capita in US$, respectively.

Table 1a: GDP in EAC (US$ millions current prices)

Year	2008	2009	2010	2011	2012	2013	2014	2015
Burundi	1,548	1,776	2,029	2,236	2,333	2,452	2,850	2,832
Kenya	36,382	37,021	40,000	41,953	50,411	55,101	61,395	63,398
Rwanda	4,869	5,381	5,783	6,521	7,361	7,680	8,070	8,297
Tanzania	27,389	28,574	31,408	33,879	39,088	44,385	47,524	45,713
Uganda	21,265	20,544	19,773	21,959	24,741	25,996	28,671	25,994

Source: EAC (2016)

Table 1b: Real GDP per capita (US$ current prices) in EAC

Year	2008	2009	2010	2011	2012	2013	2014	2015
Burundi	195	218	242	260	264	269	304	293
Kenya	952	982	1,039	1,062	1,239	1,318	1,428	1,434
Rwanda	514	554	580	638	702	715	734	737
Tanzania	673	682	715	761	871	961	1,007	964
Uganda	733	687	641	691	756	771	826	727
Mean	613	625	643	682	766	807	860	831

Source: EAC (2016)

Economies in EAC, just like many African countries, are predominantly dependent on agriculture (CAADP, 2010). The sector contributes over 30 per cent of the countries' Gross Domestic Product (GDP) and 60 per cent of all employments. The sector also plays a vital role in contributing towards foreign exchange earnings through exports, and provision of raw materials for agro-based industries in these states. About 80 per cent of the total population in the African countries lives in the rural areas, and 75 per cent of them are engaged on agriculture as the key enterprise of the rural economy (EAC, 2006). The key sector in the region is agriculture with about 80 per cent of the population of the region living in rural areas and depending on agriculture for their livelihood. The agricultural sector is dominated by smallholder mixed farming of livestock, food crops, cash crops, fishing and aquaculture (EAC. 2014). Farmers in the region face challenges with diseases, pests, and drought as well as unproductive soil. There has also been reduced production of livestock and livestock products. These problems are exacerbated by lack of reliable markets for their products and good information about pricing.

The EAC region is characterized by widely diverse climate ranging from desert to forest in relatively small areas. Rainfall seasonality is complex, changing within tens of kilometres, with altitude being an important contributing factor. The annual cycle of East African rainfall is mainly bimodal—with some areas experiencing unimodal, with wet seasons from March to May and October to December. The long rains (March to May) contribute more than 70 per cent to the annual rainfall and the short rains less than 20 per cent. Much of the inter-annual variability comes from short rains (the coefficient of variability being 74 per cent compared to 35 per cent for the Long Rains) (WWF, 2006). Owing to climate variability in different parts of the EAC region, different agro-ecological zones favour production of different food and cash crops, and livestock. Land area coverage for selected crops has shown mixed trends in the last decade in the EAC Partner States, but crop production in the EAC Partner States increased in 2013 (EAC, 2014).

Over the years, EAC region has experienced climate extremes which include: a) large variability in rainfall with occurrence of extreme events in terms of droughts and floods; b) droughts in the last 30 years–1983/84, 1991/92, 1995/96, 1999/2001, 2004/2005 (all of which led to famine); c) El-Niño-related floods of 1997/98 which were enhanced by unusual pattern of sea-surface temperatures (SSTs) in the Indian Ocean (IPCC, 2007); and, d) the La Niña-related drought of 1999/2001. The El-Niño in 1997/98 and La Niña in 1999/2000 were the most severe and devastating climate change events in the region in the past fifty years. According to results by Shongwe et al. (2009) which used data from the international Disaster Database (EM-DAT), there has been an increase in the number of reported hydro-meteorological disasters in the region from an average of less than three events per year in the 1980s to over seven events per year in the 1990s and ten events per year from 2000 to 2006, with a particular increase in floods. In the period 2000-2006, these disasters affected on average almost two million people per year (Shongwe et al., 2009). All these events have influenced agricultural production in the region, which has in turn influenced food security.

The EAC region is frequently affected by food shortages and pockets of hunger despite the regions huge potential and capacity to produce enough food for regional consumption and surplus for export to the world market. Dependence on rain-fed agriculture in the East African Community (EAC) region implies that agricultural production will continue to be highly vulnerable to climatic variability and climate change, mainly in form of shifts and changes in rainfall patterns but also increasing temperatures leading to adverse impacts to social, physical, ecological and economic systems (EAC, 2011). The impacts include: declining crops yields and increasing food insecurity; melting of snow caps and glaciers; increased frequency and intensity of droughts and floods; reduced water supply; increase in pests and diseases for livestock, wildlife and crops; among others. Increased frequency and intensity of natural disasters mainly droughts, floods and landslides which are the leading climatic-related disasters in the region are usually associated with the climatic variability phenomenon of El Niño Southern Oscillation (ENSO). This poses a major challenge to disaster risk management (DRM). These impacts have not only been predicted but are vividly being observed in many parts of the region. Therefore, decreased agricultural production and rampant food insecurity are mainly as a consequence of a changing climate in the region.

1.3 Climate Change, Agricultural and Trade Policy in East Africa Community

The challenge of climate change on food production and food security led the heads of EAC Partner States to make climate change a top priority of their common agenda and to address it in an integrated, harmonized and multi-sectoral approach. Consequently, a regional East African Community Climate Change Policy (EACCCP) was developed following a directive by the Heads of State of the East African Community (EAC). The EAC Climate Change Policy has identified adaptation and mitigation measures as key in tackling climate change. In addition, there are other efforts such as National Adaptation Programmes of Action (NAPAs) that have been put in place to address adaptation and mitigation to climate change. To compliment these efforts, there are agricultural and trade policies which aim at promoting agricultural production and trade in the region, as discussed hereunder.

1.3.1 East African Community Climate Change Policy (EACCCP)

The main aim of the policy is to address the adverse impacts of climate change in the region in response to the growing concern about the increasing threats of the negative impacts of climate change to national and regional development targets and goals. In addition, it was developed in fulfillment of the objectives of the EAC of developing policies and programmes aimed at widening and deepening cooperation among Partner States. The overall objective of the EAC Climate Change Policy is to guide Partner States and other stakeholders on the preparation and implementation of collective measures to address climate change in the region while ensuring sustainable social and economic development. The policy prescribes statements and actions to guide climate change adaptation and mitigation to reduce the vulnerability of the region and enhance adaptive capacity and build socio-economic resilience of vulnerable populations and ecosystems. In view of the high vulnerability of the EAC region to the impacts of climate change, and with the emerging associated challenges especially food insecurity, adaptation to climate change is of priority to the EAC region.

Other than the regional EAC Climate Change Policy, East Africa Community Partner States do not have national climate change policies, except Kenya which has a sessional paper on climate change. The lack of individual country climate policies, which has slowed down any effort geared towards reducing adverse impacts of climate change in individual Partner States, could be explained by the fact that before the preparation of the regional climate change policy, Partner States had already embarked on preparation and implementation of projects and programmes to address climate change. For instance, Burundi, Rwanda, Uganda and Tanzania had developed National Adaptation Programmes of Action (NAPAs), which are in various stages of implementation (EAC, 2010). There were also other individual country efforts such the National Climate Change Response Strategy (NCCRS) in Kenya which spells out the priority areas for both adaptation and mitigation activities. Tanzania is guided by National Climate Change Strategy 2012, whose overall aim is to enhance the technical, institutional and individual capacity of the country to address the impacts of climate change (United Republic of Tanzania, 2012). From the discussion, it is clear that the the only unifying policy around climate change is the EAC is the EAC Climate Change Policy (EACCCP). Explanations for lack of harmonization in developing national climate change policies are both internal and external. Internally, the political environments determine the swiftness with which issues, though identified, are addressed. Externally, there was a requirement by UNFCCC that LDCs prepare NAPAs, which excluded Kenya. These NAPAs identified immediate, urgent and priority project activities that are necessary to enhance adaptation capacities to climate change adverse impacts (EAC, 2010). This could explain why Kenya seems to have surged ahead in developing a climate change response strategy and is now developing a national climate change policy.

1.3.2 NAPAs, adaptation and mitigation strategies

EAC Partner States have committed to addressing the effects of climate change within the region. Four Member States, Burundi, Rwanda, Tanzania and Uganda, have developed NAPAs that identify immediate, urgent and priority project activities that are necessary to enhance adaptation capacities that are in various stages of implementation. Kenya has prepared a national climate change response strategy (NCCRS) and the National Climate Change Action Plan (NCCAP). NCCRS and NCCAP focus on adaptation and mitigation activities in various priority areas such as low carbon climate resilient development (including geothermal power, reforestation and climate smart agriculture), enabling policy and regulatory frameworks, adaptation and mitigation. In the NAPAs and climate change strategies, each EAC country has identified different areas of climate change adaptation and mitigation to be implemented.

For instance, Burundi intends to support climate forecasts for early warning; rehabilitation of degraded areas; safeguard the most vulnerable natural environments, including the mountain rain forests and thickets of the Rusizi flood plains; support rainwater valorization; control erosion in Mumirwa; protect the buffer zone in the Lake Tanganyika floodplain and around the lakes of Bugasera; popularize short-cycle and dryness-resistant food crops, including sweet potatoes, corn and sorghum; promote zero-grazing cattle breeding; capacity build to promote energy-saving techniques; stabilization of river dynamics of river courses in Mumirwa and Imbo; promote education for climate change adaptation; and promote hydro power micro stations (NAPA-Burundi, 2007; UNFCCC, 2014a).

Rwanda's adaptation plans include: conservation and protection of lands against erosion and floods at district level in vulnerable regions; installations and rehabilitation of hydrological and meteorological stations; monitoring round irrigation perimeters from water flows in vulnerable regions; assistance to districts of vulnerable regions to plan and implement conservation measures and water storage; increasing climate-change adaptation capacity of villages by improving drinking water, sanitation and alternative energy services; increasing modes of food distribution and health support to face extreme climatic events; and preparing and implementing a national strategy to combat deforestation and address erosion (NAPA-Rwanda, 2006; UNFCCC, 2014a).

In promoting adaptation, Tanzania has committed to: promoting drought-tolerant crops including sorghum and millets; improving the availability of water for drought-stricken communities in central Tanzania; adaptation through participatory reforestation in the Kilimanjaro Mountains; and promoting community-based mini-hydro projects (NAPA-Tanzania, 2007; UNFCCC, 2014a). Uganda's NAPA commits to: initiating community tree-growing projects for reforestation; implementing land degradation management projects to reverse land degradation; strengthening meteorological services; improving community water and sanitation projects to increase access to safe water and improved sanitation services; implementing a drought adaptation project; developing climate-change and development planning projects to integrate climate-change issues into development of planning and implementation (NAPA-Uganda, 2007; UNFCCC, 2014a).

1.3.3 EAC Agricultural and Rural Development Policy (2005-2030)

The East African Community Agriculture and Rural Development Policy (EAC-ARDP) was developed following the Council of Ministers' directive. Under the agricultural sector, the overall objectives of EAC are the achievement of food security and rational agricultural production. This is to be achieved through stimulating agricultural development, which constitutes the overall objective of the EAC Treaty regarding cooperation in agriculture and rural development in achieving food security. Further, the EAC-ARD policy aims at attaining food security through increased agricultural production, processing, storage and marketing. The EAC also formulated the Agriculture Sector and Rural Development Strategy that spells out the need for a food secure region.

In order to properly implement the East African Community Agriculture and Rural Development Policy, all the regional programmes and priorities of the Partner States were to be harmonized and supported. The EAC was to mobilize resources and guide the implementation process in an integrated manner. As a result, the EAC Partner States came up with the East African Community Agricultural and Rural Development Strategy (EAC-ARDS) which aims to strengthen the economic cooperation in the region for the benefit of their people. It provides a framework for improvement of the rural life over the next 25 years (2005-2030) through increased productivity and production of food and raw materials, and improved food security. The policy has seen some achievements in areas of: food security; promotion of inter and intra-regional trade in agricultural products; accelerating irrigation development; strengthening early warning systems; financing agricultural production; strengthening research, extension services and training; and promoting agro-based industries for value addition.

There are challenges in implementing the strategy at both the EAC and Partner State levels, thus requiring synchronizing between the two levels in terms of programmes, action plans and prioritization of actions. Synchronization is challenged by the limited financial and human resources. Financing the implementation of the EAC-ARDS has been a big challenge. It was envisaged that the strategy will be financed from a number of resources including national budgets, development partners, private sector investors, and financial institutions i.e. commercial Banks, Development Finance Institutions (DFIs) and microfinance facilities. The national budgets towards the agricultural sector are still very low, and donor support has also been inadequate to cover all the intervention areas.

1.3.4 East African Community Food Security Action Plan (2011-2015)

The EAC region is frequently affected by food shortages and hunger despite the fact that the region as a whole has a huge potential to produce enough food for regional consumption and a large surplus for export to the world market. There are many factors leading to this state of affairs but the most critical are: i) inadequate food exchange/trade between times and/or places of abundant harvest on one hand, and those with deficit; and (ii) high variability in production caused by high variability of weather which is becoming worse due to climate change. Therefore, the region formulated the Common Strategy for Food Security (CSFS) and its Action Plan that was ratified by all member states in 2010 to encourage food trade in the region. The EAC Food Security Action Plan was developed to guide the implementation and actualization of regional food security. The action plan will guide the coordination and implementation of the joint programmes and projects emanating from this plan. This was, however, not put in practice; rather, Partner States adopted generally inward-looking food security policies in each country that discourage trade of food commodities. For instance, in Tanzania, the government has been imposing domestic food price controls or trade ban (export bans) even when there is no food crisis in the country. This limits farmers and even local investors in agriculture, and reduces the incentive to increase the production of food crops in subsequent cropping season given ecological advantage (IFPRI, 2011). In addition, inefficient infrastructure makes movement of food crops from surplus to deficit areas difficult. This has given rise to informal trade which erupted due to increasing Non-Tariff Barriers (NTBs) while political motives in Partners States has made the problem even worse by imposition of trade embargos in some member states. These problems have been prevailing despite the implementation of a Custom Union (EAC-CSFS, 2010).

1.3.5 Draft East African Community Regional Livestock Policy

The East African Community has embarked on development of a regional livestock policy with the aim of reinvigorating the regional livestock industry. The draft livestock policy aims at unlocking the untapped economic potential of the sector in the region through formation of a basis for growth of the livestock sector, and promoting increased production and productivity, prevention and control of diseases, promoting market access, enhancing livestock trade, improving the nutritional base of animals in the region, and enhancing and promoting good animal production practices including management of farm animals' genetic resources and other associated livestock requirements such as availability of water and marketing infrastructure.

The Agriculture and Food Security Sectoral Council of Ministers during its 3rd meeting on the 19th of August 2011 noted that the purpose of the EAC Livestock Policy will be to guide the overall development and coordination of the livestock sector in the region. This policy will therefore restructure the livestock sector to improve its contributions to the regional GDPs. The EAC regional livestock policy is therefore expected to harmonize livestock development issues in the region in line with the EAC integration policy. It will harmonize livestock national laws, control of trans-boundary diseases, and ensure sufficient budgetary allocations to the sector. Further, harmonized regional veterinary regulations will enable mutual recognition of veterinary vaccines approved by one regulatory agency.

1.3.6 East African Community Bio-Safety Policy

All the EAC Partner States have ratified the Cartagena Protocol on Biosafety and are therefore part of the over 133 countries in the world that have agreed to contribute to an adequate level of protection in the field of safe transfer, handling and use of living modified organisms and specifically focusing on trans-boundary movements globally. The protocol came into force in September 2003 and the process of implementing the protocol involves putting in place National Bio-safety Frameworks (NBFs). The EAC Partner States have already put in place their NBFs following extensive consultations with policy makers, scientists and other stakeholders. The main components of these frameworks include the National Bio-technology/Bio-safety policies and the regulatory regimes.

Consequently, the EAC Partner States have moved a step further and have come up with a regional bio-safety policy which calls for the formulation of a harmonized regional policy on Genetically Modified Organisms (GMOs), establishment of a regional bio-technology and bio-safety unit, the need for mechanisms for resource mobilization to support capacity building and formation of strategies for public education, participation, and awareness in bio-technology and bio-safety issues.

The policy is ready for adoption by all Partner States in the region and is expected to effectively cut costs and avert duplication in testing and approval procedures of genetically modified substances in the EAC Partner States. It will also mitigate the potential impact of GMOs on inter and intra-regional trade and enhance information sharing and/or coordination on regulatory approvals on cross border movement of GMOs. It is expected to guide the region on proper use and/or management of GMO crops.

1.3.7 Agricultural trade policy

The EAC has agreed on agricultural trade policies (and key features) that affect agricultural production. These policies are ratified at the regional level and implemented by each partner state. These agreements affect trade in all agricultural commodities. The EAC has prescribed common external tariff (CET) for the region. For example, wheat imports to the region from the rest of the world face the EAC common external tariff of 35 per cent. However, in Kenya, registered millers are charged a 10 percent ad-valorem tariff. The rice imports to EAC attract an external tariff of 75 per cent *ad valorem* or US$ 345 per ton, whichever is higher. The EAC has, however, allowed Kenya, on account of low local and regional production to apply a 35 per cent *ad valorem* tariff on imports from outside the EAC, a concession that must be renewed each year. Under the EAC agreement, maize is classified among the sensitive commodities and attracts a 50 per cent duty on imports from other countries. Millet, sorghum and beans attract 25 per cent import tariff when imported from countries without the region (EAC, 2012). Tariff barriers have largely been eliminated in intra-EAC trace but there remains some non-tariff barriers (NTBs) which influence trade. A summary of the trade policies (and features) affecting agriculture in the EAC is shown below.

Trade Policies	Features
Customs Procedures and Documentation	• Addressed in the Customs Management Act • The objective is to standardize and harmonize the customs formalities (documentation and procedure) in the member states • Customs Procedures Manual was adopted by EAC Council of Ministers and application commenced in 2012/13
Customs Valuation	• Procedure applied to assign monetary value to goods or service for the purposes of import or exports • Incorporated in the EAC Customs Management Act, 2004 • Based on the implementation of the WTO Agreement on the implementation of Article VII of GATT 1994 on customs valuation.
Rules of Origin	• Used to determine the country of origin of a product within multilateral or regional trade framework • Set up in Annex III of the Protocol on the Establishment of the EAC Customs Union • Goods are defined as originating from a country if: — They are wholly produced or — Undergo substantial transformation- import content of good is no more than 60% of c.i.f value of material used for value added — Change in tariff heading
Tariffs and Other Duties	• MFM Applied Tariff structure — EAC Common External Tariff (CET) - Raw materials and capital goods are zero-rated - Intermediate goods is 10% - Finished goods 25% - Sensitive products apply 35-100%, this applies to 58 tariff lines — CET contains 5,274 lines at HS8-digit level. 99.8% carry *ad valorem* while the rest have mixed tariffs

Tariff Preferences	• EAC members can grant tariff preferences on reciprocal basis under bilateral agreements
Tariff and Tax Exemptions and Concessions	• Under Customs Union protocol, members have agreed to harmonize their duty and tax exemptions and concessions. • The EAC Council on a case-by-case basis also grants country-specific waivers
Internal Taxes	• Under EAC Common Market Protocol, members have agreed to harmonize their tax policies and laws on domestic taxes • This will remove tax distortion and facilitate free movement of goods, services and capital in order to promote investment in the community
Contingency Measures	• Contingency measures found in Article 16-20 and 24 on the Protocol Establishing the EAC Customs Union. • These contingencies include anti-dumping, countervailing and safeguards measure
Import Prohibitions, restrictions and licensing	• Provided under the Second Schedule of the EAC Customs Management Act, 2004. • EAC Member States have a schedule of prohibited products. • Import permit is required for 31 product groups under the second schedule
Standards and Technical Requirements	• Article 13 on Protocol Establishing the EA Customs Union urges removal of non-tariff barriers (NTBs) • Catalogue of East African Standards provides a comprehensive list of harmonized standards applicable to EAC
Sanitary and Phytosanitary Measures (SPS)	• Addressed in Article 108 of Treaty establishing the EAC • Provides for harmonization of SPS measures • This agreement adheres to the WTO- SPS agreement
Documentation taxation and restrictions	• These documentation requirements for exports • Addressed in the Customs Management Act
Competition and Regulatory Issues	• Article 21 of Customs Union Protocol obliges EAC member states to prohibit anti-competitive behaviours • EAC Competition Act was enacted in 2006 and established the EAC Competition Authority
Intellectual Property Rights	• Addressed in Article 103 of the EAC Treaty and Art. 104 of the EAC Common Market Protocol • This sets up the framework for the harmonization of EAC intellectual Property Rights Policies
Agriculture	• The treaty establishing the EAC emphasized the importance of agriculture and food security, and made it a key cooperation area • Several regional policies have been developed: — Agriculture and Rural Development Policy — Agriculture Rural Development Strategy — EAC Food Security Action Plan — Regional Protocol on Environment and Natural Resource Management (2006)

Source: WTO (2012)

Harmonization of regional agricultural and trade policies, and climate change policies and strategies can significantly improve agricultural production. However, there are other challenges which could be handled by national or regional policies. For instance, despite having a large land area, the EAC has low area under irrigation, with Burundi having 5.5 per cent, Tanzania 3.3 per cent, Uganda 0.1 per cent, Rwanda 0.4 per cent, and Kenya 1.7 per cent. This is low in four countries compared to SSA region average of 3.7 per cent. With climate change challenge which causes uncertainty in rainfall and the low irrigation rates in the region, more investment in irrigation is needed. In terms of fertilizer application, only Kenya has the highest application rate of 31.6kg/ha. Application rates in other countries are relatively low with 2.6kg/ha in Burundi; 1.8kg/ha in Tanzania and Uganda and Rwanda 13.7kg/ha. These low application rates can be attributed to low incomes in the region and high fertilizer prices. There have been efforts to address this problem in individual member states. For example, in 2007, Kenya started the National Accelerated Agricultural Inputs Programme (NAAIAP) to ensure access of inputs (including fertilizers) to farmers by way of vouchers redeemable in private input suppliers (Ogada et al., 2011). Similar efforts can be done at a regional scale.

The budget allocation for the agriculture sector as a percentage of national budget in the Partner States for financial year 2009/10 were very low, with Republic of Burundi allocating only 2.4 per cent of the total budget, Kenya at 4.2 per cent, Rwanda at 6.2 per cent, Tanzania 7.2 per cent and the Republic of Uganda at only 4.5 per cent. All the member states budget allocation is below the Maputo and Malabo Declarations and the CAADP initiative that require agriculture sector funding go up to 10 per cent of GDP. ASARECA and IFPRI projected that when the EAC spends at least 10 per cent of their budgets in agriculture and attracts more than 8 per cent of its FDI in agriculture by 2015, all sub-sectors such as staples, cash crops, and livestock will grow by an average of 5 per cent, per capita income by more than 3.5 per cent while GDP will grow by an average of 6 per cent.

Other efforts for agriculture development in the region include harmonization of agriculture trade policies, regulation, rules and practices, and formation of various tasks forces and other regional arrangements such as the CAADP and AGRA initiatives. Identification of the different national and regional agricultural and climate change policies influencing agriculture production is important. But of more importance is determining how these policies influence the welfare of the people and trade flows of commodities in individual Partner States, and also the whole region. It is against this background that this study was carried out to quantify the impact of trade and agricultural policies, and climate change on welfare in the EAC region. The analysis was done using a spatial equilibrium model with the objective of assessing the impact of agricultural and trade policies and climate change on welfare and trade flows in EAC.

This was operationalized in the specific objectives of:

- Assessing the impact of agricultural and trade policies on households' welfare in individual EAC member countries, and the whole EAC zone
- Assessing the impact of climate change on households' welfare in individual EAC member countries, and the whole EAC zone
- Assessing the impact of agricultural and trade policies and climate change on grain trade flows in EAC

2. Methodology

To achieve the highlighted objectives, the spatial equilibrium model (SEM) was used. This model was popularized by Takayama and Judge (1971) following the seminal work of Samuelson (1952). The model assumes production and/or consumption usually occurs in spatially separated regions (in this case Burundi, Kenya, Rwanda, Tanzania, Uganda and Rest of the World [RoW]), each of which have supply and demand relations. In a solution, if the regional prices differ by more than the inter-regional cost of transporting goods, then trade will occur and the price difference will be driven down to the transport cost (McCarl and Spreen, 1998). Modeling of this situation addresses the questions of: a) who will produce and consume what quantities; and, b) what level of trade will occur.

A typical partial-equilibrium agricultural policy model consists of:

a) producer core system, which has area equation, yield equation, production equation and supply equation;
b) consumer core system, which has food demand equation, feed demand equation, other demand (e.g. seed) equation, and total demand equation;
c) trade core system which consists of import equation and export equation;
d) price linkage equation; and,
e) model closure.

Each of these is discussed in detail and the relevant equations, data and analysis presented. Our model consists of six (6) mostly traded grains (beans, maize, sorghum, millet, rice, and wheat) in the five (5) Partner States of the EAC (Burundi, Kenya, Rwanda, Uganda, and Tanzania) and also the rest of the world.

2.1 Domestic Supply Block

Agricultural producers can increase output by increasing productivity in a given area or by putting more area under cultivation. Our hypothesis is that domestic crop production in the EAC region is determined by area and yield response functions, thus estimating acreage response only under-estimates supply response. This is because farmers in the region respond to price incentives partly through intensive application of other inputs given the same area, which is reflected in yield. This therefore requires an estimation of both acreage and yield response functions separately; and then deriving the supply response estimates from these two estimates.

Two frameworks have been developed in the literature for conducting supply response analysis. The first is a Nerlovian expectation model which facilitates the analysis of both the speed and the level of adjustment of actual acreage and yield towards desired acreage. The second is the supply function approach derived from the profit-maximizing framework (Yu et al., 2010; Mythili, 2008). Over time, the Nerlovian model has proved to be one of the most influential and successful, judged by the large number of studies using it (see for example Braulke, 1982; Leaver, 2004). The model is also superior to alternative models in that it facilitates computing short-run and long-run responses and the speed of adjustment in moving from actual to desired level of land and other inputs (Mythili, 2008).

For these reasons, the Nerlovian model is used for this analysis. The Nerlovian model is a dynamic model, stating that output (or area) is a function of expected price, output (or area) adjustment, and some exogenous variables. The reduced form of the Nerlovian model is an autoregressive model because it includes lagged values of the dependent variable (output) among its exogenous variables. Nerlovian models are built to examine the farmers' output reaction based on price expectations and partial area adjustment (Nerlove, 1958). Usually, the observed prices are market or farm gate prices after production has occurred while production decisions have to be based on the prices farmers expect to receive several months later, at harvest time (Yu et al., 2010). In economic theory, area harvested is modeled as a partial adjustment function with the current maize prices and the prices of other crops (Agcaoili and Rosegrant, 1995).

It can also be argued that majority of smallholder producers within the EAC also consume their own crop and hence do not produce solely for the market; therefore, they do not substitute one crop for another, regardless of the price (Mapila et. al., 2013). However, an equally valid argument is that farmers are embracing agribusiness and responding to prices, and hence substitution of crops is feasible even amongst smallholder farmers. Crop harvested area in each of the EAC member states is therefore specified as a response to the crop's own price, the prices of other competing crops, the projected rate of exogenous[1] (non-price) growth trends in harvested area (Rosegrant et. al., 2008; 2012, Mapila et. al., 2013).

The supply response for the different crops was estimated using the Nerlove partial adjustment model as shown in Equation 1 (See Appendix 1 for detailed discussion). The empirical equation is given by;

$$lnC_{1t} = \delta_1 + \delta_2 lnP_1 C_{1t-1} + \delta_3 lnC_{1t-1} + \delta_4 lnP_2 C_{2t-1} + \ldots, + \delta_n lnP_n C_{nt-1} + \gamma_1 time + \varepsilon_t \qquad (1)$$

1 The projected exogenous trend in harvested area captures changes in crop area resulting from factors other than direct crop price effects, such as expansion through population pressure and contraction from soil degradation or conversion of land to non-agricultural uses.

Where C_{it} is crop production at time t; P_i is the price of crop i, while δ and γ are parameters to be estimated. The main and substitutable crops were jointly estimated by a single set of equations and by the introduction of other slope coefficients to capture different responses. For instance, in estimating the supply response for maize in Kenya, the independent variables were, one period lagged real price of maize, one period lagged maize output, one period lagged price of wheat, sorghum and millet prices, and a time variable to control for exogenous growth in maize output.

2.2 Domestic Food Demand Block

This describes the second block of equations in the SEM model. Domestic demand for a commodity is the sum of its demand for food, feed, biofuels, crush, and other uses. Domestic demand for different crops in EAC is mainly composed of domestic human consumption, with some outputs going toward seed and feed, industrial use and ending stock. However, for our analysis, we will restrict ourselves to food demand. There are a number of factors that affect consumer food demand in the region. These are the price of the product; the price of related goods; the income of consumer; the preferences of consumers; and population. In our analysis, food demand is expressed as a function of the price of the commodity and the prices of other competing commodities, per capita income, and total population i.e.

$$DF_{int} = \alpha_{1int} . (PD_{int})^{\alpha 2in} . \prod_{(j \neq i)} (PD_{jnt})^{\alpha 3jn} . (INC_{nt})^{\alpha 4in} . (POP_{nt}) . e^{\varepsilon in} \qquad (2)$$

Where DF is the food demand of commodity i in country or country n; α is the demand function intercept; PD_i is the effective consumer price of commodity i; PD_j is the effective consumer price of commodity j; INC is per capita income and POP is the total population of country n; and λ and η are price and income elasticities. Own price and income elasticities of demand were estimated for using the Almost Ideal Demand System (Deaton and Muellbauer, 1980). The details of this model are discussed in Appendix 2. The empirical model of the AIDS demand model takes the form;

$$BS_{cr} = \alpha_{cr}{}^{D} + \sum^{6}_{(c'=1)} \beta^{D}{}_{cc'r} \, ln() + \delta_{cr} ln(YR_r) \qquad (3)$$

Where BS_{cr} is the budget share of commodity c in country r; $\alpha_{cr}{}^{D}$ is the intercept in the demand equation of c in country r; $\beta^{D}{}_{cc'r}$ is the coefficient on effect of price of c' on the demand of c in country r; $PD_{c'r}$ is the consumer price of commodity c in country r; and, YR_r is the nominal per capita income in country r.

2.3 Trade Block

Domestic prices are a function of world prices, adjusted by the effect of price policies. With regard to the commodity balance equation, demand and supply are still equal to each other but they are defined more broadly to include international demand (exports) and international supply (imports). Using M_{in} for imports of commodity *i* in country *n* and X_{in} for exports of commodity *i* in country *n*, we can write the equation as;

$$QS^{d}_{in} + M_{in} = DF_{in} + X_{in} \quad (4)$$

The relationship between export price and domestic prices can be expressed by setting the export parity price as the lower limit of domestic prices. Using price of exports p_{xin} as the FOB price, and NER_n as the nominal exchange rate, and TC_n as the transportation cost to the port country *n*: then, domestic price p_{din} of commodity *i* in country *n* can be expressed as:

$$p_{din} + TC_n \geq NER_n.p_{xin} \quad (5)$$

Similarly, import parity price sets the upper limit. If import p_{min} is the CIF price, then,

$$NER_n.p_{min} + TC_n \geq p_{din} \quad (6)$$

To analyze the impact of policies and climate change in the region, one can solve a competitive market equilibrium model with linear supply and linear demand functions using optimization method (e.g. maximization of net welfare) or the mixed complementarity problem (MCP) method. The MCP method has been adopted in this analysis (See details in Appendix 3).

2.4 Description of EAC Spatial Equilibrium Model

This section gives a description and the equations used in the SEM. They are classified into endogenous variables and parameters. The model considers six (6) crops (maize, beans, sorghum, millet, rice and wheat) which are the main grains traded in the EAC and RoW. The 6 region-6 crop SEM model comprises four blocks of equations: prices, supply, consumption and market clearing identities for the six crops. Tables 2a and 2b show the model variables and parameters used in the specification of SEM for EAC.

Table 2a: Endogenous variables of the model

Symbol	Endogenous variable
BS_{cr}	Budget share of commodity *c* in country *r*
S_{cr}	Supply of commodity *c* in country *r*
PS_{cr}	Producer price of commodity *c* in country *r*
PD_{cr}	Consumer price of commodity *c* in country *r*
M_{cr}	Imports of commodity *c* in country *r*
X_{cr}	Exports of commodity *c* in country *r*
PX_{cr}	Export price of commodity *c* in country *r*
$TQ_{crr'}$	Quantities of commodity *c* transported from country *r* to *r'*
YR_r	Nominal per capita income in country *r*
IXT_c	Implicit export tax associated with quota on commodity *c*

Table 2b: Parameters of the model

Symbol	Parameter
$\alpha^S{}_{cr}$	Intercept in the supply equation of *c* in country *r*
$\beta^S{}_{cc'r}$	Coefficient on effect of price of *c'* on the supply of crop *c* in country *r*
$\alpha^D{}_{cr}$	Intercept in the demand equation of *c* in country *r*
$\beta^D{}_{cc'r}$	Coefficient on effect of price of *c'* on the demand of *c* in country *r*
δ_{cr}	Coefficient on effect of price income on the demand of *c* in country *r*
$Y^o{}_r$	Original per capita income in country *r*
$PP^O{}_{cr}$	Original price for valuing output of commodity *c* in country *r*
POP_r	Population in country *r*
$TP_{rr'}$	Transportation cost from country *r* to country *r'*
$ITX_{crr'}$	Implicit tax on regional transportation of *c* from country *r* to country *r'*
PM_c	Import (CIF) price of commodity *c* in country *r*
Q_c	Export quota on price of commodity *c* in country *r*
gQ_{WC}	Intrinsic output growth rates without climate change
$E^Q{}_{Clim}$	Effect of climate change on maize production

The spatial equilibrium model (SEM) comprises of the following equations whose variables and parameters have been defined in Tables 2a and 2b.

Specification of supply

$$lnS_{cr} = \alpha^{S}_{cr} + \sum^{6}_{(c'=1)} \beta^{S}_{cc'r} \, ln(PS_{c'r}) * (1 + gQ_{WC}) \qquad (7a)$$

Specification of demand

$$BS_{cr} = \alpha^{D}_{cr} + \sum^{6}_{(c'=1)} \beta^{D}_{cc'r} \, ln(PD_{c'r}) + \delta_{cr} \, ln(YR_{r}) \qquad (7b)$$

Outflows from country *r*

$$S_{cr} \geq \sum^{6}_{(r'=1)} TQ_{rr'} + X_{cr} \qquad (7c)$$

Inflows to country *r*

$$\sum^{6}_{(r'=1)} TQ_{rr'} + M_{cr} \geq [(BS_{cr} \, Y_{r})/(PD_{cr})] \, POP_{r} \qquad (7d)$$

Regional price relations

$$PS_{cr} + TP_{rr'} + ITX_{rr'} \geq PD_{cr} \qquad (7e)$$

Import-regional price relations

$$PM_{cr} + TP_{(world\ r)} + ITX_{(world\ r)} \geq PD_{cr} \qquad (7f)$$

Export-regional price relations

$$PS_{cr} + TP_{(world\ r)} + ITX_{(world\ r)} + ITX_{c} \geq PX_{r} \qquad (7g)$$

Export quota

$$\sum^{6}_{(r=1)} X_{cr} \leq Q_{c} \qquad (7h)$$

To analyze the impact of agricultural policies, trade policies and climate change on household welfare in the region, one can solve a competitive market equilibrium model with linear supply and linear demand functions using optimization method (e.g. maximization of net welfare) or the mixed complementarity problem (MCP) method. However, as indicated earlier, we applied the mixed complementarity problem (MCP) in the analysis. The impact is captured after introducing changes in exogenous variables of the model, which in turn influence the equilibrium price. Agricultural policies were introduced by changing demand and supply parameters in the demand and supply core blocks. Trade policy was introduced by changing import and export prices. Climate change was introduced to the supply side of the equation. Its effects on area and yield are incorporated into the simulations through the intrinsic output growth rates (*gQ*) as shown in the supply block equations.

$$lnS_{cr} = \alpha^{S}_{cr} + \sum^{6}_{(c'=1)} \beta^{S}_{cc'r} \, ln(PS_{c'r}) * (1 + gQ) \quad (8a)$$

The average annual rate of growth or decline of output due to climate change is then added to the existing exogenous output growth rate. In this case *gQ* is expressed as:

$$gQ = gQ_{WC} + E^{Q}_{Clim} \quad (8b)$$

Where lnS_{cr} is the log of crop output under climate change; gQ_{WC} is the intrinsic output growth rate without climate change, while E^{Q}_{Clim} are the effects of climate change on output growth rate. Having incorporated natural growth only, we introduce climate change into the equation. Note that in this study only maize production was simulated for climate change using APSIM model both for RCP 4.5 and RCP 8.5. The RCP 4.5 assumes a lower carbon dioxide in the atmosphere, while that of RCP 8.5 is higher.

The changes in exogenous variables influence the equilibrium price. This change in price is then used in estimating the change in welfare to consumers and producers. Compensating variation (Minot and Goletti, 2000) (See derivation in Appendix 4) was used as a measure of consumer price changes and is given as;

$$CV/x_{o} \approx CR_{cr} (\Delta p_{cr})/(p_{ocr}) + 1/2 \, \varepsilon^{H}_{cr} \, CR_{cr} [(\Delta p_{cr})/(p_{ocr})]^{2} \quad (9)$$

Where CR_{cr} is the consumption ratio of commodity *c* sold in country *r* (i.e. value of consumption of *c* sold in country *r* as a proportion of income (total expenditure); Δp_{cr} is the change in price; p_{ocr} is the original price; and ε^{H}_{cr} is the Hicksian own-price elasticity of demand commodity *c* sold in country *r*. The effect on producer prices is given by:

$$\Delta x/x_{o} \approx PR_{cr} (\Delta p_{cr})/(p_{ocr}) + 1/2 \, \varepsilon^{S}_{cr} \, PR_{cr} [(\Delta p_{cr})/(p_{ocr})]^{2} \quad (10)$$

Where, Δx is the change in income; x_{o} is the original income; PR_{cr} is the production ratio of commodity *c* in country *r* (i.e. value of production of commodity *c* sold in country *r* as a proportion of income (total expenditure); and ε^{S}_{cr} is the own supply elasticity of commodity *c* sold in country *r*.

If we combine the producer welfare (impact of price changes on farming households) and consumer welfare (impact of retail prices on consuming households) equations, we obtain;

$$(\Delta w^2)/x_o = [(\Delta p'_{cr})/(p'_{ocr})]\, PR_{cr} + 1/2\, [(\Delta p'_{cr})/(p'_{ocr})]^2\, PR_{cr}\, \varepsilon^S_{cr} - [(\Delta p_{cr})/(p_{ocr})] CR_{cr} + 1/2\, [(\Delta p_{cr})/(p_{ocr})]^2\, CR_{cr}\, \varepsilon^H_{cr} \quad (11)$$

Where Δw^2 is the second order approximation of net welfare effect of a price change in commodity c in country r on households, where p' and p distinguish producer and consumer prices, respectively. The immediate welfare impact - without consumer and producer responses - can be obtained by setting the elasticities equal to zero to obtain;

$$(\Delta w^1)/x_o = [(\Delta p'_{cr})/(p'_{ocr})]\, PR_{cr} - [(\Delta p_{cr})/(p_{ocr})]\, CR_{cr} \quad (12)$$

Where w^1 is the first order approximation of net welfare effect of a price change. This is the welfare impact of a price change assuming that the consumer cannot respond to the change by adjusting consumption. Geometrically, it is a rectangular approximation of the area behind the curve. The second order approximation, w^2 takes into account the response of consumers to the higher price. It is a parallelogram approximation of consumer surplus. It is an approximation because it assumes the demand curve is linear (Minot and Goletti, 2000). Changes in commodity prices will influence trade flows within the EAC but also with other countries out of the EAC. From the models, we obtained the trade flows for the different grain crops within EAC and also with the rest of the world.

3. Data

The data used in the analysis were from EAC, FAO, World Bank, FEWSNET, and USAID-GAIN reports, etc. These data varied depending on the variable of analysis but were between the period 1966 and 2015. A description of supply and demand data is discussed below.

3.1 Supply Data

The data considered in the production core equation is the supply (production) of the different crops. For this analysis, we considered the average production of 8 years, i.e. the period between the years 2006-2013 as the base grain production (Table 3). The largest producer of maize, rice and sorghum is Tanzania while Kenya leads in wheat production.

Table 3: Grain Production in EAC in 000s MT

Crop	EAC Partner States				
	Burundi	Kenya	Rwanda	Uganda	Tanzania
Beans	210.54	573.61	400.75	444.61	996.25
Maize	174.65	3204.00	544.50	1683.84	5607.85
Millet	11.00	70.00	9.00	820.00	350.00
Rice	67.00	130.00	82.00	230.00	980.00
Sorghum	70.56	132.93	157.49	420.00	840.00
Wheat	9.00	247.00	81.00	24.00	93.00

Source: FAO (2015)

The producer price data considered for the base period was also an average of 3 years from year 2013-2015. These are shown in Table 4 and vary for the different crops in the five countries. Overall, beans have the highest price per metric ton while maize and millet prices are the least.

Table 4: Producer prices in US$/MT in EAC

Crop	EAC Partner States				
	Burundi	Kenya	Rwanda	Uganda	Tanzania
Beans	550	620	590	560	520
Maize	158	257	230	167	185
Millet	139	364	165	180	231
Rice	267	234	336	240	284
Sorghum	211	251	298	205	211
Wheat	393	350	380	330	325

Source: FAO (2015)

The grain production and grain supply prices in Tables 3 and 4 were used in estimating supply response as specified in Equation 1.

3.2 Demand Data

The data considered in the demand core equation are the consumer prices (Table 5) and consumption demand (Table 6) of the different crops. These data were for the period 2014 and 2015. From Table 4, the highest prices are reported for beans and rice in almost all countries in EAC. Data from Table 6 shows that the largest consumers of maize are Tanzania and Kenya; rice is Tanzania; and wheat is Kenya.

Table 5: Consumer prices in US$/Ton in EAC

Crop	EAC Partner States				
	Burundi	Kenya	Rwanda	Uganda	Tanzania
Beans	690	682	630	660	778
Maize	445	320	345	257	280
Millet	682	550	688	510	682
Rice	954	950	968	850	780
Sorghum	570	483	423	330	487
Wheat	563	442	662	538	531

Source: EAGC, 2015; FEWSNET 2014

Table 6: Consumption demand in Tons in EAC

Crop	EAC Partner States				
	Burundi	Kenya	Rwanda	Uganda	Tanzania
Beans	224.46	900.00	700.00	690.00	708.25
Maize	169.46	3,450.00	564.07	1,308.79	4670.49
Millet	9.83	62.90	9.00	720.00	239.33
Rice	58.00	370.00	83.00	187.00	1176.00
Sorghum	73.67	128.75	155.00	325.00	697.42
Wheat	19.50	900.00	195.00	390.00	980.00

Source: FAO (2015); USDA GAIN reports

Using the populations in respective countries and the consumption demand in Table 6, we estimated the annual per capita consumption of the different commodities in kgs (Table 7). Rwanda has the highest consumption of beans per capita (64.6kg), while Kenya has the highest per capita consumption of wheat (47.67kg). Tanzania has the highest per capita consumption of maize (94.8kg), while Uganda has the highest per capita consumption of millet (19.8kg).

Table 7: Consumption in kgs/person per year

Crop	EAC Partner States				
	Burundi	Kenya	Rwanda	Uganda	Tanzania
Beans	26.95	22.00	64.59	18.98	14.38
Maize	20.35	84.33	52.05	36.01	94.83
Millet	1.18	1.54	0.83	19.81	4.86
Rice	6.96	9.04	4.87	5.14	23.88
Sorghum	8.85	3.15	14.30	8.94	14.16
Wheat	2.34	47.67	17.99	10.73	19.90

Source: Author's estimation

The consumption levels presented in Table 7 require budgets from households' total income. Per capita income, total food expenditure, and expenditure of the six grain crops in the different EAC countries are shown in Table 8. Kenya had the highest per capita income (US$ 1,100) while Burundi has the least (US$ 256). Expenditure on grains is also shown with Kenya leading on the total expenditure allocated to grains (US$ 105.90) followed by Tanzania (US$ 77.14) and Rwanda (US$ 72.49). However, as a percent of the total food expenditure, Rwanda allocates 21.58 per cent while Uganda allocates the least (15.04%).

Table 8: Per capita income, food and grains expenditure (US$)

Income/Exp.	Burundi	Kenya	Rwanda	Uganda	Tanzania
Per capita income	256.00	1100.00	660.00	661.40	813.00
Food expenditure	146.18	542.96	335.94	308.21	422.86
Grains Exp.	41.46	105.90	72.49	46.34	77.14
% Grain: Food Expenditure	28.36%	19.50%	21.58%	15.04%	18.24%

Source: EAC (2014) and Author's estimation

Using information in the demand Tables, the budget shares for the different commodities were estimated using proportions of food expenditure and per capita income. For example, on average, Burundi uses 21.84 per cent of the total grain expenditure on maize; 1.94 per cent on millet, 44.85 per cent on beans etc. Kenya spends 36.46 per cent of all grain expenditure on maize, 20.27 per cent on beans, and the rest on the others. Tanzania spends the biggest proportion of grain expenditure on maize (34.42%) and 24.14 per cent on rice (Table 9).

Table 9: Budget shares of grains in EAC

Crop	EAC Partner States				
	Burundi	Kenya	Rwanda	Uganda	Tanzania
Beans	0.4485	0.2027	0.4969	0.2785	0.1450
Maize	0.2184	0.3646	0.2193	0.2057	0.3442
Millet	0.0194	0.0114	0.0070	0.2246	0.0430
Rice	0.1602	0.1161	0.0575	0.0972	0.2414
Sorghum	0.1216	0.0205	0.0739	0.0656	0.0894
Wheat	0.0318	0.2846	0.1455	0.1283	0.1370

Source: Author's estimation

The demand and price data in Tables 5 to 9 were used to estimate own price and income elasticities of demand for the domestic demand equation using the Almost Ideal Demand System (AIDS) model as specified in Equation 2.

4. Results

4.1 Supply Elasticities

Supply elasticities determine the response of producers due to a percentage change in producer prices. These were achieved through estimation of Equation 1. For instance, this estimation gave a short run supply response of 0.54 and a long-run response of 0.73 for maize in Kenya. This implies that in the short run, Kenyan farmers would react to 1 per cent increase in maize price by increasing their supply by 0.54 per cent. In the long run however, 1 per cent increase in price would increase maize grain supply by 0.73 per cent. Other estimates in Table 10a could be interpreted in a similar manner. Note that weather variables such as precipitation and temperature are not included in the equation, as they are included in the estimation of climate change impact.

Table 10a: Supply response elasticities for different crops in EAC

Crop	Country and Supply Response				
	Burundi	Kenya	Rwanda	Uganda	Tanzania
Beans	0.25	0.50	0.63	0.30	0.20
Maize	0.25	0.73	0.65	0.80	0.76
Millet	0.013	0.05	0.05	0.24	0.60
Rice	0.02	0.02	0.13	0.02	0.60
Sorghum	0.32	0.25	0.30	0.05	0.05
Wheat	0.05	1.21	0.60	1.80	1.20

1. Due to lack of price data, the supply response estimates for Tanzania were borrowed from literature.

2. Note that only long run supply responses are presented in this Table.

4.2 Price and Demand Elasticities

Own price and demand elasticities are the responses of consumer demand to a percentage change in own price and income, respectively. Most commodities in EAC have own price elasticities of between 0 and -1.0, indicating that as prices increase, quantity consumed declines but total spending on product rises. This is characteristic of staples and commodities with fewer substitutes. This is true for beans, maize and sorghum in Burundi; maize, rice and wheat in Kenya; all commodities in Tanzania; and all commodities but rice in Rwanda and Uganda. Although these crops are price inelastic, the increase in consumption varies for different crops as shown in Table 10b. Commodities with elasticities greater than -1.0 indicate that an increase in price causes the quantity consumed and total spending on the product to decline. This is characteristic of luxury foods, or products with many substitutes. These include millet, rice and wheat in Burundi; beans, millet and sorghum in Kenya; and, rice in Rwanda and Uganda.

Table 10b: Own price elasticities of demand in EAC

Crop	Country and Supply Response				
	Burundi	Kenya	Rwanda	Uganda*	Tanzania*
Beans	-0.95	-1.01	-0.85	-0.78	-0.87
Maize	-0.22	-0.79	-0.34	-0.68	-0.90
Millet	-1.50	-1.02	-0.85	-0.90	-0.85
Rice	-1.27	-0.84	-1.40	-1.50	-0.99
Sorghum	-0.29	-1.02	-0.41	-0.80	-0.85
Wheat	-1.72	-0.88	-0.90	-0.90	-0.80

** Borrowed from literature (Various)*

Source: Author's estimation

Table 10c presents income elasticities of demand. Commodities with income elasticities of between 0 and 1.0 indicate that as income increases, the quantity consumed increases but the share of the budget allocated to this product declines. This is true for sorghum and millet in Burundi; all except beans and wheat in Kenya; beans and millet in Rwanda; all commodities except wheat in Uganda; and all beans and maize in Tanzania. The other crops have income elasticities of more than 1.0, implying that as income increases, the quantity consumed and share of the budget allocated to this product increases.

Table 10c: Income elasticities of demand in EAC

Crop	Country and Supply Response				
	Burundi	Kenya	Rwanda	Uganda*	Tanzania*
Beans	1.25	1.10	0.87	0.54	0.99
Maize	1.14	0.93	1.03	0.68	0.78
Millet	0.45	0.77	0.61	0.45	1.01
Rice	1.71	0.91	1.11	0.80	1.05
Sorghum	0.99	0.77	1.22	0.96	1.01
Wheat	2.71	1.15	1.56	1.40	1.25

** Borrowed from literature (Various)*

Source: Author's estimation

4.3 Welfare Estimation

4.3.1 Base Model

Since climate change is recorded over an extended period, at least 30 years, we assumed a situation where the current supply and demand shifters assume a business as usual trajectory for the next 30 years. These projected figures of demand, supply, prices and other variables in year 2045 were used as the base scenario. Using historical data (FAO production data sets from 1961 to 2015), we estimated the year 2045 projections assuming these variables were to maintain the present growth rates. The production trends for the last 30 years are as shown in Table 11, with some crops such as beans, sorghum and wheat experiencing declining production in Burundi, while sorghum and millet are experiencing declining production in Rwanda and Uganda, respectively. Other crops were experiencing growth in production over the same period. Supply is also influenced by producer price which is expected to increase by an average of 1.43-fold and 3.19-fold over this period for all grains in the region.

Table 11: Natural supply growth and producer price changes (folds) in 2045

Crop	Country and Supply Response				
	Burundi	Kenya	Rwanda	Uganda	Tanzania
Beans	-0.24	1.98	2.29	1.55	4.87
Maize	0.54	3.04	6.70	7.49	3.57
Millet	0.39	6.62	7.92	-1.29	0.20
Rice	2.92	3.75	8.90	8.52	6.48
Sorghum	-1.52	1.22	-0.51	0.66	2.10
Wheat	-0.75	4.27	11.39	3.69	0.78
Producer Price	2.59	1.43	3.19	2.27	2.38

Source: FAO (2015) and Author's estimation

Demand side assumptions

The assumptions are that in the next 30 years, population and per capita income (expenditure) are expected to change. We assumed that on average the population and per capita income in EAC will grow by different magnitudes per annum. These percentages were projected for a period of 30 years, a time frame which is sufficient to have climate change (Table 12). Population growth in EAC will grow by between 2.7 and 3.7 per annum while per capita expenditure will grow by between 1.12-fold and 5.28-fold over a period of 30 years. Consumer prices are also expected to increase by between 3.51-fold and 5.71-fold over the 30-year period. Import and export prices are also expected to increase by 2 per cent per annum for all the countries.

Table 12: Demand side assumptions

Crop	Country and Supply Response				
	Burundi	Kenya	Rwanda	Uganda	Tanzania
Expenditure	1.12	4.87	2.70	5.28	2.11
Population	3.72	2.70	2.65	3.41	2.91
Consumer Price	4.22	5.71	4.25	3.51	4.78

Source: Author estimations from FAO data

It also is expected that commodity supply will change even without specific policy intervention. This is natural supply growth. FAO statistics indicate that supply of these different crops has been growing at varying rates in the different EAC Partner States. Using FAO production data sets from 1961 to 2015, we estimated the average annual growth rate and assumed a similar trend till the year 2045. Production trends for the last 30 years are shown in Table 13, where some crops such as beans, sorghum and wheat experience declining production in Burundi, while sorghum and millet are experiencing declining production in Rwanda and Uganda, respectively. The other crops are experiencing growth in production. Supply will also be influenced by producer price which is expected to increase by an average of 1.43 per cent and 2.59 per cent per annum for all cereals in the region.

Table 13: Natural supply growth and producer price changes in 2045

Crop	Country and Supply Response				
	Burundi	Kenya	Rwanda	Uganda	Tanzania
Beans	-0.24	1.98	2.29	1.55	4.87
Maize	0.54	3.04	6.70	7.49	3.57
Millet	0.39	6.62	7.92	-1.29	0.20
Rice	2.92	3.75	8.90	8.52	6.48
Sorghum	-1.52	1.22	-0.51	0.66	2.10
Wheat	-0.75	4.27	11.39	3.69	0.78
Producer Price	2.59	1.43	3.19	2.27	2.38

Source: FAO (2015) and Author's estimation

These changes were introduced in the base model to determine the change in welfare and trade flows after 30 years if status quo does not change i.e. we do not introduce new trade and agricultural policies (only existing ones remain operational) in the region till the year 2045. Further, we assume that intra-regional trade is without trade barriers but international trade between the rest of the world and EAC has barriers in the form of CETs. Table 14 shows percentage price changes in the year 2045. Price increases will be for maize in Kenya, Uganda, and Rwanda; beans in Rwanda; and wheat in Burundi. In all countries, the price of rice will be lower than it is now as supply is projected to outstrip demand. This is also true for millet in all countries except Uganda where demand will outstrip supply.

Table 14: Percentage change in price for base scenario in 2045

Crop	Country and Supply Response				
	Burundi	Kenya	Rwanda	Uganda	Tanzania
Beans	-10.4	-15.7	2.9	-9.4	-32.1
Maize	-31.6	12.8	5.6	9.7	-1.4
Millet	-26.2	-29.5	-38.5	7.5	-39.4
Rice	-66.1	-47.1	-62.7	-50.1	-46.4
Sorghum	-42.1	-32.7	-14.9	5.5	-50.7
Wheat	3.0	-6.1	-26.3	-18.6	-7.7

Source: Model estimation

Table 15 shows the total welfare changes in EAC if business as usual continues for the next 30 years. Results show that if status quo remains, the region will have an overall welfare gain (considering both first-degree and second order welfare approximations). On a country-by-country analysis, all countries have welfare gains.

Table 15: Changes in total welfare due to price changes (US$) with trade restrictions

	First order	Second order
Burundi	56,481.06	75,879.66
Kenya	186,813.15	247,766.77
Rwanda	53,828.27	82,601.40
Uganda	86,051.62	124,853.25
Tanzania	463,817.86	664,173.43
Mean	169,398.39	239,054.90

Source: Model estimation

The change in welfare was also expressed in percentage and per capita income gains. The mean percentage change in welfare is positive both for first degree approximation and second order approximation, with no country showing loses in welfare. Using per capita income, the signs are similar with those of percentage change, and changes in welfare lie between US$ 2.37 and US$ 9.42 for first degree welfare approximation and between US$ 3.44 and US$ 13.49 for second degree welfare approximation. Using the second order welfare approximation, the mean welfare per capita is US$ 7.94 (Table 16).

Table 16: Percentage and per capita change in welfare due to price changes in 2045

Crop	Welfare changes			
	Percentage		Per capita (US$)	
	First order	Second order	First order	Second order
Burundi	16.40	22.00	6.78	9.11
Kenya	7.30	9.70	4.57	6.06
Rwanda	5.90	9.00	4.97	7.62
Uganda	5.30	7.60	2.37	3.44
Tanzania	12.20	17.50	9.42	13.49
Mean	9.42	13.16	5.62	7.94

Source: Model estimation

Due to changes in demand and supply in the different countries over time, demand for commodities is expected to rise and so is supply. In countries where demand exceeds supply, imports for specific commodities can be supplied from EAC or rest of the world (RoW). In cases where supply exceeds demand, individual countries will export to EAC or RoW depending on the most profitable option. Table 17 shows intra-EAC trade flows for different commodities. From this table, Tanzania will export beans to the rest of EAC countries. Kenya will import a bulk of its maize deficit from Uganda and some from Tanzania as these two countries are expected to have maize surpluses. Kenya will also export small amounts of wheat to Tanzania. From Table 18, Uganda will also import beans from the rest of the world but will sell rice to international markets. Rwanda will also sell rice to international markets. Kenya and Rwanda will import wheat from the rest of the world to meet their domestic demands.

Table 17: Intra-EAC trade flows for base model in 2045

	EAC Partner States		
Commodity	**Origin**	**Destination**	**Quantity (000s) MT**
Beans	Tanzania	Burundi	197.09
Beans	Tanzania	Rwanda	206.03
Maize	Burundi	Rwanda	6.44
Maize	Uganda	Kenya	2,140.78
Maize	Tanzania	Kenya	292.77
Millet	Kenya	Uganda	27.13
Millet	Rwanda	Uganda	8.92
Millet	Tanzania	Burundi	12.97
Millet	Tanzania	Uganda	100.98
Rice	Burundi	Uganda	19.48
Rice	Rwanda	Kenya	95.76
Rice	Uganda	Kenya	330.93
Rice	Tanzania	Kenya	170.75
Sorghum	Tanzania	Burundi	72.17
Sorghum	Tanzania	Kenya	90.75
Sorghum	Tanzania	Rwanda	154.34
Wheat	Tanzania	Burundi	40.41

Source: Model estimation

Table 18: Grain trade flows with the rest of the world for base model in 2045

	Imports and Exports from RoW		
Commodity	**Origin**	**Destination**	**Quantity (000s) MT**
Beans	RoW	Kenya	1,883.15
Beans	RoW	Rwanda	615.36
Beans	RoW	Uganda	1,531.85
Millet	RoW	Uganda	576.77
Sorghum	RoW	Kenya	71.60
Sorghum	RoW	Uganda	360.63
Wheat	RoW	Kenya	4,452.11
Wheat	RoW	Rwanda	189.33

Source: Model estimation

4.3.2 Introducing Agricultural Policy to Base Model

We assume that EAC Partner States heed the Maputo and Malabo declarations and spend at least 10% of their budgets in agriculture and attract more than 8 per cent of the FDI in agriculture. This will increase inputs use, increase irrigation and ultimately increase production. ASARECA projects that all agricultural sub-sectors such as staples, cash crops, and livestock will grow by an average of 5 per cent, per capita income by more than 3.5 per cent while GDP will grow by an average of 6 per cent. We therefore introduced a growth of 5 per cent to cereal production in all Partner States and also a uniform 3.5 per cent increase in per capita income. We assume this happens per year within a span of 30 years, so we also adjusted population growth, grain supply and per capita income to conform to this period.

Table 19a presents the percentage change in prices of the different commodities, i.e. difference between original consumer price and the equilibrium price which is due to regional and international trade and also adherence to Maputo and Malabo declarations. We also assume a situation where trade takes place but without regional barriers while international barriers are the baseline (current ones). In all countries, there is substantial percentage decline in prices with this policy. This is because the policy boosts both demand and supply thus closing the deficit gap for most commodities.

Table 19a: Percentage change in price with agricultural policy in 2045

Crop	EAC Partner States				
	Burundi	Kenya	Rwanda	Uganda	Tanzania
Beans	-10.4	-15.7	2.9	-9.4	-32.1
Maize	-38.8	5.6	-3.7	0.8	-8.6
Millet	-54.6	-61.2	-72.9	-39.0	-56.2
Rice	-75.5	-59.4	-74.9	-64.0	-50.9
Sorghum	-71.3	-67.1	-54.2	-53.7	-84.9
Wheat	3.0	-6.1	-26.3	-18.6	-7.7

Source: Model estimation

Table 19b presents the changes in welfare after price changes. The first order approximations assume that prices change but consumers do not react to price changes while in the second order approximation, consumers do react to price changes. The first and second order welfare approximations indicate that Tanzania gains the most from trade due to the policy while Burundi has the least gains. The mean first order approximation welfare change is US$ 241,709 and US$ 356,048 million for second order approximation.

Table 19b: Percentage and per capita change in welfare due to policy change in 2045

	First order	Second order
Burundi	72,846.84	101,547.58
Kenya	259,475.46	347,784.36
Rwanda	75,611.02	120,542.22
Uganda	219,769.51	314,981.75
Tanzania	580,839.68	895,385.17
Mean	241,708.50	356,048.21

Source: Author estimation

We expressed the changes in percentage and income per capita changes for individual countries and entire region (Table 19c). The mean first order welfare changes for all the countries is 13.62 per cent with Rwanda gaining the least (8.2%) while Burundi gains 21.1 per cent. In monetary terms, the mean for all the countries is US$ 7.98 per capita, with Uganda having a welfare gain of US$ 6.05 and Tanzania having US$ 11.79 per person. The second order approximation values are expected to be higher as consumers and producers react to the price changes. The mean percentage second order welfare change is 19.8 per cent with Rwanda having welfare changes of 13.1 per cent while Burundi has a welfare gain of 29.4 per cent. In monetary terms, the mean per capita welfare is US$ 11.73 with Kenya gaining US$ 8.50 per capita while Tanzania has the highest welfare change of US$ 18.18 per capita (Table 19c). From these figures, it is is clear that investing 10 per cent of GDP on agriculture increases the welfare of the people in all the EAC member states.

Table 19c: Changes in total welfare due to price changes with agricultural policy in 2045

Crop	Welfare changes			
	Percentage		Per capita (US$)	
	First order	Second order	First order	Second order
Burundi	21.10	29.40	8.75	12.19
Kenya	10.10	13.60	6.34	8.50
Rwanda	8.20	13.10	6.98	11.12
Uganda	13.40	19.30	6.05	8.67
Tanzania	15.30	23.60	11.79	18.18
Mean	13.62	19.80	7.98	11.73

Source: Author estimation

This welfare is higher compared to the base model due to a 5 per cent growth of grain production, a 3.5 per cent per capita income increase, combined with an increase in population growth. This finding is reaffirmed in grain trade flows discussed below. Table 19d shows trade flows of the different commodities within the EAC member countries after increasing investment in GDP share to agriculture by 10 per cent. Tanzania will export beans to Rwanda and Burundi, and also export sorghum to various countries while Kenya will source most of all its maize deficit from Uganda. From the analysis, Kenya is a net importer of all commodities from EAC except wheat and millet.

Table 19d: Intra-EAC trade flows with agricultural policy in 2045

	EAC Partner States		
Commodity	**Origin**	**Destination**	**Quantity (000s) MT**
Beans	Tanzania	Burundi	154.17
Beans	Tanzania	Rwanda	1,005.22
Maize	Burundi	Rwanda	220.40
Maize	Uganda	Kenya	1,737.92
Millet	Kenya	Tanzania	62.65
Millet	Rwanda	Uganda	9.45
Rice	Burundi	Tanzania	107.32
Rice	Rwanda	Kenya	15.36
Rice	Rwanda	Tanzania	81.92
Rice	Uganda	Kenya	633.42
Sorghum	Tanzania	Burundi	133.11
Sorghum	Tanzania	Kenya	301.40
Sorghum	Tanzania	Rwanda	254.20
Wheat	Tanzania	Burundi	40.36

Source: Model estimation

Table 19e shows the trade between EAC and RoW after effecting the Maputo Declaration. From the analysis, Kenya, Rwanda and Uganda will supplement beans from the rest of the world, while all the countries except Burundi will supplement wheat imports from RoW.

Table 10e: Grain trade flows with the rest of the world with agricultural policy

Commodity	Imports and Exports from RoW		
	Origin	Destination	Quantity (000s) MT
Beans	RoW	Kenya	2,393.72
Beans	RoW	Rwanda	217.43
Beans	RoW	Uganda	1,776.96
Wheat	RoW	Kenya	6,247.30
Wheat	RoW	Rwanda	289.34
Wheat	RoW	Uganda	1,449.83
Wheat	RoW	Tanzania	1,943.67

Source: Model estimation

4.3.3 Introducing trade policy

The next set of analyses assess changes in welfare due to simultaneous changes in trade policy and agricultural policy. This section introduces a hiked EAC common external tariff on the six grain commodities. Table 20a presents percentage changes in prices of different commodities. Results show that in the next 30 years, commodity prices will be higher compared with the situation of agricultural policy only if we increase the CET by 2 to 3-fold what they are today by 2045 and adopt the Maputo/Malabo declarations on agriculture. This is because the trade policy will restrict international trade and narrow trade within the EAC region. In effect, this means that the purchasing power in the individual Partner States will be depressed as local production will not be enough to meet demand. Such a policy would overturn the gains made fromagricultural policy.

Table 20a: Percentage price changes after trade and agricultural policies in 2045

Crop	EAC Partner States				
	Burundi	Kenya	Rwanda	Uganda	Tanzania
Beans	19.60	24.60	40.50	36.40	-1.70
Maize	-38.80	5.60	-3.70	0.80	-8.60
Millet	-54.60	-32.20	-56.40	-31.40	-54.60
Rice	-58.70	-44.50	-54.10	-41.90	-43.30
Sorghum	-59.10	-52.80	-37.80	-40.90	-70.60
Wheat	42.80	43.30	3.00	30.90	34.40

Source: Model estimation

This adverse impacts are shown in the welfare estimations. For instance, the first and second order welfare approximations indicate that Tanzania will have the highest welfare gains followed by Burundi while Rwanda and Kenya have the least (Table 20b). However, the welfare measures will be much lower compared to the scenario with agricultural policy and the prevailing CETs. Increased CETs will therefore curtail trade between EAC and rest of the world.

Table 20b: Changes in total welfare due trade and agricultural policies in 2045

	First order	Second order
Burundi	48,562.94	72,077.69
Kenya	- 53,046.43	57,296.67
Rwanda	- 44,915.52	18,933.09
Uganda	-16,951.39	67,753.61
Tanzania	291,728.53	528,995.49
Mean	45,075.63	149,011.31

Source: Model estimation

These welfare gains were expressed in percentage changes and income per capita gains. The mean first order approximation welfare changes for all the countries is 2.76 per cent with Rwanda gaining the least while Burundi gains the most. In monetary terms, the mean per capita income gains for all the countries is US$ 1.17 per capita. The second order approximation values are expected to be higher as consumers and producers react to the price changes. The mean percentage second order approximation welfare change is 8.64 per cent with Rwanda having a welfare change of 2.1 per cent, while Burundi has a welfare gain of 20.9 per cent. In monetary terms, the mean per capita welfare is US$ 4.88 (Table 20c). Compared to previous scenario, there is a slight welfare decline due to trade restrictions.

Table 20c: Changes in total welfare due to agricultural and trade policies in 2045

	Welfare changes			
	Percentage		Per capita (US$)	
Crop	**First order**	**Second order**	**First order**	**Second order**
Burundi	14.10	20.90	5.83	8.66
Kenya	-2.10	2.20	-1.30	1.40
Rwanda	-4.90	2.10	-4.15	1.75
Uganda	-1.00	4.10	-0.47	1.86
Tanzania	7.70	13.90	5.92	10.74
Mean	2.76	8.64	1.17	4.88

Table 20d shows trade flows of the different commodities within the EAC after effecting trade and agricultural policies in year 2045. Tanzania will be a net exporter of most commodities. For example, the country will export beans, maize, rice and wheat as was the case in the earlier scenario, albeit more for some commodities as Partner States are restricted to import from the EAC. Kenya will import maize from Uganda and beans, sorghum and rice from Tanzania.

Table 20d: Intra-EAC trade flows with trade and agricultural policies in 2045

	EAC Partner States		
Commodity	**Origin**	**Destination**	**Quantity (000s) MT**
Beans	Burundi	Rwanda	44.20
Beans	Tanzania	Kenya	960.01
Beans	Tanzania	Rwanda	751.40
Beans	Tanzania	Uganda	928.37
Maize	Burundi	Rwanda	220.40
Maize	Uganda	Kenya	1,737.91
Rice	Burundi	Uganda	128.79
Rice	Tanzania	Kenya	623.77
Sorghum	Tanzania	Burundi	90.11
Sorghum	Tanzania	Kenya	190.00
Sorghum	Tanzania	Rwanda	200.20
Wheat	Tanzania	Burundi	34.13

Source: Model estimation

There will also be trade between EAC countries and the rest of the world despite the trade restrictions in form of CETs. Table 20e shows the trade between EAC and RoW. From the analysis, due to the high import prices from international market no country will import any commodity from the international market. However, some countries will be export millet, rice and sorghum. The effect of the CETs in this case will be counter-productive and will not achieve their intended goal of promoting regional trade while improving the welfare of the people.

Table 20e: Grain trade flows with the rest of the world due to trade and agricultural policies

Commodity	Imports and Exports from RoW		
	Origin	Destination	Quantity (000s) MT
Millet	Kenya	RoW	119.59
Millet	Rwanda	Row	18.77
Millet	Uganda	Row	480.06
Rice	Rwanda	RoW	241.83
Rice	Uganda	Row	846.06
Rice	Tanzania	Row	702.99
Sorghum	Uganda	RoW	93.90
Sorghum	Tanzania	Row	685.46

Source: Model estimation

4.3.4 Introducing climate change

Finally, we incorporate climate change into the trade and agricultural policy scenario. Climate change is introduced to the supply side of the equation. Its effects on area and yield are incorporated into the simulations through the intrinsic output growth rates. Note that in this study, only maize production was simulated for climate change using APSIM model both for RCP 4.5 and RCP 8.5. The RCP 4.5 assumes a lower carbon dioxide in the atmosphere while that of RCP 8.5 is higher (Table 21a). Therefore, the losses at RCP 4.5 are higher as there is less carbon dioxide for photosynthesis. Under representative concentration pathway (RCP 4.5), all countries lose from climate change with the highest loses being in Kenya, Tanzania and Uganda. With RCP 8.5 (where more carbon dioxide is added in the model), climate change impacts Kenya, Uganda and Tanzania negatively but is gainful to Rwanda and Burundi. Only RCP 4.5 was introduced in the model as it presents higher decline in maize production due to climate change.

Table 21a: Percent change in maize production due to climate change (APSIM)

Crop	EAC Partner States				
	Burundi	Kenya	Rwanda	Uganda	Tanzania
RCP 4.5	-0.150	-2.240	-0.100	-1.900	-0.200
RCP 8.5	0.150	-1.820	0.880	-1.210	-0.500

Source: APSIM model estimation

Table 21b presents the changes in welfare after price change due to climate change, trade and agricultural policy. The welfare changes are not significantly different from those without climate change as only one crop (maize) was considered. The welfare changes are slightly lower than in the situation without climate change (Table 20b).

Table 21b: Changes in total welfare due to price changes (US$) with climate change

	First order	Second order
Burundi	48,294.47	72,011.96
Kenya	-57,274.72	55,569.45
Rwanda	-46,346.29	18,940.09
Uganda	-19,048.14	66,843.32
Tanzania	291,234.69	528,422.48
Mean	43,372.00	148,357.46

Source: Model estimation

We also expressed the welfare in percentage changes and income per capita gains. The first order approximations are negative for Kenya, Rwanda and Uganda while the second order welfare approximations are all positive. The gains vary for different countries as shown in Table 21c but are slightly lower than the scenario without climate change.

Table 21c: Percentage and per capita change in welfare due to climate change

Crop	Welfare changes			
	Percentage		Per capita (US$)	
	First order	Second order	First order	Second order
Burundi	14.00	20.90	5.80	8.65
Kenya	-2.20	2.20	-1.40	1.36
Rwanda	-5.10	2.10	-4.28	1.75
Uganda	-1.20	4.10	-0.52	1.84
Tanzania	7.70	13.90	5.91	10.73
Mean	2.64	8.64	1.10	4.86

Source: Model estimation

Trade flows of the different grains with climate change in year 2045 are shown in Table 21f. As was the case in the earlier scenario, Tanzania will be a net exporter of beans, rice, sorghum and wheat while Kenya will source its maize deficit from Uganda. The trade of other commodities including maize remains higher than was the case with trade and agricultural policy scenario.

Table 21f: Intra-EAC trade flows with climate change

Commodity	EAC Partner States		
	Origin	Destination	Quantity (000s) MT
Beans	Burundi	Rwanda	47.70
Beans	Tanzania	Kenya	975.94
Beans	Tanzania	Rwanda	737.29
Beans	Tanzania	Uganda	945.68
Maize	Burundi	Rwanda	219.93
Maize	Uganda	Kenya	1,782.32
Rice	Burundi	Uganda	128.36
Rice	Tanzania	Kenya	637.99
Sorghum	Tanzania	Burundi	90.24
Sorghum	Tanzania	Kenya	195.83
Sorghum	Tanzania	Rwanda	200.32
Wheat	Tanzania	Burundi	34.17

Source: Model estimation

Trade between EAC countries and the rest of the world under climate change is shown in Table 21g. Just as in the earlier scenario, all countries except Burundi will import beans from RoW. The imports under this scenario are slightly higher than under trade and agricultural policy, meaning that demand is much higher with climate change as regional production cannot meet the demand. The trade flows with rest of the world are similar as was the case of the scenario with trade and agricultural policies, though the actual quantities are higher.

Table 21g: Grain trade flows with the rest of the world with climate change

Commodity	Imports and Exports from RoW		
	Origin	Destination	Quantity (000s) MT
Millet	Kenya	RoW	111.81
Millet	Rwanda	Row	18.721
Millet	Uganda	Row	420.25
Rice	Rwanda	RoW	241.46
Rice	Uganda	Row	818.52
Rice	Tanzania	Row	681.22
Sorghum	Uganda	RoW	69.02
Sorghum	Tanzania	Row	674.12

Source: Model estimation

5 Summary, Conclusion and Recommendations

5.1 Summary

We estimated and compared base scenario which maintains business as usual scenario up to the year 2045 and three other scenarios to determine how changes in different policies (trade and agricultural) and climate change influence welfare and trade flows in EAC. The base scenario projects the current business as usual scenario into the year 2045 with the assumptions that the countries will maintain the current paces of development with current policies. We, however, allowed for existing trade restrictions in form of common external tariffs (CETs). We assumed natural growth for demand side parameters such as income, population and consumer prices, and also, supply side parameters such as increase in producer prices and production growth. From this scenario, it is shown that the mean welfare change in EAC is US$ 7.94 per person.

In the second scenario, we introduced agricultural policy (the Maputo and Malabo declarations) which aim at 10 per cent investment of GDP in agriculture in year 2045. To net the impact of this policy, we assumed a situation with prevailing CETs. Results show that agricultural policy will increase welfare per person to a mean of US$ 11.73. The impact of trade policy only to the welfare is US$ 3.79 (11.73-7.94). In the third scenario, we introduced trade restrictions to the second scenario to capture the impacts of trade restrictions. Results show a decline in welfare to US$ 4.88, indicating that increased trade barriers are harmful to the welfare of individuals and EAC Partner States as they depress the welfare to levels below those observed in the base scenario.

Finally, we introduced climate change to the model with agricultural and trade policy (scenario three). Results indicate a further decline in welfare to US$ 4.86 per person. Climate change, therefore, has slight adverse impacts on welfare. The minimal impact could be explained by the consideration of maize only in climate change impact estimations. This limitation was due lack of calibrations in the APSIM model to handle the remaining crops. Therefore, the impact of climate change to other crops was assumed to be zero, which may not be the case.

Finally, it should be noted that the models used in the analysis do not factor in seasonality and climate extremes which could interfere with the projected paths. In future, it is also possible to have political interference on one or different variables in the model, which could also affect the projected outcomes. Table 22 shows a summary of per capita income welfare changes for the different scenarios considered in the analysis.

Table 22: Baseline, agricultural and trade policy and climate change per capita change in welfare in 2045

	Baseline Welfare Change (US$)	Agricultural Policy Welfare Change (US$)	Trade and Agriculturral Policy Welfare Change (US$)	Climate change, Trade and Agricultural Policy Welfare Change (US$)
Burundi	9.11	12.19	8.66	8.65
Kenya	6.06	8.50	1.40	1.36
Rwanda	7.62	11.12	1.75	1.75
Uganda	3.44	8.67	1.86	1.84
Tanzania	13.49	18.18	10.74	10.73
Mean	7.94	11.73	4.88	4.86

Source:

5.2 Conclusion

If we maintain the status quo in income growth, production growth, population increase and other macro- economic parameters, the Partner Sates in EAC will improve their current welfare from trading in key six key grain crops by US$ 7.94 per person by the year 2045. This figure varies from country to country, with Tanzania, Burundi and Rwanda having the highest gains. Over the same period, grain trade within EAC will be higher than with the rest of the world, although there will be imports of beans, sorghum and wheat from outside of the region. Prices for most grains in most of the countries will also decline.

Introducing agricultural policy in the form of Malabo and Maputo declarations on the base scenario will boost welfare in all countries in the region, and the mean welfare change will be US$ 11.73 per person with varying gains in the different countries. Grain prices will be depressed further down due to increased production and only beans and wheat will be imported into the region.

Increasing the CETs will depress trade with the rest of the world as imports will become very expensive. This will reduce welfare in all the countries substantially as the mean welfare will reduce to US$ 4.88. This is an indication that though CETs were designed to protect local production, they will do more harm if they are increased. To avoid counter productiveness, they should be maintained at their current level or even reduced. Their impact is appreciated in grain trade imports, as no single country imports grain from outside the region when CETs are increased.

5.3 Recommendations

Currently, Kenya's climate change policy is at the sessional paper stage and will soon will be a policy. The recommendations in this policy need to be adopted so as to address the impacts of climate change through adaptation and mitigation. It also needs to be synchronized with the EAC climate change policy. It is advisable that the rest of the EAC Partner States draft their own climate change policies so as to complement the already existing regional climate policy, and individual countries NAPAs, NAMAs and strategies. This will help boost crop production and will aid in closing the current grain supply and demand gap.

In light of climate change and variability, countries should seek to identify their comparative advantages in production of various grains so that they can sell the surplus production and import commodities with deficits. Each Partner Sate should identify grains it should produce with the least cost and boost its production to close the demand supply gap which will continue increasing due to income and population growth.

Countries need to invest in improving agricultural productivity by allocating more funds to the agricultural sector in line with the Maputo Declaration. This will boost production to a certain level but more should be done, as we have already demonstrated that with growth in population and incomes, not even investments under the Maputo Declaration magnitudes will close the supply gap in the future.

Partner States should ensure existing individual country agricultural policies are harmonized with regional agricultural policies and are implemented to boost agricultural production. Individual country policies should be developed with an appreciation of the regional policies to avoid conflicts between country level and regional policies.

Partner States need to avoid inward looking trade policies which hinder agricultural trade, such as export bans and embargos. In the past, individual countries such as Kenya and Tanzania have introduced trade bans and other forms of trade embargos to restrict trade. Such moves lead to losses in welfare as commodity prices are likely to increase.

There is need to reduce NTBs to trade which are increasing the transportation costs of commodities between Partner States and eventually increasing commodity prices. Although this was not explicitly analyzed in the study, it had been recorded that NTBs at time constitute up to 50 per cent of transportation costs in some countries. Partner States need to harmonize or even agree to remove any fees, licenses, or other forms of NTBs in their respective Partner States to encourage more intra-regional trade.

High CETs are counter-productive and may not achieve the desired results especially in a region that is not self-sufficient in grain production. There is need to review them downwards to make them less punitive while as the same time implementing production enhancing policies.

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Appendices

Appendix 1: Supply response model

To motivate the supply response model, we assume that the area response of commodity *i* in country n in period *t* can therefore be expressed as a function of expected relative prices of the commodity PS_{int} and prices of other commodities PS_{jnt} ; expected input costs X_{int} a number of exogenous shifters Z_{int};

$$A^d_{int} = \gamma_{1int}.(PS^e_{int})^{\gamma 2in}.\prod_{(j\neq i)} (PS_{jnt})^{\gamma 3jn}.(X_{int})^{\gamma 4in}.(Z_{int})^{\gamma 5in}.e^{uin} \quad (1)$$

Where A^d_{int} is the desired crop area under commodity *i* in country *n* or at year *t*; γ is the crop area intercept; PS^e_{int} is the effective producer price of commodity *i*; PS_{jnt} is the effective producer price of commodity *j*; X_{int} are input costs such as fertilizers and labour, while Z_{int} denotes other supply shifters such as weather variables; u_{in} accounts for unobserved random factors affecting the area under cultivation. Without loss of generality, we can drop country subscript *n* and collapse equation into a simple Nerlovian model of a single crop *i*. (Askari and Cummings, 1977; Leaver, 2004; Yu et al., 2010).

$$A^d_t = \gamma_1 + \gamma_2 PS^E_t + \gamma_3 Z_t + u_t \quad (2)$$

Where PS^E_t, which is the expected price at period *t*; γ_i is the parameter to be estimated, and specifically, γ_2 is the long run coefficient of supply response. Note that X_{int} and Z_{int} in equation (1) have been combined to the Z_t in equation (2). It should also be noted that the full adjustment to the desired allocation of land may not be possible in the short run, and the actual adjustment in area will only be a fraction δ of the desired adjustment such that:

$$A_t - A_{(t-1)} = \delta(A^d_t - A_{(t-1)}) + \psi_t \quad (3)$$

Where A_t is the actual crop area; δ the partial-adjustment coefficient; and ψ_t is an error term. Note that the price that the producer expects to prevail at harvest time cannot be observed, and one can only specify a model that explains how the producer forms expectations based on actual and past prices and other observable variables. For instance, it can be assumed that farmers adjust their expectations as a fraction λ of the deviation between their expected price and the actual price in the last period, *(t – 1)*, i.e.

$$PS^E_t - PS^E_{(t-1)} = \lambda(PS_{(t-1)} - PS^E_{(t-1)}) + \eta_t \quad (4a)$$

Which can also be written as:

$$PS^E_t = \lambda + (1 - \lambda)\, PS^E_{(t\text{-}1)} + \eta_t, \qquad 0 \leq \lambda \leq 1 \tag{4b}$$

Where PS^E_t is the expected price for period t; $PS_{(t\text{-}1)}$ is the price that prevails when decision making for production in period t occurs; λ is the adaptive-expectations coefficient; and η is a random term. Since CA^d_t and $PS^E_{(t\text{-}1)}$ are unobservable, they can be eliminated from the system by substituting Equation (2) and (4) into Equation (3). The rearrangement gives the reduced form expressed as;

$$A_t = \omega_1 + \omega_2\, PS_{(t\text{-}1)} + \omega_3\, A_{(t\text{-}1)} + \omega_4\, A_{(t\text{-}2)} + \omega_5\, Z_t + \mu t \tag{5}$$

Where, $\omega_1 = \gamma_1\delta\lambda$; ω2 = γ2δλ; which is the short run coefficient of supply response; $\omega_3 = (1-\delta) + (1-\lambda)$; $\omega_4 = -(1-\delta)(1-\lambda)$; $\omega_2 = \gamma_3\delta$; and, $\mu_t = \psi_t\, (1-\lambda)\, \psi(t-1) + \delta u_t - \delta(1-\lambda)\, u(t-1) + \gamma_2\, \delta\eta_t$. Equation (5) is the estimable form of the supply response model defined by Equations (2), (3) and (4) since only the actual output rather than the optimal output is observed in reality. The reduced form equation (5) is a distributed lag model with lagged dependent variable. The short run price response of each explanatory variable is estimated directly by its coefficient, and the long-run price response is obtained by dividing short run elasticities by an adjustment coefficient (the coefficient of the lagged dependent variables) (Yu et al., 2010). If the adjustment coefficient is close to one, it implies that farmers' adjustment of actual acreage to desired acreage is fast. On the other hand, if the adjustment coefficient is close to zero, the adjustment takes place slowly.

The second component of supply response is choosing yield as dependent variable in the response function. In this case, one can obtain the short- and long run yield or supply response with respect to own price following the same logic and adjusting the model specification to address the new research question. Crop yields are estimated as a function of past yields in combination with other variables such as price, infrastructure variables, and a time trend (Agcaoili and Rosegrant 1995). Therefore, yield is assumed to depend on the commodity price, the prices of labor and other inputs (e.g. seed, fertilizer), water (rainfall), and a projected non-price exogenous trend factor. This trend factor reflects productivity growth driven by technology improvements, including crop management research, conventional plant breeding, wide-crossing and hybridization breeding, and biotechnology and transgenic breeding. Other sources of growth considered include private sector agricultural research and development, agricultural extension and education, markets, infrastructure, and irrigation. Using the same logic as in area response, yield response is therefore given as;

$$Y^d_{int} = \beta_{1int}.(PS^e_{int})^{\beta 2in}.\prod_{(k\neq i)} (PF_{knt})^{\beta 3kn}.(X_{int})^{\beta 4in}.(Z_{int})^{\beta 5in}.e^{in} \tag{6}$$

Where Y^d_{int} is the desired crop yield of commodity *i* in country *n* at year *t*; while β is the yield intercept; PS_i is the effective producer price of commodity *i*; PF_k is the effective producer price of commodity *k*; X_i are input costs such as fertilizers and labour while Z_i denotes other supply sifters e.g. weather variables and infrastructure variables; ε_{in} accounts for unobserved random factors affecting the area under cultivation. Again, without loss of generality, we can drop the crop and country subscripts, *i*,*k* and *n*, and also collapse the prices and input costs into one variable PS^E_t, which is the expected price at period *t*. The equation can be written in an additive format as:

$$Y^d_t = \beta_1 + \beta_2 PS^E_t + \beta_3 Z_t + \varepsilon_t \qquad (7)$$

Where β_i is the parameter to be estimated, and specifically, β_2 is the long run coefficient of yield response. The yield and area response equations 2 and 7 can now be combined to give the total supply response. Therefore, the annual production (QS^d_{in}) of commodity *i* in country *n* is estimated as the product of its area and yield, which is given by:

$$QS^d_{in} = Y^d_{in} . A^d_{in} \qquad (8)$$

Supply elasticities are broken up to area and yield elasticities. Crop area elasticities simulate the supply response to changes in own-commodity[1] and competing commodity prices. Crop yield elasticities simulate the supply response of cropping intensity with respect to changes in crop prices, the cost of labour, and the cost of inputs. The absolute values of yield elasticities with respect to own-price, capital and labour add up to the crop-price elasticity.

Askari and Cummings (1977) argue that the relationship between expected prices and farmers' decisions is best expressed in terms of the acreage planted because this is how farmers translate their price expectations into action. However, Leaver (2004) asserts that by using acreage planted, the inherent assumption is that farmers can only increase their output in response to price changes by using more land. This is incorrect, since farmers could also increase output by farming their land more intensively. A further reason why acreage planted may not be the correct measure of output is that farmers may have a limited area of land available for the cultivation of crops. In this situation, since the area of land is given, the farmer cannot increase the area of cultivated land in response to his price expectations. In addition, Leaver (2004) also argues that the use of production per unit area as a measure of output is flawed in that it assumes that farmers will only respond to a price increase by producing more intensively, thereby causing production per

1 Own-price area elasticities of supply for most products in developing countries are approximately two-thirds of those in the developed countries, reflecting the difficulties that producers in developing countries face in access to markets, information, and technology (Rosegrant et. al., 2012)

hectare to increase. This measure overlooks the possibility that increasing prices may instead cause a decline in the average yield per hectare because of marginal land of an inferior quality being cultivated. A more appropriate measure of output appears to be the use of the actual produce weight because it acknowledges that farmers may respond to price incentives by using either more intensive or more extensive farming techniques. This requires the merging of the area Equation 2 and yield Equation 7 to a single output equation

$$Q_t^{PR} = \delta_1 + \delta_2 PS^E{}_t + \delta_3 Z_t + \mu_t \qquad (9)$$

An additional factor in favour of the use of the output measure is that data on tonnage produced is readily available. The supply response for the different crops was estimated using the Nerlove partial adjustment model as shown in Equation 10. The empirical equation is given by;

$$lnC_{1t} = \delta_1 + \delta_2 lnP_1 C_{(1t-1)} + \delta_3 lnC_{(1t-1)} + \delta_4 lnP_2 C_{(2t-1)} + ..., + \delta_n lnP_n C_{(nt-1)} + \gamma_1 time + \varepsilon_t \qquad (10)$$

Where C_{it} is crop production at time *t*; *Pi* is the price of crop *i*, while δ and γ are parameters to be estimated. The main and substitutable crops were jointly estimated by a single set of equations and by the introduction of other slope coefficients to capture different responses.

Appendix 2: AIDS Demand Model

The AIDS specification provides the basis for an econometric estimation of the demand parameters. We can start by choosing a general representation of preferences. The preferences are unobservable since utility cannot be observed directly. However, we estimate observable demands and then we recover *C(u,p)* and *U(x)* and *V(p,y)* by reverting to the preferences that the demand was from. Assuming,

$$Y = C(u, p, d) = A(p)u^{B(p)}.D(p, d) \qquad (1)$$

where *u* is a utility level, *p* are prices, and *d* are demographic variables. In the logarithms, this function can be expressed as:

$$lnC(u, p, d) = lnA(p) + B(p)\, lnu + lnD(p, d) \qquad (2)$$

First we need to specify a functional form for the functions *Ap* and *Bp* such that;

$$lnAp = \alpha_o + \sum^n_{(i=1)} \alpha_1 \, lnp_1 + \sum^n_{(i=1)} \sum^m_{(j=1)} \gamma_{ij} \, lnp_i \, lnp_i \quad (3)$$

$$Bp = \beta_o \prod^n_{(i=1)} p_i\hat{}(\beta_i)$$

$$lnD(p, d) = \sum^n_{(i=1)} \beta i \; lnpi \; lndk$$

Using the Shepard's Lemma, we can take the derivative of *lnC(u,p,d)* with respect to prices to derive the demand in the share form, $w = px/y$, i.e.

$$\delta lnC(u, p, d)/(\delta lnp_i) = w_i \quad (4)$$

Which after substituting for *u* gives;

$$w_i = \alpha_i + \sum^k_{(k=1)} \delta_k \, lnd_k + \sum^m_{(j=1)} \gamma_{ij} \, lnp_j + \beta_i \, ln\,[y/A(p)] + \mu_i \quad (5)$$

Note that the specification of *lnA(p)* makes the model none linear, but for estimation purposes, it can be linearized by the Stone's approximation, where;

$$lnA(p) = \sum^n_{(i=1)} w_1 \, lnp_i = P \quad (6)$$

And the stochastic representation is given by:

$$w_i = \alpha_i + \sum^k_{(k=1)} \delta_k \, lnd_k + \sum^m_{(j=1)} \gamma_{ij} \, lnp_j + \beta_i \, ln[y/A(p)] + \mu_i \quad (7a)$$

where μ_i is a random variable with mean zero and finite variance. Before estimating the own and income demand elasticities, we have to impose theoretical restrictions of homogeneity of degree one and symmetry. This is because *C(u, p, d)* assumes concavity and the requirement of homogeneity of degree one in prices implies the following restrictions;

$$\sum^n_{(i=1)} \alpha_i = 1; \sum^n_{(i=1)} \gamma_{ij} = \sum^n_{(i=j)} \gamma_{ij} = \sum^n_{(i=1)} \beta_i = 0; \sum^k_{(k=1)} \delta_k = 0 \quad (7b)$$

while symmetry implies $\gamma_{ij} = \gamma_{ji}$. By definition, the shares sum to 1, the dependent variables are linearly dependent, so the variance of the error μ is singular. Therefore, when estimating we must drop one equation. The parameters from the equation dropped can be recovered from the restrictions. The parameter estimates are invariant to the equation dropped if maximum likelihood is used. From this estimation, the matrices of own price and income elasticities for the AIDS model can be recovered by:

$$E_{ii} = -1 + \gamma_{ij}/w_i - \beta_i; \quad and \quad \eta_i = 1 + \beta_i/w_i \tag{8}$$

The empirical model of the AIDS demand model takes the form;

$$BS_{cr} = \alpha^D_{cr} + \sum^6_{(c'=1)} \beta^D_{cc'r} \ln(PD_{c'r}) + \delta_{cr} \ln(YR_r) + \mu_i \tag{9}$$

Where BS_{cr} is the budget share of commodity *c* in country *r*; α^D_{cr} is the intercept in the demand equation of *c* in country *r*; $\beta^D_{cc'r}$ is the coefficient on effect of price of *c'* on the demand of *c* in country *r*; $PD_{c'r}$ is the consumer price of commodity *c* in country *r*; and, YR_r is the nominal per capita income in country *r*.

Appendix 3: MCP Model

Using the notation by Dirkse (1994), assume that the function $F{:}C \mapsto R^n$ is a continuously differentiable mapping from an open set containing *C*, where $C \subset R^n$ is a closed set. When *C* is in the non-negative orthant i.e. $C \equiv \Re^n_+$,

there is a non-linear complementarity problem (NCP) defined by F:find $z \in R^n$ such that;

$$0 \leq F(z) \quad \perp \quad z \geq 0 \tag{1}$$

If we have two vectors *l* and *u* to define a box or rectangle *B* in R^n, then the can define the rectangle or box $B{:}=[l, u]$, where; $[l, u] \coloneqq \{z \mid l \leq z \leq u\}$. Given the function *F* and the box $B{:}=[l, u]$, the *MCP(F, B)* can be defined as:

$$\text{Given: Box } B{:}=[l, u] \text{ and a Function } F{:}B \rightarrow R^n \tag{2}$$

$$\text{Find: } z \in R\string^n, \quad w,v \in R^n_+$$
$$s.t.\ F(z) - w + v = 0$$
$$l \leq z \leq u, \quad w \geq 0, \quad v \geq 0$$
$$w^T \langle z - l \rangle = 0$$
$$v^T \langle u - z \rangle = 0$$
$$\text{And; } -\infty \leq l \leq u \leq +\infty$$

Appendix 4: Compensating variation

It is possible to define a measure of welfare (consumer surplus) using compensating or equivalent variations using the minimum expenditure function *C(u, p)*. If we hold the income constant at y_0, the compensating variation $CV(p_0, p_1, y_0)$ is the minimum quantity required to keep the consumer as well off as he was in the initial state (p_0, y_0) in the current state $(p_1, y_0 + CV)$ (Hausman, 1981). This can be expressed in terms of the expenditure function as;

$$CV(p_o, p_1, y_o) = e(p_1, u_o) - e(p_o, u_o)$$
$$= e(p_1, u_o) - y_o \qquad (1)$$

Where, $u_o = v(p_o, y_o)$ is the initial utility from the indirect utility function. A second order Taylor series approximation of the CV gives;

$$CV \cong 1/1! \sum^n_{(i=1)} [\partial e(p_o, u_o)/(\partial p_i)] (p_{1i} - p_{oi}) + 1/2! \sum^n_{(i=1)} \sum^n_{(j=1)} [\partial^2 e(p_o, u_o)/(\partial p_i \partial p_j)] (p_{1i} - p_{oi}) (p_{1j} - p_{oj}) \qquad (2)$$

If we use the Shepard's Lemma and replace $(p_{1i} - p_{oi})$ by Δp_i gives;

$$CV \cong \sum^n_{(i=1)} h_i (p_o, u_o) \Delta p_i + 1/2 \sum^n_{(i=1)} \sum^n_{(j=1)} [\partial h_i (p_o, u_o)/\partial p_j] \Delta p_i \Delta p_j \qquad (3)$$

Where $h_i(p_o, u_o)$ is the Hicksian demand for good i given the original price vector p_o. The Hicksian (compensated) demand is replaced by Marshallian (uncompensated) demand $q_i(p_o, x_o)$ at the original income level. Also, the partial derivative in the second term can replaced with Hicksian own-price elasticity of demand commodity c sold in country r ($\in^H_{cr}$) to yield:

$$CV \cong q_{cr} (p_o, x_o) \Delta p_{cr} + 1/2 \in^H_{cr} [q_{cr} (p_o, x_o)/p_{or}] \Delta p_{cr} \Delta p_{cr}. \qquad (4)$$

Where q_{cr} and p_{cr} are the quantity demanded and price of commodity c sold in country r. Both sides of this equation can be divided by the original income (x_o) and the top and bottom of the right-hand side can be multiplied by (p_{ocr}) to give:

$$CV/x_o \cong [p_{or} q_{cr} (p_o, x_o)/x_o][(\Delta p_{cr})/p_{ocr}] + 1/2 \in^H_{cr} [p_{or} q_{cr} (p_o, x_o)/p_{ocr} x_o] (\Delta p_{cr}/p_{ocr})^2 \qquad (5)$$

We can then replace the consumption ratio of commodity c sold in country r (CR_{cr}) i.e. value of consumption of c sold in country r as a proportion of income (total expenditure) can be substituted in this equation.

$$CV/x_o \cong CR_{cr} (\Delta p_{cr}/p_{ocr}) + 1/2 \in^H_{cr} CR_{cr} (\Delta p_{cr}/p_{ocr})^2 \qquad (6)$$

The assumption here is that producers in the different countries in EAC are profit maximizers. Starting from the profit function, their change in income can be written as:

$$\Delta x = \pi(p_1, w_o, z_o) - \pi(p_o, w_o, z_o) \qquad (7)$$

Where Δx is the change in income; $\pi(.)$ is the profit function; p, w, z are vectors on output prices, input prices and fixed factor quantities, respectively. Using second-order Taylor series approximation, this expression can be approximated to:

$$\Delta x \cong 1/1! \sum^{n}_{(i=1)} [\partial\pi(p_o, w_o, z_o)/\partial p_i] (p_{1i} - p_{oi}) + 1/2! \sum^{n}_{(i=1)} \sum^{n}_{(j=1)} [\partial^2\partial\pi(p_o, w_o, z_o)/\partial p_i \partial p_j] (p_{1i} - p_{oi})(p_{1j} - p_{oj}) \quad (8)$$

If we use the Shepard's Lemma and replace $(p_{1i} - p_{oi})$ by Δp_i gives:

$$\Delta x \cong \sum^{n}_{(i=1)} s_i (p_o, w_o, z_o)\Delta p_i + 1/2 \sum^{n}_{(i=1)} \sum^{n}_{(j=1)} [\partial s_i (p_o, w_o, z_o)/\partial p_j] \Delta p_i \Delta p_j \quad (9)$$

Where, $s_i (p_o, w_o, z_o)$ is the supply of good i given the original price vector p_o. If the partial in the second term is converted to own supply elasticity of commodity c sold in country r ($\in^{S}_{cr}$), then the equation transforms to:

$$\Delta x \cong s_{cr} (p_o, w_o, z_o) \Delta p_{cr} + 1/2 \in^{S}_{cr} [s_{cr} (p_o, w_o, z_o)/p_{ocr}] \Delta p_{cr} \Delta p_{cr} \quad (10)$$

Where s_{cr} and p_{cr} are supply and price of commodity c in country r. Both sides of the equation can be divided by original income (x_o) and multiplying the top and bottom of right hand side by (p_{ocr}).

$$\Delta x/x_o \cong [p_{ocr} s_{cr} (p_o, w_o, z_o)/x_o] [\Delta p_{cr}/p_{ocr}] + 1/2 \in^{S}_{cr} [p_{ocr} s_{cr} (p_o, w_o, z_o)/x_o] [\Delta p_{cr}/p_{ocr}]^2 \quad (11)$$

The production ratio of commodity c in country r (PR_{cr}) i.e. value of production of commodity c sold in country r as a proportion of income (total expenditure) can be substituted in this equation to give:

$$\Delta x/x_o \cong PR_{cr} (\Delta p_{cr}/p_{ocr}) + 1/2 \in^{S}_{cr} PR_{cr} (\Delta p_{cr}/p_{ocr})^2 \quad (12)$$

If we combine the producer welfare (impact of price changes on farming households) and consumer welfare (impact of retail prices on consuming households) equations, we obtain:

$$(\Delta w^2/x_o) = (\Delta p'_{cr})/p'_{ocr} PR_{cr} + 1/2 (\Delta p'_{cr}/p'_{ocr})^2 PR_{cr} \in^{S}_{cr} - (\Delta p_{cr}/p_{ocr}) CR_{cr} + 1/2 (\Delta p_{cr}/p_{ocr})^2 CR_{cr} \in^{H}_{cr} \quad (13)$$

Where, Δw^2 is the second order approximation of net welfare effect of a price change in commodity c in country r on households, where p' and p distinguish producer and consumer prices, respectively. The immediate welfare impact-without consumer and producer responses-can be obtained by setting the elasticities equal to zero to obtain:

$$(\Delta w^1/x_o) = (\Delta p'_{cr}/p'_{ocr}) PR_{cr} - (\Delta p_{cr}/p_{ocr}) CR_{cr} \quad (14)$$

Where, w^1 is the first order approximation of net welfare effect of a price change. This is the welfare impact of a price change assuming that the consumer cannot respond to the change by adjusting consumption. Geometrically, it is a rectangular approximation of the area behind the curve. The second order approximation, w^2 takes into account the response of consumers to the higher price. It is a parallelogram approximation of consumer surplus. It is an approximation because it assumes the demand curve is linear (Goletti and Minot, 1999).

The models explained above were estimated using GAMS software using secondary data collected from different sources including FAO, World Bank, EAC websites, FEWSNET, and other sources. The results are discussed in the section below.

Appendix 5: GAMS CODE of base model

```
*==============================================================================
* GAMS PROGRAM TO SIMULATE SUPPLY AND DEMAND FOR FIVE GOODS
* IN 5 COUNTRY MODEL (EAC COMMUNITY) WITH INTERNAL TRADE, IMPORTS AND EXPORTS
* WITH TRADE TAXES AND QUOTAS AND REGIONAL TRADE RESTRICTIONS
*MODEL WRITTEN BY PROF. RICHARD MULWA, UNIVERSITY OF NAIROBI
*==============================================================================

*BASIC MODEL INSTRUCTIONS

OPTION LP=CONOPT;
OPTION LIMCOL = 0 ;
OPTION LIMROW = 0 ;
$OFFSYMLIST ;
$OFFSYMXREF ;

*==============================================================================
*DEFINING SETS
*==============================================================================

SETS
C CROPS /BEANS
         MAIZE
         MILLET
         RICE
         SORGHUM
         WHEAT /
RW REGION INCLUDING WORLD
         /BURUNDI
         KENYA
         RWANDA
         UGANDA
         TANZANIA
         WORLD /
R(RW) REGION
        /BURUNDI
         KENYA
         RWANDA
         UGANDA
         TANZANIA/;
ALIAS (R,RR), (RW, RRW), (C,CC) ;

*SUPPLY TABLES
*=============
*--------------------------------------------------------------
TABLE PS0(C,R) PRODUCER PRICE (USD PER TON)
         BURUNDI    KENYA    RWANDA    UGANDA   TANZANIA
BEANS     550       620       590       560       520
MAIZE     158       257       230       167       185
MILLET    139       364       165       180       231
RICE      267       234       336       240       284
SORGHUM   211       251       298       205       211
WHEAT     393       350       380       330       325;

*--------------------------------------------------------------
TABLE SPE(C,R) PRICE ELASTICITY OF SUPPLY
          BURUNDI      KENYA      RWANDA     UGANDA    TANZANIA
BEANS      0.25         0.50       0.63        0.30       0.20
MAIZE      0.25         0.73       0.65        0.80       0.76
MILLET     0.013        0.05       0.05        0.24       0.60
RICE       0.02         0.02       0.13        0.02       0.60
SORGHUM    0.32         0.25       0.30        0.05       0.05
WHEAT      0.05         1.21       0.60        1.80       1.20 ;

*-----------------------------------------------------------------
TABLE S0(C,R) ORIGINAL SUPPLY (000S MT PER YEAR)
         BURUNDI         KENYA      RWANDA     UGANDA    TANZANIA
BEANS     210.54         573.61     400.75     444.61      996.25
MAIZE     174.65        3204.00     544.50    1683.84     5607.85
MILLET     11.00          70.00       9.00     820.00      350.00
RICE       67.00         130.00      82.00     230.00      980.00
SORGHUM    70.56         132.93     157.49     420.00      840.00
WHEAT       9.00         247.00      81.00      24.00       93.00  ;
*DEMAND TABLES
*=============
*-------------------------------------------------------
TABLE PD0(C,R) DEMAND PRICE (USD PER TON)
        BURUNDI     KENYA    RWANDA    UGANDA   TANZANIA
```

```
BEANS     690        682      630       660       778
MAIZE     445        320      345       257       280
MILLET    682        550      688       510       682
RICE      954        950      968       850       780
SORGHUM   570        483      423       330       487
WHEAT     563        442      662       538       531;

*-------------------------------------------------------------------
TABLE DO(C,R) ORIGINAL DEMAND (000S MT PER YEAR)
          BURUNDI        KENYA      RWANDA        UGANDA     TANZANIA
BEANS     224.46        900.00     700.00        690.00      708.25
MAIZE     169.46       3450.00     564.07       1308.79     4670.49
MILLET      9.83         62.90       9.00        720.00      239.33
RICE       58.00        370.00      83.00        187.00     1176.00
SORGHUM    73.67        128.75     155.00        325.00      697.42
WHEAT      19.50        900.00     195.00        390.00      980.00 ;

*-----------------------------------------------------------------
TABLE SH(C,R) BUDGET SHARES OF COMMODITIES
           BURUNDI     KENYA       RWANDA     UGANDA   TANZANIA
BEANS      0.4485      0.2027      0.4969     0.2785    0.1450
MAIZE      0.2184      0.3646      0.2193     0.2057    0.3442
MILLET     0.0194      0.0114      0.0070     0.2246    0.0430
RICE       0.1602      0.1161      0.0575     0.0972    0.2414
SORGHUM    0.1216      0.0205      0.0739     0.0656    0.0894
WHEAT      0.0318      0.2846      0.1455     0.1283    0.1370 ;

*----------------------------------------------------------------
TABLE DPE(C,R) OWN PRICE ELASTICITY OF DEMAND
          BURUNDI        KENYA       RWANDA        UGANDA   TANZANIA
BEANS     -0.95          -1.01       -0.85         -0.78     -0.87
MAIZE     -0.22          -0.79       -0.34         -0.68     -0.90
MILLET    -1.50          -1.02       -0.85         -0.90     -0.85
RICE      -1.27          -0.84       -1.40         -1.50     -0.99
SORGHUM   -0.29          -1.02       -0.41         -0.80     -0.85
WHEAT     -1.72          -0.88       -0.90         -0.90     -0.80 ;

*----------------------------------------------------------------
TABLE DYE(C,R) INCOME ELASTICITY OF DEMAND
           BURUNDI      KENYA        RWANDA        UGANDA    TANZANIA
BEANS       1.25         1.10         0.87          0.54      0.99
MAIZE       1.14         0.93         1.03          0.68      0.78
MILLET     0.45          0.77         0.61          0.45      1.01
RICE        1.71         0.91         1.11          0.80      1.05
SORGHUM    0.99          0.77         1.22          0.96      1.01
WHEAT       1.81         1.15         1.56          1.40      1.25 ;

*TRADE TABLES
*============
$ONTEXT
*-------------------------------------------------------------
TABLE WP(C,*)  WORLD PRICE (US$ PER TON) FOB AND CIF
               X          M
BEANS          672        1000
MAIZE          317         845
MILLET         448         900
RICE           592        1269
SORGHUM        293         500
WHEAT          418         734;


*-------------------------------------------------------------



TABLE WP(C,*)  WORLD PRICE (US$ PER TON) FOB AND CIF
               X           M
BEANS          672        800
MAIZE          317        563
MILLET         448        720
RICE           592        725
SORGHUM        293        400
WHEAT          418        544;

$OFFTEXT
```

```
TABLE WP(C,*)  WORLD PRICE (US$ PER TON) FOB AND CIF
              X            M
BEANS         420          500
MAIZE         198          352
MILLET        280          450
RICE          370          453
SORGHUM       183          250
WHEAT         261          340 ;

*-----------------------------------------------------------
TABLE TAX(C,*) TRADE TAX (FRACTION)
              X             M
BEANS         0.00          0.00
MAIZE         0.00          0.00
MILLET        0.00          0.00
RICE          0.00          0.00
SORGHUM       0.00          0.00
WHEAT         0.00          0.00 ;

*------------------------------------------------------------

TABLE QUOTA(C,*) TRADE QUOTA (TONS)
               X                  M
BEANS         999999.00          999999.00
MAIZE         999999.00          999999.00
MILLET        999999.00          999999.00
RICE          999999.00          999999.00
SORGHUM       999999.00          999999.00
WHEAT         999999.00          999999.00  ;

*-------------------------------------------------------------------------
TABLE TCOST(RW,RRW) COST OF TRANSPORTATION (USD PER TON)
          BURUNDI       KENYA      RWANDA      UGANDA    TANZANIA    WORLD
BURUNDI    0.00          180         60          100       150          295
KENYA      200           0.00       180          160       85            75
RWANDA     136           142        0.00         125       140          148
UGANDA     175           79          124         0.00      125           98
TANZANIA   90            85          120         135       0.00         150
WORLD      295           75          148         98        150          0.00;

*CLIMATE CHANGE TABLE
*------------------------------------------------------------------
TABLE CL(C,R) IMPACT OF CLIMATE CHANGE BY 2045 (PERCENT)
               BURUNDI        KENYA         RWANDA        UGANDA       TANZANIA
BEANS           0.000          0.000         0.000         0.000         0.000
MAIZE          -0.150         -2.240        -0.100        -1.900        -0.200
MILLET          0.000          0.000         0.000         0.000         0.000
RICE            0.000          0.000         0.000         0.000         0.000
SORGHUM         0.000          0.000         0.000         0.000         0.000
WHEAT           0.000          0.000         0.000         0.000         0.000;

TABLE SGR(C,R) NATURAL SUPPLY GROWTH BY 2045 (PERCENT)
               BURUNDI         KENYA         RWANDA        UGANDA       TANZANIA
BEANS         -0.00237        0.01977       0.02290       0.01551       0.04873
MAIZE          0.00538        0.03042       0.06698       0.07494       0.03566
MILLET         0.00392        0.06616       0.07924      -0.01287       0.00195
RICE           0.02918        0.03748       0.08895       0.08517       0.06479
SORGHUM       -0.01517        0.01219      -0.00509       0.00661       0.02103
WHEAT         -0.00754        0.04268       0.11392       0.03686       0.00780;

*==========================================================================
*DEFINING PARAMETERS
*==========================================================================

PARAMETERS

*SUPPLY PARAMETERS
*====================================
SA       INTERCEPT OF SUPPLY EQUATION
S0       ORIGINAL SUPPLY
SN       SUPPLY WITH NATURAL GROWTH
SC       SUPPLY WITH NATURAL GROWTH AND CLIMATE CHANGE
*TEST
```

```
STEST   SHOULD BE SAME AS S0

*DEMAND PARAMETERS
DA     INTERCEPT OF DEMAND EQUATION
DYE    INCOME COEFFICIENT OF DEMAND EQUATION
Y0     EXPENDITURE OF THE SIX CROPS PER CAPITA IN COUNTRY R (IN USD)
SHARE  EXPENDITURE SHARES OF THE DIFFERENT CEREALS
*TEST
DTEST  SHOULD BE SAME AS SHARE

*TRADE PARAMETERS
NER      NOMINAL EXCHANGE RATE (LC PER US$)
PX(C)    EXPORT PRICE (USD PER TON)
PM(C)    IMPORT PRICE (USD PER TON)

*POLICY SIMULATION PARAMETERS
PP5(R)    POPULATION BY 2045 (THOUSANDS)
PP(R)     POPULATION IN COUNTRY R (IN THOUSANDS PERSONS)
PGR(R)    POPULATION GROWTH RATE IN COUNTRY R FROM 2045 (PERCENT)
YPR(R)     INCOME GROWTH WITH MAPUTO DECLARATION
COP(R)    CONSUMER PRICE INCREASE
CPI45(C,R) CONSUMER PRICES PERCENT INCREASE BY 2045 (PERCENT)
PRP(R)  PRODUCER PRICE PERCENT INCREASE
PPI45(C,R)  PRODUCER PRICES 2045

* GRAIN EXPENDITURE PER YEAR
Y0(R)                          /  BURUNDI    41.46
                                  KENYA     105.90
                                  RWANDA     72.49
                                  UGANDA     46.34
                                  TANZANIA   77.14 /

*GROWTH IN INCOME PER YEAR

YP(R)                         /  BURUNDI    0.0112
                                  KENYA     0.0487
                                  RWANDA    0.0270
                                  UGANDA    0.0528
                                  TANZANIA  0.0211  /

*POPULATION IN COUNTRY C  (MILLINONS)

PP(R)                           / BURUNDI    8328
                                  KENYA     40909
                                  RWANDA    10837
                                  UGANDA    36350
                                  TANZANIA  49253 /

*POPULATION GROWTH IN COUNTRY C PER YEAR

PGR(R)                         / BURUNDI    0.0372
                                  KENYA     0.0270
                                  RWANDA    0.0265
                                  UGANDA    0.0341
                                  TANZANIA  0.0291 /


PRP(R)                         / BURUNDI    0.02593
                                  KENYA     0.01430
                                  RWANDA    0.03188
                                  UGANDA    0.02271
                                  TANZANIA  0.02378 /

COP(R)                         / BURUNDI    0.04219
                                  KENYA     0.05712
                                  RWANDA    0.04248
                                  UGANDA    0.03507
                                  TANZANIA  0.04781 /;


*DEFININING POLICY PARAMETERS
*===========================
PP5(R)= PP(R)*(1+(PGR(R)*30));
YPR(R)= Y0(R)*(1+YP(R)*30);
CPI45(C,R)=PD0(C,R)*(1+(COP(R))*30);
PPI45(C,R)=PS0(C,R)*(1+(PRP(R))*30);
SN(C,R)=S0(C,R)*(1+(SGR(C,R))*30);
```

```
SC(C,R)=S0(C,R)*(1+(SGR(C,R))*30)+ S0(C,R)*(CL("MAIZE",R)/100);

*DEFINING SUPPLY PARAMETERS
*==============================
SA(C,R)$(SN(C,R))= LOG(SN(C,R))- SUM(CC,SPE(C,R)*LOG(PPI45(C,R)));
STEST(C,R) = EXP(SA(C,R) + SUM(CC,SPE(C,R)*LOG(PPI45(C,R))));

*DEFINING DEMAND PARAMETERS
*==============================
SHARE(C,R) = PP5(R)*SH(C,R)*YPR(R)/CPI45(C,R);
DA(C,R)$SHARE(C,R) = SHARE(C,R)- (SUM(CC,DPE(C,R)*LOG(CPI45(C,R)))
                   - DYE(C,R)*LOG(YPR(R)));
DTEST(C,R) = DA(C,R)+ SUM(CC,DPE(C,R)*LOG(CPI45(C,R))) + DYE(C,R)*LOG(YPR(R));

*DEFINING TRADE PARAMETERS
*================================
*DEFINING TRADE PARAMETERS
*============================
NER = 1;
*REGIONAL TRADE

PX(C) = NER*WP(C,'X')*(1-TAX(C,'X')) ;
PM(C) = NER*WP(C,'M')*(1+TAX(C,'M')) ;

*DEFININING POLICY PARAMETERS
*==============================
*Y45(R)= Y0(R)*(1+YGR(R)*30);
*PP45(R)= PP(R)*(1+PGR(R)*30);

*DISPLAYING PARAMATERS
*============================
DISPLAY SA, STEST;
DISPLAY DA, SHARE, DTEST;
DISPLAY PX, PM;
*DISPLAY Y45, PP45;
*====================================================================
*DEFINITION OF VARIABLES
*====================================================================

VARIABLES
*PRICE VARIABLE
*======================
P(C,R)   EQUILIBRIUM PRICE (USD PER TON)
*SUPPLY VARIABLES
*======================
*S(C,R)   SUPPLY OF CEREALS IN DIFFERENT COUNTRIES
SS(C,R)  SUPPLY FROM DIFFERENT COUNTRIES
*DEMAND VARIABLES
*======================
*DD (C,R) DEMAND OF CEREALS IN THE DIFFERENT COUNTRIES
D(C,R)   QUANTITY DEMANDED;


*=====================================
POSITIVE VARIABLES
TQ(C,R,RR) TRANSPORTED QUANTITY ( TONS)
IXT(C) IMPLICIT EXPORT TAX (USD PER TON)
IMT(C) IMPLICIT IMPORT TAX (USD PER TON)
X(C,R) EXPORTS (THOUSAND TONS)
M(C,R) IMPORTS (THOUSAND TONS) ;

*========================================================================
*DEFINING EQUATIONS
*========================================================================

EQUATIONS
DEMAND     DEMAND EQUATION
SUPPLY     SUPPLY EQUATION
INFLOWS    TOTAL INFLOWS
OUTFLOWS   TOTAL OUTFLOWS
IN_OUT     INFLOWS AND OUTFLOWS
REG_TRADE  REGIONAL TRADE PRICE RELATIONSHIPS
EXPORTS    EXPORT PRICE RELATIONSHIPS
IMPORTS    IMPORT PRICE RELATIONSHIPS
XQUOTA     EXPORT QUOTA
MQUOTA     IMPORT QUOTA;
*=============================================================
```

```
*DEMAND OF COMMODITY C IN REGION R IS GIVEN BY DEMAND INTERCEPT PLUS OWN PRICE
*ELASTICITY OF DEMAND TIMES CONSUMER PRICE PLUS DEMAND ELASTICITY TIMES
*PERCAPITA INCOME

DEMAND(C,R)$SHARE(C,R)..
D(C,R) =E= DA(C,R) + SUM(CC,DPE(C,R)*LOG(P(C,R))) + DYE(C,R)*LOG(YPR(R));

*TDEMAND(C,R)..
*DD(C,R) =E= (SUM(CC,DD(C,R)));

*==================================================================
*SUPPLY OF COMMODITY C IN COUNTRY R EQUALS SUPPLY INTERCEPT PLUS OWN ELASTICITY
*OF SUPPLY TIMES SUPPLY PRICE

SUPPLY(C,R)..
LOG(SS(C,R))=E= (SA(C,R) + SUM(CC,SPE(C,R)*LOG(P(C,R))));

*TSUPPLY(C,R)..
*SS(C,R) =E= SUM(CC,(S(C,R)));
*==============================================================================
*OUTFLOWS = SUPPLY OF COMMODITY FROM A COUNTRY SHOULD BE GREATER OR EQUAL TO
*AMOUNTS TRASNPORTED OUT OF THE REGION PLUS EXPORT

OUTFLOWS(C,R)..
SS(C,R) =G= SUM(RR,TQ(C,R,RR)) + X(C,R);

*=============================================================================
*INFLOWS = TRANSPORTED QUANTITIES TO A REGION PLUS IMPORTS SHOULD BE GREATER
*OR EQUAL TO DEMAND

INFLOWS(C,R)..
SUM(RR,TQ(C,RR,R)) + M(C,R) =G= D(C,R) ;

*==============================================================================
*INFLOWS AND OUTFLOWS

IN_OUT(C,R)..
SS(C,R) + SUM(RR,TQ(C,RR,R)) - SUM(RR,TQ(C,R,RR)) - X(C,R) + M(C,R) =E= D(C,R);
*=============================================================================
*REGIONAL==EAST AFRICAN TRADE

*TRADE OF COMMODITY C FROM REGION R TO REGION RR
*SUPPLY PRICE OF COMMODITY C IN REGION R PLUS TRANSPORATION COST FROM R TO RR
*SHOULD BE GREATER OR EQUAL TO PRICE IN REGION RR

REG_TRADE(C,R,RR)..
P(C,R) + TCOST(R,RR) =G= P(C,RR) ;
*===============================================================================

*WORLD TRADE WITH EAC BLOCK/EXPORT REGIONAL PRICE RELATIONS
*EQUILIBRIUM PRICE IN EAC PLUS IMPLICIT EXPORT TAX IN EAC PLUS TRANSPORTATION
*COST TO THE WORLD SHOULD EQUAL EXPORT PRICES

EXPORTS(C,R)..
P(C,R) + IXT(C) + TCOST(R,'WORLD') =G= PX(C) ;

*==============================================================================
*WORLD TRADE WITH EAC BLOCK/IMPORT REGIONAL PRICE RELATIONS
*IMPORT PRICES PLUS IMPLICIT IMPORT TAX PLUS TRANSPORTATION COST INTO EAC
*SHOULD EQUAL EQUILIBRIUM PRICE

IMPORTS(C,R)..
PM(C) + IMT(C) + TCOST('WORLD',R) =G= P(C,R) ;

*============================================================================
* EXPORT QUOTAS

XQUOTA(C)..
QUOTA(C,'X') =G= SUM(R,X(C,R)) ;

*===========================================================================
*IMPORT QUOTAS

MQUOTA(C)..
QUOTA(C,'M') =G= SUM(R,M(C,R)) ;

*===========================================================================
```

```
* STARTING VALUES
*============================================================================
TQ.FX(C,R,R) = 0 ;
*IXT.FX(C)=0;
*IMT.FX(C)=0;
*X.FX(C,R)=0;
*M.FX(C,R)=0;
P.LO(C,R) = 1;
SS.LO(C,R) = 0.0001;

*==============================================================================
*INITIAL VALUES
*============================================================================
P.L(C,R)=PS0(C,R);

*============================================================================
*SOLVING THE MODEL
*=============================================================================
MODEL MARKET /DEMAND.D
              SUPPLY.SS
              IN_OUT.P
              REG_TRADE.TQ
              EXPORTS.X
              IMPORTS.M
              XQUOTA.IXT
              MQUOTA.IMT/;

MARKET.TOLINFEAS = 1E-3;
SOLVE MARKET USING MCP;
*IXT.LO(C)=-INF;
*IXT.UP(C)=INF ;
*IMT.LO(C)=-INF;
*IMT.UP(C)=INF;
```

```
*=========================================================================
*DISPLAY RESULTS
*=========================================================================
OPTION PP5: 3:0:1;
OPTION YPR: 3:0:1;
OPTION CPI45: 3:0:1
OPTION PPI45: 3:0:1
OPTION DA: 3:0:1;
OPTION SA: 3:0:1;
OPTION SN: 3:0:1;
OPTION SC: 3:0:1;
OPTION P: 3:0:1;
OPTION PX: 3:0:1;
OPTION PM: 3:0:1;
OPTION D: 3:0:1;
OPTION SS: 3:0:1;
OPTION TQ: 3:0:1;
OPTION X: 3:0:1;
OPTION M: 3:0:1;
*OPTION OUTFLOWS: 3:0:1;
*OPTION INFLOWS: 3:0:1;
OPTION IN_OUT: 3:0:1;
OPTION REG_TRADE: 3:0:1;

DISPLAY
PP5, YPR, CPI45, PPI45, P.L, DA, DTEST, SHARE, SA, SN, SC, STEST, PX, PM, TQ.L,
SS.L,
D.L, X.L, M.L, IN_OUT.L, REG_TRADE.L;


*ESTIMATING WELFARE
*=======================
*DEFINE PARAMETERS
*-------------------
PARAMETERS
```

```
PCTDP(C,R) PERCENT CHANGE IN PRICE OF CROP C IN REGION R FROM THE MODEL SOLUTION

CBR(C,R) IS THE CONSUMPTION BENEFIT RATIO FOR CROP C IN REGION R
*        PROPORTION EXPENDITURE ATTRIBUTED TO CROP C;
*CBR2(C,R) CONSUMPTION BENEFIT RATIO

PBR(C,R) IS THE PRODUCTION BENEFIT RATIO FOR CROP C IN REGION R
*        VALUE OF CROP C PRODUCTION TO TOTAL INCOME (EXPENDITURE);
*PBR2(C,R) CONSUMPTION BENEFIT RATIO

PSURP(C,R) PRODUCER SURPLUS IN REGION R
CSURP(C,R) CONSUMER SURPLUS IN REGION R
PSURP2(C,R) PRODUCER SURPLUS IN REGION R
CSURP2(C,R) CONSUMER SURPLUS IN REGION R

WELFD(C,R) TOTAL WELFARE CHANGE (NBR) FOR CROP C IN COUNTRY R FIRST DEGREE
WELF(C,R) TOTAL WELFARE CHANGE (NBR) FOR CROP C IN COUNTRY R SECOND DEGREE
WELFD1(R)  AVERAGE WELFARE CHANGE IN COUNTRY R FIRST DEGREE
WELFD2(R)  AVERAGE WELFARE CHANGE IN COUNTRY R SECOND DEGREE DEGREE

WELFV1(C,R) TOTAL WELFARE CHANGE (VALUE) FOR CROP C IN COUNTRY R FIRST DEGREE
WELFVD1(R)  AVERAGE WELFARE CHANGE (VALUE) IN COUNTRY R FIRST DEGREE
WELFV2(C,R) TOTAL WELFARE CHANGE (VALUE) FOR CROP C IN COUNTRY R SECOND DEGREE
WELFVD2(R)  AVERAGE WELFARE CHANGE (VALUE) IN COUNTRY R SECOND DEGREE
WELFCAPV1(R) WELFARE PER CAPITA (VALUE) FIRST DEGREE
WELFCAPV2(R) WELFARE PER CAPITA (VALUE) SECOND DEGREE

SSVAL(C,R)  VALUE OF SUPPLY
DDVAL(C,R)  VALUE OF DEMAND;


*ASSIGNING PARAMETER VALUES
*----------------------------

PCTDP(C,R)=(P.L(C,R)-PD0(C,R))/PD0(C,R);

SSVAL(C,R) = S0(C,R)*PS0(C,R);
DDVAL(C,R) = D0(C,R)*PD0(C,R);

CBR(C,R) = DDVAL(C,R)/(DDVAL('BEANS',R)+DDVAL('MAIZE',R)+DDVAL('MILLET',R)
          + DDVAL('RICE',R)+ DDVAL('SORGHUM',R)+ DDVAL('WHEAT',R));
PBR(C,R) = SSVAL(C,R)/(DDVAL('BEANS',R)+DDVAL('MAIZE',R)+DDVAL('MILLET',R)
          + DDVAL('RICE',R)+ DDVAL('SORGHUM',R)+ DDVAL('WHEAT',R));

PSURP(C,R) = PBR(C,R)*PCTDP(C,R)+ 0.5*SPE(C,R)*PBR(C,R)
             *(PCTDP(C,R)*PCTDP(C,R));

CSURP(C,R)= (-CBR(C,R)*PCTDP(C, R))-0.5*DPE(C,R)*CBR(C,R)
            *(PCTDP(C,R)*PCTDP(C,R));

*WELFARE IN PBR AND CBR

WELFD(C,R) =  PBR(C,R)*PCTDP(C,R)-(CBR(C,R)*PCTDP(C, R));

WELF(C,R) = PCTDP(C,R)*(PBR(C,R)-CBR(C,R))
           + 0.5*(SPE(C,R)*PBR(C,R) - DPE(C,R)*CBR(C,R))
           *(PCTDP(C,R)*PCTDP(C,R));

WELFD1(R)= (WELFD('BEANS',R)+ WELFD('MAIZE',R)+WELFD('MILLET',R)
          + WELFD('RICE',R)+ WELFD('SORGHUM',R)+ WELFD('WHEAT',R));

WELFD2(R)= (WELF('BEANS',R)+ WELF('MAIZE',R)+WELF('MILLET',R)
          + WELF('RICE',R)+ WELF('SORGHUM',R)+ WELF('WHEAT',R));
*==============================================================

PSURP2(C,R) = SSVAL(C,R)*PCTDP(C,R)+ 0.5*SPE(C,R)*SSVAL(C,R)
             *(PCTDP(C,R)*PCTDP(C,R));

CSURP2(C,R)= (-DDVAL(C,R)*PCTDP(C, R))-0.5*DPE(C,R)*DDVAL(C,R)
            *(PCTDP(C,R)*PCTDP(C,R));

*WELFARE IN VALUE

WELFV1(C,R) = SSVAL(C,R)*PCTDP(C,R)-(DDVAL(C,R)*PCTDP(C, R));

WELFVD1(R)= (WELFV1('BEANS',R)+ WELFV1('MAIZE',R)+WELFV1('MILLET',R)
```

```
          + WELFV1('RICE',R)+ WELFV1('SORGHUM',R)+ WELFV1('WHEAT',R));

WELFV2(C,R) = PCTDP(C,R)*(SSVAL(C,R)-DDVAL(C,R))
           + 0.5*(SPE(C,R)*SSVAL(C,R) - DPE(C,R)*DDVAL(C,R))
           *(PCTDP(C,R)*PCTDP(C,R));

WELFVD2(R)= (WELFV2('BEANS',R)+ WELFV2('MAIZE',R)+WELFV2('MILLET',R)
          + WELFV2('RICE',R)+ WELFV2('SORGHUM',R)+ WELFV2('WHEAT',R));

WELFCAPV1(R) = WELFVD1(R)/PP(R);

WELFCAPV2(R) = WELFVD2(R)/PP(R);

DISPLAY PCTDP, SSVAL, DDVAL,CBR, PBR, PSURP, CSURP, WELFD, WELF,
        WELFD1, WELFD2,PSURP2, CSURP2, WELFV1, WELFV2, WELFVD1,
        WELFVD2,WELFCAPV1, WELFCAPV2;
```

Appendix 6: Model with Agric Policy, Trade Policy and Climate Change

```
*=================================================================================
* GAMS PROGRAM TO SIMULATE SUPPLY AND DEMAND OF SIX COMMODITIES
* IN 5 COUNTRY MODEL (EAC COMMUNITY) WITH INTERNAL TRADE, AND
* INTERNATIONAL IMPORTS AND EXPORTS; WITH TRADE TAXES AND QUOTAS AND REGIONAL
* TRADE RESTRICTIONS|MODEL WRITTEN BY PROF. RICHARD MULWA UNIVERSITY OF NAIROBI
*=================================================================================

*BASIC MODEL INSTRUCTIONS

OPTION LP=CONOPT;
OPTION LIMCOL = 0 ;
OPTION LIMROW = 0 ;
$OFFSYMLIST ;
$OFFSYMXREF ;

*=================================================================================
*DEFINING SETS
*=================================================================================

SETS
C CROPS /BEANS
         MAIZE
         MILLET
         RICE
         SORGHUM
         WHEAT /
RW REGION INCLUDING WORLD
         /BURUNDI
         KENYA
         RWANDA
         UGANDA
         TANZANIA
         WORLD /
R(RW) REGION
        /BURUNDI
         KENYA
         RWANDA
         UGANDA
         TANZANIA/;
ALIAS (R,RR), (RW, RRW), (C,CC) ;

*SUPPLY TABLES
*=============
*-------------------------------------------------------------
TABLE PS0(C,R) PRODUCER PRICE (USD PER TON)
         BURUNDI    KENYA    RWANDA    UGANDA   TANZANIA
BEANS     550       620       590       560       520
MAIZE     158       257       230       167       185
MILLET    139       364       165       180       231
RICE      267       234       336       240       284
SORGHUM   211       251       298       205       211
WHEAT     393       350       380       330       325;

*-------------------------------------------------------------
TABLE SPE(C,R) PRICE ELASTICITY OF SUPPLY
          BURUNDI      KENYA      RWANDA     UGANDA    TANZANIA
BEANS      0.25         0.50       0.63        0.30       0.20
MAIZE      0.25         0.73       0.65        0.80       0.76
MILLET     0.013        0.05       0.05        0.24       0.60
RICE       0.02         0.02       0.13        0.02       0.60
SORGHUM    0.32         0.25       0.30        0.05       0.05
WHEAT      0.05         1.21       0.60        1.80       1.20 ;

*-----------------------------------------------------------------
TABLE S0(C,R) ORIGINAL SUPPLY (000S MT PER YEAR)
         BURUNDI        KENYA      RWANDA     UGANDA    TANZANIA
BEANS     210.54         573.61     400.75     444.61     996.25
MAIZE     174.65        3204.00     544.50    1683.84    5607.85
MILLET     11.00          70.00       9.00     820.00     350.00
RICE       67.00         130.00      82.00     230.00     980.00
SORGHUM    70.56         132.93     157.49     420.00     840.00
WHEAT       9.00         247.00      81.00      24.00      93.00  ;


*DEMAND TABLES
*=============
*-----------------------------------------------------------
```

```
TABLE PD0(C,R) DEMAND PRICE (USD PER TON)
        BURUNDI     KENYA    RWANDA    UGANDA   TANZANIA
BEANS     690        682      630       660       778
MAIZE     445        320      345       257       280
MILLET    682        550      688       510       682
RICE      954        950      968       850       780
SORGHUM   570        483      423       330       487
WHEAT     563        442      662       538       531;

*-------------------------------------------------------------------
TABLE D0(C,R) ORIGINAL DEMAND (000S MT PER YEAR)
          BURUNDI       KENYA      RWANDA       UGANDA    TANZANIA
BEANS     224.46       900.00      700.00       690.00      708.25
MAIZE     169.46      3450.00      564.07      1308.79     4670.49
MILLET      9.83        62.90        9.00       720.00      239.33
RICE       58.00       370.00       83.00       187.00     1176.00
SORGHUM    73.67       128.75      155.00       325.00      697.42
WHEAT      19.50       900.00      195.00       390.00      980.00 ;

*-----------------------------------------------------------------
TABLE SH(C,R) BUDGET SHARES OF COMMODITIES
           BURUNDI      KENYA       RWANDA     UGANDA   TANZANIA
BEANS      0.4485      0.2027      0.4969     0.2785    0.1450
MAIZE      0.2184      0.3646      0.2193     0.2057    0.3442
MILLET     0.0194      0.0114      0.0070     0.2246    0.0430
RICE       0.1602      0.1161      0.0575     0.0972    0.2414
SORGHUM    0.1216      0.0205      0.0739     0.0656    0.0894
WHEAT      0.0318      0.2846      0.1455     0.1283    0.1370 ;

*---------------------------------------------------------------
TABLE DPE(C,R) OWN PRICE ELASTICITY OF DEMAND
          BURUNDI       KENYA       RWANDA        UGANDA   TANZANIA
BEANS     -0.95         -1.01       -0.85         -0.78     -0.87
MAIZE     -0.22         -0.79       -0.34         -0.68     -0.90
MILLET    -1.50         -1.02       -0.85         -0.90     -0.85
RICE      -1.27         -0.84       -1.40         -1.50     -0.99
SORGHUM   -0.29         -1.02       -0.41         -0.80     -0.85
WHEAT     -1.72         -0.88       -0.90         -0.90     -0.80 ;

*---------------------------------------------------------------
TABLE DYE(C,R) INCOME ELASTICITY OF DEMAND
           BURUNDI      KENYA        RWANDA        UGANDA    TANZANIA
BEANS       1.25         1.10         0.87          0.54       0.99
MAIZE       1.14         0.93         1.03          0.68       0.78
MILLET      0.45         0.77         0.61          0.45       1.01
RICE        1.71         0.91         1.11          0.80       1.05
SORGHUM     0.99         0.77         1.22          0.96       1.01
WHEAT       1.81         1.15         1.56          1.40       1.25 ;
*TRADE TABLES
*============
*-----------------------------------------------------------
* WHEAT 35% EXT TARIFF
* RICE EAC 75%  TARIFF; 35% FROM EXTERNAL
* MAIZE 50%  EXT TARIFF
*MILLET, SOUGHUM, BEANS 25% EXTERNAL TARIFF
*I & M PRICES INCREASE BY 2% P.A

TABLE WP(C,*)  WORLD PRICE (US$ PER TON) FOB AND CIF
               X          M
BEANS          672       1000
MAIZE          317        845
MILLET         448        900
RICE           592       1269
SORGHUM        293        500
WHEAT          418        734;

$ONTEXT

TABLE WP(C,*)  WORLD PRICE (US$ PER TON) FOB AND CIF
               X            M
BEANS         420          500
MAIZE         198          352
MILLET        280          450
RICE          370          453
SORGHUM       183          250
WHEAT         261          340 ;
```

```
$OFFTEXT
*------------------------------------------------------------
TABLE TAX(C,*) TRADE TAX (FRACTION)
               X             M
BEANS         0.00          0.00
MAIZE         0.00          0.00
MILLET        0.00          0.00
RICE          0.00          0.00
SORGHUM       0.00          0.00
WHEAT         0.00          0.00 ;

*-------------------------------------------------------------

TABLE QUOTA(C,*) TRADE QUOTA (TONS)
               X                  M
BEANS        9999999.00         9999999.00
MAIZE        9999999.00         9999999.00
MILLET       9999999.00         9999999.00
RICE         9999999.00         9999999.00
SORGHUM      9999999.00         9999999.00
WHEAT        9999999.00         9999999.00  ;

*TRANSPORT TABLE
*---------------------------------------------------------------------------
TABLE TCOST(RW,RRW) COST OF TRANSPORTATION (USD PER TON)
           BURUNDI       KENYA      RWANDA      UGANDA    TANZANIA    WORLD
BURUNDI    0.00          180          60          100        150          295
KENYA      200           0.00        180          160        85            75
RWANDA     136           142         0.00         125        140          148
UGANDA     175           79           124         0.00       125           98
TANZANIA   90            85           120         135        0.00         150
WORLD      295           75           148         98         150          0.00;

*CLIMATE CHANGE TABLE
*------------------------------------------------------------------
TABLE CL(C,R) IMPACT OF CLIMATE CHANGE BY 2045 (PERCENT)
             BURUNDI        KENYA         RWANDA        UGANDA       TANZANIA
BEANS         0.000         0.000         0.000         0.000         0.000
MAIZE        -0.150        -2.240        -0.100        -1.900        -0.200
MILLET        0.000         0.000         0.000         0.000         0.000
RICE          0.000         0.000         0.000         0.000         0.000
SORGHUM       0.000         0.000         0.000         0.000         0.000
WHEAT         0.000         0.000         0.000         0.000         0.000;

$ONTEXT
TABLE SGR(C,R) NATURAL SUPPLY GROWTH BY 2045 (PERCENT)
             BURUNDI        KENYA         RWANDA        UGANDA       TANZANIA
BEANS        -0.114         1.335         0.609         0.849         1.114
MAIZE         0.096         0.534         1.065         1.329         0.436
MILLET        0.231        -0.606         0.645        -0.189         0.213
RICE          2.424         0.834         0.798         2.655         2.550
SORGHUM       0.906        -0.129         0.045         0.171         0.060
WHEAT         0.225         0.609         2.715         0.942         0.704;
$OFFTEXT

TABLE SGR(C,R) NATURAL SUPPLY GROWTH BY 2045 (PERCENT)
             BURUNDI        KENYA         RWANDA        UGANDA       TANZANIA
BEANS       -0.00237       0.01977       0.02290       0.01551       0.04873
MAIZE        0.00538       0.03042       0.06698       0.07494       0.03566
MILLET       0.00392       0.06616       0.07924      -0.01287       0.00195
RICE         0.02918       0.03748       0.08895       0.08517       0.06479
SORGHUM     -0.01517       0.01219      -0.00509       0.00661       0.02103
WHEAT       -0.00754       0.04268       0.11392       0.03686       0.00780;

TABLE SPR(C,R) MAPUTO DECLARATION GROWTH BY 2045 (PERCENT)
             BURUNDI        KENYA         RWANDA        UGANDA       TANZANIA
BEANS          0.05          0.05          0.05          0.05          0.05
MAIZE          0.05          0.05          0.05          0.05          0.05
MILLET         0.05          0.05          0.05          0.05          0.05
RICE           0.05          0.05          0.05          0.05          0.05
SORGHUM        0.05          0.05          0.05          0.05          0.05
WHEAT          0.05          0.05          0.05          0.05          0.05 ;

*===========================================================================
*DEFINING PARAMETERS
```

```
*===========================================================================

PARAMETERS

*SUPPLY PARAMETERS
*====================================
SA      INTERCEPT OF SUPPLY EQUATION
S0      ORIGINAL SUPPLY
SN      SUPPLY WITH NATURAL GROWTH
SC      SUPPLY WITH NATURAL GROWTH AND CLIMATE CHANGE
*TEST
STEST   SHOULD BE SAME AS S0

*DEMAND PARAMETERS
DA     INTERCEPT OF DEMAND EQUATION
DYE    INCOME COEFFICIENT OF DEMAND EQUATION
Y0     EXPENDITURE OF THE SIX CROPS PER CAPITA IN COUNTRY R (IN USD)
SHARE  EXPENDITURE SHARES OF THE DIFFERENT CEREALS
*TEST
DTEST  SHOULD BE SAME AS SHARE

*TRADE PARAMETERS
NER      NOMINAL EXCHANGE RATE (LC PER US$)
PX(C)    EXPORT PRICE (USD PER TON)
PM(C)    IMPORT PRICE (USD PER TON)

*POLICY SIMULATION PARAMETERS
PP5(R)     POPULATION BY 2045 (THOUSANDS)
PP(R)      POPULATION IN COUNTRY R (IN THOUSANDS PERSONS)
PGR(R)     POPULATION GROWTH RATE IN COUNTRY R FROM 2010 (PERCENT)
YPR(R)      INCOME GROWTH WITH MAPUTO DECLARATION
COP(R)     CONSUMER PRICE INCREASE
CPI45(C,R) CONSUMER PRICES PERCENT INCREASE BY 2045 (PERCENT)
PRP(R)  PRODUCER PRICE PERCENT INCREASE
PPI45(C,R)  PRODUCER PRICES 2045
* GRAIN EXPENDITURE PER YEAR
Y0(R)                           /  BURUNDI    41.46
                                   KENYA     105.90
                                   RWANDA     72.49
                                   UGANDA     46.34
                                   TANZANIA   77.14 /

*GROWTH IN INCOME PER YEAR

YP(R)                          /  BURUNDI    0.0462
                                   KENYA     0.0837
                                   RWANDA    0.0620
                                   UGANDA    0.0878
                                   TANZANIA  0.0561  /

*POPULATION IN COUNTRY C  (MILLINONS)

PP(R)                            / BURUNDI    8328
                                   KENYA     40909
                                   RWANDA    10837
                                   UGANDA    36350
                                   TANZANIA  49253 /

*POPULATION GROWTH IN COUNTRY C PER YEAR

PGR(R)                          / BURUNDI    0.0372
                                   KENYA     0.0270
                                   RWANDA    0.0265
                                   UGANDA    0.0341
                                   TANZANIA  0.0291 /

PRP(R)                          / BURUNDI    0.02593
                                   KENYA     0.01430
                                   RWANDA    0.03188
                                   UGANDA    0.02271
                                   TANZANIA  0.02378 /

COP(R)                          / BURUNDI    0.04219
                                   KENYA     0.05712
                                   RWANDA    0.04248
                                   UGANDA    0.03507
                                   TANZANIA  0.04781 /;
```

```
*DEFININING POLICY PARAMETERS
*==============================
PP5(R)= PP(R)*(1+(PGR(R)*30));
YPR(R)= Y0(R)*(1+YP(R)*30);
CPI45(C,R)=PD0(C,R)*(1+(COP(R))*30);
PPI45(C,R)=PS0(C,R)*(1+(PRP(R))*30);
SN(C,R)=S0(C,R)*(1+(SPR(C,R)*30)) + S0(C,R)*(1+(SGR(C,R)*30));
SC(C,R)=SN(C,R)*(1+ CL("MAIZE",R)/100);

*DEFINING SUPPLY PARAMETERS
*==============================
SA(C,R)$(SC(C,R))= LOG(SC(C,R))- SUM(CC,SPE(C,R)*LOG(PPI45(C,R)));
STEST(C,R) = EXP(SA(C,R) + SUM(CC,SPE(C,R)*LOG(PPI45(C,R))));

*DEFINING DEMAND PARAMETERS
*================================
SHARE(C,R) = PP5(R)*SH(C,R)*YPR(R)/CPI45(C,R);
DA(C,R)$SHARE(C,R) = SHARE(C,R)- (SUM(CC,DPE(C,R)*LOG(CPI45(C,R)))
                   - DYE(C,R)*LOG(YPR(R)));
DTEST(C,R) = DA(C,R)+ SUM(CC,DPE(C,R)*LOG(CPI45(C,R))) + DYE(C,R)*LOG(YPR(R));

*DEFINING TRADE PARAMETERS
*================================
NER = 1;
*REGIONAL TRADE

PX(C) = NER*WP(C,'X')*(1-TAX(C,'X')) ;
PM(C) = NER*WP(C,'M')*(1+TAX(C,'M')) ;


*DISPLAYING PARAMATERS
*============================
DISPLAY SA, STEST;
DISPLAY DA, SHARE, DTEST;
DISPLAY PX, PM;
DISPLAY CPI45, PPI45;

*=========================================================================
*DEFINITION OF VARIABLES
*=========================================================================

VARIABLES
*PRICE VARIABLE
*======================
P(C,R)   EQUILIBRIUM PRICE (USD PER TON)
*SUPPLY VARIABLES
*======================
*S(C,R)   SUPPLY OF CEREALS IN DIFFERENT COUNTRIES
SS(C,R)  SUPPLY FROM DIFFERENT COUNTRIES
*DEMAND VARIABLES
*======================
*DD (C,R) DEMAND OF CEREALS IN THE DIFFERENT COUNTRIES
D(C,R)   QUANTITY DEMANDED;


*=====================================
POSITIVE VARIABLES
TQ(C,R,RR) TRANSPORTED QUANTITY ( TONS)
IXT(C) IMPLICIT EXPORT TAX (USD PER TON)
IMT(C) IMPLICIT IMPORT TAX (USD PER TON)
X(C,R) EXPORTS (THOUSAND TONS)
M(C,R) IMPORTS (THOUSAND TONS) ;

*=============================================================================
*DEFINING EQUATIONS
*=============================================================================

EQUATIONS
DEMAND     DEMAND EQUATION
SUPPLY     SUPPLY EQUATION
*INFLOWS    TOTAL INFLOWS
*OUTFLOWS   TOTAL OUTFLOWS
IN_OUT     INFLOWS AND OUTFLOWS
REG_TRADE  REGIONAL TRADE PRICE RELATIONSHIPS
EXPORTS    EXPORT PRICE RELATIONSHIPS
```

```
IMPORTS    IMPORT PRICE RELATIONSHIPS
XQUOTA     EXPORT QUOTA
MQUOTA     IMPORT QUOTA;

*=================================================================
*DEMAND OF COMMODITY C IN REGION R IS GIVEN BY DEMAND INTERCEPT PLUS OWN PRICE
*ELASTICITY OF DEMAND TIMES CONSUMER PRICE PLUS DEMAND ELASTICITY TIMES
*PERCAPITA INCOME

DEMAND(C,R)$SHARE(C,R)..
D(C,R) =E= DA(C,R) + SUM(CC,DPE(C,R)*LOG(P(C,R))) + DYE(C,R)*LOG(YPR(R));

*TDEMAND(C,R)..
*DD(C,R) =E= (SUM(CC,DD(C,R)));

*===================================================================
*SUPPLY OF COMMODITY C IN REGION R EQUALS SUPPLY INTERCEPT PLUS OWN ELASTICITY
*OF SUPPLY TIMES SUPPLY PRICE

SUPPLY(C,R)..
LOG(SS(C,R))=E= (SA(C,R) + SUM(CC,SPE(C,R)*LOG(P(C,R))));

*TSUPPLY(C,R)..
*SS(C,R) =E= SUM(CC,(S(C,R)));
*===============================================================================
*OUTFLOWS = SUPPLY OF COMMODITY FROM A COUNTRY SHOULD BE GREATER OR EQUAL TO
*AMOUNTS TRASNPORTED OUT OF THE REGION PLUS EXPORT

*OUTFLOWS(C,R)..
*SS(C,R) =G= SUM(RR,TQ(C,R,RR)) + X(C,R);

*==============================================================================
*INFLOWS = TRANSPORTED QUANTITIES TO A REGION PLUS IMPORTS SHOULD BE GREATER
*OR EQUAL TO DEMAND

*INFLOWS(C,R)..
*SUM(RR,TQ(C,RR,R)) + M(C,R) =G= D(C,R) ;

*===============================================================================
*INFLOWS AND OUTFLOWS

IN_OUT(C,R)..
SS(C,R) + SUM(RR,TQ(C,RR,R)) - SUM(RR,TQ(C,R,RR)) - X(C,R) + M(C,R) =E= D(C,R);
*==============================================================================
*REGIONAL==EAST AFRICAN TRADE

*TRADE OF COMMODITY C FROM REGION R TO REGION RR
*SUPPLY PRICE OF COMMODITY C IN REGION R PLUS TRANSPORATION COST FROM R TO RR
*SHOULD BE GREATER OR EQUAL TO PRICE IN REGION RR

REG_TRADE(C,R,RR)..
P(C,R) + (TCOST(R,RR)) =G= P(C,RR) ;
*================================================================================

*WORLD TRADE WITH EAC BLOCK/EXPORT REGIONAL PRICE RELATIONS
*EQUILIBRIUM PRICE IN EAC PLUS IMPLICIT EXPORT TAX IN EAC PLUS TRANSPORTATION
*COST TO THE WORLD SHOULD EQUAL EXPORT PRICES

EXPORTS(C,R)..
P(C,R) + IXT(C) + TCOST(R,'WORLD') =G= PX(C) ;

*===============================================================================
*WORLD TRADE WITH EAC BLOCK/IMPORT REGIONAL PRICE RELATIONS
*IMPORT PRICES PLUS IMPLICIT IMPORT TAX PLUS TRANSPORTATION COST INTO EAC
*SHOULD EQUAL EQUILIBRIUM PRICE

IMPORTS(C,R)..
PM(C) + IMT(C) + TCOST('WORLD',R) =G= P(C,R) ;

*=============================================================================
* EXPORT QUOTAS

XQUOTA(C)..
QUOTA(C,'X') =G= SUM(R,X(C,R)) ;

*============================================================================
*IMPORT QUOTAS
```

```
MQUOTA(C)..
QUOTA(C,'M') =G= SUM(R,M(C,R)) ;

*===========================================================================
* STARTING VALUES
*===========================================================================
TQ.FX(C,R,R) = 0 ;
*IXT.FX(C)=0;
*IMT.FX(C)=0;
*X.FX(C,R)=0;
*M.FX(C,R)=0;
P.LO(C,R) = 1;
SS.LO(C,R) = 0.0001;

*=============================================================================
*INITIAL VALUES
*===========================================================================
P.L(C,R)=PS0(C,R);

*===========================================================================
*SOLVING THE MODEL
*============================================================================
MODEL MARKET /DEMAND.D
              SUPPLY.SS
              IN_OUT.P
              REG_TRADE.TQ
              EXPORTS.X
              IMPORTS.M
              XQUOTA.IXT
              MQUOTA.IMT/;

MARKET.TOLINFEAS = 1E-3;
SOLVE MARKET USING MCP;
*IXT.LO(C)=-INF;
*IXT.UP(C)=INF ;
*IMT.LO(C)=-INF;
*IMT.UP(C)=INF;

*=========================================================================
*DISPLAY RESULTS
*=========================================================================
OPTION PPI45: 3:0:1;
OPTION CPI45: 3:0:1;
OPTION DA: 3:0:1;
OPTION SA: 3:0:1;
OPTION P: 3:0:1;
OPTION PX: 3:0:1;
OPTION PM: 3:0:1;
OPTION D: 3:0:1;
OPTION SS: 3:0:1;
OPTION SN: 3:0:1;
OPTION SC: 3:0:1;
OPTION TQ: 3:0:1;
OPTION X: 3:0:1;
OPTION M: 3:0:1;
*OPTION OUTFLOWS: 3:0:1;
*OPTION INFLOWS: 3:0:1;
OPTION IN_OUT: 3:0:1;
OPTION REG_TRADE: 3:0:1;

DISPLAY
P.L, PPI45, CPI45, SN, SC, DA, DTEST, SHARE, SA, SN, SC,STEST, PX, PM,
TQ.L, SN, SS.L, D.L, X.L, M.L, IN_OUT.L, REG_TRADE.L;


*ESTIMATING WELFARE
*=========================
*DEFINE PARAMETERS
*------------------
PARAMETERS

PCTDP(C,R) PERCENT CHANGE IN PRICE OF CROP C IN REGION R FROM THE MODEL SOLUTION

CBR(C,R) IS THE CONSUMPTION BENEFIT RATIO FOR CROP C IN REGION R
*        PROPORTION EXPENDITURE ATTRIBUTED TO CROP C;
*CBR2(C,R) CONSUMPTION BENEFIT RATIO
```

```
PBR(C,R) IS THE CONSUMPTION BENEFIT RATIO FOR CROP C IN REGION R
*        VALUE OF CROP C PRODUCTION TO TOTAL INCOME (EXPENDITURE);
*PBR2(C,R) CONSUMPTION BENEFIT RATIO

PSURP(C,R) PRODUCER SURPLUS IN REGION R
CSURP(C,R) CONSUMER SURPLUS IN REGION R
PSURP2(C,R) PRODUCER SURPLUS IN REGION R
CSURP2(C,R) CONSUMER SURPLUS IN REGION R

WELFD(C,R) TOTAL WELFARE CHANGE (NBR) FOR CROP C IN COUNTRY R FIRST DEGREE
WELF(C,R) TOTAL WELFARE CHANGE (NBR) FOR CROP C IN COUNTRY R SECOND DEGREE
WELFD1(R)  AVERAGE WELFARE CHANGE IN COUNTRY R FIRST DEGREE
WELFD2(R)  AVERAGE WELFARE CHANGE IN COUNTRY R SECOND DEGREE DEGREE

WELFV1(C,R) TOTAL WELFARE CHANGE (VALUE) FOR CROP C IN COUNTRY R FIRST DEGREE
WELFVD1(R)  AVERAGE WELFARE CHANGE (VALUE) IN COUNTRY R FIRST DEGREE
WELFV2(C,R) TOTAL WELFARE CHANGE (VALUE) FOR CROP C IN COUNTRY R SECOND DEGREE
WELFVD2(R)  AVERAGE WELFARE CHANGE (VALUE) IN COUNTRY R SECOND DEGREE
WELFCAPV1(R) WELFARE PER CAPITA (VALUE) FIRST DEGREE
WELFCAPV2(R) WELFARE PER CAPITA (VALUE) SECOND DEGREE

SSVAL(C,R)  VALUE OF SUPPLY
DDVAL(C,R)  VALUE OF DEMAND;

*ASSIGNING PARAMETER VALUES
*----------------------------

PCTDP(C,R)=(P.L(C,R)-PD0(C,R))/PD0(C,R);

SSVAL(C,R) = S0(C,R)*PS0(C,R);
DDVAL(C,R) = D0(C,R)*PD0(C,R);

CBR(C,R) = DDVAL(C,R)/(DDVAL('BEANS',R)+DDVAL('MAIZE',R)+DDVAL('MILLET',R)
          + DDVAL('RICE',R)+ DDVAL('SORGHUM',R)+ DDVAL('WHEAT',R));
PBR(C,R) = SSVAL(C,R)/(DDVAL('BEANS',R)+DDVAL('MAIZE',R)+DDVAL('MILLET',R)
          + DDVAL('RICE',R)+ DDVAL('SORGHUM',R)+ DDVAL('WHEAT',R));

PSURP(C,R) = PBR(C,R)*PCTDP(C,R)+ 0.5*SPE(C,R)*PBR(C,R)
             *(PCTDP(C,R)*PCTDP(C,R));

CSURP(C,R)= (-CBR(C,R)*PCTDP(C, R))-0.5*DPE(C,R)*CBR(C,R)
            *(PCTDP(C,R)*PCTDP(C,R));

*WELFARE IN PBR AND CBR

WELFD(C,R) =  PBR(C,R)*PCTDP(C,R)-(CBR(C,R)*PCTDP(C, R));

WELF(C,R) = PCTDP(C,R)*(PBR(C,R)-CBR(C,R))
           + 0.5*(SPE(C,R)*PBR(C,R) - DPE(C,R)*CBR(C,R))
           *(PCTDP(C,R)*PCTDP(C,R));

WELFD1(R)= (WELFD('BEANS',R)+ WELFD('MAIZE',R)+WELFD('MILLET',R)
          + WELFD('RICE',R)+ WELFD('SORGHUM',R)+ WELFD('WHEAT',R));

WELFD2(R)= (WELF('BEANS',R)+ WELF('MAIZE',R)+WELF('MILLET',R)
          + WELF('RICE',R)+ WELF('SORGHUM',R)+ WELF('WHEAT',R));
*===============================================================

PSURP2(C,R) = SSVAL(C,R)*PCTDP(C,R)+ 0.5*SPE(C,R)*SSVAL(C,R)
             *(PCTDP(C,R)*PCTDP(C,R));

CSURP2(C,R)= (-DDVAL(C,R)*PCTDP(C, R))-0.5*DPE(C,R)*DDVAL(C,R)
            *(PCTDP(C,R)*PCTDP(C,R));

*WELFARE IN VALUE

WELFV1(C,R) = SSVAL(C,R)*PCTDP(C,R)-(DDVAL(C,R)*PCTDP(C, R));

WELFVD1(R)= (WELFV1('BEANS',R)+ WELFV1('MAIZE',R)+WELFV1('MILLET',R)
          + WELFV1('RICE',R)+ WELFV1('SORGHUM',R)+ WELFV1('WHEAT',R));

WELFV2(C,R) = PCTDP(C,R)*(SSVAL(C,R)-DDVAL(C,R))
           + 0.5*(SPE(C,R)*SSVAL(C,R) - DPE(C,R)*DDVAL(C,R))
           *(PCTDP(C,R)*PCTDP(C,R));

WELFVD2(R)= (WELFV2('BEANS',R)+ WELFV2('MAIZE',R)+WELFV2('MILLET',R)
```

```
          + WELFV2('RICE',R)+ WELFV2('SORGHUM',R)+ WELFV2('WHEAT',R));

WELFCAPV1(R) = WELFVD1(R)/PP(R);

WELFCAPV2(R) = WELFVD2(R)/PP(R);

DISPLAY PCTDP, SSVAL, DDVAL,CBR, PBR, PSURP, CSURP, WELFD, WELF,
        WELFD1, WELFD2,PSURP2, CSURP2, WELFV1,WELFV2, WELFVD1,
        WELFVD2,WELFCAPV1, WELFCAPV2;
```

Appendix 7: Maize production APSIM estimates (RCP 45) (NB: we take averages of Sen slope (%))

Country	Location	RCP 45 (2016-2045)				
Kenya		Yield (APSIM)	CoV	Sen slope	Sen slope (%)	P value
1	Eldoret	4.7	0.2	9.4	0.2	0.0
2	Kakamega	0.5	1.2	-16.9	-3.7	0.1
3	Kisumu	-	-	-	-	-
4	Machakos	0.9	0.1	-2.7	-0.3	0.0
5	Makindu	0.0	0.7	-3.9	-8.4	0.3
6	Mombasa	0.9	0.1	9.3	1.0	0.1
Tanzania						
1	Tanga	1.6	0.3	2.7	0.2	0.9
2	Dodoma	1.3	0.1	0.1	0.0	0.8
3	Shinyanga	3.3	0.1	-6.6	-0.2	0.2
4	Mbeya4	1.1	0.1	-2.5	-0.2	0.3
5	Mbeya5	1.3	0.1	-9.2	-0.7	0.0
6	Kilimanjaro	-	-	-	-	-
7	Morogoro	1.1	0.1	-3.7	-0.3	0.1
Uganda						
1	Arua	2.0	0.4	-50.6	-2.5	0.0
2	Iganga	2.9	0.3	-55.0	-1.9	0.0
3	Kabale	0.9	0.3	-19.3	-2.0	0.0
4	Kapchorwa	1.8	0.3	-35.2	-1.9	0.0
5	Lira	1.3	0.5	-9.8	-0.7	0.6
6	Masaka	2.1	0.5	-4.3	-0.2	0.8
7	Mbarara	1.9	0.3	-9.1	-0.5	0.3
8	Soroti	0.5	1.7	-26.6	-5.5	1.0
Burundi						
1	Bujumbura	3.6	0.1	-10.4	-0.3	0.2
2	Gisozi	3.8	0.1	-6.5	-0.2	0.0
3	Musasa	4.0	0.0	-7.1	-0.2	0.1
4	Muyinga	1.6	0.5	1.1	0.1	1.0
5	Nyanza_Lac	-	-	-	-	-
Rwanda						
1	Byumba	2.2	0.1	-1.9	-0.1	0.7
2	Gabiro	-	-	-	-	-
3	Gikongoro	3.7	0.1	-3.7	-0.1	0.6
4	Gisenyi	-	-	-	-	-
5	Kamembe	-	-	-	-	-
6	Kigali	4.0	0.1	-3.5	-0.1	0.4
7	Ruhuha	-	-	-	-	-

Appendix 8: Maize production APSIM estimates (RCP 85) (NB: we take averages of Sen slope (%))

Country	Location	RCP 45 (2016-2045)				
Kenya		Yield (APSIM)	CoV	Sen slope	Sen slope (%)	P value
1	Eldoret	4.6	0.2	55.7	1.2	0.0
2	Kakamega	0.5	1.1	-12.9	-2.5	0.1
3	Kisumu	-	-	-	-	-
4	Machakos	0.9	0.1	-0.1	0.0	0.9
5	Makindu	0.1	1.4	-7.1	-7.7	1.0
6	Mombasa	0.9	0.1	-1.0	-0.1	0.9
Tanzania						
1	Tanga	2.7	0.4	-29.7	-1.1	1.0
2	Dodoma	1.4	0.0	0.8	0.1	0.1
3	Shinyanga	1.7	0.7	-28.2	-1.6	0.3
4	Mbeya4	1.2	0.0	-1.9	-0.2	0.2
5	Mbeya5	1.5	0.0	-3.6	-0.2	0.0
6	Kilimanjaro	-	-	-	-	-
7	Morogoro	1.1	0.0	0.1	0.0	0.4
Uganda						
1	Arua	1.8	0.4	-45.6	-2.5	0.0
2	Iganga	3.2	0.4	-82.3	-2.6	0.0
3	Kabale	0.8	0.3	-15.5	-1.9	0.0
4	Kapchorwa	1.8	0.3	-38.0	-2.2	0.0
5	Lira	1.5	0.6	50.1	3.4	0.0
6	Masaka	2.7	0.4	-42.5	-1.6	0.1
7	Mbarara	2.1	0.1	-23.6	-1.1	0.0
8	Soroti	1.7		-	-	-
Burundi						
1	Bujumbura	4.1	0.0	-4.1	-0.1	0.0
2	Gisozi	4.1	0.0	-4.1	-0.1	0.0
3	Musasa	4.1	0.0	-7.2	-0.2	0.0
4	Muyinga	0.8	0.6	8.0	1.0	0.7
5	Nyanza_Lac	-	-	-	-	-
Rwanda						
1	Byumba	3.0	0.1	8.2	0.3	0.0
2	Gabiro	0.5		5.9	3.2	1.0
3	Gikongoro	4.2	0.0	-2.0	0.0	0.2
4	Gisenyi	-	-	-	-	-
5	Kamembe	-	-	-	-	-
6	Kigali	3.9	0.0	0.7	0.0	0.8
7	Ruhuha	-	-	-	-	-

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