Doctoral Dissertation

CLIMATE CHANGE, AGRICULTURAL PRODUCTIVITY AND POVERTY IN GHANA'S CONTEXT: MACRO-MICRO ANALYSIS

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Dedication

This PhD Dissertation is dedicated to my lovely late father,

Mr. Issahaku Ibrahim, who passed into eternity on 25th February, 2012

May his soul rest in perfect peace

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Summary of Dissertation

Agriculture is the backbone of the economies of most developing countries, manifested in terms of its contribution to Gross Domestic Product (GDP), exports and employment. Agricultural sector has strong linkages with the rest of the economy including agro-processing and hospitality industries, education, agro-chemicals and financial and business services sectors. Evidence consistently shows that agricultural growth is highly effective in poverty reduction. Studies in Côte d'Ivoire and Indonesia demonstrate the effectiveness of the agriculture in poverty reduction. The contribution of the agricultural sector to the economies of many developing countries may be undermined by changing and uncertain climate. Agriculture is heavily dependent on the weather and climate in many developing countries, and any change in climate can have perverse effects on agricultural production.

Most studies on climate impact tend to focus on direct sectoral impact ignoring the indirect effects. Few studies attempting to capture the indirect effect of change in climate is conducted at global, regional and country levels, which has less focus on its effects on households. This study combines general equilibrium and partial equilibrium models to analyze both the direct and indirect effects of change in climate on the food crops sub-sector in Ghana. More specifically, this study analyzes the impact of climate change on welfare of farm families through its impact on agricultural productivity. To do this, this study uses Feasible Generalized Least Squares (FGLS) and Structural Ricardian models to analyze the impact of climate change on yields and net revenues of major food crops, respectively, as the first step. Climate change impacts on net revenue per hectare are modeled as agricultural productivity shock parameters. At the second step, a CGE model is used to analyze the logical structure of the Ghanaian economy. The climate change induced productivity parameters are introduced as shocks in the macro model. This allows for the analysis of the impact of climate change on

macro aggregates like gross sectoral output, import and exports as well as aggregate welfare measures like GDP and equivalent variation. At the third and final step, the macro impact of climate change is traced to the household level by linking the CGE model to a micro-simulation model. This allows for the estimation of poverty impact of climate change.

Impact of climate change on yields of major food crops do not always match its impact on net revenues. In this study, yields and revenues of maize and sorghum tend to move in the same direction. For instance, the impact of climate change on maize rice is negative and this is matched by reduced levels of maize revenue. Climate change will increase sorghum yield and this matched increased earnings from the cultivation of sorghum. In the cases of other crops, climate change impact on yields and revenues tend to move in the opposite direction. For instance, climate change raises cassava yield but its impact on net revenue is negative. Climate change will have yield-reducing effects on yields of rice and yam, but its impact on their net revenue will be positive. This conclusion makes crop yield a weak predictor of the climate change impact on the welfare of farming households.

The pervasive nature of climate change will surely have some indirect effects beyond the sector where shocks originate from. It is immediately known that climate change will negative effect on cassava and maize while its effect on other crops is positive. Apart from the direct effect on sectoral output, imports and exports, the climate change induced productivity shock spreads thought the Ghanaian, although in most of cases, the effect is minimal. One notable sector where the indirect effect of climate change will be palpable is the livestock. Climate change will reduce livestock output and exports but it will induce increased importation of livestock into the country.

It is a difficult exercise to establish direct link between climate change and poverty. Most previous studies attempt to link climate change to poverty are not successful in truly linking

climate change and poverty. Against this backdrop, this study uses a combination of analytical tools to indirectly establish a link between poverty and climate change

Results of this study show that climate change induced productivity shock will worsen poverty levels among farming households in Ghana with variation across socioeconomic groups. In general, climate change will worsen poverty levels of all farmers, but, surprisingly, farmers with tertiary education will be worse affected. It may be due to the fact that this category of farmers tends to be engaged in the commercial cultivation of some food crops which make them susceptible to climatic variability. If they adapt, they will also benefit the most from their efforts. By location, climate change will not initially affect poverty levels of farmers residing in coastal and savanna ecological zones, but poverty depth and severity will increase. From 2020, climate change will worsen all measures of poverty, which will be ameliorated by adaptation through crop switching. Although adaptation may be beneficial to farmers, the stubbornly high poverty levels in the savanna zone may call for additional policy measures to deal with this canker. By civil status, climate change will worsen poverty incidence of married farmers, but has not effect on that of farmers who are single. Poverty depth and severity of categories will worsen. With adaptation, however, the poverty risk increasing effect is reversed. By gender, climate change will not affect poverty incidence of female farmers in the initial years but it will do in the latter years. For male farmers, climate change will worsen poverty levels throughout the projection period. Adaptation will reduce poverty risk among both male and female farmers but female farmers will benefit more.

This study suggests streamlining of input markets to ensure access to fertilizer, use of heat and drought tolerant seeds, and efficient pesticide/herbicide application for subsistent food crop farmers. In addition to input markets, programs to promote access to output market should be supported to ensure that improved crop yields is not achieved at the expense of net

revenue growth. The study also recommends use of community-based radio and other media outlets, and extension officers to disseminate climate related information and technological innovations to farmers in order to avert projected plummeting yields of some major food crops resulting from climate change and to optimize use of farm inputs and technologies in farming. Female headed households have proven to be better managers of household resources to improve members living conditions. A policy to empower female household heads in particular and female spouses in general will help optimize use of household resources to combat debilitating poverty among food crop farmers. Microcredit schemes whereby women groups are trained and given business loans can help empower women and reduce their vulnerability. Married or divorced household heads are more at risk of poverty vis-à-vis household heads who are single. Social protection programme which links support to the obligation of household heads to enroll children in schools, joining national health insurance schemes or immunization can lessen financial burden of farm families in a more sustainable way. Poverty is higher among older or less educated farm families with high dependency ratio. General training in functional literacy will not increase farmers' acceptance of productivity enhancing technical innovations, but also make them employable in the non-agricultural sector thereby enhancing family. Most poor households reside in the savanna zone. A sizeable percentage is also found in the forest zone. By combining zonal and household targeting, location-specific and household characteristics can be used in identifying the poor from the non-poor for any poverty alleviation support that may be forthcoming.

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Acronyms and Abbreviations

Amsl	above mean sea level
^oC	Degree Celsius
CCC	Canadian Climate Change
CD	Cobb-Douglas
CES	Constant Elasticity of Substitution
CET	Constant Elasticity of Transformation
CGE	Computable General Equilibrium
CIAT	International Center for Tropical Agriculture
Cm	Centimeters
CO_2	Carbon dioxide
CPI	Consumer Price Index
EV	Equivalent Variation
FAO	Food and Agriculture Organization
FGLS	Feasible General Least Squares
FGT	Foster-Greer-Thorbecke
GDP	Gross Domestic Product
GEPA	Ghana Environmental Protection Agency
GHS	Ghana Cedis
GLSS V	Fifth round of Ghana Living Standard Survey
GMET	Ghana Meteorological Agency
GSS	Ghana Statistical Service
Ha	Hectares
IPCC	Intergovernmental Panel on Climate Change
Kg	Kilogram
LES	Linear Expenditure System
ML	Maximum Likelihood
MOFA	Ministry of Food and Agriculture
NEPAD	New Partnership for Africa's Development
OLS	Ordinary Least Squares

OSU	Oregon State University
R & D	Research and Development
SAM	Social Accounting Matrix
SRID	Statistics, Research and Information Directorate
SSA	Sub-Saharan Africa
UKTR	United Kingdom Transient
UNECA	United Nations Economic Commission for Africa
USA	United States of America
USD	United States Dollars

1 Background

1.1 Introduction

Agriculture is the backbone of the economies of most developing countries, a sector upon which the livelihoods of majority of their populations depend (IPCC, 2007). Agriculture contributes at least 40% of exports, 30% of Gross Domestic Product (GDP), up to 30% of foreign exchange earnings and 70 to 80% of employment in the Sub-Saharan Africa (SSA) region as a whole (UNECA, 2005). Agriculture has strong linkages with many aspects of the economy including agro-processing and hospitality industries, and food grants for education, animal feed, agro-chemicals and financial and business services sectors. Evidence consistently shows that agricultural growth is highly effective in poverty reduction. Kakwani (1993) applied the additive property of Foster-Greer-Thorbecke (FGT) measures to a 1985 Côte d'Ivoire household survey and found elasticity of poverty with respect to agricultural output to be much larger (-1.8) than other sectors such as services (-0.1) and industry (-0.1). Thorbecke and Jung (1996) used FGT poverty measures and a Social Accounting Matrix (SAM) to decompose the contribution of each sector to poverty alleviation in Indonesia, and found the primary sector to be superior to industry and services.

The contribution of the agricultural sector to the economies of many developing countries is thwarted by changing and uncertain climate. Agriculture is arguably the most vulnerable sector to climate change. Given the heavy dependence of many developing countries on rain-fed agriculture, any change in climate can have perverse effects on agricultural productivity. Most studies on climate impact tend to focus on direct sectoral impact ignoring the indirect effects. Few studies attempting to capture the indirect effect of change in climate is conducted at global, regional and country levels, which has less focus on its effects on households.

This study intends to combine general equilibrium and partial equilibrium models in analyzing both the direct and indirect effects of change in climate on the food crops sub-sector in Ghana.

1.2 Study area

Ghana is located in the south central coast of West Africa between latitudes 4.5^0 N and 11.5^0 N and longitudes 3.5^0 W and 1.3^0 E. It borders with the Republic of Togo in the east, Burkina Faso in the north and La Cote D'Ivoire in the west. It spans an area of 238,500 square kilometers, with 230,000 square kilometers of land area, 8,500 square kilometers of water and 539 square kilometers of coastline. Ghana has a relatively flat terrain with a series of plateaus at different elevations, with the highest point of 880 meters above mean sea level (amsl) at the peak of Mount Afadjato.

Agriculture is the backbone of the Ghanaian economy. The sector engages about 57% of economically active population in Ghana and contributes to about 34% of its GDP (MOFA, 2008). About 57% of arable land in Ghana is put into cultivation. About 90% of farms are less than 2 hectares in size, although there are some large farms and plantations, particularly for rubber, oil palm and coconut (GSS, 2000; 2005). Main system of farming is traditional with hoe and cutlass being the main farming implements. There is little mechanized farming, but bullock farming is practiced in some places, especially in the Northern part of the country.

Climate pattern in Ghana varies by agro-ecological zones. Broadly speaking, there are three ecological zones: savanna, forest and coastal zones (Fig. 1.1). Mean annual temperature is generally high ranging from 24^0 C to 30^0 C across ecological zones. The wettest area is the extreme southwest in the forest zone where annual rainfall is about 2000mm. The driest area is wedge-like strip in the coastal zone where the annual rainfall is about 750mm (Government of Ghana, 2008). The savanna zone covers large parts of northern, upper east and upper west regions, and relatively smaller portions of Brong Ahafo and Volta regions. The climate, soils and other physical conditions in this zone are more suitable for cultivation of cereals like maize, sorghum, millet and rice. Other crops such as cashew, cassava, yam, potato and vegetables can be grown. In fact, apart from maize, largest production of cereals comes from this part of the country. This zone is also characterized by unimodal rainfall pattern (April - October). The forest zone covers greater part of Brong Ahafo, Volta, Ashanti, eastern and western regions. This zone is noted for the cultivation of root and tuber and cash crops including cocoa, cassava, plantain and cocoyam. This zone has bi-modal rainfall pattern (March-July and August-November) where a crop like maize is cultivated twice a year. The coastal zone parts large parts of Greater Accra and Central regions, and crops such as maize and vegetables can be cultivated in this zone.

The incidence of poverty also varies across agro-ecological zones. Headcount poverty ranges from 15% in the coastal zone to 70% in the savanna zone with a national average poverty incidence of 28% (GSS, 2005).The amount and pattern of rainfall play a key role in determining agricultural productivity (Seini et al., 2004). Past and future climate trends of Ghana indicate a decreasing rainfall amount and increasing temperature patterns (GEPA, 2007).

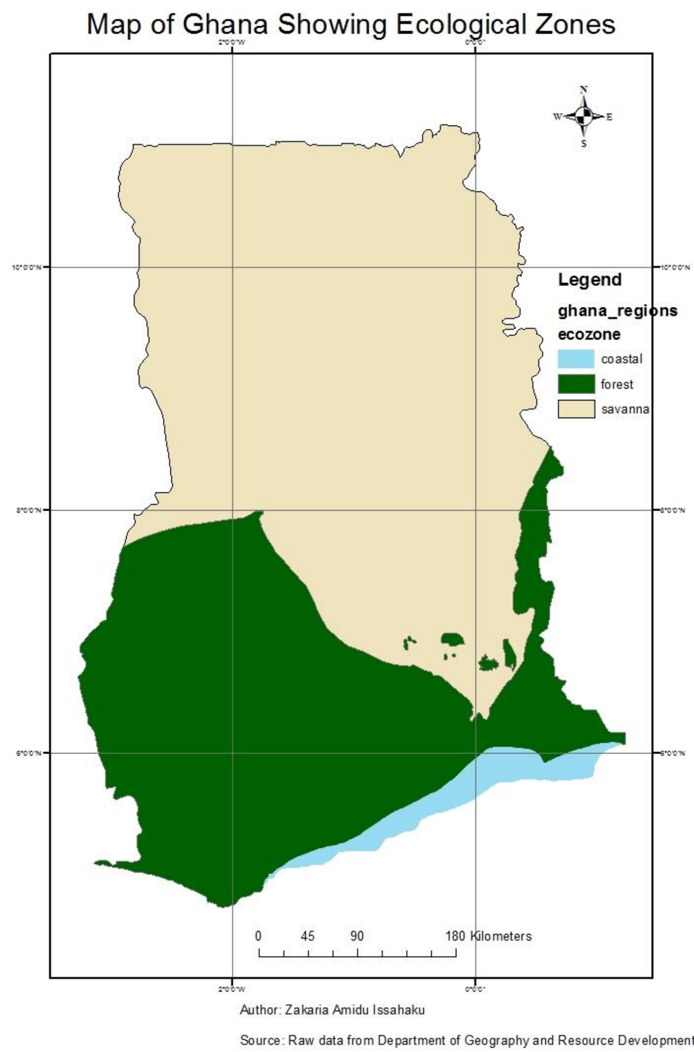

Fig. 1.1 Map of Ghana showing ecological zones

1.3 Selected crops

This study focuses on five major food crops only of cassava, maize, sorghum/millet, rice and yam. These crops are grown for home consumption and for sale in the domestic market to meet household financial needs. These crops were chosen because they contribute significantly to GDP. These crops constitute about 80% of food crops contribution to agricultural GDP and feature prominently in the diet of most Ghanaians (Breisinger et al., 2007). Supply of rice has a high import component. Ghana is currently self-sufficient in the production of the above-mentioned crops except rice.

Table 1.1 Production of major food crops in Ghana in 2009 (Figures in metric tonnes)

Regions	Cassava	Maize	Sorghum	Rice	Yam
Western	711,946	79,011		20,111	99,883
Central	2,036,500	226,423		5,089	17,290
Eastern	3,062,770	303,400		19,739	762,050
Greater Accra	67,525	3,309		2,940	
Volta	1,558,484	97,057	5,048	60,700	360,897
Ashanti	1,265,027	211,363		12,468	911,900
Brong Ahafo	2,606,974	471,416		5,794	2,377,145
Northern	961,240	202,322	136,577	190,089	1,337,701
Upper West		70,660	121,420	7,605	385,820
Upper East		51,144	87,495	111,274	
Total	12,270,466	1,716,104	350,540	435,808	6,252,685

Source Statistics, Research and Information Directorate (SRID), Ministry of Food and Agriculture

The five crops considered in this study have different distinguishing characteristics. Cassava (Manihot esculenta) is a short-lived perennial crop which is grown mainly for its tubers. The tubers can be left in the soil for up to three years and serve as a "famine reserve" (Winch, 2006). The leaves can be used as vegetables during the lean season (Jones, 1959). Cassava is grown in places with warm and humid climate. Cassava is cultivated in all ecological zones in Ghana but the forest zone account for largest proportion of its production volume.

Maize (Zea mays) is the most important cereal crop cultivated in Ghana. In adequate rainfall conditions, yields of maize can be higher than any other cereal. It is also preferred by most farmers for its higher quality as compared to sorghum or millet (Winch, 2006). Wet and mildly warm climates are suitable for maize cultivation. Maize can be grown in every part of the country. All ecological zones produce a sizeable proportion of maize output in the country.

Sorghum (Sorghum bicolor) is a grass crop used for animal and human food. Sorghum is the staple food in many dry African countries. Mildly wet and mildly warm climate is conductive for the cultivation of sorghum. Sorghum is mainly grown in the savanna ecological zone in the northern part of the country.

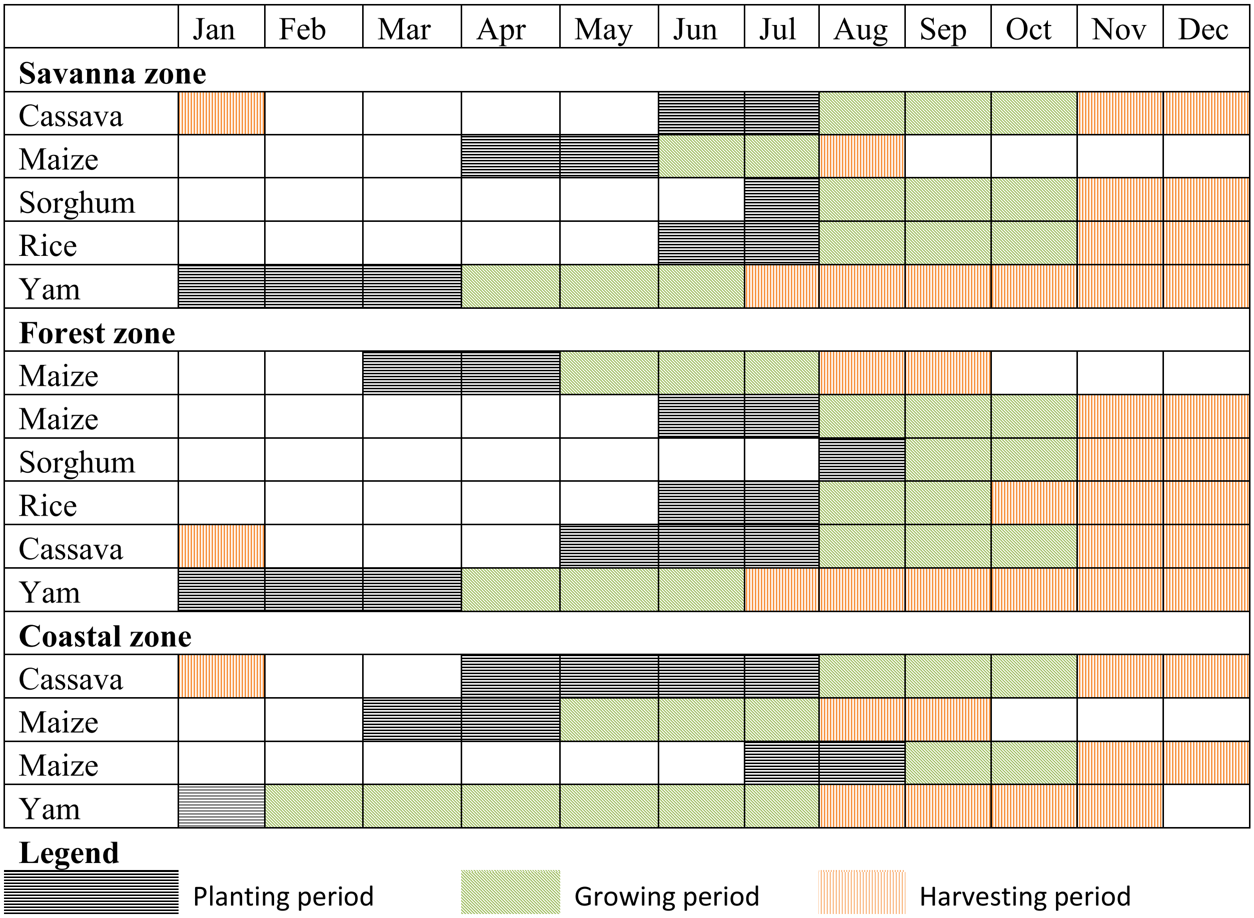

Fig. 1.2 Cropping calendar for major food crops in Ghana

Source Food and Agriculture Organization (FAO) Retrieved 20 June 2012, from http://www.fao.org/agriculture/seed/cropcalendar/searchbycountry.do

Rice is the seed of the monocot plants Oryza sativa (Asian rice) or Oryza glaberrima (African rice). It is the grain with the second-highest worldwide production, after maize. Rice is the most important grain with regard to human nutrition and caloric intake, providing more than one fifth of the calories consumed worldwide by the human species. Oryza glaberrima is a fast growing plant that resists drought, weeds and pests. It needs relatively little care, and people in Africa like its taste and serve it regularly as ritual food at village festivals and weddings as well as on other occasions. Yields of Oryza glaberrima are relatively low, and do not exceed 3t/ha, even with chemical fertilization. Each branch of the panicle also holds only a single grain, an obvious disadvantage when compared to Oryza sativa. The African rice species also shatter easily, wasting precious grain.

Yam (Dioscorea sp.) is perennial herbaceous crop cultivated for the consumption of their starchy tubers in Africa, Asia, Latin America, the Caribbean and Oceania. Some varieties of these tubers can be stored up to six months without refrigeration, which makes them a valuable resource for the yearly period of food scarcity at the beginning of the wet season. Yam is cultivated under humid tropical conditions. Currently, a large percentage of the output of both rice and yam comes from the savanna areas of the country.

Ghana is currently self-sufficient in the production of all the above mentioned crops in question except rice, imports of which has been increasing over the past decade.

1.4 Objectives and contribution to the literature

Agriculture is identified as one of the key sectors where appropriate climate change policy can help improve livelihoods in Ghana. Climate change policy discussions tend to focus more on mitigation rather than adaptation. Meanwhile, the mitigation measures are, to a large extent, the obligation of the developed countries under the Kyoto protocol. The government is therefore distracted from pursuing its primary objective of assisting farming households to adapt efficiently to adverse effects of climate change (Sarpong and Anyidoho, 2012). This study sheds more light on the need to adopt/support measures/policies that will enhance farm-level adaptation. The overarching objective of this study, therefore, is to assess the impact of climate change on the Ghanaian economy and on poverty through its impact on agricultural productivity taking into account the role of autonomous adaptation by farmers. More specifically, this study intends to:

- Analyze climate impact on yields of the five selected food crops;
- Estimate the impact of climate on net revenue per hectare for the crops in question;

- Trace the indirect effect of change in climate on the economy; and
- Assess how change in climate affects the economic conditions of farming households who cultivate these crops.

This thesis contributes to the literature on climate change impacts on smallholder farmers as well as climate change policies not only in Ghana but other countries of similar economic structure.

1.5 Structure of the remaining chapters

The rest of this thesis is structured as follows. Chapter 2 reviews previous studies relating to the impact of climate change on agriculture, highlighting the methods and the key findings from these studies. The first part of the review of previous studies relates to the application of experimental biophysical simulation, econometric and general equilibrium/integrated assessment approaches in analyzing climate change impact on crop yields and farm revenue, and food supply across various parts of the globe including Africa and Asia. Studies which use general equilibrium/ integrated assessment models can adequately deal with a myriad of effects emanating from climate change. The second part of the literature review provides a detailed exposition of various adaptation measures available to farmers in coping with Climate change impacts. The adaptive options range from farm-level adaptive responses such as varying the types of crops/varieties or combination of crops grown and farm management practices to conscious policy measures pursued by governments to avert catastrophic effects of climate change and variability on farm outcomes and living standards. The last segment of the literature review attempts to establish a link between climate change and poverty through its impact of agricultural productivity. That is, climate change will ultimately affect poverty through channels of changes in food supply and prices, farm income and real wages.

Chapter 3 gives a broad overview of the integrated assessment technique (a partial equilibrium model is linked to or combined with a general equilibrium model) adopted for this study. The workhorse of this integrated assessment approach is the Computable general equilibrium (CGE) model, which has the capability to capture indirect effects (aggregate food supply, inflation, GDP, employment or private consumption) of economic shocks such as climate change. To start with, a structural ricardian model is used to estimate the impact of climate variables on net revenue per hectare, a proxy for agricultural productivity, which has an added advantage of separating climate change impact with and without adaptation. Climate-induced change in this productivity measure is introduced in the CGE model to analyze climate change impact on macroeconomic aggregates such as such as GDP. In order to trace the effect of the climate induced productivity shock, a household simulation model is further linked to the CGE model to allow for the analysis of living conditions (poverty) of individual households. Also discussed in this chapter is a description of the data utilized for this study. The data used for CGE model is the Social Accounting Matrix (SAM) for Ghana which is consistent with economic structure of Ghana. Since the SAM data alone is appropriate for macro level analysis, it is complemented by data from the fifth round of the Ghana Living Standards Survey (GLSS V) in order to incorporate heterogeneous households in analyzing climate change impact on poverty. Data from regional weather stations is also construct climate variables. Although analyzed, the impact of climate on crop yield is estimated merely for the sake of comparing the results with its effect on net revenue in order to enhance overall understanding of this study.

Chapters 4, 5, 6, 7 and 8 constitute the analysis section of this study. In chapter 4, an econometric model is used to assess the impact of climate on actual crop yield. Noting that climate change also induces high production risk in the form of yield variability. Climate change impact on crop yield is therefore estimated taking into this inherent production risk. In chapter 5, the analysis is extended by assessing climate change impact on net revenue per hectare using an econometric approach which allows for separate calculation of climate change impact with and without adaptation. Noting that climate change has indirect effects on the macroeconomic aggregates and living conditions of farming households, chapter 6 simulates the impact of climate change on key macroeconomic indicators such as private consumption, trade balance and GDP by linking the structural ricardian model to a general equilibrium framework. Chapter 7 tracks down the effect of climate change on household poverty by linking the CGE model from chapter 6 to a micro simulation model using household survey data. To identify drivers of poverty among farm families, chapter 8 evaluates factors which drive poverty among farming households in Ghana. By so doing, we will be able to identify poorer households with some appreciable level of precision, and in combination with results from chapter 7, we should be able to estimate the cost of eliminating poverty among social groups identified in this study.

Chapter 9 concludes the thesis by summarizing the main findings of this research. A comparison between climate change on crop yield and net revenue per hectare is carried out here. Also highlighted in the final chapter is indirect effect of climate change on sectoral output at the macro level and poverty at the household level. Finally, recommendations based on the findings of this study are put forward for consideration of policymakers.

2 Literature review

2.1 Introduction

This chapter reviews various approaches used in climate change impact research. It also explains various climate change adaptation options available to farmers to counteract negative climate change effects. It also lucidly explains how climate change affects income and poverty status of farm families in Ghana. The rest of this chapter is structured as follows. Section 2.2 summarizes previous studies which analyze the relationship between climate change and experimental crop yield using biophysical crop simulation models. Section 2.3 examines the impact of climate change on actual (empirical) crop yield and land value or net revenue with the aid of econometric (regression) methods. Section 2.4 hinges on studies which examine the economic impact of climate using integrated assessment models which combines two or more methods to assess climate impact. Since adaptation measures moderates the effect of climate change, section 2.5 reviews various adaptation strategies that are undertaken at both national and farm levels to ameliorate adverse climate change impact. Section 2.6 describes the linkage between climate change, agricultural productivity and poverty. In section 2.7, the summary of all key issues discussed in this chapter is presented.

2.2 Biophysical crop simulations models

Crop simulation models draw on controlled experiments where crops are grown in field or laboratory settings to simulate different climates and levels of CO_2 in order to estimate yield responses of a specific crop variety to certain climates and other variables. Biophysical growth models are likely to be more accurate than models based on past trends as future climate conditions are likely to differ from past conditions (Sonka and Lamb, 1987).

Biophysical models are widely used to estimate the impact of climate change on crop yields. Parry et al. (1999) analyze the effect of climate change on wheat, maize, soybean and rice yields during the 21st century. Under various climate scenarios, this study predicts more damaging effects of climate change on yields of these crops in India and Nigeria between 1990 and 2020 as compared to other countries. Some scenarios forecast slightly widespread yield losses across Sub-Saharan Africa vis-à-vis other regions. In analyzing climate change effect on maize yields in Botswana, Chipanshi et al. (2003) use three climate scenarios: United Kingdom Transient (UKTR), Canadian Climate Change (CCC) and Oregon State University (OSU) models to analyze effect of climate on crops. This study predicts increase in maize yield under OSU scenario and a decrease under the two other scenarios in both eastern and western regions but the yield losses are more severe in the western region. For sorghum, decline in yield under CCC and UKTR scenarios is observed in both eastern and western regions but yield losses are doubled in the western region. Gain in sorghum yield is predicted in both regions under OSU scenario. In Mali, Butt et al. (2005), under CCC scenario, predict increase in maize yields and a decrease in sorghum yields.

Biophysical models have several limitations which may influence prediction accuracy. They require daily weather data, which greatly limits the areas over which it can be applied. Furthermore, actual crop yields are likely to be lower than yields under experimental conditions in biophysical models (Rosenzweig and Parry, 1994). Lastly, the estimates of these models do not, however, include the effects of farmer adaptation to changing climate conditions, thereby overstating damages of climate change to agricultural production (Mendelsohn and Dinar, 1999).

2.3 Regression analysis

Regression analysis uses statistical methods to quantify the influence of climatic factors on agricultural productivity. Two commonly used econometric methods for assessing climate impact on agricultural productivity are empirical crop yield models and ricardian analysis.

2.3.1 Empirical crop yield models

Empirical crop yield models use statistical methods to quantify the influence of climatic factors on crop yield. Advances in computational techniques have greatly assisted the application of regression techniques but their popularity is mainly due to their ability to distinguish the impact of climate on crop yields from other factors. The empirical yield models are based on time series and/or cross-sectional data observed at the farm level or aggregated at the regional level. This approach allows the quantification of the past effect of one factor (climate variables) on crop yields in an actual cropping context. The estimated coefficients of climate variables can be used to predict the impact of future climate change on crop yield.

Lobell and Field (2007) study over the period 1961-2002 at the global level attributes about 47% of variation in maize yield to the vagaries of the weather. Lobell and Asner (2003), in a study in USA from 1982 to 998, indicate 1ºC warming during the growing season reduces maize yield by 17% and temperature is estimated to be responsible for 25% of maize yield trend. A negative relationship between maximum temperature and wheat yields is also observed by Nicholls (1997) in Australia. During the study period of 1952-1992, the author observes that the mean annual minimum temperature increased by 1.02°C, the mean annual maximum temperature increased by 0.58°C and mean annual precipitation increased by 39mm. A multiple linear regression reveals that the impact of rainfall is very small and a 1% increase in the mean annual maximum temperature decreases wheat yield by 0.6%. However, they estimate that a 1% increase in minimum temperature leads to a 0.5% increase in wheat yields. Peng et al. (2004) evaluate the impact of temperature on rice yields using weather and agronomic data from an experimental plot in the Philippines from 1979 to 2003. They observe an increase of 0.35°C in mean annual maximum temperature and a 1.13°C increase in mean annual minimum temperature. Their statistical analysis indicates that a 1°C increase in the minimum temperature during the growing season entails a 10% yield decrease. The maximum temperature does not appear to have a significant impact.

Ben Mohamed et al. (2002) use self-made scenarios rather than conventional scenarios to project future impact of climate change on crop yield. Using warmer and drier (temperature: 20%, rainfall: –10 %) scenario, they estimate future effect on three regions of Dosso, Maradi and Zinder in Niger. Based on the results of this study, millet yield is projected to decline by 11% in the Dosso and Maradi. Extending this analysis, Van Duivenbooden et al. (2002) predict groundnut yield to reduce by 11% in all the three regions while cowpea yield is expected to decline by 12% in Maradi and Zinder. A statistical analysis of climate change impacts on five major US crops conducted by Chen et al. (2004) also establishes a detrimental impact of temperature on maize yields. They, however, note that the magnitude of estimated coefficients depends on functional form of the model. Temperature effect on mean crop yield in linear specification is lower than in Cobb-Douglas form but yield variability is higher in linear rather than Cobb-Douglas specification. The problem of function form is more pronounced in the case of soybeans (Chen et al., 2000). Marginal warming changes yields by -0.27% and 0.06%, in the linear and Cobb-Douglas models, respectively. Apart from misspecification of functional form, the omission of some important variables might also lead to biased coefficients in the model (Greene, 2000). Furthermore, the correlation between different agro-climatic determinants makes it difficult for multiple regression analyses to identify the exact relationship between the dependent variable and each explanatory variable. This correlation might lead to incorrect signs (Katz, 1977) and/or increased variability of the coefficient estimates (Snee, 1973). Besides estimation issues, estimated coefficients may not necessarily be valid for prediction as coefficients represent the impact of past climate conditions on agricultural outcomes. If future climate values are not within the range of previously observed values, then the relationship between the dependent variable and climate conditions may change. Finally, data requirements place a major constraint on regression analyses. Data are not always accurately measured or even available. The use of experimental data addresses the former problem but such data are costly. Limited data availability may also lead to omitted variable bias.

2.3.2 The Ricardian cross-sectional analysis

This approach explores the relationship between land values or net revenue and climate variables (usually temperature and precipitation) on the basis of statistical estimates from farm survey or country-level data. The "traditional" Ricardian analyses implicitly account for contemporaneous farm level adaptations. That is, Ricardian analyses explain land values or net revenues which reflect the costs and benefits associated with each farming practice, including adaptation measures. However, they do not provide estimates of the effect of each adaptation. The "Structural" Ricardian analyses address this shortcoming by modeling and measuring the effect of different adaptive measures (Seo and Mendelsohn, 2008b).

Few Ricardian analyses use farm land value to explain the impact of climate change. Mendelsohn et al. (1994) played a pioneering role in estimating the influence of agro-climatic factors on farm land value. Using crop revenue as weights, this study predicts an increase in land values as a result of climate change in the US. This result was corroborated by the estimates of Reinsborough (2003) study on Canada. Using farmers' perceptions of land value across eleven African countries, Maddison et al. (2006) forecast damaging climate change impacts for Africa while acknowledging large disparities across countries. They observe that countries with warmer climates suffer greater losses. For instance, land values are expected to drop by 19.9% and 30.5% in hotter Burkina Faso and Niger respectively but will decrease by 1.3% and 4% respectively in cooler Ethiopia and South Africa respectively.

A more common approach in Ricardian analyses uses net revenue as an alternative to land value. In an imperfect land market conditions as in the case of many developing countries, the net revenue approach is more preferable (Kumar and Parikh, 1998; Sanghi et al., 1998). In India, Kumar and Parikh (1998) report negative effect of temperature on net revenue. The effect of precipitation is positive but is smaller in magnitude than the temperature effect, resulting in negative global effect. Results of Sanghi et al. (1998) study support that of Kumar and Parikh (1998). Mano and Nhemachena (2006) study on Zimbabwe reports that both warming and drying decrease net revenue but drying will have less damaging effect. Kurukulasuriya and Mendelsohn (2006b) study on eleven African countries reports more moderate effect of warming and drying. Deressa and Hassan (2009) also predict negative effect of warming and drying on farm net revenue during the season 2003/2004, with more damaging effects in future years.

Ricardian approach is without limitations. Most ricardian methods use single year data which may not representative of past and future years and, thus, likely to be biased by abnormal climatic, agronomic or economic conditions. This problem can be addressed by using panel data or by repeating the estimation over two or more years to ascertain the similarity of the results (Mendelsohn et al., 1994; Deschênes and Greenstone, 2007). The assumption of constant prices under the ricardian model is misleading as it fails to capture producer price changes leading to underestimation of climate change effects (Cline, 1996). Mendelsohn (2000), however, talks down the problem of constant price assumption unless there is a catastrophic change in prices.

2.4 Integrated assessment models

Integrated analysis usually uses results of biophysical or econometric models as an input into a partial or general equilibrium model to estimate climate change impacts. Most of the time, the crop simulation models and econometric approaches as explained above are linked with a general equilibrium models to simulate the impact of climate change on economic outcomes. Integrated assessment studies use computable general equilibrium (CGE) models to capture interactions between the agricultural sector and other economic sectors. The inter-sectorial nature of these models allows the simulation of economic activity through incomes and expenditures. Furthermore, CGE models include international trade flows, which allow these models to account for inter-regional or global effects.

Rosenzweig and Parry (1994) and Parry et al. (1999; 2004) assess climate change impact on world food production. Using projected climate change scenarios, and crop growth models, future food crop yields are predicted. Economic impacts of crop yield changes are then estimated using the Basic Linked System (BLS), a world food trade model. Rosenzweig and Parry (1994) find about 6% of the population facing the risk of going hungry as a result of decrease in cereal production. Parry et al. (1999) also project a decrease in cereal production and an increase in prices and the number of people at risk of hunger by 2080 in developing countries. By contrast, developed regions are expected to benefit from climate change through increased production of cereals. Consequently, the economic gap between developed and developing regions is expected to widen during the 21st century. Parry et al. (2004) reports decrease in crop yields as a result of climate change in developing countries but the yield losses are lower than the gains made by developed countries.

Darwin et al. (1995) link Future Agricultural Resources Model (FARM) to a CGE model to analyze economic impact of climate change. This study predicts a decrease in world cereal supply by 18.8% under the OSU scenario compared to 1990 supply but it does not take into account consumer surplus losses. Cline (2007) predicts that climate-induced yield reduction increases output prices, which translates into stable net revenues for producers and welfare losses for consumers. Cline's study projects decline in GDP in Southeast Asia but an increase in GDP in Canada.

One of the weaknesses of general equilibrium models is the calibration of the economic model, whereby CGE models are assigned to fit production data for a single year and some parameters are "guesstimated". Another shortcoming is that CGE models include all sectors with the sectoral detail of production function often less sophisticated than in partial equation models.

2.5 Climate change adaptations

Climate change tends to have adverse effects on farm outcomes but the damaging effect of varying climate can be partly ameliorated by appropriate adaptation. As enshrined in IPCC (2001:6), "adaptation has the potential to reduce adverse impacts of climate change and to enhance beneficial impacts, but will incur costs and will not prevent all damages".

Adaptation measures are categorized according to their intent and purposefulness, timing and duration; scale and responsibility; and form (Smit and Skinner, 2002). By intent and purposefulness, adaptations undertaken are classified as spontaneous or autonomous vis-à-vis conscious or planned actions (Carter et al. 1994; Bryant et al. 2000; Smit et al. 2000). Within socio-economic systems, public sector adaptations are usually planned strategies, such as investments in government programs, but private sector and individual adaptations can be autonomous, planned or a combination of the two. For example, the decisions of a producer who, over many years, gradually phases out one crop variety in favor of another that seems to do better in the climatic conditions might be considered autonomous, but they are also consciously undertaken.

Timing of adaptation differentiates responses that are anticipatory (proactive), concurrent (during), or responsive (reactive).While logical in principle, this distinction is less clear cut in practice. For example, a producer who has experienced several droughts over recent years, and expects drought frequency to remain similar or increase in the future, may adjust certain production practices or financial arrangements to manage drought risks. The timing distinction is not helpful here, as this is both a reactive and proactive adaptation.

Duration of adaptation distinguishes responses according to the time frame over which they apply, such as tactical (shorter-term) versus strategic (longer-term) (Stakhiv 1993; Smit et al. 1996). In agriculture, tactical adaptations might include adjustments made within a season, which involve dealing with a climatic condition, such as drought, in the short term. Tactical adaptations might include selling of livestock, purchasing feed, plowing down a crop or taking out a bank loan. Strategic adaptations refer to structural changes in the farm operation that would apply for a subsequent season, or a longer term. Thus, strategic adaptations might include changes in land use, crop type or use of insurance.

Adaptations can also be distinguished according to the scale at which they occur and the agent responsible for their development and employment. In agriculture, adaptations occur at a variety of spatial scales, including farm, region and nation (Smithers and Smit 1997). At the same time, responsibility can be differentiated among the various actors that undertake or facilitate adaptations in agriculture including individual producers (farmers), agri-business (private industries), and governments (public agencies) (Smit et al. 2000). However, most discussions of adaptation do not distinguish the roles of different decision-makers. For example, a commonly espoused adaptation in agriculture is the use of crop development for changed climatic conditions. Such an adaptation would likely involve government agencies (encouraging this focus in breeding research), corporations (developing and marketing new crop varieties), and also producers (selecting and growing new crops). Any realistic assessment of adaptation options needs to systematically consider the roles of the various stakeholders.

Adaptation in agriculture occurs via a variety of processes and can take many different forms at any given scale or with respect to any given stakeholder. Bryant et al. (2000) identify forms of adaptation at the farm-level to include modification of resource management, purchasing crop insurance, and diversification. They also identify different forms of policy level adaptations including aid for research and development, incentive strategies and infrastructure measures. Differentiating responses to climate change according to form provides a useful framework for understanding adaptation in agriculture.

2.5.1 Farm level adaptations

Farm level adaptations are farmers' direct reactions to changing climate. Early climate impact studies do not take into account farmers' adaptive responses to changing climatic, economic or institutional environments, a bias known as "dumb farmer scenario" (Mendelsohn et al., 1994). Usually, farmers adapt to climate change by modifying the set of crops farmers choose to plant and their agronomic practices.

Crop selection

Early studies that assume that farmers do not vary the set of cultivated crops even if they observe decline in their yields in the face of climate change. In recent times, however, experts favor varying crops mix on the part of farmers to fit a particular climate in the future as a way of adaptation. This can be done either by selecting better varieties of the same crops or shifting to different set of crops.

Introduction of new crop varieties improves crop yields in a changed climate. Crop varieties which are late maturing, heat and drought and pest and disease resistant, produce better yields. With expected lengthening of the growing season, Corobov (2002) study on Moldova find the adoption of late-maturing maize hybrids as a good adaptive measure that markedly enhances maize yields. Alexandrov and Hoogenboom (2000) also report that varieties of maize with shorter vegetative cycle in South-eastern USA increase maize yields. Adopting the new maize cultivars doubles maize yields. Butt et al. (2005) also confirm that the adoption of heat resistant crop varieties plays an important role in the response of crop yields to climate change. They show that heat tolerant varieties of sorghum, millet, cotton, maize, cowpeas, and rice considerably cut yield losses in Mali as compared to standard crop varieties.

In a more drastic fashion, farmers can adopt new crops to reflect new climatic conditions. Kurukulasuriya and Mendelsohn (2006a) and Seo and Mendelsohn (2008a) use multinomial choice models to assess how climate influences farmers' planting decisions. Kurukulasuriya and Mendelsohn (2006a) find that farmers in Africa plant millet and groundnut in drier and hotter locations while maize and beans are grown in wetter and moderately warmer places. Similarly, Seo and Mendelsohn (2008a) reports that farmers in warmer climate of South America prefer squash, fruits and vegetables while those in cooler climate favor potatoes and maize. The authors predict that farmers may, in the future, reshuffle their crop mixes in order to maximize farm net revenue. In a general equilibrium framework, Darwin et al. (1995) find that changes in crop mix and primary factor inputs greatly moderates the adverse effect of climate change. They concluded that about 80% of climate induced decrease in world cereal supply can be avoided by switching crops and adjusting inputs. Adopting new crop (crop switching) involves spatial crop shifts whereby crop production areas are moved to places where the climate is more suitable or newly suitable land. In Mali, Butt et al. (2005) predicts southward migration of crop production with a change in climate and this adaptive option will salvage 33% of projected total welfare losses.

It is imperative to note that crop choices are not motivated by yield or net revenue optimizing decisions alone but also consumer preferences. According to Chipanshi et al. (2003: 341), “producers accustomed to eating maize would rather grow maize than sorghum, even where there is evidence that sorghum is the ideal crop”. Perception of farmers about risk also influences crop choice. Risk-averse farmers always play it safe by choosing crops with lower yield variance (Kaiser et al., 1993) even if there is an option of choosing new high yielding crop varieties. Spatial crop shifts can also destroy the tropical rainforest thereby denying millions who depend on the forest of their livelihood (Darwin et al., 1995).

Management practices

Farmers can reduce adverse effects of climate change by varying their cultivation methods. The commonest practices are fertilizer application, crop timing and water management.

Fertilizer application is commonly agricultural practice used to counter yield reductions caused by climate change. Under experimental conditions in Romania, Cuculeanu et al. (1999) show that that an increase in fertilization enhances maize yields. Under the baseline climate condition (1961-1990), maize yields increase from 10.6 to 13.5 tons per hectare if nitrogen deficiency is reduced from 50% to 10%. Haim et al. (2008) show negative effect of excessive fertilizer application in Israel. Under plausible climate scenarios, they prove that excessive fertilizer can reduce both wheat yield and revenue.

Modifying the timing of cultural operations can help moderate the adverse effect of changing climate. The extension of the growing season is expected to increase crop yields. Molua (2002) indicates that adapting to climate change changing sowing and harvesting dates is a beneficial exercise. Through a ricardian analysis, he reports that varying planting and harvesting dates raises farm net revenues in south-western Cameroon. In South-eastern USA, Alexandrov and Hoogenboom (2000) predict the moderating effects of different planting dates in the face of warming. It was found that increasing sowing date of maize by at least 30 days in Athens (Georgia) vis-à-vis base year (1961-1990) reduces yield losses. Cuculeanu et al. (1999) and Haim et al. (2008) also find damage-reducing effect of changing planting dates. Changing planting dates reduces the negative effects of climate change on cotton and maize yields and revenues.

Water management is another adaptive measure available to farmers. Kabubo-Mariara and Karanja (2006) and Gbetibouo and Hassan (2005) use a structural ricardian method to investigate the influence of irrigation on farmers' net revenues in Kenya and South Africa respectively. Mano and Nhemachena (2006) find net revenues of Zimbabwean farmers cultivating on irrigated lands to be higher as compared to dry land. In the context of the whole Africa, Kurukulasuriya and Mendelsohn (2006b) find similar results comparable to Mano and Nhemachena (2006) estimate. Reilly et al. (2001) even find higher maize yield gains on US irrigated land than on dry land. However, the findings of Deressa et al. (2005) study on South African sugar cane farmers indicate that irrigation is not an efficient adaptation strategy. They find no significant difference between net revenues of irrigated and dry lands.

Adapting to climate change through agronomic practices is not costless and this tends to prevent quite a good number of farmers from putting together appropriate adaptive responses. Kabubo-Mariara and Karanja (2006) notes that majority of farmers in Kenya are constrained financially from adapting to climate change. Further, while most agronomic practices such as land preparation and weed control improve crop yield, a few practices pose other challenges. For instance, altering planting dates can conflict with other crop planting (Alexandrov and Hoogenboom, 2000).

2.5.2 National or regional level adaptations

The role of government in an attempt to adapt to changing climate cannot be underestimated. Public interventions can reduce climate change impacts by enhancing farmers' adaptive capacity. Smit and Skinner (2002) observe a growing recognition of macro-level policies in adaptation studies. IPCC (2007) acknowledge the role of training, research and development (R&D) and financial incentives in adaptation. Government invests in technologies to develop high-yielding, heat and drought tolerant crops for farmers; it also invests to develop early warning systems to accurately predict weather and forecast seasonal climate; it provides agricultural subsidy, insurance and support to cushion farmers against crop yield losses; and government can also use trade instruments to minimize aggregate welfare losses from climate change (Smit and Skinner, 2002; Smith and Lenhart, 1996).

Government expenditure on research programmes leads to technological innovations which increase the adaptation options to farmers. Technological innovations relate to crop development, weather information systems and resource management (Smit and Skinner, 2002). Research and development (R&D) plays an important role in the development of new high heat- and drought-tolerance crop varieties, which offer opportunities for farmers to adapt to climate change. Reilly and Schimmelpfenning (1999) recognize the significance of intellectual property rights in agricultural research and crop variety development especially in developing countries to protect return to investments. Development of information systems to predict weather and climate change can also assist farm adaptation. Daily and weekly weather forecasts can help farmer take decisions on timing of cultural operations. Water and farm-level resource management innovations constitute another way to improve farmers' adaptive capacity. Since changing rainfall patterns modify water availability, development of regional scale irrigation systems or desalinization technologies helps minimize yield losses (Smit and Skinner, 2002).

Government programmes in the form of agricultural subsidies, crop insurance and assistance to stabilize income or alleviate risks of revenue losses due to natural disasters can enhance farmers' incentive to adapt to climate change (Smit and Skinner, 2002). Government programmes should be crafted carefully to avoid ills associated with government failure. For instance, crop-specific farm programmes may reduce the incentive of farmers to switch crops and diversify livelihood activities thereby exposing farmers to yield and revenue losses year after year (Smith and Lenhart, 1996). Government investment in education does not only enhance capacity of farmers to cope better with climate change (Yohe et al., 2003) but also equipped them with skills to be engaged in other economic ventures other than crop production.

Governments often use trade instruments to manage economic shocks including those emanating from climate change. Reduced crop production necessitates lowering of trade barriers to allow for importation of essential food crops in mitigating total welfare losses (Smith and Lenhart, 1996). Liberalization promotes the adoption of better crop mixes and improves access to market-related information including international crop prices (Rosenzweig and Parry, 1994; Lewandrowski and Brazee, 1993). Various parts of the globe are affected differently by trade liberalization and climate change (O'Brien and Leichenko, 2000) with some regions being double losers and others double winners. Africa is a double loser because of its high level of climate change vulnerability and at the same time weaker terms of trade. In their global study, Darwin et al. (1995) confirm the damaging reducing effect of trade liberalization on world cereal production. In Mali, Butt et al. (2005) also reports of positive effects of trade liberalization on economic welfare.

2.6 Climate change, agricultural productivity and poverty

This section explains the channels through which climate change affect agricultural productivity, output and poverty. Agricultural productivity is defined in several ways by different researchers, be it crop yield, output per worker or net revenue per hectare. Irrespective of the measure used, many studies show that improvements in agricultural productivity are important for poverty reduction (Mellor 1999; Thirtle et al. 2003). Agricultural productivity determines the price of food, which then determines wage costs and the competitiveness of tradable goods leading to a confluence of effects that determine the real income effects of farming households (World Bank 2007).

Fig. 2.1 illustrates how climate change will affect agricultural productivity, and the outcomes of the interaction with the rest of the economy. Most studies point to the adverse impact of climate change on agricultural productivity, as earlier stated. In this study, crop yield and net crop revenue serve as proxies for agricultural productivity, which are expected to be negatively impacted by climate change. However, efficient autonomous farm-level adaptations can mitigate some but not all of the adverse effects of climate change. The residual effects of climate change after accounting for adaptation will reflect in reduced levels of total domestic supply of food in the country. The negative output effects will put pressure on food prices, hurting the welfare of all net food buyers in both rural and urban settings through decreased demand for food. The strength of food price effects depends on the tradability of the good and the elasticity of demand. The decreased demand for food will reduce on-farm employment which, in turn, impact negatively on food demand. The combined effect of high prices, reduced food demand and on-farm employment will result in lower real wages and farm household real income. With weakened purchasing power, farmers demand for non-farm goods and services will decline, with its knock-on effects on non-farm employment. This has feedback effect on farm household real income. Together with lower real wages, low levels of non-farm employment will reduce non-farm household real income. These indirect effects on climate change on both farm and non-farm household real income will ultimately make it harder to achieve poverty reduction targets in the future.

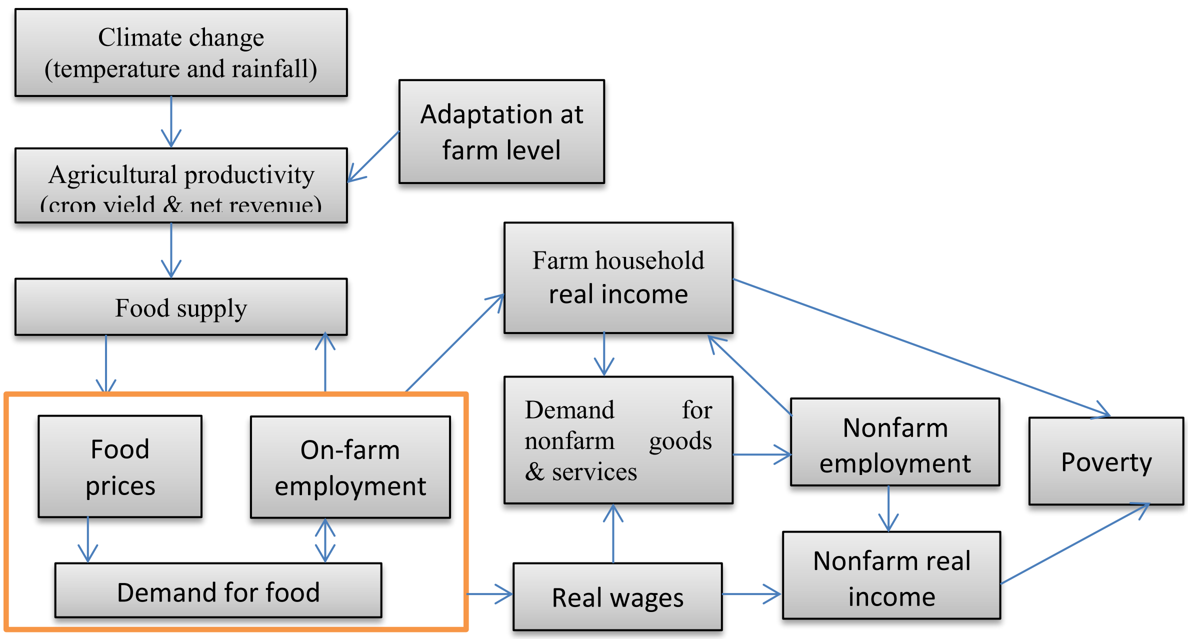

Fig. 2.1 Linkage between climate change, agricultural productivity and poverty
Source Adapted from Schneider and Gugerty (2011)

2.7 Conclusion

This chapter reviews methods used in analyzing climate change effects. Methods used are classified as biophysical crop simulation models, regression analysis and integrated assessment models.

Biophysical crop simulation models estimate the relationship between environmental variables and experimental crop yields. This approach is likely to be more accurate than models based on past trends as future climate conditions are likely to differ from past conditions. The estimates of these models do not, however, include the effects of farmer adaptation to changing climate conditions, thereby overstating damages of climate change to agricultural production (Mendelsohn and Dinar, 1999).

Regression analysis uses statistical methods to quantify the influence of climatic factors on actual crop yields and land values or net revenues. Some econometric approaches adequately account for contemporaneous farm level adaptations (Seo and Mendelsohn, 2008b). The assumption of constant prices under regression models is misleading as it fails to capture producer price changes leading to underestimation of climate change effects (Cline, 1996).

In integrated analysis, crop simulation models and econometric approaches as explained above are linked with a general equilibrium models to simulate the impact of climate change on economic outcomes. Integrated assessment studies use computable general equilibrium (CGE) models to capture interactions between the agricultural sector and other economic sectors. The inter-sectorial nature of these models allows the simulation of economic activity through incomes and expenditures. Furthermore, CGE models include international trade flows, which allow these models to account for inter-regional effects. Although CGE models adequately captures price effects, the calibration of the economic model is carried to fit production data for a single year and some parameters are "guesstimated". They are also less sophisticated sectoral detail of production than partial equilibrium models as all sectors are included in the model.

Apart from the above, this chapter also shows that many beneficial adaptation strategies exist to cope with the detrimental effects of climate change, both at the farm and regional or national levels. Furthermore, the channels through which climate change directly affect agricultural productivity together with its effects on poverty is thoroughly expatiated. Some climate impact studies based on regression analysis and integrated assessment models can account for adaptation while those based on biophysical crop simulation models do not. Based on the above review, this adopts the integrated assessment approach to examine climate change impact on the agricultural sector in Ghana, by linking an econometric model to a CGE model so that both the indirect effects of climate change and farm-level adaptations can be adequately catered for in this study.

3 Research methodology

3.1 Introduction

This study adopts the integrated assessment model to analyze impact of climate-induced change in cropland productivity on the Ghanaian economy and living conditions of farming households. The pervasive nature of Climate Change effects requires a Computable General Equilibrium (CGE) model to capture various direct and indirect interactions between factor markets, goods markets, households, government, private firms and foreign partners. That is, CGE models are used when the external shocks are expected to have general equilibrium effects, with significant indirect effects that partial equilibrium analysis fails to capture. In the case of large shocks like climate Change, these indirect effects can magnify or counteract the direct effects with potentially major implications for the final results. Climate change impact is captured in the CGE model through cropland productivity parameter estimated using the Ricardian model. The principal advantage of using a CGE model in policy analysis is that it takes into account the numerous and complex interactions throughout the economy.

In this chapter, the processes involved in linking partial equilibrium models to CGE framework is described in section 3.2. Most CGE models operate with the unrealistic assumption of representative households in analyzing distributional impact of economic shocks. It is, thus, more preferable to include all actual households in the CGE framework rather than household categories. In section 3.3, the method used for integrating actual households in national household survey into the CGE model is explained. Section 3.4 summarizes the data forms used to carry out this research. Section 3.5 concludes this chapter.

3.2 Linking partial equilibrium models to CGE framework

Shocks and policies directly affecting one part of the economy may have substantial indirect effects on the other parts of the economy, that are automatically taken into account using general equilibrium analysis. Some of the earlier explained partial equilibrium models in chapter 2 are linked to Computable General Equilibrium (CGE) framework to assess the direct and indirect effects of climate change.

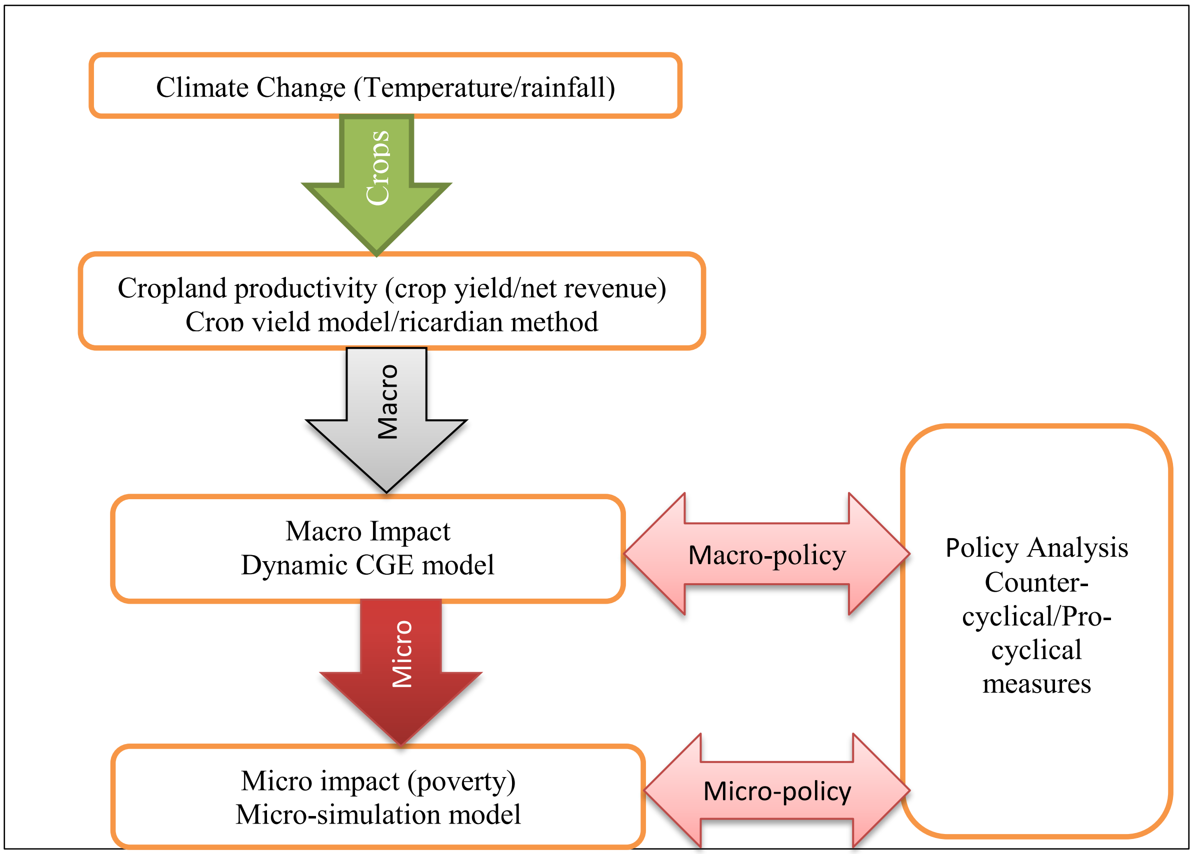

Fig. 3.1 Flow chart for implementing integrated assessment model

In analyzing the direct effect, two econometric approaches are used to estimate the effects of climate variables on crop yield and net revenue. Stochastic production function approach is used to assess the effect of climate variables on crop yield while ricardian cross-sectional method is employed to estimate the effect of climate variables on net revenue in Ghana. The coefficients of these models can be used to generate climate-induced cropland productivity shock parameters that are introduced into a CGE model. In this study, the ricardian method is linked to the CGE framework to estimate the indirect effect of climate change on key macroeconomic variables such as private consumption, GDP, inflation, exchange and trade balance. The ricardian method is chosen in tracing the indirect effect because it is capable of differentiating climate change effects with and without adaptation. To trace climate change impact to the household level, the CGE framework is further linked to a household micro-simulation model to analyze the poverty impact of climate-induced productivity shocks as shown in Fig. 3.1.

3.3 Integrating households into a CGE framework

The CGE model performs poorly in capturing impacts at the household level. Attempts to model distributional impacts within a CGE model has come with a barrage of criticisms. The traditional approach, as summarized by Lofgren et al. (2004), makes use of "representative" households rather than actual/real households. The representative household approach is based on a very strong theoretical assumption that the choices of households belonging to a given category may be represented by the choices of a unique household that maximizes its utility in such a way that these choices coincide with the aggregated choices of a large number of heterogeneous individuals. Distributional impacts are simply captured through extending the disaggregation of the representative households in order to identify as many household categories, generally corresponding to different socio-economic groups, as possible. This approach makes it possible to analyze the impacts of policies on incomes and welfare between groups (inter-group distribution) but not within groups as intra-household distribution is assumed to be fixed. It provides information neither on poverty impacts (as the poor may be found in many different socio-economic groups and in varying proportions) nor on intra-group distribution. In order to address the first limitation, some authors have applied a fixed income distribution function among households within each household group in order to compute poverty indices (such as the FGT indices). One way is to assume a log-normal distribution, where the variance is estimated from the base year data (De Janvry et al., 1991). Meanwhile, Decaluwe et al. (2000) argue that a beta distribution is preferable to other distributions because it can be skewed to the left or right and thus may better represent the types of income distributions commonly observed within household groups. Yet, Boccanfuso et al. (2003) underscore the difficulty of using restrictive functional forms as distribution could change before and after simulations, and large variations in poverty indices may arise depending on the functional form employed. Kirman (1992) argues that this hypothesis is not very realistic given that, outside the most restrictive behavioral hypotheses, there is neither theoretical justification to affirm that the aggregation of individual choices necessarily leads to the same solution as the choice of a representative individual nor guarantee that the reaction of the representative household entails that any change in the model will be the same as the aggregated reaction of the individuals it represents.

An alternative approach is to integrate separately all individual households from a household survey directly into a CGE model, making it possible to conduct an explicit analysis of the poverty impact of macro-economic shocks on each household. Fully Integrated (FI) models include in the CGE model as many households as there are in the household survey. The main advantage of this approach, compared to the previous approach, is that it allows for intra-group income distributional changes. However, FI models require reconciliation between figures in the SAM (national accounts) and that of the survey, which might prove problematic. This approach suffers from serious implementation challenges. Because of the model size and complexity, it is easy to avoid the difficulty of capturing discrete micro-econometric behavior such as changes in employment status (Bibi et al., 2010).

The representative household problem is avoided since individual household behavior and income distribution is directly captured without the need to impose any functional form.

Constructing an integrated CGE micro-simulation model is technically straightforward since one merely shifts from a model with representative households to real households by integrating every household from a nationally representative household survey. As in the representative household approach, each household has an income and expenditure vector, but here these are all actual households. All the regular assumptions of a basic CGE model can be retained although, obviously, more sophisticated approaches can be envisaged. The only notable change in the CGE model is to increase the number of households in the set defining household elements. The first applications of this approach date to the very end of the 1990s and are reviewed in Cockburn (2006). Cockburn (2006) and Cockburn et al. (2008) fully integrate 3,388 and 24,797 households into CGE models for Nepal and the Philippines respectively, without sacrificing the disaggregation of factors, sectors and products required, capturing the links between macro-economic shocks and poverty and income distribution.

3.4 Data

This study basically relies on 2005 Ghana Social Accounting Matrix (SAM), fifth round of Ghana Living Standards Survey (GLSS V) and Ghana Meteorological service (GMET) data. A SAM is an economy-wide data framework that usually represents the real economy of a single country. More technically, a SAM is a square matrix in which each account is represented by a row and a column. Each cell shows the payment from the account of its column to the account of its row – the incomes of an account appear along the rows and the expenditures along the columns. The underlying principle of double-entry accounting requires that, for each account in the SAM, total revenue (row total) equals total expenditure (column total). In this study, 2005 SAM for Ghana will serve as an input in the CGE model. It identifies 59 production sectors consisting of 27 agriculture sectors, 22 industry and 10 services. There are 6 factors of production of labor (skilled, unskilled and family), capital (agricultural and non-agricultural) and land (agricultural). The GLSS is a multi-purpose survey of households in Ghana, which collects information on the many different dimensions of living conditions including income, consumption, education, health and employment and other socioeconomic and demographic variables. These data are collected on a countrywide basis. 8,687 households containing 37,128 members

The integrated approach requires consistent data between the SAM and GLSS. Given differences in data sources, it is inevitable that there will be inconsistencies in data between the SAM and the household survey. Data reconciliation is necessary to the integration process. Survey data must be adjusted to establish a link to, and ensure consistency with, the SAM underlying the CGE model. There is no magic recipe for reconciliation. A thorough understanding of both datasets is required and reasonable assumptions have to be made with the ultimate aim of creating a better and coherent dataset with the least possible adjustments.

Poverty is analyzed using Foster-Greer-Thorbecke (FGT) indices (Foster et al., 1984) computed using DAD software (Duclos et al., 2001). Indeed, prior data adjustment in household survey data is normally required for standard poverty/inequality analysis even outside of an integrated CGE micro-simulation framework. Deaton (1997) confirms that, in household surveys, it is more difficult to collect reliable information on income than on consumption, although consumption data are not without their faults. Income underreporting and measurement errors are likely to result from the desire to hide revenues from other family members, neighbors or eventual tax authorities, as well as from the long (usually one-year) recall periods involved for intricate sources of income such as returns to assets, agricultural output and seasonal activities. This is further aggravated by the fact that most households in developing countries receive their income from informal production activities in which family income and business revenues are often combined. Thus, the absence of formal accounting in these activities and within the household make it impossible to constitute an accurate picture of the income of producer households and often lead to underestimated income (or overestimated expenditures) generated by these activities.

3.5 Conclusion

This section describes the procedures used to analyze the effect of climate change on farm and welfare outcomes in Ghana. Integrated assessment framework is adopted to estimate direct and indirect effects of climate change. Empirical crop yield and ricardian methods are used to estimate direct effects of climate change. Linking the ricardian method to a CGE framework adequately captures the indirect effects at both national and household levels.

CGE models are usually criticized because of the assumption of representative household. That is, the behavior of household categories may not represent individual household behavior. Integrated all actual 8687 households in the GLSS V into the CGE model cures this problem thereby allowing for efficient estimation of distributional impact of climate change.

This study uses data mainly from 2005 Ghana Social Accounting Matrix (SAM), fifth round of Ghana Living Standards Survey (GLSS V) and Ghana Meteorological service (GMET) data. The integrated approach requires consistent data between the SAM and GLSS. Data reconciliation between these two data sets ensures that survey data is consistent with the SAM underlying the CGE model.

4 Yield Sensitivity of Major Food crops to Changing Climate: Feasible Generalized Least Squares Method

4.1 Introduction

Climate is one of the most important inputs in agricultural production system. The hard truth that the world is getting hotter and drier is of a major concern to many a developing country dependent on agriculture as their main livelihood source. Precipitation and frequency of extreme events such as floods and droughts can reduce crop yields and increase risks in agricultural production in many countries located in the lower latitudes. In Ghana, agriculture is largely rain-fed, and the vagaries of the weather determine agricultural productivity. Farmers usually respond to reduction in crop yield by putting more land into cultivation. It is therefore no wonder that yield levels of major food crops are significantly lower than their potential levels, indicating a potential of raising outputs of major food crops through crop productivity growth. Cassava, maize, sorghum, rice and yam have yield gaps of 57.5%, 40%, 33.33%, 40% and 38%, respectively (MOFA, 2007). Increasing agricultural growth by land expansion may not be sustainable because farmers are not only limited by plot size in their possession but also difficulties associated with managing large tracts of land under cultivation. Increasing production of major staple crops can be enhanced by utilizing the land more intensively thereby closing these crop yield gaps (Breisinger et al., 2009).

It is imperative to note that adopting intensive farming is not free from the adverse effects of changing climate. More recent literature points to the adverse impact of changing climate on crop productivity. A review of climate impact literature on various crops by Knox et al. (2010) indicates that yields of cassava, sorghum, millet and maize will decrease in West Africa through adverse effects of climate change. Warming and drying exacerbate stresses in crop plants, potentially leading to catastrophic yield reductions: It affects water availability for irrigation; it also reduces soil fertility, health and nutrient availability; and it also increases incidence of pests and diseases and weeds. Sagoe (2006) used crop simulation model to analyze climate change impact on root crops in Ghana and the results indicate reductions in yields of cassava and cocoyam under all projected climate scenarios. Analysis of projected climate change impact in Ghana's initial communication to Inter-governmental Panel on Climate Change (IPCC) also indicates reductions in yields of maize in the transition zone, located between the forest and the savanna ecological zones in Ghana (GEPA, 2001). The afore-mentioned analyses and other similar studies are based on crop simulation models which show relationship between environmental variables including climate and the growth of crop plants. The effect of climate on crop yield may be more complex than just mere climate-crop plant growth relationship. Other factors can reverse an otherwise positive or negative effect of climate on crop yield. The failure to take into account the role of non-environmental variables denoting farm or farmer characteristics and/or management practices by farmers may undermine the use of crop simulation models in climate research.

Based on national survey data, this chapter paper intends to extend this line of analysis by using the stochastic production function approach, which considers and incorporates some socioeconomic variables in analyzing climate impact on the mean and variance of food crop yields in Ghana. In the next section, methods used to assess the effect of farm inputs including climate variables on crop yield are explained in detail. Firstly, the empirical model is described with appropriate mathematical equations explaining why this method is chosen for this study. Section 2 presents and describes the data used in this study. The summary statistics of those variables are also presented. In section 4.3, model results are presented and discussed. The impact of climate variables on mean and variance of crop yield is analyzed here. In section 4.4, regression coefficients together with trend of climate variables are used to simulate the impact of changing climate on crop yield in future years. The last section presents the summary of the research findings and proceeds to make recommendations for consideration of policymakers.

4.2 Methodology

4.2.1 Empirical Model

This study is based on the notion that climate is one of the important determinants of crop productivity. The first step in assessing potential costs and climate change adaptation strategies is to determine the effect of climate variability on crop yields (Cabas et al., 2010). One of the methods to measure the sensitivity of crop yields to changing climate is to analyze how actual crop yields vary across different locations with different climatic conditions (Mendelsohn and Dinar, 2009). Regression models have the potential flexibility to integrate both physiological determinants of yield including climate and socioeconomic factors. With this approach, an appropriate production function is specified in order to isolate the effect of climate from the effects of other confounding variables including modern inputs and the socioeconomic variables. In recent years, researchers tend to use production risk, also known as stochastic production function developed Just and Pope (1978) to analyze effect of production inputs on crop yields. More formally, the effect of climate on crop yield is specified as follows:

$$Y = f(X, \beta) + h(X, \alpha)^{\frac{1}{2}} \in \qquad (4.1)$$

Y is crop yield; X is vector of independent variables; $\in$ is stochastic error term which is assumed to be independently and normally distributed with mean of zero and variance of one. The first term [f (X,β)] represents the effects of inputs on mean of crop output or yield, also known as the deterministic component of crop yield; and second term $[h(X, \alpha)^{1/2} \in]$

represents the effects of inputs on variance of crop output or yield, as known as the stochastic component of crop yield. The symbols β and α represent vector of model parameters for the deterministic and stochastic components respectively. The idea behind the above specification is that the effects of the independent variables on mean crop yield should not a priori be tied to the effects of independent variables on the variance of crop yield.

There are two approaches to estimating the stochastic production function as in equation (4.1): Maximum Likelihood (ML) and Feasible Generalized Least Square (FGLS) methods. In smaller samples, ML method provides more efficient parameter estimates. For larger samples such as in the case of this study, the FGLS approach is preferable (Cabas et al., 2010) and it is thus adopted in this study in estimating equation (4.1).

$$Y = f(X, \beta) + \mu \tag{4.2}$$

$$\ln \mu^2 = h(X, \alpha)^{\frac{1}{2}} + \in \tag{4.3}$$

$$Y^* = f^*(X, \beta) + \mu^* \tag{4.4}$$

$$Y^* = Y/\exp(h(X, \beta)^{\frac{1}{2}});\ f^*(X, \beta) = f(X, \beta)/\exp(h(X, \beta)^{\frac{1}{2}});\ \text{and } \mu^* = \mu/\exp(h(X, \beta)^{\frac{1}{2}}).$$

The symbol μ is the heteroskedastic (non-constant) error term of the production function; Y^* and μ^* are the values of crop yield and the error term adjusted for heteroskedasticity, and exp(.) is the exponential function used to find the antilog of the heteroskedastic error term.

Following the procedure of Cabas et al. (2010), equation (4.1) is estimated in three steps using FGLS. The first stage of the FGLS estimation procedure regresses crop yield, Y, on the vector of explanatory variables, X, as in equation (4.2) with the resulting least squares residuals used at the second stage to estimate the marginal effects of explanatory variables on the variance of crop yield. In the second stage, the square of residuals from the first stage are regressed on h(X, α) as in equation (4.3). If equation (4.2) is not in logarithmic form, it is advisable to use the log of the squared residuals from the first stage rather the untransformed values. The third and final stage uses the predicted error terms from the second stage as weights for generating the FGLS estimates for the mean yield equation as in equation (4.4). The resulting estimator of β in the final step is consistent and asymptotically efficient under a broad range of conditions and the whole procedure corrects for the heteroskedastic disturbance term (Just and Pope, 1978; Cabas et al., 2010).

To simulate the impact of future climate on the yield of these major food crops, the coefficients of equation (4.4) together with predicted changes in temperature and rainfall is used as in equation (4.5).

$$\%\widehat{\Delta Y}=100*[\exp(\beta_1 \Delta T) - 1]+100*[\exp(\beta_2 \Delta R) - 1] \quad (4.5)$$

$\%\widehat{\Delta Y}$ is the predicted percentage change in crop yield; β_1 and β_2 are the coefficients of temperature and rainfall, respectively; ΔT is the difference in temperature between future years and average annual temperature over the period 1961-2010; and ΔR is the change in rainfall between future years and average annual temperature over the period 1961-2010.

4.2.2 Data and Descriptive Statistics

This study analyzes the effects of climate variables on mean and variance of crop yield using data from fifth round of Ghana Living Standards Survey (GLSS V) compiled by Ghana Statistical Service (GSS) in 2005/2006 as well as climate (temperature and rainfall) data sourced from Ghana Meteorological Service Agency for ten weather stations in each geographical region across the length and breadth of the country. The GLSS V data contains information on socioeconomic characteristics of 8,687 households. For the purpose of this study, 3,574 farming households which cultivate at least one of the five major crops of cassava, maize, sorghum, rice and yam are considered.

Five different crop yields expressed in kg/ha are used as the dependent variables: cassava, maize, sorghum, rice and yam. Crop yield is calculated by dividing total crop output by hectares of harvested farm area. Yields of the major food crops are generally low. The mean crop yields range from a low of about 524.56kg/ha for sorghum to a high of about 2,705.25 kg/ha for cassava as shown in Table 4.1. Before being used in the model, crop yields are transformed logarithmically to enhance model fit.

Table 4.1 Description and summary statistics of model variables

Variables	N	Mean	Standard Deviation	Minimum	Maximum
Crop yield					
Cassava (kg)	953	2705.25	5368.28	0	39239.3
Maize (kg)	1426	1313.33	2357.98	0	19704.4
Sorghum (kg)	398	524.56	686.80	0	3890.67
Rice (kg)	239	644.02	808.45	0	4825.11
Yam (kg)	469	2277.29	5543.27	3.17	49309.70
Climate					
Temperature (^{0}C)	3574	26.25	0.97	24.85	30.32
Rainfall (cm)	3574	14.51	3.45	4.75	23.21
Socioeconomic					
Household size	3574	5.47	3.41	1	29
Age-head (years)	3574	45.58	14.45	18	95
Gender-head (=1 if female)	3574	0.14	0.35	0	1
Education-head (years)	3574	2.79	4.46	0	16
farm size (ha)	3574	2.05	4.96	0.02	124.21
Farm inputs					
Fertilizer	3574	4.61	27.41	0	400.22
Pesticide/weedicide	3574	4.35	16.25	0	133.47
Purchased seeds	3574	4.30	15.84	0	148.29
Hired labor	3574	42.71	96.10	0	1216.02
Machinery	3574	9.80	0.28	0	150

Source Calculated from 2005 Ghana Living Standard Survey and Ghana Meteorological Agency data
Notes All farm inputs are in GHS; 0.92 GHS is equivalent to 1 United States dollar as of 2005.

The independent variables used in study include five input variables (fertilizer, pesticide, seeds/seedlings, hired labor and machinery) indicating use of farm inputs (Table 4.1). This category of non-climate variables is hypothesized to have positive effect on all crop yields since enhanced use of fertilizers, pesticides, new crop varieties, hired labor and machinery are likely to increase crop yield. Generally speaking, farmers do not adequately use farm inputs in Ghana for various reasons including weak financial position. The average expenditures on farm inputs are GHS 4.61, GHS 4.35, GHS 4.30, GHS 42.71 and GHS 9.80 for fertilizer, pesticide/weedicide, seeds/seedlings, hired labor and machinery, respectively. Additional explanatory variables obtainable from the survey data are household size, gender, age and education of household head and farm size. Household size, age and education have hypothesized positive effect on crop yield. Average household size of farmers who grow these major food crops have greater than the national average of four (4) because of the importance of family labor on their farms. Average age of family heads is about 46 years who are mostly males with less than three years of formal education. Although majority of Ghanaian food farmers cultivate cassava and maize, they cultivate on a plot with average size of about 2 hectares. Hypothesized effect of farm size is negative because of diminishing returns to employing additional land in farming.

The climate variables used in this study are average normal monthly temperature and average normal monthly rainfall in effective growing seasons for the crops in question. The climate data covers fifty years (1961-2010), a long enough period to be used to construct normal climate variables. Climate variables (temperature and rainfall) are constructed to synchronize crop-specific growing periods of all selected crops. The climate data is, in turn, matched with locations of farming households as identified in the GLSS V. Ghana is generally a warm country with high temperature all year round. Normal temperature during the effective growing season of crops is about 26 °C. It is hypothesized that high temperature will impact negatively on yields of the crops in question. Normal rainfall during effective growing season for crops about 14.5cm per month. Since all crops need wet conditions up to a certain threshold, it is hypothesized that rainfall will have positive effect of all yields of all crops.

4.3 Presentation of results and discussion

This section presents and discusses the results of the three step FGLS estimation process of equation (4.1). Before the estimation was carried out, some validity checks of model data were undertaken to ensure that no outliers skew expected model results. Diagnostic tests indicate that model has neither multicollinearity problems. Breusch-Pagan/Cook-Weisberg test, however, revealed presence of heteroskedasticity, implying that analyzing this data using just ordinary least squares method would not produce efficient parameter estimates, although they would still be unbiased. This confirms the appropriateness of the FGLS method for this study, which helps to resolve the problem of heteroskedasticity.

4.3.1 Climate effects on unadjusted mean yield

The first stage of the FGLS estimation method involves running OLS regression of crop yields on the set of the independent variables selected for this study as in equation (4.2). Since the error term is heteroskedastic, its parameter estimates are inefficient and unreliable. The results of the first stage FGLS method is presented in Table 4.2. The fit of the model for these crops ranges from 10.10% for cassava to 41.54% for rice.

From Table 2, it can be seen that most socioeconomic characteristics of households have no significant effect on yields of crops. Household size and education of household head have no significant effect on crop yields. Age and gender of household head have no significant effect on crop yields except maize. Coefficients on age and gender of the household heads are negative and positive for maize. This implies that male household heads earn lower yields on maize relative to males while older household heads receive lower yields relative to younger heads. Farm size has negative coefficient for all food crops in question. This means yields of all crops are higher for smaller farms vis-à-vis larger farms.

Table 4.2 Results of first stage Feasible Generalized Least Squares

Variables	Cassava	Maize	Sorghum	Rice	Yam
Intercept	-0.0098 (3.9847)	2.1642 (3.5079)	-7.8594 (4.035)	16.9376*** (3.8500)	-2.1513 (4.7713)
temperature (°C)	0.2498 (0.1581)	0.1527 (0.1428)	0.1547 (0.1587)	-0.4644*** (0.1680)	0.2213 (0.1386)
Rainfall (cm)	-0.0092 (0.0192)	0.0004 (0.0207)	0.5671*** (0.1320)	0.0924 (0.0605)	0.1416** (0.0681)
Household size	0.0076 (0.0223)	-0.0126 (0.0127)	0.0088 (0.0178)	-0.0176 (0.0200)	-0.0485 (0.0226)
Age of household head	0.0050 (0.0044)	-0.0047* (0.0028)	-0.0086 (0.0040)	-0.0003 (0.0051)	-0.0004 (0.0056)
Female household head	-0.1460 (0.1556)	-0.3376*** (0.1187)	-0.0013 (0.2606)	0.0469 (0.2689)	0.1272 (0.2956)
Education of household head	0.0039 (0.0133)	0.0005 (0.0090)	-0.0254 (0.0229)	-0.0228 (0.0223)	-0.0048 (0.0209)
Farm size	-0.3376*** (0.0370)	-0.0586*** (0.0088)	-0.0444*** (0.0075)	-0.1614*** (0.0184)	-0.0390*** (0.0115)
Fertilizer	-0.0291 (0.0703)	0.1116*** (0.0378)	0.1295* (0.0697)	0.1600** (0.0712)	0.1318* (0.0709)
Pesticide	0.0589 (0.0543)	0.0464 (0.0348)	0.0752 (0.1393)	0.0231 (0.0776)	0.2440*** (0.0785)
Purchased seeds	0.0587 (0.0564)	0.0766** (0.0371)	0.0428 (0.0782)	-0.0537 (0.0709)	-0.0266 (0.0691)
Hired labor	0.0810** (0.0332)	0.1071*** (0.0219)	0.1479*** (0.0388)	0.1149*** (0.0419)	0.0993** (0.0420)
Machinery	0.0542 (0.0481)	0.1051*** (0.0338)	0.1119* (0.0589)	0.0045 (0.0643)	0.1657*** (0.0628)
R^2	0.1227	0.1010	0.2443	0.4154	0.1378
Observations	952	1424	397	237	469

Notes *** means significant at 1%, ** means significant at 5% and * means significant at 10%; the dependent variable is the log of crop yield; and Figures in parenthesis are standard errors of regression estimates

By and large, farm inputs have significant positive effect on crop yields. Coefficients of fertilizer have significant positive signs for maize, sorghum, rice and yam, indicating direct relationship between fertilizer use and yields of these crops and rice. Pesticide and improved seeds/seedlings have significant and positive effect on yields of yam and maize. The effect of these inputs on yields of other crops is not statistically significant. Hired labor is the only input which has significant and positive effect on yields of all crops in question. Machinery has significant positive effect on yields of maize, sorghum and yam.

Without accounting for heteroskedasticity, climate variables have no significant effect on yields of cassava and maize. Temperature has significant negative coefficients for rice regression, indicating an inverse relationship between temperature and rice yield. Temperature has no significant effect on yields of other crops. The sign of rainfall coefficient is significantly positive for sorghum and yam, indicating a direct relationship between rainfall, and yields of sorghum and yam.

4.3.2 Climate effects on crop yield variability

The regression coefficients of the second step FGLS as in equation (4.3) is presented in Table 4.3. The goodness of fit of the crop yield variance model as evidenced by R^2 ranges 10.42% for maize to 27.77% for rice.

From Table 4.3, it can be observed that most variables have no or weak significant effect on variance of crop yield. Household size, age, gender and education of household head have no statistically significant effects on variances of all crop yields. Farm size has significant positive effect on yield variances of all crops except sorghum. In fact, it is only non-climate variable with strongly significant effect on crop yield variability. The positive sign of farm size coefficients indicates that increased production through land expansion will ultimately increase production risk. Fertilizer and pesticide significant increase variance of yields of yam and rice, except pesticide, respectively.

Climate variables have no significant effect on yield variance of cassava, rice and yam, but statistically significant effect on variability of maize and sorghum yields. Temperature has significant negative effect on variance of maize yield but it has no significant effect on other crops. This implies that warming reduces production risk of maize while it has no effect on other crops. Similarly, rainfall has significant positive effect on the yield variances of maize and sorghum but it has no significant effect on other crops, implying that additional rains will increase production risk of these crops.

Table 4.3 Results of second stage Feasible Generalized Least Squares

Variables	Cassava	Maize	Sorghum	Rice	Yam
Intercept	8.7376 (6.5378)	-3.7735 (6.6074)	-13.3756 (11.2167)	29.6479*** (8.8639)	-22.9864*** (8.8249)
Temperature (°C)	0.1366 (0.2594)	0.7549*** (0.2691)	0.3100 (0.3785)	-0.6868* (0.3869)	0.9824*** (0.2563)
Rainfall (cm)	-0.0447 (0.0316)	-0.2530*** (0.0389)	0.9099*** (0.3141)	0.0013 (0.1385)	0.5129*** (0.1259)
Household size	0.0423 (0.0367)	-0.0072 (0.0239)	0.0229 (0.0418)	-0.0943** (0.0452)	-0.1237*** (0.0418)
Age of household head	0.0295*** (0.0073)	-0.0115** (0.0052)	-0.0140 (0.0096)	-0.0133 (0.0117)	0.0132 (0.0103)
Female household head	-0.1427 (0.2553)	-0.4933** (0.2237)	-0.0524 (0.6216)	-0.3067 (0.6184)	0.0369 (0.5468)
Education of household head	0.0569*** (0.0218)	0.0325* (0.0169)	-0.0159 (0.0545)	-0.0793 (0.0506)	0.0157 (0.0387)
Farm size	-0.6568*** (0.0608)	-0.0458*** (0.0166)	-0.0668*** (0.0179)	-0.1838*** (0.0422)	-0.0720*** (0.0212)
Fertilizer	-0.3555*** (0.1154)	0.1925*** (0.0712)	0.0369 (0.1661)	0.3530** (0.1638)	0.0748 (0.1311)
Pesticide	0.2905*** (0.0891)	0.0481 (0.0655)	-0.0465 (0.3237)	0.1729 (0.1749)	0.4443*** (0.1453)
Purchased seeds	0.0450 (0.0926)	0.2043*** (0.0699)	0.2692 (0.1864)	-0.2159 (0.1630)	-0.0593 (0.1278)
Hired labor	0.0773 (0.0545)	0.1610*** (0.0413)	0.2947*** (0.0924)	0.3594*** (0.0965)	0.1697** (0.0776)
Machinery	0.1002 (0.0789)	0.1091* (0.0638)	0.1671 (0.1406)	-0.1232 (0.1478)	0.2077* (0.1162)
R-squared	0.1623	0.1042	0.1353	0.2777	0.1448
Observations	953	1424	397	237	469

Notes *** means significant at 1%, ** means significant at 5% and * means significant at 10%; the dependent variable is the log of crop yield; and Figures in parenthesis are standard errors of regression estimates

4.3.3 Climate effects on adjusted mean crop yield

The third stage of the FGLS estimation method involves running a regression of crop yields on the set of the independent variables selected for this study using the estimated error terms from section 3.2 as weights. By correcting for heteroskedasticity, the explanatory power of the mean crop yield regression improves with stronger goodness of model fit; The R^2 of this model is a higher for all crops than that of the unadjusted mean crop yields as explained in section 3.1. Additionally, purging the model of heteroskedastic problems does not only enhance the efficiency and reliability of model coefficients, but also their signs and the magnitudes change thereby impacting on the overall model analysis. The results of the second stage FGLS regression is presented in Table 4.4.

Household size has statistically significant positive effect on yields of cassava, maize and sorghum. Family labor supports in on-farm activities including clearing, sowing, weeding and harvesting of these crops during the growing season when demand for alternative labor sources are high in farming communities. Given that a plot size of a typical smallholder rice farmer is about 2 hectares as indicated in Table 4.1, sowing seeds by broadcasting may not require much labor. Further, rice has some commercial element whereby a grower or group of growers hire combine harvesters rather than family hands, and this makes the cultivation of this crop more attractive to farmers with smaller family size. Age of household head has negative effect on maize and sorghum yields but it has significant positive effect on yields of rice. This means that younger household heads who are engaged in maize and sorghum cultivation achieve higher yields as compared to older heads; Yields of rice, however, is higher among older farmers. The coefficient of gender is negative for the cassava, maize and rice regressions but not statistically significant for other crops, implying that male headed homes gain higher yields from the cultivation of these crops but there is no significant difference statistically in yields of other food crop between male and female headed homes. Education of the household head has no significant effect of yields of food crops in Ghana. The coefficient of farm size is negative for all crops. The inverse field size hypothesis, indicating inverse relationship between crop yield and farm size, holds for all crops (Cabas et al. 2010). This implies crop yield will reduce as more and more marginal land is put into cultivation in most locations.

Table 4.4 Results of Third Stage Feasible Generalized Least Squares

Variables	Cassava	Maize	Sorghum	Rice	Yam
Intercept	-18.2829*** (4.3159)	-0.2901 (3.7778)	-1.2999 (4.6419)	29.8557*** (5.3543)	0.3379 (6.3983)
temperature	0.9549*** (0.1726)	0.2860* (0.1554)	-0.0946 (0.1604)	-1.0554*** (0.2334)	0.1473 (0.1819)
Rainfall	-0.0224 (0.0239)	-0.06563*** (0.0217)	0.5641*** (0.1519)	0.2546*** (0.0930)	0.1194 (0.1011)
Household size	-0.0453* (0.0243)	0.0120 (0.0119)	0.0040 (0.0193)	-0.0681*** (0.0163)	-0.0573** (0.0273)
Age-head	0.0201*** (0.0054)	-0.0073*** (0.0026)	-0.0073* (0.0040)	-0.0018 (0.0067)	-0.0020 (0.0077)
Female-head	-0.2269 (0.2071)	-0.2921** (0.1152)	0.0636 (0.2553)	0.0501 (0.3050)	0.0364 (0.4357)
Education-head	-0.0501** (0.0155)	0.0032 (0.0101)	-0.0279 (0.0219)	-0.0646** (0.0291)	-0.0159 (0.0295)
Log of farm size	-0.2741*** (0.0175)	-0.0431*** (0.0041)	-0.0331*** (0.0023)	-0.0518*** (0.0064)	-0.0157*** (0.0042)
Fertilizer	0.0212 (0.0798)	0.1494*** (0.0446)	0.1469* (0.0885)	0.3264*** (0.1178)	0.1800* (0.0985)
Pesticide	0.0338 (0.0783)	0.0669 (0.0413)	0.1094 (0.1723)	0.1463 (0.1288)	0.2506* (0.1509)
Purchased seeds	0.0199 (0.0834)	0.1084** (0.0444)	0.0273 (0.1041)	0.0569 (0.0988)	-0.0254 (0.1001)
Hired labor	0.1278*** (0.0429)	0.1022*** (0.0230)	0.1150** (0.0502)	0.1441** (0.0628)	0.0752 (0.0551)
Machinery	0.0168 (0.0687)	0.0969*** (0.0365)	0.2166*** (0.0684)	0.1381 (0.0889)	0.1601* (0.0893)
R-squared	0.4416	0.1610	0.7052	0.5907	0.17.15
Observations	952	1424	397	237	469

Notes *** means significant at 1%, ** means significant at 5% and * means significant at 10%; the dependent variable is the log of crop yield; and Figures in parenthesis are standard errors of regression estimates

Researches in experimental plant physiology show that the soil fertility can be enhanced by adding several soil nutrient supplements to the soil (Ramteke and Shirgave 2012). Fertilizer improves yields of maize and yam but it has negative effect on the yield of cassava. The positive effect of fertilizer on yam yield may reflect the application of inorganic required by yam plants for tuber development. High fertilizer input in cassava may promote vegetative growth at the expense of the tubers, resulting in low yields. Pesticide use has significant positive effect on yields of cassava, maize and yam but it has no significant effect on the yields of other crops. Purchased seeds/seedlings increase yields of maize but it has significant negative effect on yields of sorghum and rice. This is an indication that improved varieties will bring about higher yield in maize even under subsistence agricultural conditions, which is consistent with findings of Awoniyi et al. (2007) in the guinea savanna of Kwara state, Nigeria. However, in the case of sorghum, farmers will be better-off if they use local varieties of these crops.

Climate variables tend to have mixed effects on yields of food crops. Temperature has significant negative effect on yields of maize and rice but its effect on yield of yam is significantly positive. If temperature increases by 1 °C, yields of maize and rice will decline by 38.90% and 36.33%, respectively. This indicates that maize and rice are more susceptible to increase in temperature, which is clearly in line with hypothesis that additional warming will reduce crop yields in countries located within the tropics. Warming, however, increase yield of yam in Ghana. The coefficient of rainfall is positive for maize, sorghum and yam but it is not significant for other crops. Positive effect of additional rains on yields of maize confirms the fact that maize is a rain loving crop which benefits from reasonably wet climatic conditions. Sorghum requires a reasonable amount of water from germination up till heading. Additional rains after heading can, however, be harmful. Yam also requires enhanced soil moisture to ensure smooth plant and tuber development. Although rainfall has no significant impact on rice yield, it may be true in rice growing areas in Ghana. Rice is mostly cultivated in the valley bottoms of the drier savanna ecological zone with waterlogged soils. Marginal increase in rainfall may not bring about significant increase in yield of rice.

4.4 Climate change impact on yield of food crops

Climate variables in this study are mean monthly temperature and rainfall for growing seasons of the five food crops considered under this study. Trend analysis of climate variables over the period 1961-2010 shows that temperature is projected to increase in growing seasons of all crops considered under this study while rainfall is projected to decrease in growing seasons of all crops except sorghum, which will experience an increase. Figures 4.1, 4.2, 4.3, 4.4 and 4.5 show the trends of temperature and rainfall for cassava, maize, sorghum, rice and yam, respectively. Temperature during growing seasons for all crops over the period 1961-2010 is on an increasing trend. The annual rate of temperature rise during the growing season for all crops in question is about 0.02 ^{0}C. With the exception of sorghum, rainfall amounts tend to be decreasing for all other crops over the period. Monthly average rainfall during maize growing season has the highest rate of decline of 0.21cm. Rainfall declines at the rate of 0.140cm and 0.104cm for yam and rice, respectively. The least rate of rainfall decline is 0.013cm during the growing season for cassava. Rainfall, however, increases at a rate of 0.061cm during the sorghum cropping season.

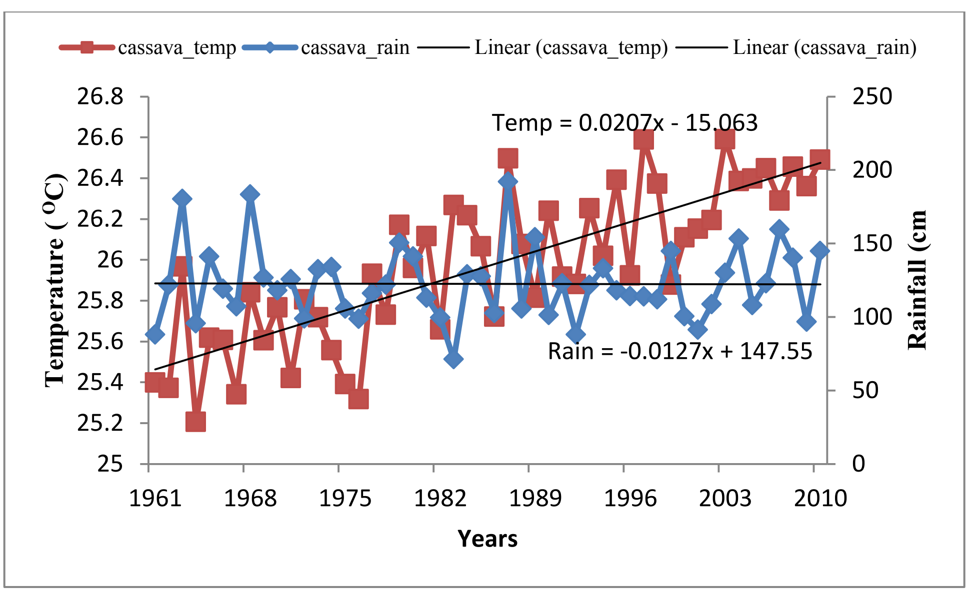

Fig. 4.1 Trend of temperature and rainfall during cassava growing season

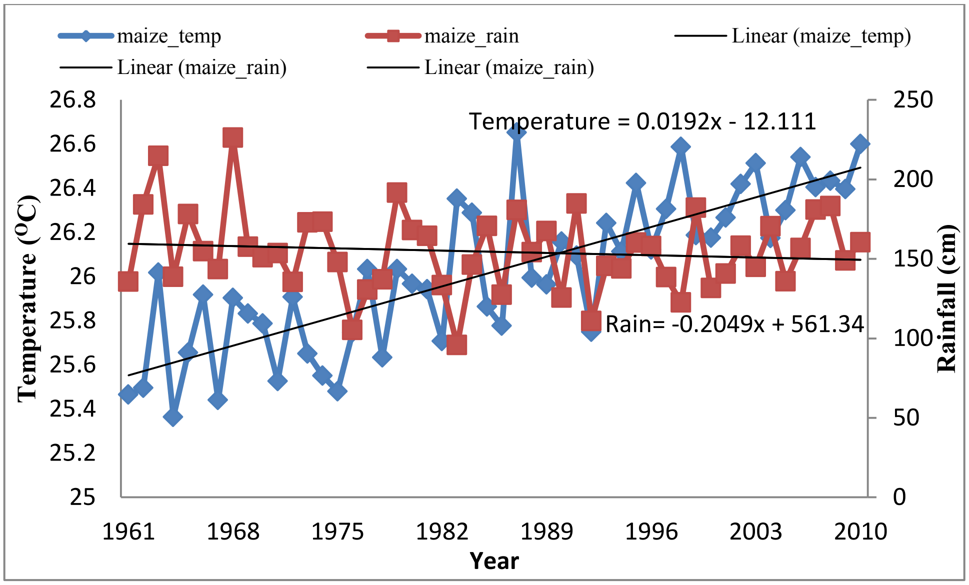

Fig. 4.2 Trend of temperature and rainfall during maize growing season

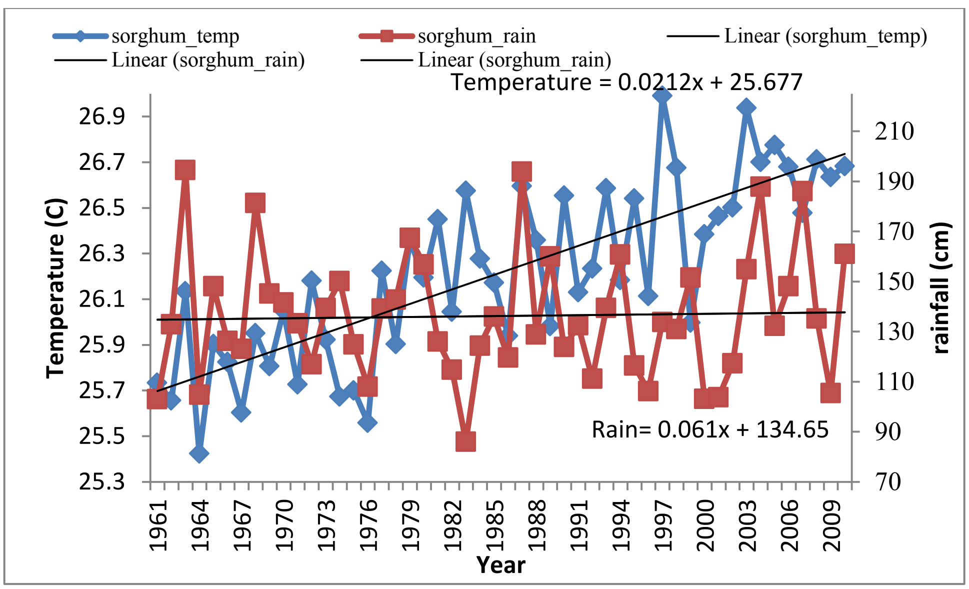

Fig. 4.3 Trend of temperature and rainfall during sorghum growing season

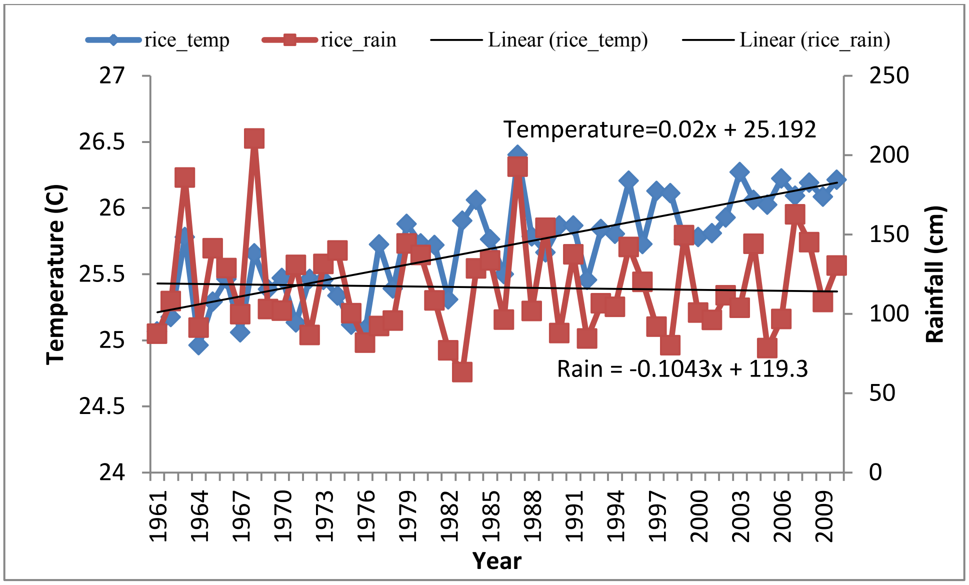

Fig. 4.4 Trend of temperature and rainfall during rice growing season

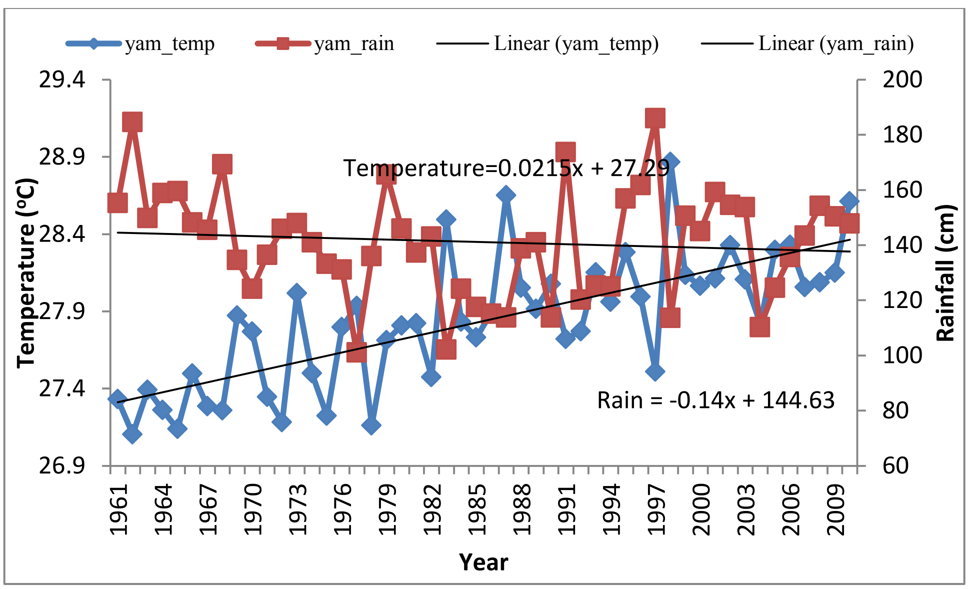

Fig. 4.5 Trend of Temperature and rainfall during yam growing season

Combining the coefficients of climate trends as in figures 4.1-5 and regression coefficients for climate variables from Table 4.4, we can estimate the future impact of climate change on crop yield as specified in equation 4.5 of section 4.2.1. It can be seen from Table 4.5 that climate change will raise the yields of cassava, maize and sorghum but it will impact negatively on yields of rice and yam. Cassava yield is expected to increase by 10.51%, 22.11% and 34.88% for 2015, 2020 and 2025, respectively. Maize yield is projected to go up by 7.74%, 20.04% and 30.94% for 2015, 2020 and 2025, respectively. Similarly, sorghum yield is projected to increase by 17.17%, 39.08% and 64.57% for 2015, 2020 and 2025, respectively. The yields of rice and yam will reduce by 22.11% and 6.43%, respectively, in 2015. The yield of these crops will progressively reduce until 2025 when yields will reduce by as much as 59.99%g and 17.33% for rice and yam, respectively.

Table 4.5 Impact of climate change on crop yield

	Cassava	Maize	Sorghum	Rice	Yam
2015	10.51%	7.74%	17.77%	-22.45%	-6.43%
2020	22.11%	20.04%	39.08%	-42.35%	-12.19%
2025	34.88%	30.94%	64.57%	-59.99%	-17.33%

Note All figures represent changes from the base year of 2010

4.5 Summary, conclusions and recommendations

This study uses national household survey to analyze impact of climate variables on yields of major food crops in Ghana. Using FGLS method, the study effectively accounted for the problems of heteroskedasticity which has the potential of blighting efficiency of parameter estimates. Climate variables tend to have mixed effects on yields of food crops. Warming reduces yields of maize and rice but increases that of yam. This indicates that maize and rice are more susceptible to increase in temperature, which is clearly in line with hypothesis that additional warming will reduce crop yields in countries located within the tropics. Rainfall has positive effect on yields of maize, sorghum and yam but it has no significant effects on yields of other crops. Positive effect of additional rains on yields of maize confirms that fact that maize is a rain loving crop which benefits from reasonably wet climatic conditions. Sorghum has high water requirement from germination up till heading. Additional rains after heading can, however, be harmful. Yam also requires enhanced soil moisture to ensure smooth plant and tuber development. Rainfall has no significant on rice yield; this may be true in rice growing areas in Ghana. Rice is mostly cultivated in the valley bottoms of the drier savanna ecological zone with waterlogged soils. Marginal increase in rainfall may not bring about significant increase in yield of rice.

The use of farm inputs improves yields of some of the crops except cases of misapplication and late use of pesticides in periods of pest attack. The effects of inputs are economically smaller as compared to climate variables. Apart from climate variables and crop inputs, some socioeconomic variables, especially farm size, household size and gender of household heads also have significant influence on crop yields. This study therefore suggests streamlining of input markets to ensure access to fertilizer, use of heat and drought tolerant seeds, and efficient pesticide/herbicide application for subsistent food crop farmers.

Using the coefficients of the FGLS model to project the future impact of climate change based on historical trend of climate variables, the study finds climate change to detrimental effects on yields of maize, rice and yam. Its impact on yields of cassava and sorghum are projected to be positive. This study recommends use of community-based radio and other media outlets, and extension officers to disseminate climate related information and technological innovations to farmers in order to avert projected plummeting yields of some major food crops resulting from climate change and to optimize use of farm inputs and technologies in farming.

5 Climate Change Impact on Revenue of Major Food Crops: Structural Ricardian Cross-Sectional Analysis

5.1 Introduction

Agriculture is the backbone of the economies of most developing countries, serving as a source of food, foreign exchange earnings and employment for millions of people. Despite these visible contributions of agriculture, it suffers from perennial neglect from governments of sub-Saharan countries. Less than 10% of annual budgeted revenue of these countries is allocated to agricultural sector (NEPAD 2009). This problem of low investment will be exacerbated by threat of global warming and its associated effects on temperature and rainfall patterns and ultimately farming. It is, thus, predicted that African countries with low adaptive capacity will suffer the unfriendly brunt of climate change since a larger proportion of their economies are in climate sensitive sectors.

In Ghana, agricultural production is largely small-holder and rain-fed (GEPA 2007). Slight change in weather and climate is expected to pose major challenges to the growth and development of Ghana's agriculture (Nankani 2009). Prompted by threats of vagaries of weather and climate, some researchers have attempted to investigate its impacts on crop production in Ghana. Based on crop simulations model, Sagoe (2006) reports that climate change will reduce yields of cassava by 3%, 13.5% and 53% in 2020, 2050 and 2080 respectively, but cocoyam yield is expected to decline by 11.8%, 29.6% and 68% in 2020, 2050 and 2080 respectively. Ghana Environment Protection Agency (GEPA) concludes from analysis of climate change impact on cereals that it will reduce yield of maize by 6.9% in 2020 but that of millet will remain unaffected because it is more drought-tolerant (GEPA 2001). International Center for Tropical Agriculture (CIAT) (2011) used crop prediction model, MAXNET, to analyze impact of climate on cocoa in Ghana and La Cote d'Ivoire for 2030 and

2050. This study concludes that climate change will reduce land suitability for cocoa in the Lagunes and Sud-Comoe in Côte d'Ivoire whereas an increase in land suitability for cocoa will be observed in Kwahu Plateau in Ghana. In other areas, land suitability will remain same with the right adaptive measures. Some areas which are not currently under cocoa cultivation can become suitable for cocoa production in the future (18 Montagne in La Côte d'Ivoire).

Previous climate impact studies on crop production in Ghana tend to be more reliant on crop simulation models, describing the relationship between climate and crop growth, and ignoring farmers' actions to moderate the adverse effects of changing climate (dumb farmers scenario). Granted that food crop farmers, the poorest segment of Ghanaian society, depend on the weather for their livelihood, this chapter uses structural Ricardian model to assess the impact of climate on major food crops based on national survey data. This approach incorporates efficient adaptive responses by farmers (Mendelsohn and Dinar, 1999). Findings of this study are expected to contribute to climate impact literature and provide useful information government may need in crafting appropriate adaptation policy for Ghana.

5.2 Empirical strategy

This study uses a Ricardian method to analyze the impact of climate variables on revenues from major food crops (cassava, maize, sorghum, rice and yam) in Ghana. It is so named because of the original observation of David Ricardo (1772-1823) that the value of land reflects its net productivity and, by extension, farm net revenue reflects its net productivity (Kurukulasuriya and Mendelsohn, 2006b). This approach captures not only the direct effect of climate on net revenue but also the adaptation response by farmers to mitigate damages associated with sub-optimal climatic conditions. This study adopts the Structural Ricardian technique whereby farmers respond to changing climate by switching crops. It is basically a micro-econometric model whereby a farmer chooses j among J crops in the first stage, and maximizes net revenues in the second stage conditional on those choices (Mendelsohn, 1994; Mendelsohn and Dinar, 2009; Seo and Mendelsohn, 2007). Based on utility theory, a crop is chosen if it gives the farmer highest net revenue as compared to other crops (Train, 2003). Equations (5.1) and (5.2) are econometric specification of net revenue and crop choice equations, respectively.

$$\pi_j = X_i \beta_j + U_j \tag{5.1}$$

$$\pi_{ji} = Z_i \gamma_j + \epsilon_j \tag{5.2}$$

Where, Z_i is a vector of explanatory variables for crop choice equation; X_i is a vector of independent variables for the revenue equation; π_j is net revenue per hectare, β_j and γ_j vector of coefficients for revenue and crop choice equations respectively; U and $\in$ are the error terms for revenue and crop choice equations respectively.

Efficient and consistent estimates of equation (5.1) cannot be obtained if U_j and ϵ_j are correlated resulting in what is often called selectivity bias. Heckman (1979) developed a two-step procedure to correct self-selection bias in cases of binary choices while Lee (1983) and Dubin and McFadden (1984) developed the approach to apply to multiple choice. Dubin and McFadden (1984) approach to polychotomous choice, which has been enhanced by Bourguignon et al. 2007), is more appealing in that the inclusion of multiple correction terms allow us not only to attribute a selection bias in the estimation of earnings to the allocation of individuals with better or worse unobserved characteristics in farming, but also to link the selection bias to the allocation of individuals to each other alternative (Zheren, 2008). That is, it allows for identification of selection bias and its source. This study employs the Dubin and McFadden (1984) approach for correction of bias in a two-stage process as five crops are involved. With the assumption that $\in$ is independently and identically Gumbel distributed, logistic specification of equation (5.2) as in equation (5.3), indicating the probability (P_{ji}) that a farmer chooses a particular crop, is estimated by multinomial logistic regression at the first stage.

$$P_{ji}=\frac{\exp(Z_i\gamma_j)}{\sum_{k=1}^{k}\exp Z_i\gamma_j)} \qquad (5.3)$$

At the second stage, equation (5.1) is estimated by including as additional explanatory variables the selection bias correction terms (calculated from the first stage) other than the chosen crop in each crop revenue regression (Dubin and McFadden 1984). Equation (5.4) below is the selection bias corrected (conditional) revenue regression based on equation (5.1):

$$\ln\pi_j=X_i\varphi_j+\sigma\sum_{k\neq 1}^{k} r_k\left(\frac{P_k \ln P_k}{1-P_k}+\ln P_j\right)+w_j \qquad (5.4)$$

$\ln\pi_j$ is the logarithm of net revenue per hectare; the second term on the right-hand side is the selection bias correction term; X_i is a vector of independent variables that including climate variables; φ_j is a vector of parameters; and w_j is the error term. $\ln P_j$ is logarithm of crop probability (P_i); σ stands for standard deviation of error term in equation (5.2); and r_k is the correlation coefficient between error terms in equations (5.1) and (5.2). The above correction of selection bias provides fairly good estimation of net crop revenue even if crop choices are completely independent of each other (Bourguignon 2007).

Having estimated equations (5.3) and (5.4), expected revenue of a typical farm V is calculated as the sum of the probabilities of each crop choice times the conditional net revenue of that crop choice as follows:

$$V=\sum_{j=1}^{J} P_j(Z_i).\pi_j(Z_i) \qquad (5.5)$$

Expected net revenue denotes long term average farm net revenue. Marginal effect of climate on expected net revenue comes from two sources: effect on the probability of crop choice and effect on conditional net revenue per hectare. To analyze the marginal impact of climate on expected net revenue, equation (5.5) is differentiated with respect to climate variables to obtain equation (5.6):

$$\frac{\partial V}{\partial Z_c} = \frac{\partial P_j}{\partial Z_c} \cdot \pi_j + \frac{\partial \pi_j}{\partial Z_c} \cdot P_j \tag{5.6}$$

Marginal effect of climate variables on probability of crop selection, $\partial P_j / Z_c$, is estimated by differentiating equation (5.5) as follows:

$$\frac{\partial P_j}{\partial Z_c} = P_j \left[\gamma_j - \sum_{k=1}^{J} P_k \gamma_k \right] \tag{5.7}$$

The marginal effect of climate variables on conditional net revenue, $\partial \pi_j / Z_c$, can also be estimated by differentiating equation (5.4) as shown below:

$$\frac{\delta \pi_j}{\delta z_c} = \varphi_j \pi_j \tag{5.8}$$

The above approach assumes profit maximization behavior subject to exogenous production conditions, no change in technology, no change in input and output prices and no carbon fertilization (Mendelsohn and Dinar, 1999). More importantly, there is no full cost accounting in adapting to changing climate by switching crops. The cost of switching to new crops such as seeds and new equipment paid by farmers are correctly captured as adaptation cost. However, cost of crop failures resulting from trials of new crops and costs associated with retiring capital equipment is not captured (Kurukulasuriya and Mendelsohn, 2006a).

The approach was first applied in the United States and later used in other countries to predict the damages from changes in climate (Mendelsohn et al. 1994; Sanghi et al. 1998, Mendelsohn and Neumann 1999; Mendelsohn et al. 2001). Ricardian method was used to examine impact of climate change on cropland based on a survey of more than 9,000 farmers in eleven African countries including Ghana and the results show that net revenues fall with drying and warming (Kurukulasuriya and Mendelsohn 2006a). Seo and Mendelsohn (2008b) developed a Structural Ricardian model to analyze impact of climate on choice of farm type and farm revenue. Results indicate that warming and drying prompts farmers to switch from crop-only or livestock-only or rain-fed farms to mixed farming or irrigated crops. Warming and drying also reduce incomes from crop-only or livestock-only or rain-fed farms whereas incomes from mixed farms and irrigated farms increase. Seo and Mendelsohn (2007) also used structural Ricardian model to assess climate impact on African livestock choices and number. The results indicate that warming enable farmers to switch from beef cattle to more heat-tolerant goats and sheep. Drying prompts farmers to switch from cattle and sheep to goats and chickens.

In general, studies using the Ricardian approaches point to the slight beneficial effects of warming and drying to U.S. and other countries in temperate zones but likely harmful effects to tropical and semi-tropical countries where most developing countries including Ghana are located.

5.3 Data and summary statistics

This study uses data mostly from the fifth round of the Ghana Living Standards Survey (GLSS V) conducted by Ghana Statistical Service (GSS) in 2005/2006. All non-climate variables used in this study are extracted from GLSS V. Data on climate variables were obtained from Ghana Meteorological Agency (GMET) covering ten weather stations (Wa, Navrongo, Tamale, Sunyani, Kumasi, Koforidua, Ho, Saltpond, Accra and Takoradi) across the length and breadth of the country. The climate data covers fifty years (1961-2010). Climate normal variables (temperature and rainfall) are constructed to synchronize crop-specific growing periods of all selected crops. The climate data is, then, matched with the farming households in the GLSS V.

Table 5.1 Description and summary statistics of model variables

Variables	Description	Cassava	Maize	Sorghum	Rice	Yam
Net revenue per hectare (GHS)	gross crop revenue minus costs of inputs	306.40 (489.42)	200.97 (386.28)	166.25 (312.79)	135.06 (292.42)	327.62 (429.62)
temperature (°C)	monthly mean temperature (°C) for 1961-2010 during growing season	25.4875 (0.3717)	25.9912 (0.3689)	26.8790 (0.4362)	26.5583 (0.8245)	27.7326 (1.2230)
Rainfall (cm)	monthly mean rainfall (cm) for 1961-2010 during growing seasons	11.1582 (3.3234)	16.1399 (2.8539)	16.3079 (0.3332)	15.1723 (2.1574)	14.1799 (2.3635)
Household size	number of individuals living in a household	4.4981 (2.6621)	5.2177 (3.2068)	5.9215 (2.8457)	5.9762 (3.3382)	5.8404 (3.5137)
Age of household head	age in years of the head of household	48.2102 (14.8061)	45.0842 (14.9315)	48.2987 (14.9838)	46.5397 (14.7679)	47.5019 (15.7328)
Gender of household head	dummy variable (0=male; 1=female)	0.3002 (0.4585)	0.1669 (0.3730)	0.1089 (0.3119)	0.1032 (0.3054)	0.1288 (0.3354)
Education of household head	Schooling years of household head	4.1547 (4.8565)	3.2112 (4.7925)	0.7823 (2.84956)	1.1984 (3.3443)	1.8096 (3.8363)
Farm size (ha)	Farm size in hectares(ha)	1.6428 (3.7547)	2.5761 (8.8999)	1.8091 (1.8371)	3.7735 (10.7838)	2.9981 (6.1471)
Crop price (GHS)	price per kilogram of crop output in 2005 (GHS)	0.3774 (0.2928)	0.3364 (0.8148)	0.3130 (0.2070)	0.4245 (0.5771)	0.1394 (0.0940)
N	Number of observations	1299	1378	395	126	520

Notes °C=Degree Celsius; GHS=Ghana Cedis; cm=centimeter; 1US$=0.92GHS; figures in parenthesis are standard deviations model variables.
Source Calculated from 2005 Ghana Living Standard Survey and Ghana Meteorological Agency data

Net revenue per hectare is calculated as the difference between gross crop revenue (sales of processed and unprocessed produce, in-kind receipts and the value of home consumed produce) and crop expenses (fertilizer, pesticide, seedlings, hired labor, irrigation and processing cost) divided by the number of hectares of harvested area. The vector of independent variables X consists of climate variables and non-climate variables. The climate variables are monthly mean temperature (temperature) and monthly mean rainfall (rainfall) during growing season for respective crops. The non-climatic independent variables include household size, age, gender and years of education of the household head and farm size. The independent variables for the crop choice equation, Z, include all explanatory variables for the revenue equation in X above and the selling price of the crops in question (cassava, maize, sorghum, rice and yam).

The summary statistics of model variables is presented in Table 5.1. Net revenue per hectare is higher among the tuber crops (cassava and yam) as against the cereals. The unit price of crops ranges from 14 pesewas for yam to 42 pesewas for rice. That is, among the five food crops, rice attracts the highest output price. All growing areas have high temperature of about 26^0 C. Levels of rainfall range from about 11cm for rice to 160cm for maize. A typical farmer who grows any of these crops is likely to be a male aged 46 years with at least a year of formal education, five household members and a farm size of about 2 hectares.

5.4 Results and discussion

In this section, an estimation of an econometric model for farmers' cropping decisions under profit maximizing conditions is carried out. This model is estimated in a two stage process. At the first stage, equation (2.3) is estimated using multinomial logit method. At the second stage, equation (2.4) is estimated using Ordinary Least Squares (OLS) method. Crop output price is included as an additional explanatory variable in crop choice equation but not in the revenue equation to ensure model identification. In the ensuing sections, the results of the two equations are presented and discussed.

5.4.1 Impact of climate variables on crop choices

This section assesses the impact of climate on farmers' probability of selecting crops using a multinomial crop choice regression. The dependent variable is crop choice variable, indicating five major food crops grown in Ghana (cassava, maize, sorghum, rice and yam). Mean monthly temperature and rainfall for growing seasons of selected crops are the main variables of interest. The other variables which are controlled for in this model are household size, age, gender and education of household head, farm size and output price variables for the selected crops.

Since coefficients of logit regressions are maximum likelihood estimates, they cannot be used to assess average impact of climate variables on crop choice. Table 5.2 therefore presents the regression results of the multinomial logit model in terms of marginal effects. There are 3,718 observed plots in the regression. Household size has significant negative marginal effect for maize indicating maize less often selection among households with large sizes. Household size has no significant effect on the probability of selecting other crops. The coefficients on age of household head have significant positive effect on cassava and yam but significant negative effect on maize, meaning that older household heads are more likely to select cassava and yam and less likely to choose maize. Age of household has not statistically significant effect on the choice of rice and sorghum. Coefficients on female household head are significantly positive for cassava, and negative for sorghum and rice. This implies that cassava is often chosen by female farmers while sorghum and rice are often grown by male households. Coefficients on education of household head are significantly positive for cassava, maize and yam, and negative for sorghum and rice. This implies that cassava, maize and yam are often chosen by educated farmers while sorghum and rice are often grown by less educated households. Coefficients on log of farm size are negative for cassava and positive for rice and yam, indicating that small scale farmers are more likely to select cassava while large scale farmers often grow rice and yam. Output prices tend to have positive effect on the probability of selecting cassava, maize and rice, but negative effect on yam selection. The negative effect of yam price per kilogram may be due to the fact that higher input prices or production costs often reflect in output prices thereby negatively affecting crop selection.

Table 5.2 Crop choice multinomial logit regressions: marginal effects

Variables	Cassava	Maize	Sorghum	Rice	Yam
Temperature (°C)	-0.5924*** (0.0310)	-0.6416*** (0.0619)	0.5646*** (0.0564)	0.3836*** (0.0448)	0.2858*** (0.0395)
Rainfall (cm)	-0.1255*** (0.0093)	0.1949*** (0.0091)	-0.0139*** (0.0044)	-0.0369*** (0.0060)	-0.0185*** (0.0037)
Household size	0.0047 (0.0039)	-0.0150*** (0.0043)	0.0050 (0.0023)	0.0040 (0.0026)	0.0012 (0.0013)
Age of household head	0.0033*** (0.0007)	-0.0032*** (0.0008)	0.0001 (0.0005)	-0.0007 (0.0005)	0.0005* (0.0003)
Female household head	0.0840*** (0.0284)	0.0054 (0.0314)	-0.0551*** (0.0160)	-0.0451** (0.0185)	0.0107 (0.0117)
Education of household head	0.0121*** (0.0022)	0.0122*** (0.0029)	-0.0143*** (0.0022)	-0.0120*** (0.0024)	0.0020** (0.0009)
Log of farm size	-0.0320*** (0.0097)	-0.0074 (0.0118)	0.0005 (0.0069)	0.0295*** (0.0085)	0.0095** (0.0043)
Output price	0.1589*** (0.0229)	0.2682*** (0.0386)	-0.0334 (0.0354)	0.0519*** (0.0111)	-0.4457*** (0.0510)

Notes *** means significant at 1%, ** means significant at 5% and * means significant at 10%; number of observations=3,718; LR chi2 (32) = 5375.93***, Pseudo R^2= 0.5303 and Log likelihood= -2380.7675; This model correctly predicts 89.30% for cassava, 80.84 for maize, 50.63% for sorghum, 71.71% for rice and 89.80% for yam; Figures in parenthesis are standard errors of regression coefficients; and cassava is the base outcome; The marginal change denotes 1 ^{0}C increase in temperature and 1cm increase in rainfall.
Source Authors' calculations

Climate variables have statistically significant effect on the probability of selecting crops. The coefficients on temperature are negative for cassava and maize but positive for sorghum, rice and yam. This means that higher temperature decreases the probability of selecting cassava and maize but increases the selection of sorghum, rice and yam. An increase in temperature by 1^{o}C will reduce the probability of selecting cassava and maize by 59.24% and 64.16%, respectively, while the probability of selecting sorghum, rice and yam will increase by 56.46%, 38.36% and 28.58%, respectively. The coefficients on rainfall are significantly negative for cassava, sorghum, rice and yam but positive for maize, implying that higher rains decrease the likelihood of selecting cassava, sorghum, rice and yam but increase the likelihood of selecting maize. Marginal increase in rainfall will reduce the probability of selecting cassava, sorghum, rice and yam by 12.55%, 1.39%, 3.69% and 1.85%, respectively, while maize selection increases by 19.49%. That is, in warm and dry places, sorghum, rice and yam are more likely to be selected while in cooler and wet locations, maize will be more preferable. Cassava is grown in places with relatively cooler and wet climate.

5.4.2 Climate impact on conditional crop revenue

The impact of climate variables on net revenues from major food crops is assessed using selection bias corrected (conditional) revenue equation from equation (5.4). The dependent variable is the log of net revenue per hectare. The independent variables are mean monthly temperature, rainfall, household size, age, gender and educational attainment of the household head and log of farm size. Sample selection bias correction terms estimated at the first stage from the results of multinomial regressions are included as additional explanatory variables for each crop regression other than the crop for which the regression is run. This specification provides the best fit of the model.

Table 5.3 shows the results of conditional net revenue regressions of the five major crop species cultivated in Ghana. Many climate variables have statistically significant impact on net revenues of crops. Mean monthly temperature has significant positive effect on net revenues of cassava and sorghum but negative effect on revenue of other crops. Rainfall has positive influence on sorghum revenues and negative effect on cassava and maize revenues, but it has not significant effect on revenue of other crops. Household size has significant positive effect on net revenues of all crops with the exception of rice. Positive sign of household size coefficient for most crops is not surprising because family labor supports farmers during planting, weeding and harvesting periods especially in many developing countries including Ghana. Age and gender of the household head have no significant effect on revenues of all crops. That is, there is no significant difference in net revenue between older and younger farmers, and between male and female farmers. Educational attainment of the household head has significant influence on revenues of cassava and rice. Educated farmers tend to receive higher profits from rice cultivation while less educated farmers earn higher revenue from cultivation of cassava.

Table 5.3 Conditional revenue regressions of major food crops in Ghana

Variables	Cassava	Maize	Sorghum	Rice	Yam
Intercept	-5.4124 (4.6270)	0.8559 (7.4926)	-101.2667*** (25.1420)	42.1662 (35.6907)	7.0730 (5.1679)
temperature (°C)	0.4336** (0.1820)	0.1944 (0.2883)	3.4120*** (0.8705)	-1.4458 (1.3444)	-0.0254 (0.1547)
rainfall (cm)	-0.0802*** (0.0451)	-0.0820** (0.0347)	0.7924*** (0.2044)	-0.0178 (0.2115)	-0.1132 (0.0879)
household size	0.0681*** (0.0168)	0.0672*** (0.0140)	0.1323*** (0.0263)	0.0605 (0.0575)	0.0632*** (0.0175)
age of household head	0.0008 (0.0034)	.0008365 .0029603	.0032304 .0050926	.0039505 .0119072	.0007198 .0039979
Female household head	-0.0715 (0.1002)	-0.0501 (0.1293)	0.0122 (0.2172)	0.6022** (0.6994)	0.1004 (0.2024)
Education of household head	-0.0202*** (0.0097)	-0.0022 (0.0123)	-0.0442 (0.0306)	0.1406** (0.0643)	-0.0051 (0.0208)
Log of farm size	-0.8244*** (0.0472)	-0.6615*** (0.0436)	-0.9544*** (0.1200)	-0.7951*** (0.2047)	-0.5340*** (0.0797)
Cassava selection		0.0531 (0.3416)	0.8490 (2.1969)	0.3129 (1.1517)	-1.8719 (1.7488)
Maize selection	-0.5460 (0.5358)		-3.0271*** (1.2440)	1.6670** (1.5785)	-0.0254 (0.7493)
Sorghum selection	3.6744*** (1.1360)	-0.5445 (0.9751)		-1.3788** (0.9565)	-1.4418 (0.9522)
Rice selection	-3.2123*** (1.2122)	-0.5843 (0.9061)	-0.2390 (1.5153)		2.9571** (1.3547)
Yam selection	0.0277 (0.4882)	1.0989** (0.5055)	2.0238*** (0.4327)	-0.5276 (0.9496)	
R^2	0.3078	0.2765	0.4159	0.3148	0.2329
F-statistic	37.52***	33.90***	20.00***	3.22***	12.39***
N	940	988	321	89	461

Notes The dependent variable is the log of net revenue per hectare; *** denotes significant at 1%, ** denotes significant at 5% and * denotes significant at 10%; figures in parenthesis are bootstrapped standard errors of regression coefficients.
Source from authors' calculations

Apart from the factors explained earlier, farm size and crop selection terms also have statistically significant effect on some crops. Farm size has significant negative effect on earnings of all crops. Mendelsohn and Dinar (2009) attribute this to the omission in cost calculation of household labor which overstates net earnings of smaller farms. It is also explained by the higher management intensity on smaller farms as compared to larger ones.

Statistical significance of the some crop selection terms indicates the presence of selection bias and this model would not produce efficient parameter estimates if this model were to be estimated using unadjusted OLS regression. The significant coefficients of sorghum and rice selection are positive and negative, respectively, in the cassava regression. This implies that farmers who the selection model predicts would select cassava will earn higher revenue if they actually select sorghum and lower net revenue if they actually grow rice. The coefficient of yam selection is positive in the maize regression indicating that farmers who the model predicts would select maize will actually earn higher if they actually select yam. The coefficients of maize and yam selection terms are negative and positive, respectively, in the sorghum regression indicating that farmers who the model predicts would select sorghum will actually earn lower revenue if they actually select maize and higher revenue if yam is actually selected. Farmers who actually select maize instead of rice as predicted by the model will earn higher revenue, while those who actually select sorghum will earn lower revenue. Similarly, farmers who actually select rice instead of yam as predicted by the model will earn higher revenue.

Results of the crop revenue regressions in Table 5.3 are partly consistent with that of crop selection equation in Table 5.2. For instance, coefficients of rainfall are negative for cassava and maize regressions, and this is matched by decreased probability of selecting these crops. Warming increases the likelihood of selecting of sorghum and this is matched by increased probability of selecting sorghum. The direction of impact of climate variables on the probability of selecting some crops is not matched by that of net revenue. Temperature and rainfall reduce the likelihood of selecting cassava and sorghum, respectively, but this is matched by corresponding effect of these climate variables on net revenue. Although climate variables have no significant effect on revenues of rice and yam, temperature and rainfall have positive and negative effect, respectively, on the probability of selecting rice and yam. The above analysis implies that farmers' choice of the major food crops is not largely motivated by profit optimizing behavior. Cultural factors[1] which sanction the use of these crops in preparing traditional dishes and other rituals in Ghanaian society may explain the irrational choice of these crops and thus defy neoclassical understanding of producer behavior.

5.5 Simulating climate change impact on expected net revenue

This section assesses the impact of climate change on expected net revenue (long term net revenue) in Ghana. In line with the idea of permanent income hypothesis, farmers strategize to minimize fluctuations in farm revenues by switching from crops with lower earnings over time to stabilize earnings from crop production (Friedman 1957).

Table 5.4 Changes in future climate from past trends

	Change in temperature (^{O}C)			Change in rainfall (cm)		
	2015	2020	2025	2015	2020	2025
Cassava	0.1033	0.2067	0.3100	-0.0633	-0.1265	-0.1898
Maize	0.0960	0.1921	0.2881	-1.0246	-2.0492	-3.0737
Sorghum	0.1060	0.2121	0.3181	0.3049	0.6098	0.9147
Rice	0.1000	0.2001	0.3001	-0.5213	-1.0426	-1.5639
Yam	0.1073	0.2146	0.3219	-0.7002	-1.4004	-2.1007

To analyze climate change impact on farm outcome, results of equations (5.5) and (5.6) as presented in Tables 5.2 and 5.3 together with changes in climate variables from past trends in Table 5.4 can be used. The deviations of future temperature from past trends for growing seasons of all crops are projected to be positive (Table 5.4). The deviations of Rainfall in the future from past trends are projected to be negative in growing seasons of all crops except

[1] There are yam festivals for many ethnic groups in Ghana. Most traditional Ghanaian dishes are prepared from cassava and maize in many locations. In the northern part of Ghana, sorghum is used in preparation of traditional dishes during funerals.

sorghum, which will experience positive rains. Using these projections of climate variables in Table 5.4 together with regression coefficients for climate variables from Tables 5.2 and 5.3, we can estimate the future impact of climate change on expected net crop revenue.

Table 5.5 Impact of climate change on expected net revenue of food crops in Ghana

	No climate change adaptation			Climate change adaptation		
	2015	2020	2025	2015	2020	2025
Cassava	-5.33%	-10.65%	-15.98%	-3.55%	-7.02%	-10.42%
Maize	-26.13%	-52.25%	-78.38%	-22.18%	-44.06%	-65.62%
Sorghum	5.56%	11.12%	16.68%	13.10%	29.00%	48.82%
Rice	5.76%	11.52%	17.29%	5.34%	10.74%	16.19%
Yam	4.36%	8.72%	13.08%	5.48%	11.05%	16.72%

Notes All figures are in Ghana Cedis (GHS), monetary currency of Ghana. As of 2005, 1 USD =0.92 GHS; Expected net revenue of base year (2010) is GHS161.82; figures in parenthesis are in percentage difference from base year expected revenue

It can be seen from Table 5.5 that climate change will have negative effect on expected revenue per hectare of cassava and maize while its effect on sorghum, rice and yam are projected to be positive. Expected cassava revenue will decrease by 5.33%, 10.61% and 15.98% for 2015, 2020 and 2025, respectively, while maize revenue will decrease by 26.13%, 52.25% and 78.38% for 2015, 2020 and 2025, respectively. The effect of climate change is, however, positive for sorghum, rice and yam. By 2015, 2020 and 2025, expected sorghum revenue will increase by 5.56%, 11.12% and 16.68%, respectively; expected rice revenue will go up by 5.76%, 11.52% and 17.29% for 2015, 2020 and 2025, respectively; and expected yam revenue is also projected to increase by 4.36%, 8.72% and 13.08%, respectively. If farmers adapt to climate change by switching among the food crops in question, it will not only maximize expected net revenues of sorghum and yam alone, but also minimize the losses in cassava and maize. Sorghum revenue will increase by 13.10% in 2015 and 48.82% in 2025; yam revenue will also inch up by 5.48% in 2015 and 16.72% in 2025. It is observed that there is no much difference in expected rice revenue in terms of climate change impact with and without adaptation. With climate change adaptation, losses in expected cassava and maize revenues are projected to decline. Cassava revenue will decline by 3.155% in 2015 and 10.42% in 2025; yam revenue will also decline by 22.18% in 2015 and 65.62% in 2025.

5.6 Conclusion and recommendation

This study analyzes the impact of climate variables on the probability of selecting among five major food crops and on their net revenues in Ghana using a two-stage econometric process. At the first stage, a multinomial logit regression is used to analyze the effect of climate variables on crop choice while a selection bias corrected net revenue regression based on the multinomial logit regression is used to assess the impact of climate on revenues of farmers at the second stage. The results of the multinomial regression show that warming is likely to prompt farmers to switch from cassava and maize to the cultivation of sorghum, rice and yam while additional rainfall increases the likelihood of selecting maize instead of the other crops in question. Farmers' choice of crops tends to be partly consistent with revenue predictions. Coefficients of rainfall are negative for cassava and maize regressions, and this is matched by decreased probability of selecting these crops. Warming increases the likelihood of selecting of sorghum and this is matched by increased probability of selecting sorghum. The direction of impact of climate variables on the probability of selecting some crops is not matched by that of net revenue. Temperature and rainfall reduce the likelihood of selecting cassava and sorghum, respectively, but this is matched by corresponding effect of these climate variables on net revenue. The above analysis implies that farmers' choice of maize and sorghum is not largely motivated by profit optimizing decisions. Cultural factors which sanction the use of these crops in preparing traditional dishes and other rituals in Ghanaian society may explain the irrational choice of these crops and thus defy neoclassical understanding of producer behavior.

Climate change impact will not have same effect across crops. Climate change is projected to raise expected revenues of sorghum, rice and yam. The positive climate change impact on sorghum and yam will be much enhanced if farmers adapt to climate change by switching among food crops. It is observed that there is no much difference in expected rice revenue in terms of climate change impact with and without adaptation. Climate change will impact negatively on expected revenues of cassava and maize, but these revenue losses will be minimized if farmers adapt by crop-switching.

From the foregoing discussions, it can be discerned that adaptation to changing climate through crop switching has beneficial outcomes in Ghana. Crop switching is an adaptation option but it is not without cost. Farmers who adopt crop switching can only use available crop varieties. In this regard, public investment in research on high-yielding, heat-tolerant and flood-prone varieties of the above mentioned food crops is suggested in order to make crop switching a beneficial exercise for farmers.

6 Macroeconomic Implications of Climate Change on Smallholder Food Crop Production in Ghana

6.1 Introduction

It is more or less a settled debate that climate change affects agricultural production systems in developing countries. Various methods have been employed to analyze its effects with majority being partial equilibrium models. However, climate change is a phenomenon which affects various aspect of human activity and partial equilibrium models are not suitable in tracing the indirect effects of climate change. It is therefore no wonder that recent studies increasingly use general equilibrium models in order to capture both the direct effects of climate change within the agricultural sector and the indirect effects on the rest of the economy. Computable General equilibrium (CGE) model is therefore proposed in this study to analyze the economy-wide impact of climate change.

CGE models in dynamic form are based on optimal growth theory whereby the behavior of economic agents is characterized by perfect foresight. In this case, economic agents tend to pursue intertemporal optimization of consumption and investment. However, application of this method is a challenge to modelers and it still remains on the roster of researchers for some time now. In order to perform impact of exogenous shocks between periods, this study adopts a static CGE approach, but the model is solved repeatedly from year to year. That is, the overall model will, thus, be a series of static CGE models that are linked between periods by exogenous and endogenous variable updating procedure based on the assumption that economic agents are myopic. Capital is updated endogenously using capital accumulation equation while total labor supply is updated exogenously between periods. Other variables such as public expenditure, transfers, technological change and debt accumulation can also be adjusted exogenously.

6.2 Model Structure

A CGE model is formulated as a set of simultaneous linear and non-linear equations, which define the behavior of economic agents, as well as the economic environment in which these agents operate. This environment is described by market equilibrium conditions, macroeconomic balances, and dynamic updating equations. The model assumes that the behavior of its agents is based on adaptive expectations rather than on the forward looking expectations that underlie pure inter-temporal optimization models. The CGE model is made up of four main blocks: production, international trade, institutions and macroeconomic closures.

In this model, production is carried out in 15 economic sectors or activities by combining primary factors with intermediate inputs using a Leontief specification (Equations 6.1 and 6.2). The two primary factors of production used in the model are labor and capital. Producers in the model make decisions in order to maximize profits subject to constant returns to scale technology, with the choice between primary factors being governed by a Cobb-Douglas production (Equation 6.3 and Fig. 6.1).

$$\mathrm{VA_i = v_i QA_i} \tag{6.1}$$

$$\mathrm{QINTA_i = io_i QA_i} \tag{6.2}$$

$$\mathrm{VA_i = A_i LD^{\alpha} KD^{1-\alpha}} \tag{6.3}$$

QA_i, VA_i and $QINTA_i$ are output, valued added and intermediates of economic sector i, respectively; v_i, oi_i and α are share of value added in gross output, share of intermediates in gross output and share of labor in value added of economic sector i, respectively; and LD and KD denotes sectoral labor and capital stock, respectively.

A producer's profit is defined as the difference between the revenue and the cost of primary factors and intermediate inputs. Each activity produces one or more commodities according to fixed yield coefficients, and a commodity may be produced by more than one activity. The revenue of each activity is identified by the level of the activity, yields, and commodity prices at the producer level. Since the producers maximize their profit, they employ factors up to the point where the marginal revenue product of each factor is equal to its wage.

Substitution possibilities exist between production for the domestic and the foreign markets. This decision of producers is governed by a constant elasticity of transformation (CET) function, which distinguishes between exported and domestic goods, and by doing so, captures any time or quality differences between the two products (Equation 6.3 and Fig. 6.1).

$$QX_c = \alpha t_c[\delta t_c(QE_c)^{\rho t_c} + (1-\delta t_c)(QD_c)^{\rho t_c}]^{\frac{1}{\rho t_c}} \quad (6.3)$$

$$QQ_c = \alpha q_c[\delta q_c(QM_c)^{-\rho q_c} + (1-\delta q_c)(QD_c)^{\rho q_c}]^{\frac{1}{\rho q_c}} \quad (6.4)$$

QX_c, QQ_c, QD_c, QE_c and QM_c are aggregate domestic outputs, composite supply, domestic demand, exports and imports, respectively; δt_c, αt_c and ρt_c are share parameter, scale parameter and parameter for domestic and export commodity substitution in the CET function, respectively; and δq_c, αq_c and ρq_c are share parameter, scale parameter and parameter for domestic and import commodity substitution in the CES function, respectively.

Profit maximization drives producers to sell in those markets where they can achieve the highest returns. These returns are based on domestic and export prices. Under the small-country assumption, Ghana is assumed to face a perfectly elastic world demand at a fixed world price. The final ratio of exports to domestic goods is determined by the endogenous interaction of relative prices for these two commodity types. Domestically produced commodities that are not exported are supplied to the domestic market.

Substitution possibilities exist between imported and domestic goods under a CES Armington specification (Armington, 1969) (Equation 6.4 and Fig. 6.1). Such substitution can take place both in final and intermediates Transaction costs are incurred on exports, imports and domestic sales. These costs are treated as a fixed share per unit of commodity, and generate demand for trade and transportation services. The final composite good, containing a combination of imported and domestic goods, is supplied to both final and intermediate demand. Intermediate demand is determined by technology and by the composition of sectoral production. Final demand is dependent on institutional incomes and the composition of aggregate demand.

This model has three institutional units: households, government and the rest of the world. Households are categorized into rural and urban while other institutions are aggregated as single units. Each Household category is assumed to have identical preferences, and is therefore modeled as 'representative' consumers. The main source of income for households is returns to factors of production. The supply of capital is fixed within a given time-period and is immobile across sectors, thus implying that capital earns sector-specific returns. Labor supply is assumed to be perfectly elastic at a given real wage. Each activity pays an activity-specific wage that is the product of the economy-wide wage and a fixed activity-specific wage distortion term. In addition, households also receive transfers from other institutions including other households. Households use their income to pay direct taxes, consume, make transfers to other institutions, and save. Household consumption includes both home and marketed commodities. Home commodities are purchased at producer prices, while marketed commodities are purchased at market prices.

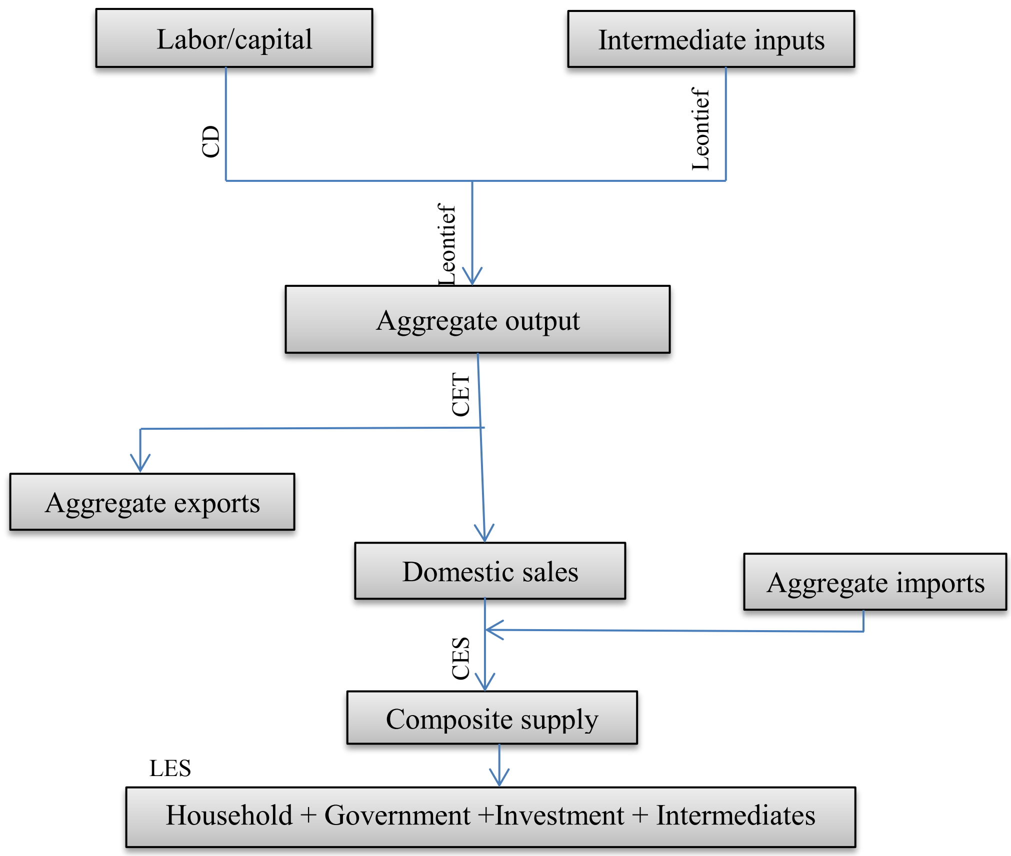

Fig. 6.1 Production technology and commodity flow

Notes The abbreviations CD, CET, CES and LES stand for Cobb-Douglas, Constant Elasticity of Transformation, Constant Elasticity of Substitution and Linear Expenditure System, respectively.
Source Adapted from Thurlow (2003)

The total consumption is allocated across different commodities according to a linear expenditure system (LES) demand function, which is derived from the maximization of a Stone-Geary utility function subject to income constraint (Equation 6.4 and Fig. 6.1). The LES specification allows for the identification of supernumerary household income that ensures a minimum level of consumption ((Equation 6.5). The remainder of household income is for saving. Savings by households are collected into a savings pool from which investment is financed.

$$U_c = \prod_c (QH_c - Cmin_c)^{\gamma_c} \tag{6.4}$$

$$PQ_c QH_c = PQ_c Cmin_c + \beta_c (EH_c - \sum_c Cmin_c\, PQ_c) \tag{6.5}$$

U_c, QH_c and $Cmin_c$ are utility obtained from consuming commodity c, household consumption of commodity c and minimum consumption of commodity c, respectively; PQ_c and EH_h are composite price of commodity c and total household expenditure on commodity; and γ_c and β_c are average budget share and the marginal budget share.

The government collects taxes and receives transfers from other institutions (Fig. 6.2). The government uses its income for two purposes: purchasing commodities for consumption and making transfers to other institutions. In this current model, government's role as a consumer is treated separately from the production of government services. The government also makes payments to the rest of the world. The latter is specified as an activity producing services for which the government institution is the primary consumer. Government consumption is fixed in quantity whereas government transfers to domestic institutions (households and rest of the world) are fixed in real terms (CPI-indexed). Government savings is the difference between government income and expenditure. The final institution is the rest of the world. Transfer payments between the rest of the world and domestic institutions are all fixed in foreign currency unit. Foreign savings (current account deficit) is the difference between foreign currency spending and receipts of the economy.

Production is linked to demand through the generation of factor incomes and the payment of these incomes to domestic institutions. Balance between demand and supply for both commodities and factors are necessary in order for the model to reach equilibrium. This balance is imposed on the model through a series of system constraints. The model includes three macroeconomic balances (closures): government balance, the external balance (current account of the balance of payments) and the savings-investment balance. For the government balance, it is assumed that government savings is a flexible residual. For the external balance, which is expressed in foreign currency, it is assumed that the real exchange rate is flexible while foreign savings (the current account deficit) is fixed. Concerning the savings-investment balance, the total value of private savings is assumed to adjust to the investment. Real investment quantities are assumed to be fixed at an exogenous level. It is also assumed that the private savings is automatically mobilized to fully meet the demand for the investment which is fixed in real terms. Finally, the consumer price index is chosen as the numéraire such that all prices in the model are relative to the weighted unit price of households' initial consumption bundle. The model is also homogenous of degree zero in prices, implying that a doubling of all prices does not alter the real allocation of resources.

The above description of the CGE model cannot capture second-period effects of exogenous shocks and therefore needs to be augmented by updating some selected parameters based on the modeling of inter-temporal behavior and results from previous periods. The process of capital accumulation is modeled endogenously, with previous-period investment generating new capital stock for the subsequent period. Although the allocation of new capital across sectors is influenced by each sector's initial share of aggregate capital income, the final sectoral allocation of capital in the current period is dependent on the capital depreciation rate and on sectoral profit-rate differentials from the previous period. Sectors with above-average capital returns receive a larger share of investible funds than their share in capital income. The converse is true for sectors where capital returns are below-average. It is assumed that a growing population generates a higher level of consumption demand and therefore raises the level of minimum consumption of the level of household. It is assumed that there is no change in marginal rate of consumption for commodities, implying that new consumers have the same preferences as existing consumers. Growth in real government consumption and transfer spending is also exogenously determined between periods, since within-period government spending is fixed in real terms. Furthermore, projected changes in the current account balance are exogenously accounted for.

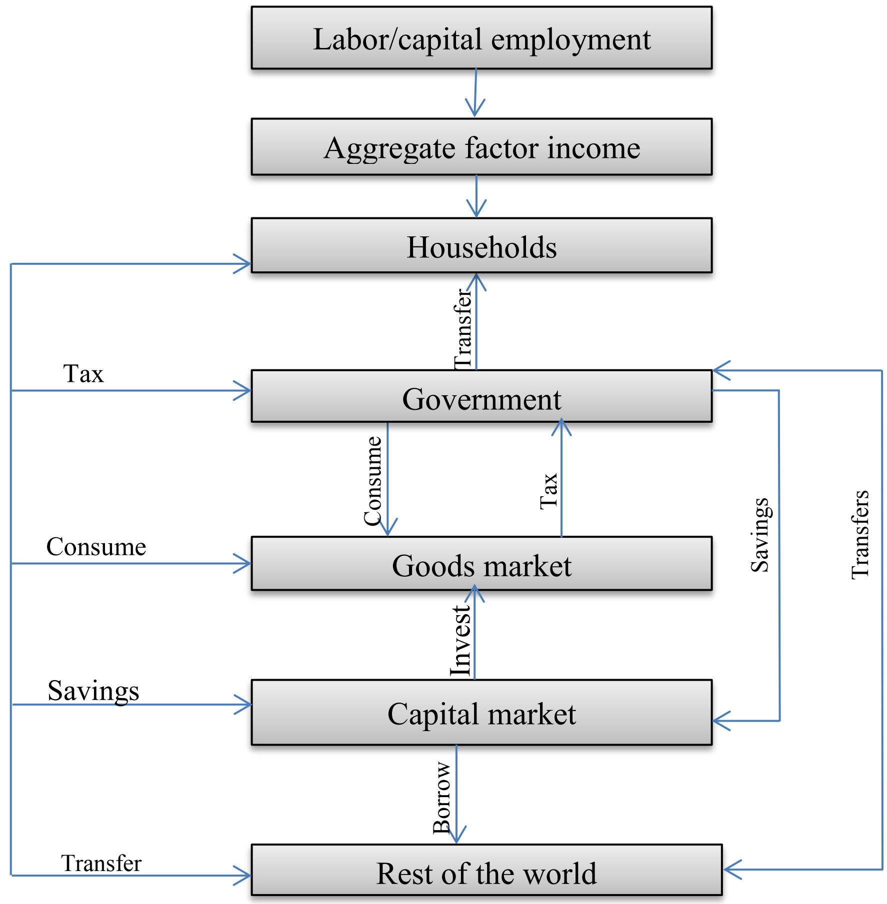

Fig. 6.2 Income and domestic demand
Source Adapted from Thurlow (2003)

6.3 Data sources

6.3.1 Social Accounting Matrix

The main data source is the Social Accounting Matrix (SAM) for CGE models. As a data framework, the SAM is a comprehensive and disaggregated snapshot of the socioeconomic system during a given year. It provides a classification and organizational scheme for the data useful to analysts and policymakers. It incorporates explicitly various crucial relationships among variables such as the mapping of the factor income distribution from the structure of production and the mapping of the household income distribution from the factor income distribution. SAM is a square matrix in which each account has its own row and column. The payments (expenditures) are listed in columns and the receipts are recorded in rows. As the sum of all expenditures by a given account (or subaccount) must equal the total sum of receipts or income for the corresponding account, row sums must equal the column sums of the corresponding account. For example, the total income of a given institution (say a specific socioeconomic household group) must equal exactly the total expenditures of that same institution. Hence, analysts interested in understanding how the structure of production influences the income distribution can obtain useful insights by studying the SAM.

Table 6.1 presents a basic SAM. It can readily be seen that it incorporates all major transactions within a socioeconomic system. Whereas the SAM in Table 6.1 is a snapshot of the economy, Fig. 6.1 which reproduces all of the transformations appearing in Table 6.1, can be interpreted more broadly as representing flows (over time) which, in turn, have to be explained by structural or behavioral relationships. The CGE model is calibrated to fit the updated 2010 Ghana SAM.

Table 6.1 Updated 2010 Social Accounting Matrix for Ghana

	Act	Com	Fact	Hold	Govt	Savi	Tax	Rest	Total
Act		90269							90269
Com	44037	2958		44209	8038	14655		18440	132337
Fact	46232								46232
Hold			44096		2473			1043	47612
Govt							11744	2969	14713
Savi				1750	3521			9384	14655
Tax		7955	2136	1653					11744
Rest		31155			681				31836
Total	90269	132337	46232	47612	14713	14655	11744	31836	

Notes: Acts=production activities; coms=commodities; fact=factors; hold=household; Savi=savings/investment; tax=taxes; rest=rest of the world; all amounts in ten thousand Ghana Cedis (GHS); 1 United States dollar=1.60 GHS as of December, 2010; all values are in GHS'000,000
Source: updated from Breisinger et al.n (2007)

6.3.2 Behavioral parameters of the CGE model

Identifying behavioral parameters (elasticities) for CGE model is always a difficult task to modelers, especially in the cases of developing countries. The preferred method to identify the elasticities is to estimate them directly from an appropriate dataset by using econometric models. Unfortunately, it is usually difficult to obtain time series data that are long enough for running regressions to estimate these parameters. In some cases, it is costly and, in some others, it is simply impossible to obtain the necessary data. Therefore, the most commonly suggested methods are searching previous econometric works on similar cases (literature searches) and/or trying to guess the best values.

Table 6.2 Elasticity parameters used in this model

Parameters		**Value**
Armington elasticity of substitution between imported and domestically produced gods		3
Elasticity of transformation between exported and domestically produced goods		3
Income elasticity of demand for maize	Rural	0.48
	Urban	0.53
Income elasticity of demand for rice	Rural	0.70
	Urban	0.83
Income elasticity of demand for sorghum	Rural	0.84
	Urban	0.73
Income elasticity of demand for cassava	Rural	0.69
	Urban	0.66
Income elasticity of demand for yam	Rural	0.87
	Urban	0.69
Income elasticity of demand for oils and nuts	Rural	0.79
	Urban	0.88
Income elasticity of demand for fruits and vegetables	Rural	0.75
	Urban	0.93
Income elasticity of demand for other crops	Rural	0.57
	Urban	0.73
Income elasticity of demand for livestock	Rural	0.87
	Urban	1.10
Income elasticity of demand for fish	Rural	0.55
	Urban	0.74
Income elasticity of demand for dairy products	Rural	0.63
	Urban	0.86
Income elasticity of demand for non-agricultural goods	Rural	0.85
	Urban	0.89

In this study, an attempt is made to minimize the use of external parameters from literature. Our choice of elasticities for the CGE model is reported in Table 6.2. The Armington and CET elasticity parameters are borrowed from other literature on CGE modeling. The income elasticity parameters are estimated econometrically from the fifth round of Ghana living standard survey data.

6.4 Climate change transmission mechanism and scenarios

This chapter intends to incorporate the impact of climate variables into the CGE model to analyze economy-wide impact of climate change in Ghana. It relies on results from Structural Ricardian cross-sectional analysis of Chapter 5 to examine economy-wide effects of changing climate. In this sense, net revenue per hectare is used as proxy for agricultural productivity. This approach has an added advantage of analyzing climate change induced agricultural productivity with and without adaptation scenarios. The output of the ricardian analysis in Table 5.5 of Chapter 5 is introduced as productivity shock to the economy by applying to the relevant sector. Granted that A_0 is an initial crop productivity shock parameter in the CGE model, climate change impact is introduced to the food crop sub-sector at time t as in equations (6.6) and (6.7).

$$A_t = A_0(1+\%\Delta R_t) \quad (6.6)$$

$$\Delta A_t = A_0\%\Delta R_t) \quad (6.7)$$

Where, A_t, ΔA_t and ΔR_t are agricultural productivity at time t, changes in agricultural productivity from the baseline and $\%\Delta R_t$ is the percentage change in agricultural productivity calculated from the structural ricardian model (climate change induced) in Chapter 5. In the baseline estimation, climate change impact parameter is set to zero (both ΔA_t and $\%\Delta R_t$ are equal to zero).

Table 6.3 Future changes in food crop productivity from base year in Ghana

	2010	2015		2020		2025	
	Base year	Without adaptation	With Adaptation	Without adaptation	With Adaptation	Without adaptation	With Adaptation
Cassava	1.89	-0.10	-0.20	-0.30	-0.07	-0.13	-0.20
Maize	1.86	-0.49	-0.97	-1.46	-0.41	-0.82	-1.22
Sorghum	1.86	+0.10	+0.21	+0.31	+0.24	+0.54	+0.91
Rice	1.86	+0.11	+0.21	+0.32	+0.10	+0.20	+0.30
Yam	1.98	+0.09	+0.17	+0.26	+0.11	+0.22	+0.33

Before introducing the productivity shock as in Table 6.3, the static CGE model in 2010 will be updated to have a baseline projection of the model. Household minimum consumption in the LES function, government expenditure and transfers between institutions will be exogenously updated every year using the population growth rate of 3% in the baseline projection. Additionally, capital stock is endogenously updated every year at a capital accumulation rate of 10%. In order to assess impact of climate change on food crop output and how it is propagated throughout the economy, the agricultural productivity parameters as in Table 6.3 are introduced into the CGE model for all the projection years. The productivity parameter of maize and cassava are projected to decline while those of rice, sorghum and yam are predicted to decline in future periods (Table 6. 3).

6.5 CGE Model results

Climate change has direct effect on food crop production Ghana through its effect on crop productivity. Table 6.5 shows that climate change will reduce maize output by 5.40%, 16.40% and 33.70% for 2015, 2020 and 2025, respectively, relative to baseline output projections if farmers do not adapt through crop switching. With adaptation, maize output reduces by 3.50%, 10.80% and 22.10% for 2015, 2020 and 2025, respectively. Cassava output decreases by 1.40% in 2015, 3.60% in 2020 and 6.50% in 2025 if farmers do not adapt. If they do, cassava output will remain unchanged in 2015, but will decrease by 0.60% in 2020 and 1.40% in 2025. The effect of climate change on outputs of rice, sorghum and yam are positive with and without adaptation. The increase in rice output will be slight lower if farmers adapt by crop switching. In the cases of sorghum and yam, Climate change adaptation increase output appreciably. Without adaptation, sorghum output will 0.80%, 2.30% and 4.40% in 2015, 2020 and 2025, respectively. Sorghum output will, however, increase by 7.20%, 18.10% and 31.50% in 2015, 2020 and 2025, respectively. Yam output will go up by 2.10%, 5.10% and 9.00% in 2015, 2020 and 2025, respectively, without adaptation. Output of yam will increase by 5.3% in 2015, 12.50% in 2020 and 21.20% in 2025. That is, adaptation maximizes an already positive sorghum and yam outputs while in the case of rice, it results in lower output.

Apart from the above direct effects, the climate-induced productivity shock has indirect effects on the other sectors of the economy. Livestock sector tends to have strongest linkages with food crop production. The food crop productivity shock will reduce livestock output with and without adaptation. Livestock output will reduce by 2.50%, 6.00% and 9.70% in 2015, 2020 and 2025, respectively, if there is no adaptation. These losses in output will be somewhat reduced if farmers adapt to climate change by switching crops. In that case, livestock output will reduce by 1.50%, 3.70% and 6.00% in 2015, 2020 and 2025, respectively. In general, the productivity shock will have minimal impact on output of other sectors. Without adaptation, the climate-induced productivity shock will reduce outputs of other sectors by less than 1%. But, with adaptation, the impact on outputs of the other sectors, though still minimal, will become positive.

Table 6.4 Climate change impact on total sectoral output

	2015		2020		2025	
Sector	Without adaptation	With Adaptation	Without adaptation	With Adaptation	Without adaptation	With Adaptation
Maize	-5.40%	-3.50%	-16.40%	-10.80%	-33.70%	-22.10%
Rice	1.80%	1.70%	3.80%	3.60%	6.10%	5.70%
Sorghum	0.80%	7.20%	2.30%	18.10%	4.40%	31.50%
Cassava	-1.40%	0.00%	-3.60%	-0.60%	-6.50%	-1.40%
Yam	2.10%	5.30%	5.10%	12.50%	9.00%	21.20%
Oil & nuts	-0.20%	0.20%	-0.40%	0.40%	-0.50%	0.50%
Fruits & vegetables	-0.10%	0.40%	-0.30%	0.50%	-0.40%	0.50%
Other crops	-0.10%	0.30%	-0.30%	0.40%	-0.40%	0.40%
Cocoa	-0.30%	-0.40%	-0.20%	0.30%	0.10%	0.70%
other exports	-0.20%	-0.30%	-0.20%	-0.20%	-0.20%	0.00%
Livestock	-2.50%	-1.50%	-6.00%	-3.70%	-9.70%	-6.00%
Forestry	-0.30%	-0.40%	-0.30%	0.10%	-0.10%	0.60%
Fishing	-0.20%	0.20%	-0.30%	0.40%	-0.40%	0.40%
Dairy products	-0.20%	0.10%	-0.50%	0.10%	-0.60%	0.10%
Non-agricultural	-0.10%	0.40%	-0.10%	0.60%	0.00%	0.90%

Extending the analysis, the climate-induced productivity shock has notable effects on exports as shown in Table 6.6. Without adaptation, the shock will reduce exports of cassava by 17.60%, 33.20% and 46.90% in 2015, 2020 and 2025, respectively. With adaptation, these losses will be minimized as exports will be reduced by 6.60%, 12.50% and 18.00% in 2015, 2020 and 2025, respectively. In the case of yam, exports will increase by 26.80%, 58.30% and 95.10% in 2015, 2020 and 2025, respectively, without adaptation. Exports of yam will increase appreciably by 62.70%, 149% and 265% in 2015, 2020 and 2025, respectively, with adaptation. As in the case of total output, the food crop productivity shock has indirect effects on the exports of other sectors. In general, the shock will dampen exports of other productive sectors, but the effects are minimal. This implies that the major food crops have weak linkages with non-food crop exporting sectors of the economy.

Table 6.5 Climate change impact on sectoral exports

	2015		2020		2025	
Sector	Without adaptation	With Adaptation	Without adaptation	With Adaptation	Without adaptation	With Adaptation
Cassava	-17.60%	-6.60%	-33.20%	-12.50%	-46.90%	-18.00%
Yam	26.80%	62.70%	58.30%	149.00%	95.10%	265.00%
Oil & nuts	-0.30%	-0.80%	-0.50%	-1.10%	-0.50%	-1.20%
Fruits & vegetables	-0.30%	-0.80%	-0.50%	-1.10%	-0.60%	-1.10%
Cocoa	0.10%	-0.40%	0.10%	-0.60%	0.10%	-0.60%
other exports	-0.20%	-0.60%	-0.30%	-0.80%	-0.40%	-0.90%
Forestry	-0.40%	-0.90%	-0.60%	-1.00%	-0.60%	-0.90%
Fishing	-0.40%	-0.60%	-0.60%	-0.70%	-0.80%	-0.70%
Non-agricultural	-0.40%	-0.60%	-0.70%	-0.70%	-0.90%	-0.70%

Table 6.6 Climate change impact on sectoral imports

	2015		2020		2025	
Sector	Without adaptation	With Adaptation	Without adaptation	With Adaptation	Without adaptation	With Adaptation
Maize	47.80%	33.50%	118.10%	74.70%	207.50%	120.30%
Rice	-0.70%	0.20%	-1.20%	0.10%	-1.60%	0.00%
Other crops	0.00%	1.40%	-0.10%	1.90%	-0.30%	1.90%
Livestock	2.90%	3.10%	3.70%	3.80%	3.80%	3.90%
Dairy products	0.50%	1.40%	0.50%	1.80%	0.30%	1.70%
Non-agricultural	0.30%	1.60%	0.50%	2.10%	0.90%	2.50%

The climate-induced shock is projected to have strong impact on imports. Imports of maize relative to base line projections will increase by 47.80%, 118.10% and 207.50% for 2015, 2020 and 2025, respectively, if farmers do not adapt to climate change (Table 6.6). With benefits of adaptation, maize imports is expected to increase by 33.50%, 74.70% and 120.30% in 2015, 2020 and 2025, respectively. Rice imports will decrease by 0.70% in 2015, 1.20% in 2020 and 1.60% in 2025. Instead of reducing imports further, climate change adaptation rather increase rice imports minimally in 2015 and 2020, but imports will not deviate from trend projections in 2025. Generally, imports of other sectors will increase, indicating stronger linkages of the food crop sub-sector with the rest of the economy (Table 6.7). Without adaptation, food sector productivity shock will have minimal effects on other crops, dairy and non-agricultural sectors. With adaptation, however, imports of other crops are predicted to increase by 1.40%, 1.90% and 1.90% in 2015, 2020 and 2025, respectively. Imports of livestock are projected to increase by 3.10%, 3.80% and 3.90% in 2015, 2020 and 2025, respectively. Imports of dairy products will also increase by 1.40%, 1.80% and 1.70% in 2015, 2020 and 2025, respectively. Imports from the non-agricultural sector will increase by 1.60%, 2.10% and 2.50% in 2015, 2020 and 2025, respectively.

Table 6.7 Climate change impact on welfare

	2015		**2020**		**2015**	
	Without adaptation	With Adaptation	Without adaptation	With Adaptation	Without adaptation	With Adaptation
GDP	0.10%	0.30%	0.20%	0.30%	0.20%	0.30%
EV (rural)	-1.00%	3.90%	-1.30%	3.80%	-1.50%	3.80%
EV (urban)	0.20%	2.00%	0.10%	2.00%	0.10%	2.10%

The crop productivity shock has welfare implications (Table 6.8). With and without adaptation, the productivity shock will raise Gross Domestic Product (GDP) minimally. It is expected to go up by less than 0.50% in the projection periods. In terms of Equivalent Variation (EV), overall welfare of Ghanaian households will experience differential effects (Table 6.8). Without adaptation, welfare of rural folks will decline by 1.00%, 1.30% and 1.50% for 2015, 2020 and 2025, respectively. With adaptation, however, their welfare is projected to improve by 3.90%, 3.80% and 3.80% in 2015, 2020 and 2025, respectively. Without adaptation, welfare of urban dwellers will experience minimal improvement. With adaptation, the impact on the welfare of urban dwellers follows the trend of rural folks. The EV will increase by 2.00%, 2.00% and 2.10% for 2015, 2020 and 2025, respectively. It can be said that rural households benefits more with welfare-enhancing adaptation vis-à-vis urban dwellers.

6.6 Summary and conclusion

This study analyzes the economy-wide impact of climate change on food crop production in Ghana. Using an updated 2010 SAM together with external parameter estimates, a recursive dynamic CGE model was calibrated for simulation of future impact of climate change on food crop production.

Having calibrated the baseline case, a climate-induced productivity shock was introduced into the model in order to project the climate change impact on the Ghanaian economy with and without adaptation. The results of the study indicates that climate change directly decreases total output of maize and cassava but losses in output are much mitigated if farmers adapt to the changing climate by switching crops. The effect of climate change on rice output is negative and any attempt to adapt cannot reverse the declining trend of their output. Without adaptation, outputs of sorghum and yam are projected to increase and adaptation is expected to maximize outputs of these crops. Apart from the above direct effects, the climate-induced productivity shock also has indirect effects on the other sectors of the economy. The food crop productivity shock will reduce livestock output with and without adaptation. These losses in output will be somewhat reduced if farmers adapt to climate change by switching crops. In general, the productivity shock will have minimal impact on output of other sectors.

Extending the analysis, the climate-induced productivity shock has notable effects on international trade. The shock will reduce cassava exports but these losses in exports will be minimized if they adapt to climate change by switching crops. The climate shock will increase yam exports which will be maximized through adaptation. In general, the shock will dampen exports of other productive sectors, but the effects are minimal. This implies that the major food crops have weak linkages with non-food crop exporting sectors of the economy. The climate-induced shock will increase maize imports if farmers do not adapt to climate change, but with benefits of adaptation, maize imports will reduce as more and more imports are substituted by local production. Climate-induced shock will reduce rice imports, and any attempt to adapt will raise rice imports. The stronger linkages of the food crop sub-sector with the rest of the economy are evident in the trends in their export volumes.

The productivity shock will result in differential welfare implications. It has minimal impact on GDP. The shock will reduce welfare of rural people but they will witness welfare enhancement if they adapt to climate change. The welfare of urban dwellers will also experience improved welfare from the shock.

7 The distributional impact of changing climate on food crop farmers in Ghana

7.1 Introduction

Climate change represents a serious challenge to poverty reduction efforts around the globe (Skoufias et al. 2011). There are increasing concerns that the change in the patterns of climatic variability will add to the already high vulnerability of poor households and exacerbating incidence, severity and persistence of poverty in developing countries. These concerns are borne out of the fact that many developing countries are highly dependent on agriculture and other climate-sensitive natural resources for their livelihood, and that they also lack sufficient financial and technical capacities to manage or cope with increasing climate risk. Climate change is likely to have a negative effect on agricultural productivity, particularly in the tropical regions, and to directly impact on poor people's livelihood assets including their health, access to water and natural resources, homes and infrastructure (World Bank 2010a).

Majority of previous studies on poverty impacts of climate change tend to ignore the effect of aggregate economic growth on poverty and household welfare. The few studies on poverty impact of climate change report that it will slow the pace of global poverty reduction, although the expected poverty impact will be relatively modest and far from reversing the declining trend of poverty emanating from years of continued economic growth (Skoufias et al. 2011). It is further argued that the estimated impacts of climate change on agricultural yields are generally a poor predictor of the poverty impacts of climate change at the national level due to heterogeneity in the ability of households to adapt. There is a variety of mediating factors that can mitigate the impacts on the level of household welfare, as well as the distribution of these impacts across different households. The list of such factors includes: the extent of autonomous adaptation by households, such as the ability to migrate or switch employment between agricultural and nonagricultural occupations, the extent of policy induced adaptation through prices and explicit government programs, such as providing access to credit and insurance. Also, the distribution of productive endowments (irrigated and non-irrigated land, skilled and unskilled labor), and the dual role of rural households as consumers and producers of food -and whether they are net consumers or producers- will determine how the impacts are distributed among the population. Economic growth, often absent in the discussion of future impacts of a warming world, will have a tremendous ameliorating effect through the decrease of the food expenditure share in total expenditure, and the reduction of the relative weight of agriculture in national GDP (Nordhaus, 1993). Even though aggregate impacts of climate change on poverty may seem modest, it is does not imply that the impacts will be equally distributed among the population. It is noted that the impacts of climate change are generally regressive, with disproportionate negative effect on the poor rather than the rich. To analyze how climate change will affect specific sectors of the population, one needs to use household-level data and explicitly model the channels through which future warming will affect economic activity.

There are several channels through which climate change affect household welfare including its negative effects on agricultural productivity, health, access to water and natural resources, and infrastructure. Few studies attempt to shed light on these links between climate change and poverty. Considering the complexities involved in modeling some of these channels, this chapter focuses on agricultural productivity channel alone. That is, this chapter analyzes the climate change impacts on poverty through its effects on agricultural productivity. Analysis of this nature will provide useful information in tackling poverty today, as well as in preparing for how to adapt to climate change in the future.

7.2 Methodology

7.2.1 Modelling procedure

Climate change is pervasive which requires a combination of macro- and micro analysis to adequately capture both its direct and indirect effects. Macroeconomic analysis assesses the impact of macro shocks and policies on variables such as wage rates, employment, and food and non-food prices. Given the magnitude of the shocks engendered by climate change, a computable general equilibrium (CGE) framework is required to incorporate the structural aspects of the economy and capture the numerous and complex direct and indirect interactions between factor markets, good markets, households, government and the foreign partners. However, CGE models cannot distinguish the impacts on individual households and their members, as is required to evaluate the impacts of shocks on the poverty.

The microeconomic approach models individual and household behavior using data from household surveys. The effects of the climate change on households and individuals can be captured in terms of changes in commodity prices and expenditure. The extent to which such effects impact on household and individual welfare depends primarily on their income sources and consumption patterns. To make an appropriate microeconomic analysis, we need to take account of the ability of households and individuals to substitute among consumer goods, according to their relative prices, and to adjust their sources of income. The CGE framework is then linked to a microeconomic model in a “top-down” fashion to assess the various impacts of the climate change on households.

To adequately capture the direct and the indirect effects of climate change on poverty, a CGE Micro-simulation model is used. This approach has an added advantage of incorporating both productivity shock and household level poverty into the CGE model analysis all at the same time in a more effective manner.

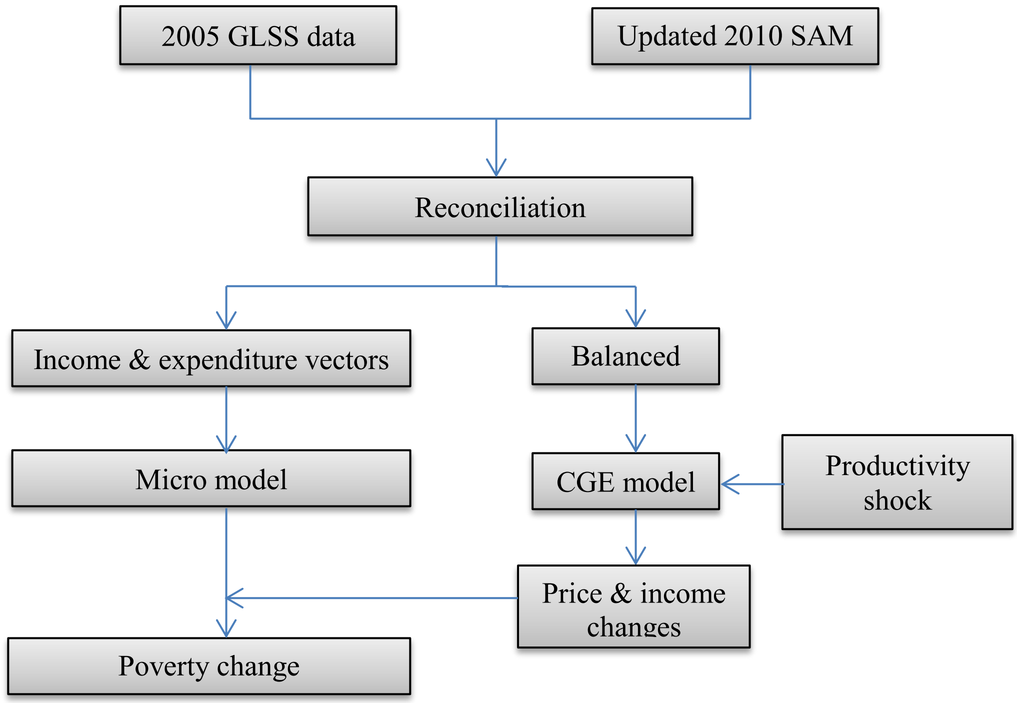

Fig. 7.1 Data reconciliation between macro SAM and GLSS V
Source Adapted from Thurlow (2003)

Four types of data sets are used to estimate the impact of climate on poverty: 2005 SAM, GLSS V data, behavioral parameters and the productivity shock parameters. The values for the behavioral parameters and the productivity shock remain the same as in the macro level analysis in Chapter 6. The main source of data for the CGE model is the 2005 micro SAM for Ghana. The original data is updated to base year of 2010. The SAM is aggregated into 15 productive sectors, 15 commodities, two primary factors and one household category while other accounts remain the same. The second data set used is the 2005/6 GLSS V data. The survey data contains income and expenditure information of 8,687 households selected from all regions of the country at the district, zone, region and national level. The poverty analysis is carried out on 4,067 farming households. In this dataset, household expenditures included all payments made for both agricultural and non-agricultural commodities. They comprised consumption of own and purchased goods from agriculture, industry and service sectors.

7.2.2 Analyzing the extent of poverty among farming households

In order to assess the distributional and welfare impacts of climate shocks, changes in commodity prices and household expenditure are transmitted from the CGE model into the micro model. Existing Macro-Micro models differ primarily in the type of effects examined and the mechanism of linking these two components. As mentioned by Essama-Nssah et al. (2007), one can identify three types of effects in tracking distributional impact of macroeconomic shocks and policies: price effects, reallocation effects, and the endowment effects.

The micro analysis distinguishes 12 consumption categories. Commodity prices changes are estimated at the sectoral level in the CGE model, which correspond to the categories of commodities identified in the micro analysis. These groups thus dictate the minimal sectoral decomposition in the CGE model. It is, of course, possible for the CGE model to be disaggregated further, in which case price variations from several sectors would be aggregated before being passed on to the micro analysis. Extreme care is taken to ensure that the definition and contents of the commodity groups (sectors) in the CGE analysis correspond exactly to their counterparts in the micro analysis.

Another variable transmitted from the CGE model is household consumption. Consumption values in the household survey must be converted to an annual basis where required. Total consumption is obtained by aggregating purchases, self-consumption and gift values over all household consumption categories to calculate total household consumption. Individual consumptions per adult equivalent are calculated by dividing total household consumption by the total number of adult equivalents in the household (assuming a unitary model). For this purpose, we use the “caloric requirements” approach to determine equivalence scales.

In order to evaluate the impacts of the climate change on poverty, it is essential to adjust in household consumption in the micro model in the face of changes in prices and income at the macro level. For this purpose, there are at least three different approaches (demand system, cobb-Douglas and CPI approaches). The demand system is not appropriate for this study since community level price questionnaire, required for the estimation of commodity prices, is not available. The CPI approach does not provide information on prices of commodities with variation in prices across households. The Cobb-Douglas approach uses unit values to calculate the prices of commodities which maintain household level variation in commodity prices. This makes this approach more appropriate for this study. Consumption per adult equivalent ($X_{t,h}$) is normalized using household specific price deflator ($\Gamma_{t,h}$) as in equations (7.1) and (7.2).

$$e_{t,h} = \frac{X_{t,h}}{\Gamma_{t,h}} \tag{7.1}$$

$$\Gamma_{t,h} = \prod_k \left(\frac{P_{t,k}}{P_{0,k}}\right)^{w_{h,k}} \tag{7.2}$$

$e_{t,h}$ is real consumption per adult equivalent at time t; $\Gamma_{t,h}$ is household-specific consumer price deflator; $P_{t,k}$ is price of good k at time t; $P_{0,k}$ is the price of good k at time 0; $w_{h,k}$ is the budget share at time t of household h for good k; and Π_k is the multiplication sign.

Poverty analysis is conducted with the assumption that consumption is shared equitably according to caloric needs among members of each household. As a consequence, individuals are considered to suffer from poverty if they belong to a poor household (household for which per-adult equivalent consumption expenditure is less than the poverty line). The standard FGT (1984) measures of poverty (poverty incidence, poverty depth and poverty severity) are calculated for all individuals in the base year and each of the simulation years for each scenario (Equation 7.3).

$$P_0=\frac{1}{N}\sum_{i=1}^{n}\left(\frac{g_i}{z}\right)^0=\frac{n}{N} \tag{7.3}$$

$$P_1=\frac{1}{N}\sum_{i=1}^{n}\left(\frac{g_i}{z}\right)^1 \tag{7.4}$$

$$P_2=\frac{1}{N}\sum_{i=1}^{n}\left(\frac{g_i}{z}\right)^2 \tag{7.5}$$

In the case of Equation 7.3, an individual household is assigned a value of 1 if g_i is greater than zero and 0 otherwise. Values of g_i/z and $(g_i/z)^2$ in Equations 7.4 and 7.5, respectively are assigned to individual households if g_i is greater than zero and 0 otherwise.

7.3 Climate change impact on poverty among farming households

This section presents the results of a CGE Micro-simulation model which analyzes the poverty impact of climate change through its impact on agricultural productivity among farming households over the period 2010-2025. This approach keeps separate the impact of climate change on poverty with and without adaptation through crop switching.

The results of this model show that climate change has differential impact on farming households in Ghana. At the national level, poverty levels are projected to reduce from 2010 to 2025 (Table 7.1). In 2010, the incidence, depth and severity of poverty among farming households are 45.72%, 17.92% and 9.67%, respectively. Baseline projections of all poverty are expected to decline over the period 2015-2025. Poverty incidence is projected to decline to 32.23%, 31.15% and 29.10% for 2015, 2020 and 2025, respectively. Poverty depth, depicting the cost of eliminating poverty, will also decline to 12.84%, 11.34% and 10.25% for 2015, 2020 and 2025, respectively. Like poverty incidence and depth, poverty severity will decline to 6.61%, 5.75% and 5.16% for 2015, 2020 and 2025%, respectively. With climate change, living conditions of farming households will worsen, the full effects of which will be somewhat ameliorated through farm-level adaptation (crop switching). In all projection years, poverty levels (incidence, depth and severity of poverty) are lower if farmers adapt to climate change by switching crops than when they do not.

Table 7.1 Climate change impact on welfare of farmers

		Poverty incidence	Poverty depth	Poverty severity
2010		45.72	17.92	9.67
2015	Baseline projection	32.23	12.84	6.61
	Without adaptation	34.47	13.03	6.72
	With adaptation	34.00	13.00	6.43
2020	Baseline projection	31.15	11.34	5.75
	Without adaptation	31.98	11.75	5.99
	With adaptation	30.87	11.06	5.55
2025	Baseline projection	29.10	10.25	5.16
	Without adaptation	30.66	10.92	5.55
	With adaptation	29.01	9.96	4.97

Notes All figures are expressed in percentages

The impact of climate change is not the same across farming households (Table 7.2). There are variations in poverty levels over the projection period by education, marital status and gender of household head and location. Poverty levels tend to be higher for households or individuals with high educational attainments than those with lower educational background. In 2010, levels of poverty incidence are 54.31%, 29.90%, 20.75% and 15.91% for those households headed by people with no formal, primary, secondary and tertiary education, respectively, whereas depth and severity of poverty follow the trend of poverty incidence. Baseline projections of all poverty measures depict a declining trend from 2010 to 2025 irrespective of educational attainment. For households headed by persons with no formal education, poverty incidence will decrease to 43.27%, 39.90% and 37.55% for 2015, 2020 and 2025, respectively. Poverty incidence is projected to decline to 16.54%, 13.66% and 12.22% among households headed by those with primary education for 2015, 2020 and 2025, respectively. Poverty incidence is projected to decline to 11.57%, 10.62% and 8.56% among households headed by those with secondary education for 2015, 2020 and 2025, respectively. For households headed by individuals with tertiary education, poverty incidence is projected to decline to 8.25% for the projection years (2015, 2020 and 2025). The trend of poverty depth and severity follows that of poverty incidence for all households with heads of various educational qualifications other than those with tertiary education. Although poverty incidence of household heads with tertiary education will remain same over the projection years, depth and severity of poverty, however, will decline from earlier to latter years. The declining trend of depth and severity of poverty is indicative of continually reducing cost of eliminating poverty among farm families over the period 2010-2025.

Climate change will make it harder to achieve reduced poverty levels. Climate change will deteriorate the extent of poverty as indicated by higher values of all poverty measures vis-à-vis the baseline for all projection years (Table 7.2). If farmers adopt crop-switching as an adaptive measure, some negative effects of climate change on the extent of poverty will be ameliorated among households headed by individuals with no formal, primary or secondary education. For households headed by persons with tertiary education, crop-switching adaptation will not affect poverty incidence, but it will counter the negative effects of climate change on levels of poverty depth and severity.

By location, climate change will have varying impacts on poverty levels among farmers (Table 7.3). In 2010, poverty incidence is 33.85%, 20.61% and 67.75% for farming households residing in forest, coastal and savanna agro-ecological zones, respectively. In the forest zone, poverty incidence is projected to decline to 20.87%, 17.97% and 16.40% for 2015, 2020 and 2025, respectively. Farmers residing in the coastal zone will witness reduction in poverty incidence to 11.65%, 8.53% and 6.96% for 2015, 2020 and 2025, respectively, while farmers in the savanna zone will experience reduction in poverty incidence to 56.89%, 53.64% and 50.91% for 2015, 2020 and 2025, respectively.

Table 7.2 Poverty impact of climate change among farmers by levels of education

		Poverty incidence	Poverty depth	Poverty severity
No formal education				
2010		54.31	23.09	12.93
2015	Baseline projection	43.27	17.12	9.03
	Without adaptation	43.55	17.35	9.18
	With adaptation	42.91	16.78	8.78
2020	Baseline projection	39.90	15.27	7.92
	Without adaptation	40.79	15.80	8.25
	With adaptation	39.42	14.89	7.65
2025	Baseline projection	37.55	13.92	7.14
	Without adaptation	39.32	14.80	7.69
	With adaptation	37.26	13.52	6.88
Primary education				
2010		29.90	7.41	2.87
2015	Baseline projection	16.54	3.98	1.49
	Without adaptation	16.54	4.08	1.52
	With adaptation	16.44	3.93	1.46
2020	Baseline projection	13.66	3.12	1.17
	Without adaptation	14.36	3.29	1.22
	With adaptation	13.73	3.07	1.13
2025	Baseline projection	12.22	2.55	0.97
	Without adaptation	13.18	2.79	1.04
	With adaptation	12.50	2.50	0.93
Secondary education				
2010		20.75	6.50	3.22
2015	Baseline projection	11.57	4.10	2.06
	Without adaptation	11.98	4.16	2.10
	With adaptation	11.57	4.03	2.02
2020	Baseline projection	10.62	3.55	1.77
	Without adaptation	10.66	3.65	1.85
	With adaptation	10.25	3.48	1.74
2025	Baseline projection	8.56	3.19	1.57
	Without adaptation	10.25	3.32	1.70
	With adaptation	8.56	3.10	1.56
Tertiary education				
2010		15.91	5.19	2.16
2015	Baseline projection	8.25	2.85	1.13
	Without adaptation	10.15	2.97	1.15
	With adaptation	10.15	2.90	11.11
2020	Baseline projection	8.25	2.41	0.86
	Without adaptation	10.15	2.55	0.90
	With adaptation	10.15	2.41	0.85
2025	Baseline projection	8.25	2.02	0.68
	Without adaptation	10.15	2.25	0.73
	With adaptation	10.15	2.03	0.67

Notes all figures are in percentages

Levels of poverty depth and severity for all zonal categories tend to follow the trend of poverty incidence. Climate change tends to worsen all measures of poverty vis-à-vis the baseline projections for all locations. Without climate change adaptation, poverty incidence will be 20.90%, 18.70% and 16.40% for 2015, 2020 and 2025, respectively, which are higher than the baseline projections. Similar trends of poverty incidence are observed in the coastal and savanna zones whereby climate change will trigger higher poverty incidence than the baseline projections. The negative effects of climate change on poverty levels in all agro-ecological zones will be mitigated if farmers adapt to changing climate. Both poverty depth and severity are higher relative to the baseline without adaptation, and lower with adaptation in all locations and for all projection years. Although adaptation may be beneficial to farmers, the stubbornly high poverty levels in the savanna zone may call for extra effort or policy measures to deal with this menace.

Climate impact on poverty levels also varies by marital status of farmers (Table 7.4). In 2010, poverty incidence was 47.19%, 38.07% and 33.10% for married, separated and unmarried farmers, respectively. It is projected that poverty incidence among married farmers will be 36.28%, 33.10% and 31.15% for 2015, 2020 and 2025, respectively. Among separated farmers, poverty incidence is projected to be 22.29%, 19.05% and 17.42% for 2015, 2020 and 202, respectively, while the unmarried farmers will be 28.48%, 21.45% and 20.96% headcount poor, respectively. Poverty depth and severity among farmers will also follow the trend of poverty incidence. With respect to marital status, climate change is predicted to worsen poverty levels in all projection years. Without climate adaptation, poverty levels among married farmers will be slightly higher than those attained under baseline projections, as evidenced by higher levels of poverty incidence, depth and severity (Table 7.4). With climate change adaptation, poverty levels will be lower relative to the baseline projections for all spousal categories, as evidenced by lower levels of poverty incidence, depth and severity. This implies the proportion of the population who are poor and the cost involved in eliminating poverty for all spousal categories will decline in all projection years relative to the baseline projection (Table 7.4).

Table 7.3 Poverty impact of climate change among farmers by location

		Poverty incidence	Poverty depth	Poverty severity
Forest zone				
2010		33.85	9.48	3.90
2015	Baseline projection	20.87	5.54	2.13
	Without adaptation	20.90	5.67	2.19
	With adaptation	20.75	5.52	2.12
2020	Baseline projection	17.97	4.47	1.67
	Without adaptation	18.70	4.72	1.77
	With adaptation	17.97	4.45	1.68
2025	Baseline projection	16.40	3.73	1.38
	Without adaptation	17.15	4.10	1.52
	With adaptation	16.63	3.81	1.41
Coastal zone				
2010		20.61	4.45	1.51
2015	Baseline projection	11.65	2.23	0.72
	Without adaptation	11.80	2.38	0.76
	With adaptation	11.80	2.28	0.73
2020	Baseline projection	8.53	1.65	0.52
	Without adaptation	9.97	1.88	0.59
	With adaptation	8.73	1.76	0.56
2025	Baseline projection	6.96	1.30	0.42
	Without adaptation	8.90	1.61	0.50
	With adaptation	8.21	1.45	0.46
Savanna zone				
2010		67.75	31.93	18.84
2015	Baseline projection	56.89	24.54	13.54
	Without adaptation	57.38	24.82	13.74
	With adaptation	56.39	23.95	13.11
2020	Baseline projection	53.64	22.24	12.02
	Without adaptation	54.34	22.89	12.48
	With adaptation	52.88	21.50	11.52
2025	Baseline projection	50.91	20.50	10.93
	Without adaptation	53.17	21.63	11.71
	With adaptation	49.96	19.67	10.43

Notes All figures are in percentages

Climate impact on poverty levels of farmers also varies by their gender. In 2010, poverty incidence is projected to be 33.35% and 48.50% for female and male farmers, respectively. Poverty incidence among female farmers will decline to 20.46%, 17.14% and 15.73% for 2015, 2020 and 2025, respectively, while poverty incidence among male farmers will be 37.21%, 34.18% and 31.99% for 2015, 2020 and 2025, respectively.

Table 7.4 Poverty impact of climate change among farmers by marital status

		Poverty incidence	Poverty depth	Poverty severity
Married farmers				
2010		47.19	19.01	10.34
	Baseline projection	36.28	13.77	7.10
	Without adaptation	36.50	13.97	7.21
2015	With adaptation	36.01	13.50	6.90
	Baseline projection	33.30	12.18	6.18
	Without adaptation	34.07	12.62	6.44
2020	With adaptation	32.92	11.87	5.96
	Baseline projection	31.15	11.03	5.54
	Without adaptation	32.83	11.74	5.97
2025	With adaptation	30.78	10.78	5.34
Separated farmers				
2010		38.07	11.73	5.78
	Baseline projection	22.29	7.45	3.78
	Without adaptation	22.68	7.60	3.85
2015	With adaptation	22.52	7.37	3.70
	Baseline projection	19.05	6.42	3.28
	Without adaptation	20.21	6.72	3.43
2020	With adaptation	19.24	6.36	3.20
	Baseline projection	17.42	5.72	2.95
	Without adaptation	18.34	6.17	3.17
2025	With adaptation	17.77	5.69	2.87
Unmarried farmers				
2010		33.10	13.83	7.46
	Baseline projection	28.48	9.95	5.03
	Without adaptation	28.48	10.12	5.09
2015	With adaptation	26.13	9.81	4.90
	Baseline projection	21.45	8.83	4.32
	Without adaptation	22.13	9.10	4.46
2020	With adaptation	22.13	8.66	4.16
	Baseline projection	20.96	8.11	3.82
	Without adaptation	21.63	8.56	4.08
2025	With adaptation	21.63	7.90	3.66

Notes all figures are in percentages

Climate change is projected to slow down the rate of poverty reduction among both male and female farmers. With climate change, poverty incidence among female farmers is projected to be 20.73%, 18.12% and 16.44% for 2015, 2020 and 2025, respectively, while male farmers will experience poverty incidence of 37.44%, 34.97% and 33.74% for 2015, 2020 and 2025, respectively. These levels of poverty incidence among female and male farmers are slightly higher than those of baseline projections. With climate change adaptation, the levels of poverty incidence among both female and male farmers will fall lower than under baseline trends for the projection years. Both depth and severity among both female and male farmers tend to follow the trend of poverty incidence for all projection years, implying that the cost of eliminating poverty will fall in subsequent years. Climate change, however, makes it harder to achieve poverty reduction targets, as evidenced by higher levels of poverty incidence, depth and severity among both female and male farmers vis-à-vis baseline trends for all projection years. If farmers to respond to climate change through crop switching, its negative will somewhat ameliorated, as shown by lower levels of poverty compared to the baseline trends (Table 7.5).

Table 7.5 Poverty impact of climate change among farmers by gender

		Poverty incidence	Poverty depth	Poverty severity
Females				
2010		33.35	9.91	4.53
2015	Baseline projection	20.46	6.06	2.74
	Without adaptation	20.73	6.20	2.81
	With adaptation	20.56	6.01	2.69
2020	Baseline projection	17.14	5.05	2.29
	Without adaptation	18.12	5.32	2.41
	With adaptation	17.29	5.04	2.25
2025	Baseline projection	15.73	4.37	2.00
	Without adaptation	16.44	4.78	2.18
	With adaptation	15.95	4.41	1.96
Males				
2010		48.40	19.66	10.78
2015	Baseline projection	37.21	14.31	7.44
	Without adaptation	37.44	14.51	7.56
	With adaptation	36.90	14.02	7.23
2020	Baseline projection	34.18	12.70	6.50
	Without adaptation	34.97	13.14	6.77
	With adaptation	33.80	12.36	6.27
2025	Baseline projection	31.99	11.52	5.84
	Without adaptation	33.74	12.25	6.28
	With adaptation	31.84	11.17	5.63

Notes all figures are in percentages

7.4 Cost implications of climate change impact on levels of poverty

A lot of effort is required by policymakers to reduce poverty among farming households in Ghana. The total number of farming households used in this study is 4,067, which correspond to national population of 12,959,515 people (52.47% of the national population) as of 2010.

Out of this number, the number of the headcount poor is 5,925,479. Table 7.6 shows the cost involved in eliminating poverty among farming households based on how far individuals farmers' incomes are from the poverty line. Ghana is expected to benefit from economic growth which will reflect in lower levels of poverty and hence, lower poverty expenditure on the farm poor. Baseline projections indicate that poverty expenditure on farm families will decline from GHS 282.09 in 2015 million to GHS 225.18 million in 2025.

Table 7.6 Cost of eliminating poverty among farming households

	Baseline projection	Without adaptation	With adaptation	Benefits of adaptation
2015	282.09	286.31	276.73	9.58
2020	249.06	258.12	243.00	15.12
2025	225.18	239.92	218.92	21.00

Notes All figures are Million Ghana cedi (GHS); 1 US$=1.43 GHS as of December 2010

7.5 Findings

This chapter analyzes the impact of climate change on poverty among farming households through its impact on agricultural productivity. Dynamic CGE Micro-simulation model to trace the distributional impact of the climate change shock.

The study finds that climate change induced productivity shock will worsen poverty levels among farming households in Ghana. By educational attainment, climate change will worsen poverty levels, but, surprisingly, farmers with tertiary education will be worse affected. It may be due to the fact that this category of farmers tends to be engaged in the commercial cultivation of rice and other food crops which make them susceptible to climatic variability. If they adapt, they will also benefit the most from their efforts. By location, climate change will not initially affect poverty levels of farmers residing in coastal and savanna ecological zones, but poverty depth and severity. From 2020, climate change will worsen all measures of poverty, which will be ameliorated by adaptation through crop switching.. Although adaptation may be beneficial to farmers, the stubbornly high poverty levels in the savanna zone may call for additional policy measures to deal with this canker. By civil status, climate change will worsen poverty incidence of married farmers, but has not effect on that of farmers who are single. Poverty depth and severity of categories will worsen. With adaptation, however, the poverty risk increasing effect is reversed. By gender, climate change will not affect poverty incidence of female farmers in the initial years but it will do in the latter years. For male farmers, climate change will worsen poverty levels throughout the projection period. Adaptation will reduce poverty risk among both male and female farmers but female farmers will benefit more.

Poverty-related expenditure on farm families is expected to continually reduce in all projection years. Climate change will raise government expenditure but appropriate farm level adaptation will inure to the benefit of government through reduce even lower levels vis-à-vis the baseline case.

8 Determinants of Poverty among Major Food Crop Farmers

8.1 Introduction

Ghana has made significant progress towards poverty reduction. Incidence of poverty has declined from 51.7% in 1991 to 39.5% in 1998 and further to 28.5% in 2005. This has resulted in reduction in the number of poor people in Ghana from 7.9 million in 1991 to 6.2 million in 2005 (GSS, 2007). The remarkable fall in poverty is not experienced evenly across various segments of society. The forest and coastal ecological zones witnessed drop in headcount poverty to less than 20% while headcount poverty in the northern savanna zone still remain high at 52-88%. The northern savanna zone makes for about 45% of the headcount poor, although accounting for only 22% of the population (GSS, 2007). Food crop farmers, disproportionately resident in the savanna ecological zone, accounting for 43% of the population and 69% of the headcount poor, have high poverty incidence of 68% (GSS, 2007).

Most previous studies on poverty in Ghana including GSS (2007) among others deal with identification and analyzing the extent of poverty in Ghana, with only a few (Ennin et al., 2011) attempting to quantify the impacts of the factors influencing poverty. Despite high level of poverty among food crop farmers, no studies, to the best of knowledge, have been conducted to investigate the determinants of poverty among this category of Ghanaian society to enhance sustainable anti-poverty policy programmes. The objective of this study was therefore to empirically determine the factors that help households exit from chronic poverty.

The rest of this chapter is structured as follows: section 8.2 elaborates on the issue of poverty and reviews past researches on the subject matter; section 8.3 describes the econometric models used to investigate poverty conundrum among food crop farmers; section 8.4 presents and discusses the results of the study; and the last section draws conclusions based on the results of the study and at the end make recommendation for consideration of policy makers.

8.2 Review of literature

Poverty has many facets and can be viewed from many angles, be it lack of access to basic needs, impaired access to and use of productive resources, outcome of inefficient use of common resources and result of “exclusive mechanisms” (Ajakaiye and Adeyeye, 2001). Normally, individuals or households are considered poor if they are incapable of purchasing a certain basket of goods and services including food, shelter, water and healthcare (Streeten and Burki, 1978). Low income, unemployment/underemployment, and inadequate endowment of human capital impairs access to productive resources (agricultural land, physical capital and financial assets) and reduces the capability of individuals to convert those resources to a higher quality life (Sen, 1985; Adeyeye, 2000). Inefficient use of common resources resulting from weak policy environment, inadequate infrastructure, and weak access to technology or credit can generate pockets of poverty. An individual can be excluded from partaking in development if his/her field of expertise cannot be accommodated in the labor market, vested interest ceasing control of activities in goods and factor markets or an individual having troubled relationship with the community (Silver, 1994).

Originally, the poor were blamed for being poor and that their character and attitude sustain poverty. In this sense, poverty was seen as a way of life and transferred from generation to generation in a “vicious circle” unless income level increases significantly high enough to pull that person out of the poverty trap (Lewis, 1966). Lewis (1954), based on dual economy paradigm, argues that people are poor because they are engaged in the traditional sector which is characterized by local ineptitude and weak response to economic incentives to work hard. In the view of Marxists, society is comprised of few rich capitalists who exploit the labor of the poor miserable masses for their own benefit. Poverty is, thus, perpetuated in the process.

In this modern era, level and distribution of income occupies a central place in poverty related discussions. That is, poverty emerges from changes in level and distribution of income which result in reduced access to basic services such as food, housing or water. Poverty cannot be attributed solely to personal attributes alone but also geographical or locational characteristics of where people live (Holzer, 1991; Aikaeli, 2010). Direct relationship between poverty and income growth supports the assertion that productive work is the way out of poverty, and strategies to expand economic opportunities and promote income growth are sine quo non to sustained poverty reduction.

Sen and Palmer-Jones (2006) report that poverty in India is determined by where one lives and places with low potential for irrigation have higher incidence of poverty. Decorn and Krishnan (1998) concludes from a study in Ethiopia and Tanzania between 1989 and 1995 that households with substantial human and physical capital and better access to roads and towns have both lower poverty levels and more likely to get better off over time. Using micro-level panel data from villages in rural Ethiopia, Decorn (2001) notes that the main driver of poverty during the initial phases of the economic reform (1989-1995) is relative price changes, which alter the returns to factors of production such as land, labor and human capital. Andet et al. (2006) find poverty to be lower the more educated household heads are while incidence of poverty is high in households with large sizes. They also find variation in poverty by household's geographical location. Astrup and Desus (2001) find that households with educated heads, working members and high asset ownership are less poor while large households are poorer. Solow (1957) and Nelson (1964) argue that education adds to the effectiveness of labor through technical progress. Okurul et al. (2002) found that large household sizes increase one's probability of being poor. Verner (2006) argues rural folk are poorer because of low level of education. Bogale et al. (2005) attributes persistence of rural poverty in Ethiopia to an entitlement failure including lack of access to land, human capital and oxen and recommends improved targeting in order to reach the poorest of the poor. Hunt (2002) attributes differences in economic status in USA to the differences in household religious beliefs. Households who are members of dominant religions such as Protestants tend to have individualistic beliefs that their own effort can be rewarded with high incomes thereby making them less poor. Others who are of minor religions like Jews or moslems attribute their economic circumstances to bad luck or weak socio-economic systems which provide less economic opportunities rather than one's own abilities or efforts. Marital status of household heads may contribute to reduce levels and probability of poverty (Grinstein-Weiss et al, 2004). They argue that married couples tend to work harder to meet daily financial demands of the home while at the same time pulling together part of their earnings as savings for a rainy day as compared to as compared to single parents or the unmarried.

Medeiros and Costa (2006) argues that there is no evidence of consistent difference in poverty between male and female headed homes. In using Foster-Greer-Thorbecke (FGT) measures to analyzing poverty levels among women in Latin America, they alluded to the fact that poverty is high among households headed by females but find no significant difference in poverty from male headed homes. Maharjan and Joshi (2011) and Joshi et al. (2012) use binary logistic models to analyze the determinants of food security and poverty in Nepal respectively. According to Maharjan and Joshi (2011), households in Nepal are food-insecure because of limited access to productive resources resulting from illiteracy, large farm families and higher dependency ratio, subsistent nature of agriculture with small farm size, limited irrigation and fertilizer, and wage labor dependence. Joshi et al. (2012) find household size, operational landholding, livestock holding, education and dependency ratio to be the main drivers of poverty in the Patan and Melauli VDCs of Nepal. Apata et al. (2010) identify smallholder farmers as the majority of the poor in southwestern Nigeria. According to them, access to micro-credit, education, livestock assets and access to extension services are the main drivers of poverty but find not significance of age of the household head on the likelihood of being poor.

Based on repeated cross-sectional data from Ghana Living Standards Survey for 1991/92, 1998/99 and 2005/2006, Ennin et al. (2011) use a binary logistic model to examine the factors influencing poverty incidence in Ghana. The results of their study indicate that large agricultural households headed by illiterate living in the savanna ecological zone are increasing probability of becoming poorer. They, however, find weak significant difference in the probability of being poor between males and females. This study extends this line of analysis by assessing the determinants of incidence, depth and severity of poverty among farming households in Ghana using additional statistical methods. The focus on farm families is instructive because this category of people produces food, a basic need which is a key element in poverty measurement and analysis in developing countries including Ghana. Since there is overrepresentation[2] of this category of Ghanaians in the number of the poor, it is methodologically preferable to carry out poverty analysis within this group rather than for the entire population (Medeiros and Costa, 2006). This approach cures the problem of perceived overrepresentation of farm families in poverty discourse in agricultural developing countries including Ghana.

[2] This relates the size of a sub-group on the poor to the size of this sub-group in the entire population. In this sense, increased poverty in the sub-group may be neutralized by the reduction in numbers of the sub-group in the entire population, indicating no change in poverty status when, in fact, there is a change. This can mislead policy makers in the decision making.

It can be concluded from the above exposition that the major factors identified in driving poverty in most deprived communities are a plethora of various socioeconomic and demographic variables including income and asset ownership, education, religion, gender, marital status, dependency ratio and location. Unlike Ennin et al. (2011), this study uses the above mentioned factors to analyze both the extent and the determinants of poverty with focus on only households who grow at least one of the five major food crops of cassava, maize, sorghum, rice and yam.

8.3 Analytical framework

This study uses a Probit model to analyze the determinants of poverty incidence, and a Tobit regression model (Tobin, 1958) to analyze the determinants of poverty depth and severity among farming households. In this vein, a household is poor if its real consumption per adult equivalent is below the poverty line of GHS 370.89 (US$ 403.14). The general specification of a limited dependent variable for analyzing poverty determinants is as follows:

$$poor_h^* = \beta_k X_h + \varepsilon_h \tag{8.1}$$

$$poor_h = \begin{cases} poor_h^* & \text{if } poor_h^* > 0 \\ 0 & \text{if } poor_h^* \leq 0 \end{cases} \tag{8.2}$$

Where $poor_h^*$ is the latent variable which indicates poverty measure; ε_h is the stochastic error term which is normally distributed in both Probit and Tobit models; β_k is the vector of model parameters; and X_h is a vector of independent variables; $poor_h^*$ is the latent variable indicating poverty measure which is equal to 1, g_i/z and $(g_i/z)^2$ for incidence, depth and severity of poverty, respectively for each poor household and 0 for each non-poor household, as earlier explained in Chapter 7. That is, $poor_i^*$ is only observed if the real consumption per adult equivalent hit a certain threshold (poverty line).

The marginal impact of k explanatory variables on the incidence of poverty is specified as in Equation 8.3 while their marginal effect on poverty depth and severity is specified as in Equation 8.4.

$$\frac{\partial P(poor_i=1)}{\partial X_i}=\emptyset(\beta_k X_h)\beta \qquad (8.3)$$

$$\frac{\partial P(poor_i^*)}{\partial X_i}=\beta_k \qquad (8.4)$$

The symbol $\emptyset(.)$ denotes standard normal probability density function. It is important to note that, unlike ordinary least square regressions, marginal effect as in Equation 8.3 varies with the values of the explanatory variables.

8.4 Data description

This study utilizes data from the fifth round of Ghana Living Standard Survey (GLSS V), compiled by the Ghana Statistical Service (GSS), from October 2005 to September 2006, to assess the extent and determinants of poverty among farmers cultivating the major food crops in Ghana. GLSS V contains information on demographic and socioeconomic conditions of 8,687 households covering 37,128 individuals. Out of the total number of households, this study covers only 4,067 households who cultivate at least one of the five major food crops in question.

All model variables are created using data from the GLSS V. Real consumption per adult equivalent is the most important variable in this model. It is obtained by summing household expenditure on essential goods including home consumption. Rather than dividing by household size, the number of adult equivalent is computed and used as divisor to take care of varying nutritional needs of household members by age and gender. The nominal household consumption is then converted into real consumption value using regional Consumer Price

Index (CPI)[3] as a deflator. Household income is also converted into Real income per adult equivalent using the same procedure as in the case of real consumption per adult equivalent. Asset index is constructed using a wide ranging list of more than thirty items including land, radio, television, tractors, houses, and cooking utensils. The asset index is generated using principal component analysis based on the survey data.

Table 8.1 Description and summary statistics of independent variables for the logistic model

Variable	Variable Description	Mean	Standard Deviation	Hypothesis
Age of head	Age (in years) of household head	46.98	15.11	+/-
Dependency ratio	Number of household members aged 0-14 plus those aged 60+ divided by the workforce aged15- 60	1.05	0.89	+
Log of income	Logarithm of household real income per adult equivalent (GHS)	5.55	1.62	-
Asset index	Index of household assets calculated using principal component analysis	-0.17	5.32	-
Male	Gender of household head (= 1 if male and 0 if female)	0.80	0.40	+/-
Divorced	Civil status of household head (=1 if divorced or widowed & 0 otherwise)	0.19	0.39	+
Single	civil status of household head (=1 if single and 0 otherwise)	0.03	0.18	+
Basic	Education of household head (=1 if basic and 0 otherwise)	0.24	0.43	-
Secondary	Education of household head (=1 if secondary and 0 otherwise)	0.05	0.21	-
Tertiary	education of household head (=1 if tertiary and 0 otherwise)	0.018	0.12	-
Coastal	ecological zone (=1 if coastal and 0 otherwise)	0.15	0.36	-
Savanna	ecological zone (=1 if savanna and 0 otherwise)	0.44	0.50	+
Moslem	Religion of household head (=1 if moslem & 0 otherwise)	0.19	0.39	+
Traditional	religion of household head (=1 if traditional and 0 otherwise)	0.15	0.35	+
Free thinker	religion of household head (=1 if free thinker and 0 otherwise)	0.08	0.28	-

Notes The exchange rate of Ghana Cedis (GHS) to the United States dollars in 2006 is 0.92; the negative sign on the mean value of asset index indicates "less than average"

Source Authors' calculation from GLSS V data

[3] The regional consumer price index is used because the community price questionnaire is not currently available for GLSS V. The community price questionnaire enables the calculation of deflators at cluster rather than regional levels.

Other variables used in this study are gender, age, education and civil status of household heads, dependency ratio, religion and location. The gender of household head is 1 if household is headed by male and 0 otherwise. Education, civil status, religion and location are categorical variables. Education is categorized into illiterate, basic, secondary and tertiary; marital status is categorized into married, divorced and single; religion is categorized into Christian, Moslem, traditional and free thinker; and location is categorized into forest, coastal and savanna. All categorical variables are converted into dummy variables to facilitate model estimation. For each categorical variable, all elements except one are included as additional explanatory variables when running regressions to avoid the problem of dummy variable trap. That is, illiterates, Christian, married and forest for categorical variables education, religion, civil status and ecological zones respectively are, thus, dropped as displayed below in Table 8.1.

Table 8.1 above shows that a typical household cultivating at least one of the crops in question is headed by illiterate, male, married, Christian head aged 46 years, residing in the savanna ecological zone whose family together with one dependent lives on an annual per capita income of GHS 257.54 with less than average asset holdings. The last but one column in Table 8.1 indicates the expected direction of impact of the various independent variables on the probability of households being poor.

8.5 Presentation of results and discussion

This study analyzes determinants of poverty among farmers who grow five major food crops. The FGT poverty measures are used as independent variables in this study. To identify the drivers of poverty among farming households, Probit and Tobit models are used to assess the underlying factors driving poverty among major food crop farmers. The Probit model whereby a binary variable, indicating whether a household is poor or not ($poor_i$), is regressed on a set of independent variables consisting of real income per adult equivalent, asset index, gender, age, education, religion, marital status, household dependency ratio, and location is used to analyze poverty incidence. The Tobit model is used to analyze the depth and severity of poverty.

The results of the Probit model for poverty incidence and Tobit model for poverty depth and severity are displayed in Table 8.2. Male headed households have significantly higher likelihood of being poor as compared to females. This may be due to the fact male homes are highly represented in the sample of households for this study (about 80%). Additionally, females generally are engaged in petty trading to supplement family income. On the other hand, there are fewer job opportunities accessible by unskilled male farmers during the dry season. The probability of being headcount poor is 8.79% higher among male headed homes. Probability of being poor is not significantly different between married and divorced household heads but does differ significantly from single household heads. Being single reduces one's probability of poverty by 29.32%. Probability of being poor significantly increases with the age of the household heads because they become less productive at advanced age. This indicates that households headed by older header heads may not be receptive to new technology and farming practices which enhances farm productivity and incomes.

Households with higher dependency ratios tend to have higher probability of being poor. A unit increase in the dependency ratio raises the probability of being poor by 8.15%. Education attainment of the household head has significant positive effect on the likelihood of a household being poor. Household head with basic level of education has a reduced probability of pushing a household into poverty as compared to illiterate household heads. Increasingly reduced probabilities of household poverty are observed from a lower educational ladder to a higher one. Education at basic, secondary and tertiary levels reduces probability of poverty by 10.51%, 27.36% and 35.80% as compared to being illiterate.

Table 8.2 Probit and Tobit results of poverty among major food crop farmers: marginal effects

	Poverty incidence	Poverty depth	Poverty severity
Male	0.0879*** (0.0291)	0.0304*** (0.0081)	0.0195*** (0.0051)
divorced	-0.0431 (0.0304)	-0.0184** (0.0086)	-0.0112** (0.0054)
Single	-0.2932*** (0.0444)	-0.0791*** (0.0118)	-0.0451*** (0.0077)
Age of head	0.0017** (0.0007)	0.00053*** (0.0002)	0.0003*** (0.0001)
Dependency ratio	0.0815*** (0.0103)	0.0253*** (0.0029)	0 .0150*** (0.0018)
Basic	-0.1051*** (0.0224)	-0.0468*** (0.0063)	-0.0301*** (0.0040)
Secondary	-0.2736*** (0.0371)	-0.0907*** (0.0092)	-0.0558*** (0.0059)
Tertiary	-0.3580*** (0.0520)	-0.1082*** (0.0141)	-0.0667*** (0.0091)
coastal	-0.0776*** (0.0267)	-0.0291*** (0.0077)	-0.0192*** (0.0049)
Savanna	0.2663*** (0.0212)	0.1073*** (0.0070)	0.0705*** (0.0044)
Moslem	-0.0406 (0.0261)	-0.0149** (0.0071)	-0.0109** (0.0044)
Traditional	0.0572* (0.0305)	0.0340*** (0.0089)	0.0274*** (0.0057)
free thinker	0.0383 (0.0325)	0.0051 (0.0098)	0.0018 (0.0061)
Log of income	-0.1096*** (0.0059)	-0.0401*** (0.0016)	-0.0263*** (0.0010)
Asset index	-0.0066*** (0.0017)	-0.0015*** (0.0005)	-0.0007** (0.0003)

Notes *** means significant at 1%, ** means significant at 5% and * means significant at 10%; Pseudo R-squared is 20.62% the poverty incidence Probit regression; Pseudo R-squared for poverty depth and severity Tobit regressions are 31.34% and 48.32%, respectively.

The likelihood of poverty is highest in the savanna ecological zone, followed by the forest and the coastal zones in that order. By virtue of a food crop farmer residing in the coastal zone, they have an additional reduction in probability of poverty by 7.76% whereas those of the savanna zone have an additional increase in probability of poverty by 26.630% as compared to forest zone food crop farmers. There is no difference among Christian, Moslems and free thinkers in the probability of being headcount poor. The followers of African traditional religion, however, have higher incidence of poverty.

Predictably, both household real income per adult equivalent and wealth have significant negative effects on the probability of being poor. The real household income captures short run effects while the wealth index traces the long term impact of household financial resources. Households with higher real incomes tend to spend more resulting in low poverty. Higher wealth index indicates that the household has resource buffers which it can deliberately dispose of in times of seasonal crisis or crop failure to smoothen consumption.

Table 8.2 also displays the results of Tobit model explaining the determinants of depth and severity of poverty among farming households in Ghana in the third and fourth columns, respectively. Just like poverty incidence, depth and severity of poverty are higher among male heads relative to females. Poverty depth and severity are 3.04% and 1.95% higher in male headed homes. There is significant difference in poverty depth and severity between household heads who are married and those who are not. Household heads who without partners are less deeply and severely poor. The depth and severity of poverty are 1.84% and 1.12% lower respectively for divorced heads, 7.91% and 4.51% lower for single household heads. Both age of household head and the dependency ratio significantly increase depth and severity of poverty. While the effect of age is not economically large, a unit increase in the dependency ratio increases poverty depth and severity by 2.53% and 1.50%, respectively. There is an inverse relationship between poverty depth and severity, on one hand, and level of education, on the other hand. Poverty depths are 4.68%, 9.07% and 10.82% lower for household heads with basic, secondary and tertiary education, respectively. Similarly, poverty severities are 3.01%, 5.58% and 6.67% lower for household heads with basic, secondary and tertiary education.

Households in the coastal ecological zone have 2.91% lower poverty depth while those in the savanna zone have 10.73% higher poverty depth relative to those residing in the forest zone. Poverty severity follows the trend of poverty depth. Poverty severity is 1.92% lower in the coastal zone but 7.05% higher in the savanna zone relative to the forest ecological zone. Relative to Christians, Moslems have lower poverty depth and severity of 1.49% and 1.09% respectively, whereas traditionalists have higher poverty depth and severity of 3.40% and 2.74% respectively. There is, however, no significant difference in depth and severity of poverty between Christians and free thinkers. The effects of both household income and assets on poverty depth and severity are statistically significant but the effect of assets is not economically large (less than 1%). One percent increase in household income reduces depth and severity of poverty by 4.01% and 2.63%, respectively.

8.6 Conclusion and recommendations

Ghana's poverty reduction efforts over the years have resulted in reduced levels of poverty in Ghana. However, poverty among major food crop farmers still remains unacceptably high. This article attempts to assess the extent and determinants of poverty among this segment of Ghanaian society who are overburdened with poverty.

Based on Ghana national survey data, FGT poverty index is used to calculate incidence, depth and severity of poverty among farmers who grow five major food crops in Ghana. Logit and Tobit models are used to assess the underlying factors driving poverty among major food crop farmers. The results of the logit and the Tobit regressions identify gender, education and civil status of household head, location and income as important factors explaining variation in poverty incidence across Ghana. The direction of impact of all explanatory variables is the same across all poverty measures (incidence, depth and severity). Although there are some differences between the explanatory variables used in this study and in Ennin et al. (2011), the results of the common variables are consistent except those indicating gender and age of the household heads. Female headed households have proven to be better managers of household resources to improve members living conditions. A policy to empower female household heads in particular and female spouses in general will help optimize use of household resources to combat debilitating poverty among food crop farmers. Microcredit schemes whereby women groups are trained and given business loans can help empower women and reduce their vulnerability. Married or divorced household heads are more at risk of poverty vis-à-vis household heads who are single. Social protection programme which links support to the obligation of household heads to enroll children in schools, joining national health insurance schemes or immunization can lessen financial burden of farm families in a more sustainable way. Poverty is higher among older or less educated farm families with high dependency ratio. General training in functional literacy, entrepreneurship and management will not only increase farmers' acceptance of productivity enhancing technical innovations, but also make them employable in the non-agricultural sector thereby enhancing family income. Most poor households reside in the savanna zone. A sizeable percentage is also found in the forest zone. By combining zonal and household targeting, location-specific and household characteristics can be used in identifying the poor from the non-poor for any poverty alleviation support that may be forthcoming.

In the nutshell, there is no single specific government policy or program that can serve as a silver bullet to eliminate poverty among farm families once and for all. However, by adopting a combination of measures such as the above, poverty can be reduced among food crop farmers in Ghana.

9 Summary of findings and recommendations

9.1 Introduction

This chapter summarizes the impact of climate change on living conditions of farming households and attempt to draw conclusions from the major findings of this study. To analyze the impact of climate change on welfare of farming households, this study used FGLS and Structural Ricardian models to analyze the impact of climate change on yields and net revenues of major food crops as the first step. Climate change impacts on net revenues are modeled as agricultural productivity parameters. At the second step, a CGE model is used to analyze the logical structure of the Ghanaian economy. The climate change induced productivity parameters are introduced as shocks in the macro model. This allows for the analysis of the aggregate impact of climate change on macro aggregates like gross sectoral output, import and exports as well as aggregate welfare measures like GDP and equivalent variation. At the third and final step, the macro impact of climate change is traced to the household level by linking the CGE model to a micro-simulation model. This allows for the estimation of poverty impact of climate change.

9.2 Crop yield and net crop revenue per hectare

Impact of climate change on yields of major food crops do not always match its impact on net revenues. In this study, yields and revenues of maize and sorghum tend to move in the same direction. For instance, the impact of climate change on maize rice is negative and this is matched by reduced levels of maize revenue. Climate change will increase sorghum yield and this matched increased earnings from the cultivation of sorghum. In the cases of other crops, climate change impact on yields and revenues tend to move in the opposite direction. For instance, climate change raises cassava yield but its impact on net revenue is negative. Climate change will have yield-reducing effects on yields of rice and yam, but its impact on their net revenue will be positive. This conclusion makes crop yield a weak predictor of the climate change impact on the welfare of farming households.

Table 9.1 Comparison of climate impact on crop yield and net revenue

	Cassava	Maize	Sorghum	Rice	Yam
Yield	+	-	+	-	-
Net revenue	-	-	+	+	+

9.3 Indirect effects of climate change induced agricultural productivity shock

The pervasive nature of climate change will surely have some indirect effects beyond the sector where shocks propagate. It is immediately known that climate change will negative effect on cassava maize while its effect on other crops. Apart from the direct effect on sectoral output, imports and exports, the climate change induced productivity shock spreads thought the Ghanaian, although in most of cases, the effect is minimal. One notable sector where the climate change effect will be palpable is the livestock. Climate change will reduce livestock output and exports but it will induce increased importation of livestock into the country.

9.4 Climate change and poverty

It is a difficult exercise to establish direct link between climate change and poverty. Most previous studies attempt to link climate change to poverty are not successful in truly linking climate change and poverty. Against this backdrop, this study uses a combination of analytical tools to indirectly establish a link between poverty and climate change

Results of this study show that climate change induced productivity shock will worsen poverty levels among farming households in Ghana with variation across socioeconomic groups. In general, climate change will worsen poverty levels of all farmers, but, surprisingly, farmers with tertiary education will be worse affected. It may be due to the fact that this category of farmers tends to be engaged in the commercial cultivation of some food crops which make them susceptible to climatic variability. If they adapt, they will also benefit the most from their efforts. By location, climate change will not initially affect poverty levels of farmers residing in coastal and savanna ecological zones, but poverty depth and severity will increase. From 2020, climate change will worsen all measures of poverty, which will be ameliorated by adaptation through crop switching. Although adaptation may be beneficial to farmers, the stubbornly high poverty levels in the savanna zone may call for additional policy measures to deal with this canker. By civil status, climate change will worsen poverty incidence of married farmers, but has not effect on that of farmers who are single. Poverty depth and severity of categories will worsen. With adaptation, however, the poverty risk increasing effect is reversed. By gender, climate change will not affect poverty incidence of female farmers in the initial years but it will do in the latter years. For male farmers, climate change will worsen poverty levels throughout the projection period. Adaptation will reduce poverty risk among both male and female farmers but female farmers will benefit more.

9.5 Recommendations

Having analyzed the impact of climate change on agricultural productivity and on poverty, the following recommendations are put forward for the consideration of policymakers:

- Input markets should be streamlined to ensure access to fertilizer, use of heat and drought tolerant seeds, and efficient pesticide/herbicide application for subsistent food crop farmers.
- In addition to input markets, programs to promote access to output market should be supported to ensure that improved crop yields at the expense of net revenue growth.
- The study found detrimental effect of climate change on yields of some major food crops (maize, rice and yam). In this regard, The study recommends use of community-based

radio and other media outlets, and extension officers to disseminate climate related information and technological innovations to farmers in order to avert projected plummeting yields of some major food crops resulting from climate change and to optimize use of farm inputs and technologies in farming.

- Female headed households have proven to be better managers of household resources to improve members living conditions. A policy to empower female household heads in particular and female spouses in general will help optimize use of household resources to combat debilitating poverty among food crop farmers. Microcredit schemes whereby women groups are trained and given business loans can help empower women and reduce their vulnerability.
- Married or divorced household heads are more at risk of poverty vis-à-vis household heads who are single. Social protection programme which links support to the obligation of household heads to enroll children in schools, joining national health insurance schemes or immunization can lessen financial burden of farm families in a more sustainable way.
- Poverty is higher among older or less educated farm families with high dependency ratio. General training in functional literacy will not increase farmers' acceptance of productivity enhancing technical innovations, but also make them employable in the non-agricultural sector thereby enhancing family.
- Most poor households reside in the savanna zone. A sizeable percentage is also found in the forest zone. By combining zonal and household targeting, location-specific and household characteristics can be used in identifying the poor from the non-poor for any poverty alleviation support that may be forthcoming.

9.6 Limitations of study

There are several limitations of this study with regard to assumptions, methods and data that reduce reliability of the findings of this study. For instance, the multinomial logit regression used in analyzing climate change impact on crop choice operate with the assumption that one primary crop is chosen at any point in time. This strong assumption may not be true in planting decisions of many farmers who, in the face of adverse climatic conditions, may cultivate two or more crops. This therefore limits the scope of applicability of these research findings. Additionally, the econometric analyses employed in this study are based on assumption that yield and revenue responses to climate variables observed over period 1961-2010 will remain same into the future. It is also assumed that adaptive measures adopted by famers in the past will continue to be employed in the future. But yield and revenue may improve in the future because of expected adoption of technical innovations which might not be available in both the past and the present (Jayne et al., 2002). This may open up opportunities for adaptation than can be currently imagined.

Like in many regression analyses, the econometric models used in this study may also be criticized on the grounds of omission of several explanatory variables deemed to be relevant in parameter estimation due to dearth of data. Furthermore, the data used for this study is cross-sectional and may not be the most appropriate data type for analysis of climate change impact. Since cross-sectional data is used in this study anyway, it will be only fair to acknowledge that panel or pooled cross-sectional data may provide more accurate estimates of climate change impact. This issue should be taken up in related future studies on climate change impact.

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Appendix 1 Equivalence scale based on daily caloric intakes by gender and age (in percentage of an adult male 18-30 years old)

Household composition	**Equivalent Scales**	
Young children		
<1	0.32	
1-2	0.44	
2-3	0.52	
3-5	0.60	
Older children	**Boys**	**Girls**
5-7	0.71	0.67
7-10	0.81	0.69
10-12	0.85	0.75
12-14	0.92	0.81
14-16	1.02	0.83
16-18	1.10	0.83
Adult	**Men**	**Women**
18-30	1	0.77
30-60	0.96	0.79
>60	0.81	0.71

Notes The caloric requirements for an adult male aged 18-30 used to estimate the food poverty line is normally 2450 kcal a day

Source FAO/WHO/UNU (1985)

Appendix 2 GAMS codes for Computable General Equilibrium Model for Ghana

```
***1. SET DECLARATIONS ---------------------------------------------------------------------
$ontext
In this section, all sets are declared. They are divided into the following groups:

a. model sets (appearing in the model equations)
b. calibration sets (used to initialize variables and define model  parameters)
c. report sets (used in report files)
$offtext

SETS
**a. model sets
 AC          global set for model accounts - aggregated microsam accounts
/amaiz, arice, asorg, acass, ayams, aponu, afruv, aocro, acoco, aoexp, alive, afore, afish,
adair, anagr, cmaiz, crice, csorg, ccass, cyams, cponu, cfruv, cocro, ccoco, coexp, clive,
cfore, cfish, cdair, cnagr, trcs, labor, capital, hrur, hurb, govt, dtax, stax, mtax, etax, savi, rest,
total
/
 ACNT(AC)    all elements in AC except TOTAL
 A(AC)       activities
/amaiz, arice, asorg, acass, ayams, aponu, afruv, aocro, acoco,aoexp, alive, afore, afish,
adair, anagr
/
 C(AC)       commodities
 /cmaiz, crice, csorg, ccass, cyams, cponu, cfruv,cocro, ccoco, coexp, clive, cfore, cfish,
 cdair, cnagr
 /
 AAGR(A)     agricultural activities
 /amaiz, arice, asorg, acass, ayams, aponu, afruv, aocro, acoco, aoexp, alive, afore, afish
/
 ANAGR(A)    non-agricultural activities
 /adair, anagr/

  AF(AAGR) major food crops
 /amaiz,  arice, asorg, acass, ayams
/

 CAGR(C)     agricultural commodities
 /cmaiz, crice, csorg, ccass, cyams, cponu, cfruv, cocro, ccoco, coexp, clive, cfore, cfish
/
 CNAGR(C)    non-agricultural commodities
 /cdair, cnagr/

 CD(C)       commodities with domestic sales of output
 CDN(C)      commodities without domestic sales of output
 CE(C)       exported commodities
```

```
 CEN(C)     non-export commodities
 CM(C)      imported commodities
 CMN(C)    non-imported commodities
 CX(C)      commodities with output
 F(AC)       factors
 /labor, capital/
 INS(AC)     institutions
 /hrur, hurb, govt, rest/
 INSD(INS) domestic institutions
 /hrur, hurb, govt/
 H(INSD) domestic non-government institutions
 /hrur, hurb/

**b. calibration sets
 CINV(C)    fixed investment goods
 /cnagr/
 CT(C)       transaction service commodities
/cnagr/
 CTD(C)      transaction service commodities
 /cmaiz, crice, cocro, clive, cdair, cnagr /

 YR  years of projections
 /2010*2025/

 ALIAS
 (AC, ACP)  ,  (A, AP, APP),(AAGR, AAGRP),(ANAGR, ANAGRP)
 (C,CP, CPP), (CE, CEP)    , (CM, CMP),(YR, YRP),
 (F, FP), (INS, INSP), (INSD, INSDP), (H, HP)
 ;
 ACNT(AC) =YES; ACNT('total')=NO;
 ALIAS  (ACNT,ACNTP);

$call gdxxrw.exe GAMS_input6.xls par=micro_SAM6 rng=sheet3!a48:aq90
parameter micro_SAM6(AC,ACP)  Ghana macro SAM ;
$gdxin GAMS_input6.gdx
$load micro_SAM6
$gdxin

$call gdxxrw.exe GAMS_input4.xls par=leselas rng=sheet1!a1:c13
parameter leselas(*,*)  income elasticity parameter of h;
$gdxin GAMS_input4.gdx
$load leselas
$gdxin

leselas(C,H)=leselas(C,H);

display leselas,micro_SAM6;
```

```
***SAM adjustments

*In this section, some minor adjustments are made in the SAM (when needed) to fit the model
*structure.


*Adjustment for sectors with only exports and no domestic sales
*If there is a very small value for domestic sales, add the discrepancy
*to exports
* micro_SAM6(C,'rest')$(ABS(SUM(A, micro_SAM6(A,C))-(micro_SAM6(C,'rest')
*-micro_SAM6('etax',C))) LT 1.E-6)=SUM(A,micro_SAM6(A,C))- micro_SAM6('etax',C);

*micro_SAM6('rest',C)$(ABS(SUM(A, micro_SAM6(A,C))-(micro_SAM6('rest',C)
*-micro_SAM6('mtax',C))) LT 1.E-6)=SUM(A,micro_SAM6(A,C))- micro_SAM6('mtax',C);

$ontext
*Netting transfers between domestic institutions and RoW.
 micro_SAM6(INSD,'rest')   = micro_SAM6(INSD,'rest') - micro_SAM6('rest',INSD);
 micro_SAM6('rest',INSD)   = 0;

*Netting transfers between factors and RoW.
 micro_SAM6('rest',F)= micro_SAM6('rest',F) - micro_SAM6(F,'rest');
 micro_SAM6(F,'rest')= 0;

*Netting transfers between government and domestic non-
*government institutions.
 micro_SAM6('H1','govt') = micro_SAM6('H1','govt') - micro_SAM6('govt','H1');
 micro_SAM6('govt','H1') = 0;

*Eliminating payments of any account to itself.
 micro_SAM6(ACNT,ACNT) = 0;
$offtext
 PARAMETER
 tdiff(AC) column minus row total for account AC;
        micro_SAM6('total', ACNTP) = SUM(ACNT, micro_SAM6(ACNT, ACNTP));
        micro_SAM6(ACNT, 'total') = SUM(ACNTP, micro_SAM6(ACNT, ACNTP));
        tdiff(ACNT) = micro_SAM6('total', ACNT) - micro_SAM6(ACNT, 'total');
 DISPLAY micro_SAM6,tdiff;

*Additional set definitions based on country micro_SAM6=====================

*CD is the set for commodities with domestic sales of domestic output
*i.e., for which (value of sales at producer prices)
*           > (value of exports at producer prices)
 CD(C) = YES$
   (SUM(A, micro_SAM6(A, C)) GT (micro_SAM6(C, 'rest')-micro_SAM6('etax', C)));
```

```
 CDN(C) = NOT CD(C);

 CE(C)  = YES$(micro_SAM6(C, 'rest'));
 CEN(C) = NOT CE(C);

 CM(C)  = YES$(micro_SAM6('rest', C));
 CMN(C) = NOT CM(C);

 CX(C) = YES$SUM(A, micro_SAM6(A,C));

*CT(C)=YES$(CTD(C) OR CTM(C));
* CT(C)$(micro_SAM6(C,'trcs') + micro_SAM6('trcs',C))=YES;

*ALEO(A) = YES; ACES(A) = NO;

*If activity has no intermediate inputs, then Leontief function has to
*be used at the top of the technology nest
*ACES(A)$(NOT SUM(C, micro_SAM6(C,A))) = NO;
*ALEO(A)$(NOT ACES(A)) = YES;

 DISPLAY
 micro_SAM6,CD, CDN, CE, CEN, CM, CMN, CX;

***2. PARAMETER DECLARATION
 PARAMETERS
**Parameters appearing in model equations*****
 alphava(A)     shift parameter for CD of AAGR labor and land
 alphaq(C)      shift parameter for Armington function
 alphat(C)      shift parameter for CET function
 deltava(F,A)   share parameter for CD of composite labor
 deltaq(C)      share parameter for Armington function
 deltat(C)      share parameter for CET function
 rhoq(C)        Armington function exponent
 rhot(C)        CET function exponent
 sigmaq(C)      elasticity of substitution bt. dom goods and imports for c
 sigmat(C)      elasticity of transformation bt. dom sales and exports for c
 beta(C,H)      marg share of hhd cons on marketed commodity c
 bshr(C,H)      budget share for marketed commodity c and household h
 gamma(C,H)     per-cap subsist cons of marketed com c for hhd h
 yelas(C,H)     household H income elasticity of commodity C
 elasch(H)      elasticity check
 bshrch(H)      budget share check
 fris(H)        frisch paremeter
 cwts(C)        weight of commodity c in the CPI
 ica(C,A)       qnty of c as intermediate input per unit of activity a
 inta(A)        aggregate intermediate input coefficient
 iva(A)         aggregate value added coefficient
```

trnsfr(*,*) transfers fr. inst. or factor ac to institution ins
trnshh(H) transfers from household to household
theta(A,C) yield cofficients
shctd(CT) share of transactions
tmag(C) margin on commodity c
icd(C) trade input of c per unit of comm'y cp produced & sold dom'ly
mpsbar(H) marg prop to save for dom non-gov inst ins (exog part)
ty(H) exogenous tax rate
qbarg0(C) xogenous (unscaled) government demand
qbarg(C) exogenous (unscaled) government demand
qbarinv(C) exogenous (unscaled) investment demand
shif(H) household h share in factor income
**taxes
tf(F) rate of direct tax on factors (soc sec tax)
tshr(C) transaction charge
tm(C) import tariff rate for commodity c
te(C) export subsidy rate for commodity c
tq(C) rate of sales tax for commodity c
ta(A) rate of subsidy on producer gross output value
**Parameters for definition of model parameters
alphava0(A) shift parameter for CD of AAGR labor and land
* alphavan0(ANAGR) shift parameter for CD of ANAGR labor and capital
*Check parameters
cwtschk check that CPI weights sum to unity

***PARAMETER FOR VARIABLE INITIALIZATION
*prices
GADJ0 government adjustment
IADJ0 invstement adjustment
MPS0 mps adjustment factor
TYADJ0 direct tax adjustment factor
PA0(A) output price of activity a
PD0(C) demand price for com'y c produced & sold domestically
PDS0(C) supply price for com'y c produced & sold domestically
PE0(C) price of exports
PINTA0(A) price of intermediate aggregate
PM0(C) price of imports
PQ0(C) price of composite good c
PVA0(A) value added price
PWE0(C) world price of exports
PWM0(C) world price of imports
PX0(C) average output price
CPI0 consumer price index (PQ-based)
EXR0 exchange rate
**labor market
QF0(F,A) quantity demanded of factor f from activity a
QFS0(F) quantity of factor supply

```
 WF0(F)         economy-wide wage (rent) for factor f
 WFDIST0(F,A)   factor wage distortion variable
 WFA(F,A)       wage for factor f in activity a (used for calibration)
 PRK0           price of capital
 KSHR0(A)       sector share of new capital
 PR0(A)         sectoral profit rate
 APR0           average profit rate
 QK0(A)         allocation of new capital
 QFK0(A)        capital stock in next stock
**production volume
 QA0(A)         level of domestic activity
 QX0(C)         level of output
 QVA0(A)        quantity of aggregate value added
 QINT0(C,A)     quantity of intermediate demand for c from activity a
 QINTA0(A)      quantity of aggregate intermediate input
**demand volume
 EH0(H)         household consumption expenditure
 QH0(C,H)       quantity consumed of marketed commodity c by hhd h
 QINV0(C)       quantity of fixed investment demand
 EG0            total current government expenditure
 QG0(C)         quantity of government consumption
 QD0(C)         quantity of domestic sales
 MARGIN0(C)     demand for commodity c as trade or transport margin
 QQ0(C)         quantity of composite goods supply
 TABS0          total absorption
**international trade
 QE0(C)         quantity of exports
 QM0(C)         quantity of imports
 WALRAS0        savings-investment imbalance (should be zero)
**income & savings
 YF0(F)         factor income
 YHF0(H)        factor income for households
 YH0(H)         total income of h
 SH0(H)         household savings
 FSAV0          foreign savings
 YG0            total current government income
 GSAV0          government savings
;
scalar
dep        capital depreciation rate/0.10/
int        interest rate /0.10/
rok        return on capital/0.20/
***3. INITIALIZATION OF PARAMETERS & VARIABLES
 PARAMETERS
 PSUP(C)    initial supply-side market price for commodity c
;
 PSUP(C) = 1;
```

```
PDS0(C)$CD(C)   = PSUP(C);
PE0(C)$CE(C)    = PSUP(C);
PM0(C)$CM(C)    = PSUP(C);
EXR0  = 1;
PA0(A)    = 1;

ta(A) = micro_SAM6('etax',A)/(micro_SAM6('total',A));
QVA0(A)= SUM(F,micro_SAM6(F,A));
PVA0(A)= SUM(F,micro_SAM6(F,A))/QVA0(A);
QA0(A) =
SUM(F,micro_SAM6(F,A))+micro_SAM6('etax',A)+SUM(C,micro_SAM6(C,A));
iva(A)   =  QVA0(A)/(QA0(A)*(1-ta(A)));
QX0(C)$CX(C)  = SUM(A, micro_SAM6(A,C));
QE0(C)$CE(C)  = micro_SAM6(C,'rest')-micro_SAM6('etax',C);
PWE0(C)$QE0(C)= (micro_SAM6(C,'rest')/EXR0) / QE0(C);
te(C)$CE(C)   = micro_SAM6('etax',C)/micro_SAM6(C,'rest');
QD0(C)$CD(C)  =  QX0(C)-QE0(C);
tmag(C)$CTD(C) = micro_SAM6('trcs',C)/QD0(C);
PD0(C)$CD(C) = (PDS0(C)*QD0(C)*(1+tmag(C)))/QD0(C);
PX0(C)$CX(C)= (PDS0(C)*QD0(C) + PE0(C)*QE0(C))/QX0(C);
QM0(C)$CM(C)  = (micro_SAM6('rest',C)+micro_SAM6('mtax',C))/PM0(C);
PWM0(C)$QM0(C)= (micro_SAM6('rest',C)/EXR0) / QM0(C);
tm(C)$CM(C) = micro_SAM6('mtax',C)/micro_SAM6('rest',C);
QQ0(C)$(CD(C) OR CM(C))=QD0(C) + QM0(C) ;
PQ0(C)$QQ0(C) = (micro_SAM6(C,'total')-micro_SAM6(C,'rest'))/QQ0(C);
tq(C)   =  micro_SAM6('stax',C)/(PQ0(C)*QQ0(C));
theta(A,C)   = micro_SAM6(A,C)/micro_SAM6('total',A);
QINTA0(A) =  SUM(C,micro_SAM6(C,A));
QINT0(C,A)$PQ0(C) = micro_SAM6(C,A)/PQ0(C);
ica(C,A)$(QINTA0(A)$PQ0(C)) = micro_SAM6(C,A)/PQ0(C)/QINTA0(A);
inta(A) = QINTA0(A) / (QA0(A)*(1-ta(A)));
PINTA0(A)     = SUM(C, ica(C,A)*PQ0(C)) ;
icd(C)$CT(C) =  micro_SAM6(C,'trcs')/QD0(C);
display icd,ta,te,tm,tq,PVA0,PINTA0,PM0,PQ0, QD0;
*DEMAND COMPUTATIONS=====

*Demand computations=====
*Defining factor employment and supply.
QF0(F,A)= micro_SAM6(F,A);
* QFL0(A)= micro_SAM6('Labor',A);
* QFK0(A)= micro_SAM6('capital',A);
*Defining employment for aggregate factors in factor nesting
* QFS0(F) = SUM(A, QF0(F,A));
QFS0(F) = SUM(A, micro_SAM6(F,A));
*Activity-specific wage is activity labor payment over employment
WFA(F,A)$micro_SAM6(F,A)=micro_SAM6(F,A)/micro_SAM6(F,A);
*Economy-wide wage average is total factor income over employment
```

```
 WF0(F)$SUM(A, micro_SAM6(F,A))   = SUM(A, micro_SAM6(F,A))/SUM(A,
micro_SAM6(F,A));
*Wage distortion factor

 WFDIST0(F,A)$WF0(F) = WFA(F,A)/WF0(F);
***calculation of value added shares for Cobb Douglas function
 deltava(F,A)= micro_SAM6(F,A)/SUM(FP,micro_SAM6(FP,A));
***Estimating shift parameters for Cobb Douglas function
 alphava(A)=QVA0(A)/PROD(F, micro_SAM6(F,A)**deltava(F,A));
* alphava(A)=1;
**average capital rental rate
 PRK0=PQ0('cnagr');

APR0=SUM(A,(PRK0*micro_SAM6('capital',A)/SUM(AP,PRK0*micro_SAM6('capital',AP)
))*WF0('capital')*WFDIST0('capital',A));
***share of new capital

KSHR0(A)=(micro_SAM6('capital',A)/SUM(AP,micro_SAM6('capital',AP)))*(0.5*(WF0('ca
pital')*WFDIST0('capital',A)/APR0-1)+1);
* kshr(A)=micro_SAM6('capital',A)/SUM(AP,micro_SAM6('capital',AP));
* QFK0(A)= QF0('capital',A)*(1+QK0(A)/QF0('capital',A)-0.20)
 DISPLAY
QF0,QFS0,WFA,WF0,WFDIST0,PQ0,QVA0,APR0,KSHR0,QQ0,QD0,theta,PX0,PVA0,QA
0,alphava,deltava;

***CPI weight by comm'y = hhd cons value for comm'y / total hhd cons value
*CPI does not consider on-farm consumption.
 cwts(C)       = SUM(H,micro_SAM6(C,H))/(SUM((CP,HP), micro_SAM6(CP,HP)));
 CWTSCHK       = SUM(C, cwts(C));
 CPI0          = SUM(C, cwts(C)*PQ0(C)) ;

 DISPLAY PINTA0,CWTSCHK,CPI0,PQ0,PD0,PDS0,PM0,PE0,QD0,QE0;

***Estimating paremeters for international trade
*Compute exponents from elasticites
 sigmat(C)$(CEN(C) OR (CE(C) AND CDN(C))) = 0;
 sigmaq(C)$(CMN(C) OR (CM(C) AND CDN(C))) = 0;
 sigmat(C)$(CE(C) AND CD(C))        = 3.0;
 sigmaq(C)$(CM(C) AND CD(C))        = 3.0;
 rhot(C)$(CE(C) AND CD(C)) = (1/sigmat(C))+1;
 rhoq(C)$(CM(C) AND CD(C))= (1/sigmaq(C))-1;

*CET transformation
 deltat(C)$(CE(C) AND CD(C))= 1/(1+(PD0(C)/PE0(C))*(QE0(C)/QD0(C))**(rhot(C)-1));
 alphat(C)$(CE(C) AND CD(C))=QX0(C)/(deltat(C)*QE0(C)**rhot(C)+(1-
deltat(C))*QD0(C)**rhot(C))**(1/rhot(C));
```

```
 display rhot,deltat;
*armington aggregation
 PARAMETER
 predeltaq(C)  dummy used to define deltaq
 predeltat(C)  dummy used to define deltaq;
 predeltaq(C)$(CM(C) AND CD(C)) = (PM0(C)/PD0(C))*(QM0(C)/QD0(C))**(1+rhoq(C));
 deltaq(C)$(CM(C) AND CD(C))= predeltaq(C)/(1 + predeltaq(C)) ;
 alphaq(C)$(CM(C) AND CD(C))= QQ0(C)/(deltaq(C)*QM0(C)**(-rhoq(C))
              +(1-deltaq(C))*QD0(C)**(-rhoq(C)))**(-1/rhoq(C)) ;

***transaction services
 MARGIN0(C)$CT(C)  = (icd(C)*QD0(C))/PQ0(C);

***Institution block
*household income & expenditure
 shif(H)  = SUM(F,micro_SAM6(H,F))/SUM((HP,FP),micro_SAM6(HP,FP));
 YF0(F) =  SUM(A,micro_SAM6(F,A));
 tf(F)   = micro_SAM6('dtax',F)/micro_SAM6('total',F);
 YHF0(H) = SUM(F,micro_SAM6(H,F));
* YHF0(H) = shif(H)*SUM(F,(1-tf(F))*YF0(F));
 trnsfr(H,'rest') = micro_SAM6(H,'rest')/EXR0;
 trnsfr(H,'govt')= micro_SAM6(H,'govt')/CPI0;
 trnshh(H)= SUM(HP,micro_SAM6(H,HP))/CPI0;
 YH0(H) =  YHF0(H)+trnsfr(H,'rest')*EXR0+trnsfr(H,'govt')*CPI0+trnshh(H)*CPI0;
*Scaling factors for savings and direct tax shares
 SH0(H) = micro_SAM6('savi',H);
 MPS0(H)= micro_SAM6('savi',H)/(micro_SAM6('total',H)-micro_SAM6('dtax',H));
 ty(H)  = micro_SAM6('dtax',H)/micro_SAM6(H,'total');
 fris(H)   = -5.8;
 QH0(C,H)$PQ0(C)  = micro_SAM6(C,H)/PQ0(C);
 EH0(H)     = (1-MPS0(H))*(1-ty(H))*YH0(H)+trnshh(H)*CPI0;
* EH0(H)     = SUM(C,PQ0(C)*QH0(C,H));
 bshr(C,H)= micro_SAM6(C,H)/SUM(CP,micro_SAM6(CP,H));
 bshrch(H)= SUM(C,bshr(C,H));
 bshr(C,H)=bshr(C,H)/bshrch(H);
 elasch(H) = SUM(C,bshr(C,H)*leselas(C,H));
 leselas(C,H)=leselas(C,H)/elasch(H);
 beta(C,H)= bshr(C,H)*leselas(C,H);
* QH0(C,H)$PQ0(C)  = micro_SAM6(C,H)/PQ0(C);
 gamma(C,H)$bshr(C,H)=((SUM(CP, micro_SAM6(CP,H)))/PQ0(C))*( bshr(C,H) +
beta(C,H)/fris(H));
* gamma(C,H)$bshr(C,H)=(SUM(CP, QH0(CP,H)))*( bshr(C,H) + beta(C,H)/fris(H));
* QH0(C,H)=gamma(C,H)+(beta(C,H)*(EH0(H)-
(SUM(CP,PQ0(CP)*gamma(CP,H)))))/PQ0(C);


**government revenue & expenditure
```

```
 YG0= micro_SAM6('govt','total');
 EG0   = micro_SAM6('total','govt')-micro_SAM6('savi','govt');
 trnsfr('govt','rest')= micro_SAM6('govt','rest')/EXR0;
 trnsfr('rest','govt')=(micro_SAM6('rest','govt'))/EXR0;
 trnsfr(H,'govt')=(micro_SAM6(H,'govt'))/CPI0;
 qbarg(C)  = micro_SAM6(C,'govt')/PQ0(C);
 QG0(C)      = qbarg(C);
 GADJ0        = 1;
 GSAV0 = micro_SAM6('savi','govt');
**Fixed investment
 qbarinv(C)$CINV(C)=micro_SAM6(C,'savi')/PQ0(C);
 QINV0(C)$CINV(C) =  qbarinv(C);
 IADJ0    = 1;
 FSAV0    = micro_SAM6('savi','rest')/EXR0;
 QINV0(C)$CINV(C) = (SUM(H,SH0(H))+GSAV0+FSAV0)/PQ0(C);
 PRK0  = SUM(C,PQ0(C)*(QINV0(C)/SUM(CP,QINV0(CP))));
 QK0(A) = (KSHR0(A)*(SUM(C,rok*PQ0(C)*QINV0(C))/PRK0));
* QFK0(A) = 0.8*QF0('capital',A)+QK0(A);
 QFK0(A)= QF0('capital',A)*(1+QK0(A)/QF0('capital',A)-0.20);
 WALRAS0=0;
* WALRAS0=SUM(C,PQ0(C)*QINV0(C))-SUM(H,SH0(H))-GSAV0-FSAV0;
 TABS0 =
SUM((C,H),PQ0(C)*QH0(C,H))+SUM(C,PQ0(C)*QG0(C))+SUM(C,PQ0(C)*QINV0(C))+S
UM(C,MARGIN0(C));
 display
trnsfr,YHF0,YF0,QK0,PRK0,QINV0,MARGIN0,SH0,ty,YG0,EG0,shif,WALRAS0,GSAV0,
FSAV0,gamma,EH0,QG0,QH0,bshr,beta,YH0;
***3.VARIABLES
 VARIABLES
*prices
 CPI         consumer price index (PQ-based)
 EXR          exchange rate (dom. currency per unit of for. currency)
 GADJ         government demand scaling factor
 IADJ        investment scaling factor (for fixed capital formation)
 PA(A)       price of activity a
 PVA(A)       value-added price for activity a
 PD(C)       domestic price of domestic output c
 PX(C)       producer price for commodity c
 PDS(C)       supply price for com'y c produced & sold domestically
 PE(C)       export price for c (domestic currency)
 PINTA(A)     price of intermediate aggregate
 PM(C)       import price for c (domestic currency)
 PQ(C)       composite commodity price for c
 PWE(C)      world price of exports
 PWM(C)      world price of imports
**factor market
 QF(F,A)      quantity demanded of factor f from activity a
```

```
QFS(F)        quantity of factor supply
WF(F)         economy-wide wage (rent) for factor f
WFDIST(F,A)   factor wage distortion variable
APR           economywide rental price of capital
KSHR(A)       sector share of new capital
PRK           price of capital
QK(A)         allocation of new capital
QFK(A)        capital stock
**quantities
QA(A)         level of activity a
QX(C)         quantity of aggregate marketed commodity output
QVA(A)        quantity of aggregate value added
QD(C)         quantity sold domestically of domestic output c
QE(C)         quantity of exports for commodity c
QH(C,H)       quantity consumed of commodity c by household h
QINT(C,A)     qnty of commodity c as intermediate input to activity a
QINTA(A)      quantity of aggregate intermediate input
QINV(C)       quantity of investment demand for commodity c
QM(C)         quantity of imports of commodity c
QQ(C)         quantity of goods supplied domestically (composite supply)
QX(C)         quantity of domestic output of commodity c
MARGIN(C)     quantity of trade and transport demand for commodity c
*income & savings
FSAV          foreign savings (foreign currency)
TYAD          direct tax scaling factor
WALRAS        savings-investment imbalance (should be zero)
WALRASSQR     Walras squared
YF(F)         factor income
YHF(H)        transfer of income to household h from factor f
YH(H)         income of household h
EH(H)         household consumption expenditure
SH(H)         household savings
MPS(H)        marginal propensity to save
YG            government revenue
QG(C)         quantity of government consumption
EG            government expenditures
GSAV          government savings
TABS          total absorption
;

*** 4. EQUATION DECLARATIONS
EQUATIONS
*Price block
PMDEF(C)      domestic import price
PEDEF(C)      domestic export price
PDDEF(C)      dem price for com'y c produced and sold domestically
PQDEF(C)      value of sales in domestic market
```

```
 PXDEF(C)       value of marketed domestic output
 PADEF(A)       output price for activity a
 PINTADEF(A)    price of aggregate intermediate input
 PVADEF(A)      value-added price
 CPIDEF         consumer price index
*production & commodity block
 LEOAGGINT(A)   Leontief aggreg intermed dem (if Leontief top nest)
 LEOAGGVA(A)    Leontief aggreg value-added dem (if Leontief top nest)
 QADEF(A)       output levels of  activity a
 PRODFN(A)      Cobb-Douglas production function for AAGR activity
 FACDEM(F,A)    demand for labor from activities
 APRDEF         economy wide rental price of capital
 QKDEF(A)       allocation of new capital to A
 PRKDEF         price of capital
 KSHRDEF(A)     sectoral share of capital
 QFKDEF(A)      capital stock in next period
 INTDEM(C,A)    intermediate demand for commodity c from activity a
 COMPRDFN(C)    production function for commodity c and activity a
 CET(C)         CET function
 CET2(C)        domestic sales and exports for outputs without both
 ESUPPLY(C)     export supply
 ARMINGTON(C)   composite commodity aggregation function
 COSTMIN(C)     first-order condition for composite commodity cost min
 ARMINGTON2(C)  comp supply for com without both dom sales and imports
 QTDEM(C)       demand for transactions (trade and transport) services
*Institution block
 YFDEF(F)       factor incomes
 YHFDEF(H)      factor incomes for households
 YHDEF(H)       total incomes of domest non-govt institutions
 EHDEF(H)       household consumption expenditures
 YHDEF(H)       total incomes of domest non-govt institutions
 SHDEF(H)       household savings
 HMDEM(C,H)     cons demand by hhd h for marketed commodity c
 INVDEM(C)      fixed investment demand
 GOVDEM(C)      government consumption demand
 EGDEF          total government expenditures
 YGDEF          total government income
*System constraint block
 COMEQ(C)       composite commodity market equilibrium
 FACEQ(F)       factor market equilibrium
 CURBAL         current account balance (of RoW)
 GOVBAL         government balance
 SAVINVBAL      savings-investment balance
 TABSEQ         total absorption
 OBJEQ          Objective function
;
```

```
*** 5. EQUATION DEFINITIONS
*Price block
 PMDEF(C)$CM(C).. PM(C) =E= PWM(C)*(1 + tm(C))*EXR;
 PEDEF(C)$CE(C).. PE(C) =E= PWE(C)*(1 - te(C))*EXR;
 PDDEF(C)$CD(C).. PD(C) =E= (QD0(C)*PDS(C)*(1+tmag(C)))/QD0(C);
 PQDEF(C)$(CD(C) OR CM(C)).. PQ(C)*(1-tq(C))*QQ(C) =E=
PD(C)*QD(C)+PM(C)*QM(C);
 PXDEF(C)$CX(C).. PX(C)*QX(C) =E= PDS(C)*QD(C) + PE(C)*QE(C);
 PADEF(A)..       PA(A) =E= SUM(C, PX(C)*theta(A,C));
 PINTADEF(A)..    PINTA(A) =E= SUM(C, PQ(C)*ica(C,A));
 PVADEF(A)..      PVA(A)*QVA(A)=E= PA(A)*(1-ta(A))*QA(A)-PINTA(A)*QINTA(A) ;
 CPIDEF..         CPI =E= SUM(C, cwts(C)*PQ(C)) ;
*production & commodity block
 LEOAGGINT(A)..  QINTA(A) =E= inta(A)*(1-ta(A))*QA(A) ;
 LEOAGGVA(A)..   QVA(A)   =E= iva(A)*(1-ta(A))*QA(A) ;

**lower lvel CD production nest
 PRODFN(A)$alphava(A)..  QVA(A)=E=alphava(A)*PROD(F,QF(F,A)**deltava(F,A));
**payment for factors of production
 FACDEM(F,A)..   QF(F,A) =E= deltava(F,A)*PVA(A)*QVA(A)/WF(F)*WFDIST(F,A);
 APRDEF..  APR =E=
SUM(A,(PRK*QF('capital',A)/SUM(AP,PRK*QF('capital',AP)))*WF('capital')*WFDIST('cap
ital',A));
*output & intermediate demand aggregation
 INTDEM(C,A)$ica(C,A).. QINT(C,A) =E= ica(C,A)*QINTA(A);
**commodity production function
 COMPRDFN(C)$CX(C)..          QX(C) =E= SUM(A,theta(A,C)*QA(A));
*international trade
 ARMINGTON(C)$(CM(C) AND CD(C))..QQ(C)=E= alphaq(C)*(deltaq(C)*QM(C)**(-
rhoq(C))
                 +(1-deltaq(C))*QD(C)**(-rhoq(C)))**(-1/rhoq(C));

 COSTMIN(C)$(CM(C) AND CD(C)).. QM(C) =E=QD(C)*((PD(C)/PM(C))
                 *(deltaq(C)/(1-deltaq(C))) )**(1/(1 + rhoq(C)));

 ARMINGTON2(C)$((CD(C) AND CMN(C)) OR (CM(C) AND CDN(C)))..QQ(C)=E=
QD(C)+QM(C);

 CET(C)$(CE(C) AND CD(C)).. QX(C) =E= alphat(C)*(deltat(C)*QE(C)**rhot(C) +
                        (1 - deltat(C))*QD(C)**rhot(C))**(1/rhot(C)) ;

 ESUPPLY(C)$(CE(C) AND CD(C)).. QE(C)  =E= QD(C)*( PE(C)/PD(C)
                 *(1-deltat(C))/deltat(C) )**(1/(rhot(C)-1) );
 CET2(C)$((CD(C) AND CEN(C)) OR (CE(C) AND CDN(C)) )..QX(C) =E= QD(C) +
QE(C);

 QTDEM(C)$CT(C).. MARGIN(C) =E=  SUM(CP,icd(CP)*QD(CP))/PQ(C);
```

```
***institutional block=
**household income
 YFDEF(F)..YF(F) =E=  SUM(A, WF(F)*WFDIST(F,A)*QF(F,A));
 YHFDEF(H).. YHF(H) =E= shif(H)*SUM(F,(1-tf(F))*YF(F));
 YHDEF(H)..  YH(H)=E=
YHF(H)+trnsfr(H,'govt')*CPI+trnsfr(H,'rest')*EXR+trnshh(H)*CPI;
* EHDEF(H).. EH(H) =E= SUM(C, PQ(C)*QH(C,H));
 EHDEF(H).. EH(H) =E= (1-MPS(H))*((1-ty(H))*YH(H))+trnshh(H)*CPI;
 SHDEF(H).. SH(H)=E= MPS(H)*((1-ty(H))*YH(H));
* HMDEM(C,H)$beta(C,H).. QH(C,H)=E=gamma(C,H)+(beta(C,H)*(EH(H)-
(SUM(CP,PQ(CP)*gamma(CP,H)))))/PQ(C);
 HMDEM(C,H)$beta(C,H).. PQ(C)*QH(C,H)=E=PQ(C)*gamma(C,H)+beta(C,H)*(EH(H)-
SUM(CP,PQ(CP)*gamma(CP,H)));

**investment demand
* INVDEM(C)$CINV(C).. QINV(C)=E=IADJ*qbarinv(C);
 INVDEM(C)$CINV(C).. QINV(C)=E=(SUM(H,SH(H))+GSAV+FSAV)/PQ(C);
 PRKDEF.. PRK=E= SUM(C,PQ(C)*(QINV(C)/SUM(CP,QINV(CP))));
 KSHRDEF(A)..
KSHR(A)=E=(QF('capital',A)/SUM(AP,QF('capital',AP)))*(0.5*(WF('capital')*WFDIST('cap
ital',A)/APR-1)+1);
 QKDEF(A)..  QK(A)=E=KSHR(A)*(SUM(C,rok*PQ(C)*QINV(C))/PRK);
* QFKDEF(A)..  QFK(A)=E=QF('capital',A)*(1+QK(A)/QF('capital',A)-0.20);
**government revenue & expenditure
 GOVDEM(C).. QG(C)=E= GADJ*qbarg(C);
 YGDEF..  YG =E= SUM(H,ty(H)*YH(H))
            +SUM(F, tf(F)*YF(F))
            +SUM(C, tm(C)*PWM(C)*QM(C))*EXR
            +SUM(A,ta(A)*PA(A)*QA(A))
            +SUM(C, te(C)*PWE(C)*QE(C))*EXR
            +SUM(C, tq(C)*PQ(C)*QQ(C))
            +trnsfr('govt','rest')*EXR;
 EGDEF..  EG =E=
SUM(C,PQ(C)*QG(C))+trnsfr('rest','govt')*EXR+SUM(H,trnsfr(H,'govt'))*CPI;

***system constraint block
 FACEQ(F).. SUM(A, QF(F,A)) =E= QFS(F);
 COMEQ(C).. PQ(C)*QQ(C)$(CD(C) OR CM(C))=E=
SUM(A,PQ(C)*QINT(C,A))+SUM(H,PQ(C)*QH(C,H))+PQ(C)*QG(C)+PQ(C)*QINV(C)+P
Q(C)*MARGIN(C);
 CURBAL.. SUM(C,PWM(C)*QM(C))+trnsfr('rest','govt')=E=SUM(C,
PWE(C)*QE(C))+SUM(H,trnsfr(H,'rest'))+trnsfr('govt','rest')+FSAV*EXR;
 GOVBAL.. GSAV =E= YG-EG;
 SAVINVBAL.. SUM(C,PQ(C)*QINV(C))=E=SUM(H,
SH(H))+GSAV+FSAV*EXR+WALRAS;
```

```
TABSEQ..TABS=E=SUM((C,H),PQ(C)*QH(C,H))+SUM(C,PQ(C)*QG(C))+SUM(C,PQ(C)
*QINV(C))+SUM(C,MARGIN(C));
* OBJEQ..        WALRASSQR=E=WALRAS*WALRAS;

*MODEL
MODELS
 CGE5  Open-economy model
 /
*Price block (10)
 PMDEF.PM
 PEDEF.PE
 PDDEF.PD
 PQDEF.PQ
 PXDEF.PX
 PADEF.PA
 PINTADEF.PINTA
 PVADEF
 CPIDEF
*Production and trade block (17)
 LEOAGGINT
 LEOAGGVA
 PRODFN
 FACDEM
 APRDEF
 INTDEM.QINT
 COMPRDFN
 CET
 CET2
 ESUPPLY
 ARMINGTON
 COSTMIN
 ARMINGTON2
 QTDEM.MARGIN
*Institution block (12)
 YFDEF.YF
 YHFDEF.YHF
 YHDEF.YH
 EHDEF.EH
 SHDEF
 HMDEM.QH
 EGDEF.EG
 YGDEF.YG
 GOVDEM.QG
 INVDEM.QINV
 QKDEF
 PRKDEF
```

```
 KSHRDEF
* QFKDEF
*System-constraint block (9)
 FACEQ
 COMEQ.QQ
 CURBAL
 GOVBAL
 SAVINVBAL.WALRAS
 TABSEQ.TABS
* OBJEQ
 /
 ;
*INITIALISATION
 GADJ.L      = GADJ0;
* IADJ.L      = IADJ0;
 CPI.L       = CPI0;
 EH.L(H)     = EH0(H);
 EG.L        = EG0;
 EXR.L       = EXR0;
 FSAV.L      = FSAV0;
 GSAV.L      = GSAV0;
 PA.L(A)     = PA0(A);
 PD.L(C)     = PD0(C);
 PDS.L(C)    = PDS0(C);
 PE.L(C)     = PE0(C);
 PINTA.L(A)  = PINTA0(A);
 PM.L(C)     = PM0(C);
 PQ.L(C)     = PQ0(C);
 PVA.L(A)    = PVA0(A);
 PWE.L(C)    =PWE0(C);
 PWM.L(C)    =PWM0(C);
 PX.L(C)     = PX0(C);
 PRK.L       = PRK0;
 QA.L(A)     = QA0(A);
 QD.L(C)     = QD0(C);
 QE.L(C)     = QE0(C);
 QF.L(F,A)   = QF0(F,A);
 QFS.L(F)    = QFS0(F);
 QK.L(A)     = QK0(A);
 KSHR.L(A)   = KSHR0(A);
* QFK.L(A)    = QFK0(A);
 WF.L(F)     = WF0(F);
 WFDIST.L(F,A)= WFDIST0(F,A);
 APR.L       = APR0;
 QH.L(C,H)   = QH0(C,H);
 QINT.L(C,A)  = QINT0(C,A);
 QINTA.L(A)   = QINTA0(A);
```

```
QINV.L(C)    = QINV0(C);
QG.L(C)      = QG0(C);
QM.L(C)      = QM0(C);
QQ.L(C)      = QQ0(C);
QX.L(C)      = QX0(C);
MARGIN.L(C)  = MARGIN0(C);
QVA.L(A)     = QVA0(A);
YG.L         = YG0;
YH.L(H)      = YH0(H);
YF.L(F)      = YF0(F);
SH.L(H)      =SH0(H);
YHF.L(H)     = YHF0(H);
WALRAS.L     = WALRAS0;
TABS.L       = TABS0;

*DISPLAY
*alphava1, alphava_L,alphava_LL, alphaq,     alphat,     beta, deltaq, deltat,  cwts,    ica,
*theta,  qbarg,   qbarinv, rhoq,rhot, te,sigmaq, sigmat, tm,tq, tf,tbary
* ;
*DISPLAY
*PA.L, PD.L, PDS.L,PE.L, PINTA.L, PM.L, PQ.L, PVA.L, PWE.L, PWM.L, PX.L,
*QA.L, QD.L, QE.L, QF.L, QH.L, QINT.L, QINV.L, QM.L,  QQ.L,   QX.L, QXAC.L,
*QT.L, QVA.L, YF.L, YHF.L,YH.L
*;
*10. FIXING VARIABLES NOT IN MODEL AT ZERO
 PD.FX(C)$(NOT CD(C)) = 0;
 PDS.FX(C)$(NOT CX(C)) = 0;
 PE.FX(C)$(NOT CE(C)) = 0;
 PM.FX(C)$(NOT CM(C)) = 0;
 PX.FX(C)$(NOT CX(C)) = 0;
 PINTA.FX(A)$(NOT QINTA0(A))=0;
 PQ.FX(C)$(NOT QQ0(C)) = 0;
 PVA.FX(A)$(NOT QVA0(A))=0;
 QA.FX(A)$(NOT micro_SAM6('total',A))=0;
 QD.FX(C)$(NOT CD(C)) = 0;
 QM.FX(C)$(NOT CM(C)) = 0;
 QX.FX(C)$(NOT CX(C)) = 0;
 QE.FX(C)$(NOT CE(C)) = 0;
 QF.FX(F,A)$(NOT QF0(F,A))=0;
 QFK.FX(A)$(NOT QFK0(A))=0;
 QFS.FX(F)$(NOT QFS0(F))=0;
 QK.FX(A)$(NOT QK0(A))=0;
 WF.FX(F)$(NOT WF0(F))=0;
 WFDIST.FX(F,A)$(NOT WFDIST0(F,A))=0;
 QG.FX(C)$(NOT micro_SAM6(C,'govt')) = 0;
 QH.FX(C,H)$(NOT beta(C,H)) = 0;
 QINT.FX(C,A)$(NOT micro_SAM6(C,A)) = 0;
```

```
 QINTA.FX(A)$(NOT QINTA0(A)) = 0;
 QINV.FX(C)$(NOT CINV(C)) = 0;
 QM.FX(C)$(NOT CM(C)) = 0;
 QVA.FX(A)$(NOT QVA0(A))=0;
 QQ.FX(C)$(NOT PQ0(C))=0;
 MARGIN.FX(C)$(NOT CT(C)) = 0;
 QX.FX(C)$(NOT CX(C)) = 0;
 YH.FX(H)$(NOT YH0(H))= 0;
 YHF.FX(H)$(NOT YHF0(H)) = 0;
 YF.FX(F)$(NOT (SUM(A,micro_SAM6(F,A)))) = 0;
*SELECTING CLOSURES
$ONTEXT
In the simulation file, SIM.GMS, the user chooses between
alternative closures. Those choices take precedence over the choices
made in this file.

In the following segment, closures is selected for the base model
solution in this file. The clearing variables for micro and macro
constraints are as follows:

FACEQUIL - WF: for each factor, the economywide wage is the
market-clearing variable in a setting with perfect factor mobility across
activities.

CURACCBAL - EXR: a flexible exchange rate clears the current account of
the RoW.

GOVBAL - GSAV: flexible government savings clears the government
account.

SAVINVBAL - SADJ: the savings rates of domestic institutions are scaled
to generate enough savings to finance exogenous investment quantities
(investment-driven savings).

The CPI is the model numeraire.
$OFFTEXT
**labor market
 WFDIST.FX('labor',A) = WFDIST0('labor',A);
 WF.LO('labor')      = -INF;
 WF.UP('labor')      = +INF;
 WF.L('labor')       = WF0('labor');
 QF.LO('labor',A)          = -INF;
 QF.UP('labor',A)          = +INF;
 QF.L('labor',A)     = QF0('labor',A);
 QFS.FX('labor')     = QFS0('labor');
**capital market
 WFDIST.LO('capital',A) = -INF;
```

```
 WFDIST.UP('capital',A) = +INF;
 WFDIST.L('capital',A)  = WFDIST0('capital',A);
* WFDIST.FX('capital',A)  = WFDIST0('capital',A);
 WF.FX('capital')       = WF0('capital');
 QF.FX('capital',A)     = QF0('capital',A);
 QFS.LO('capital')      = -INF;
 QFS.UP('capital')      = +INF;
 QFS.L('capital')       = QFS0('capital');
***foreign exchange market closure
 PWM.FX(C)  = PWM0(C);
 PWE.FX(C)  = PWE0(C);
 FSAV.FX = FSAV0;
 EXR.LO  = -INF;
 EXR.UP  = +INF;
 EXR.L   = EXR0;
**savings-investment closure
 MPS.FX(H) = MPS0(H);
* IADJ.FX    = IADJ0;
* MPS.LO('hurb') = -INF;
* MPS.UP('hurb') = +INF;
* MPS.L('hurb')  = MPS0('hurb');
* MPS.FX(H)  = MPS0(H);
**government closure
 GSAV.LO   = -INF;
 GSAV.UP   = +INF;
 GSAV.L   = GSAV0;
* GADJ.UP  = +INF;
* GADJ.LO  = -INF;
* GADJ.L   =  GADJ0;
 GADJ.FX   =  GADJ0;
* MARGIN.FX(C)=MARGIN0(C);
* CPI.FX    = CPI0;
* PDS.FX(C) =PDS0(C);

*SOLVE STATEMENT FOR BASEoption limrow=15;
CGE5.scaleopt= 1;
CGE5.HOLDFIXED= 1;
CGE5.TOLINFREP= .0001 ;
option domlim=5
option reslim=1000;
OPTION MCP=MILES;
EXECERROR=0;
SOLVE CGE5 USING MCP;
*QF.FX('capital',A)=2*QF0('capital',A);
*SOLVE CGE5 USING MCP;

DISPLAY
```

PA.L,PD.L,PE.L,PM.L,PQ.L,PVA.L,PWE.L,PWM.L,PX.L,WF.L,WFDIST.L,QA.L,QD.L,QE.L,
alphava,deltava,QVA.L,QF.L,QFK.L,QK.L,KSHR.L,QH.L,QINTA.L,QINV.L,QE.L,QM.L,QQ.L,QX.L,YHF.L,YH.L,
YG.L,EG.L, QK.L,WALRAS.L;

Appendix 3 GAMS codes for CGE simulation file

```
*REPORT SETUP AND BASE REPORT

*SET AND PARAMETERS FOR REPORTS

SET
 SIM  simulations
    /BASE      base simulation
     ADAPN     productivity shock without adaptation
     ADAPT     productivity shock without adaptation
    /
 ACGDP  GDP items
 /
 GDPMP1  GDP at market prices (from spending side)
 PRVCON  private consumption
 GOVCON  government consumption
 INVEST  investment
 EXP     exports of goods and servicers
 IMP     imports of goods and servicers
 NITAX   net indirect taxes
 GDPFC   GDP at factor prices
 GDPMP2  GDP at market prices (from income side)
 GDPGAP  gap bt alternative calculations for GDP at market prices
 /

 ACGDP1(ACGDP)  components of GDP at market prices
 /
 PRVCON  private consumption
 GOVCON  government consumption
 INVEST  investment
 EXP     exports of goods and servicers
 IMP     imports of goods and servicers
 /
;
 PARAMETERS
 ALPHAVASIM(A,SIM,YR)  productivity prameter for A
 QFSIM(F,A,SIM,YR)     factor demand at time
 QFSSIM(F,SIM,YR)      factor supply at time
 FSAVSIM(SIM,YR)       foreign savings
 GSAVSIM(SIM,YR)       government savings
 GAMASIM(C,H,SIM,YR)   minimum consumption
 IADJSIM(SIM,YR)       investment adjustment factor
 GADJSIM(SIM,YR)       government expendiyure adjustment
 TRNSHHSIM(H,SIM,YR)   transfer to household from other households
 TRNSHGSIM(H,SIM,YR)   transfer to household from government
 TRNSHRSIM(H,SIM,YR)   transfer to household from rest of world
```

TRNSGRSIM(SIM,YR) transfer to government from rest of world
TRNSRGSIM(SIM,YR) transfer to rest of world from government
QXSIM(C,SIM,YR) total output

ALPHAVAREP(A,SIM,YR) productivity prameter for ANAGR
QFSREP(F,SIM,YR) supply of labor
QFREP(F,A,SIM,YR) demand for labor
FSAVREP(SIM,YR) foreign savings (foreign currency)
GSAVREP(SIM,YR) government savings
GAMAREP(C,H,SIM,YR) minimum consumption
GADJREP(SIM,YR) government expenditure adjustment
TRNSHHREP(H,SIM,YR) transfer to household from other households
TRNSHGREP(H,SIM,YR) transfer to household from government
TRNSHRREP(H,SIM,YR) transfer to household from rest of world
TRNSGRREP(SIM,YR) transfer to government from rest of world
TRNSRGREP(SIM,YR) transfer to rest of world from government
WFREP(F,SIM,YR) average wage of factor
WFAREP(F,A,SIM,YR) sector specific wage
WFDISTREP(F,A,SIM,YR) wage distortion factor
APRREP(SIM,YR) average profit rate
PWEREP(C,SIM,YR) world export price
PWMREP(C,SIM,YR) world import price
CPIREP(SIM,YR) consumer price index
PRKREP(SIM,YR) unit price of capital at time t
QKREP(A,SIM,YR) quantity of new capital by AAGR at time t
KSHRREP(A,SIM,YR) sectoral share in capital stock
EXRREP(SIM,YR) exchange rate (dom. currency per unit of for. currency)
IREP(SIM,YR) total investment
IADJREP(SIM,YR) investment scaling factor (for fixed capital formation)
SHREP(H,SIM,YR) household savings
PAREP(A,SIM,YR) price of activity a
PVAREP(A,SIM,YR) value-added price for activity a
PDREP(C,SIM,YR) domestic price of domestic output c
PXREP(C,SIM,YR) producer price for commodity c
PDSREP(C,SIM,YR) supply price for com'y c produced & sold domestically
PEREP(C,SIM,YR) export price for c (domestic currency)
PINTAREP(A,SIM) price of intermediate aggregate
PMREP(C,SIM,YR) import price for c (domestic currency)
PQREP(C,SIM,YR) composite commodity price for c
QAREP(A,SIM,YR) level of activity a
QXREP(C,SIM,YR) quantity of aggregate marketed commodity output
QVAREP(A,SIM,YR) quantity of aggregate value added
QDREP(C,SIM,YR) quantity sold domestically of domestic output c
QEREP(C,SIM,YR) quantity of exports for commodity c
QHREP(C,H,SIM,YR) quantity consumed of commodity c by household h
QINTREP(C,A,SIM,YR) qnty of commodity c as intermediate input to activity a
QINTAREP(A,SIM,YR) quantity of aggregate intermediate input

```
QINVREP(C,SIM,YR)   quantity of investment demand for commodity c
QMREP(C,SIM,YR)     quantity of imports of commodity c
QQREP(C,SIM,YR)     quantity of goods supplied domestically (composite supply)
QXREP(C,SIM,YR)     quantity of domestic output of commodity c
MARGINREP(C,SIM,YR) quantity of trade and transport demand for commodity c
FSAVREP(SIM,YR)     foreign savings (foreign currency)
WALRASREP(SIM,YR)   savings-investment imbalance (should be zero)
YFREP(F,SIM,YR)       factor income
YHFREP(H,SIM,YR)       transfer of income to household h from factor f
YHREP(H,SIM,YR)       income of household h
EHREP(H,SIM,YR)       household consumption expenditure
YGREP(SIM,YR)         government revenue
QGREP(C,SIM,YR)       quantity of government consumption
EGREP(SIM,YR)         government expenditures
TABSREP(SIM,YR)       total absorption
QDSTREP(SIM,YR)       stock change
GDPREP(*,SIM,YR)      nominal GDP data
EVREP(H,SIM,YR)       equivalent variation
;

**Macro and factor closures
**capital demand projections
QFSIM('capital',A,SIM,YR)  = QF0('capital',A)*(1.10**(ORD(YR)-1));

**labor supply projection
QFSSIM('labor',SIM,YR)  = QFS0('labor')*(1.03**(ORD(YR)-1));

**government expenditure projection
GADJSIM(SIM,YR) = GADJ0*(1.03**(ORD(YR)-1));

**household minimum consumption projection
GAMASIM(C,H,SIM,YR) = gamma(C,H)*(1.03**(ORD(YR)-1));

**transfer payments & receipts projections
TRNSHGSIM(H,SIM,YR) = trnsfr(H,'govt')*(1.03**(ORD(YR)-1));

TRNSHHSIM(H,SIM,YR) = trnshh(H)*(1.03**(ORD(YR)-1));

TRNSHRSIM(H,SIM,YR) = trnsfr(H,'rest')*(1.03**(ORD(YR)-1));

TRNSRGSIM(SIM,YR)   = trnsfr('rest','govt')*(1.03**(ORD(YR)-1));

TRNSGRSIM(SIM,YR)   = trnsfr('govt','rest')*(1.03**(ORD(YR)-1));

**agriculturalproductivity shock for major food crops
ALPHAVASIM(A,SIM,YR)=alphava(A);
ALPHAVASIM('acass','ADAPN',YR) = alphava('acass')*(1-(0.010051*(ORD(YR)-1)));
```

```
ALPHAVASIM('amaiz','ADAPN',YR) = alphava('amaiz')*(1-(0.028316*(ORD(YR)-1)));
ALPHAVASIM('asorg','ADAPN',YR) = alphava('asorg')*(1+(0.0068476*(ORD(YR)-1)));
ALPHAVASIM('arice','ADAPN',YR) = alphava('arice')*(1+(0.0032888*(ORD(YR)-1)));
ALPHAVASIM('ayams','ADAPN',YR) = alphava('ayams')*(1+(0.0121122*(ORD(YR)-1)));
ALPHAVASIM('acass','ADAPT',YR) = alphava('acass')*(1-(0.003173*(ORD(YR)-1)));
ALPHAVASIM('amaiz','ADAPT',YR) = alphava('amaiz')*(1-(0.020534*(ORD(YR)-1)));
ALPHAVASIM('asorg','ADAPT',YR) = alphava('asorg')*(1+(0.043331*(ORD(YR)-1)));
ALPHAVASIM('arice','ADAPT',YR) = alphava('arice')*(1+(0.0028104*(ORD(YR)-1)));
ALPHAVASIM('ayams','ADAPT',YR) = alphava('ayams')*(1+(0.02628*(ORD(YR)-1)));

DISPLAY

ALPHAVASIM,GAMASIM,QFSSIM,GADJSIM,TRNSHRSIM,TRNSHGSIM,TRNSGRSI
M,TRNSRGSIM;

LOOP((SIM,YR),
alphava(A)          = ALPHAVASIM(A,SIM,YR);
trnshh(H)           = TRNSHHSIM(H,SIM,YR);
trnsfr(H,'govt')    = TRNSHGSIM(H,SIM,YR);
trnsfr(H,'rest')    = TRNSHRSIM(H,SIM,YR);
trnsfr('govt','rest') = TRNSGRSIM(SIM,YR);
trnsfr('rest','govt') = TRNSRGSIM(SIM,YR);
gamma(C,H)          = GAMASIM(C,H,SIM,YR);

**labor market
WFDIST.FX('labor',A) = WFDIST0('labor',A);
WF.LO('labor')      = -INF;
WF.UP('labor')      = +INF;
* WF.L('labor')     = WF0('labor');
QF.LO('labor',A)    = -INF;
QF.UP('labor',A)    = +INF;
* QF.L('labor',A)   = QF0('labor',A);
QFS.FX('labor')     = QFSSIM('labor',SIM,YR);
**capital market
WFDIST.LO('capital',A) = -INF;
WFDIST.UP('capital',A) = +INF;
* WFDIST.L('capital',A)  = WFDIST0('capital',A);
WF.FX('capital')      = WF0('capital');
QF.FX('capital',A)    = QFSIM('capital',A,SIM,YR);
QFS.LO('capital')     = -INF;
QFS.UP('capital')     = +INF;
* QFS.L('capital')    = QFS0('capital');
***foreign exchange market closure
PWM.FX(C)  = PWM0(C);
PWE.FX(C)  = PWE0(C);
FSAV.LO    = -INF;
FSAV.UP    = +INF;
```

```
* FSAV.L     = FSAV0;
 EXR.FX     = EXR0;
**savings-investment closure
* MPS.FX('hrur') = MPS0('hrur');
* MPS.LO('hurb') = -INF;
* MPS.UP('hurb') = +INF;
 MPS.FX(H)  = MPS0(H);
**government closure
 GSAV.LO   = -INF;
 GSAV.UP   = +INF;
* GSAV.L   = GSAV0;
* GADJ.UP  = +INF;
* GADJ.LO  = -INF;
* GADJ.L   =  GADJ0;
 GADJ.FX   =  GADJSIM(SIM,YR);
* MARGIN.FX(C)=MARGIN0(C);
* CPI.FX    = CPI0;
* PDS.FX(C) =PDS0(C);

 option limrow=15;
 CGE5.scaleopt= 1;
 CGE5.HOLDFIXED= 1;
 CGE5.TOLINFREP= .0001 ;
 option domlim=5 ;
 option reslim=1000;
 OPTION MCP=MILES;
* EXECERROR=0;
 DISPLAY "Before solve", alphava;
 SOLVE CGE5 USING MCP;
 DISPLAY "After solve",alphava;

 ALPHAVAREP(A,SIM,YR)=alphava(A);
 WFAREP(F,A,SIM,YR)   = WF.L(F)*WFDIST.L(F,A);
 WFREP(F,SIM,YR)= WF.L(F);
 WFDISTREP(F,A,SIM,YR)= WFDIST.L(F,A);
 QFREP(F,A,SIM,YR)    = QF.L(F,A);
 QFSREP(F,SIM,YR)     = QFS.L(F);
 PWEREP(C,SIM,YR)     = PWE.L(C);
 PWMREP(C,SIM,YR)     = PWM.L(C);
 FSAVREP(SIM,YR)      = FSAV.L;
 GSAVREP(SIM,YR)      = GSAV.L;
 CPIREP(SIM,YR)       = CPI.L ;
 TRNSHHREP(H,SIM,YR)  = trnshh(H);
 TRNSHGREP(H,SIM,YR)  = trnsfr(H,'govt');
 TRNSHRREP(H,SIM,YR)  = trnsfr(H,'rest');
 TRNSGRREP(SIM,YR)    = trnsfr('govt','rest');
 TRNSRGREP(SIM,YR)    = trnsfr('rest','govt');
```

```
 GAMAREP(C,H,SIM,YR)  = gamma(C,H);
 PRKREP(SIM,YR)       = PRK.L;
 QKREP(A,SIM,YR)      = QK.L(A);
 KSHRREP(A,SIM,YR)   = KSHR.L(A);
 EGREP(SIM,YR)        = EG.L;
 EXRREP(SIM,YR)       = EXR.L;
 APRREP(SIM,YR)       = APR.L;
 PAREP(A,SIM,YR)      = PA.L(A);
 PMREP(CM,SIM,YR)     = PM.L(CM);
 PDREP(C,SIM,YR)      = PD.L(C);
 PEREP(CE,SIM,YR)     = PE.L(CE);
 PQREP(C,SIM,YR)      = PQ.L(C);
 PVAREP(A,SIM,YR)     = PVA.L(A);
 PXREP(C,SIM,YR)      = PX.L(C);
 QAREP(A,SIM,YR)      = QA.L(A);
 QDREP(C,SIM,YR)      = QD.L(C);
 QEREP(CE,SIM,YR)     = QE.L(CE);
 QHREP(C,H,SIM,YR)    = QH.L(C,H);
 QINTREP(C,A,SIM,YR)  = QINT.L(C,A);
 QINVREP(C,SIM,YR)    = QINV.L(C);
 QMREP(CM,SIM,YR)     = QM.L(CM);
 QQREP(C,SIM,YR)      = QQ.L(C);
 QXREP(C,SIM,YR)      = QX.L(C);
 QGREP(C,SIM,YR)      = QG.L(C);
 EHREP(H,SIM,YR)      = EH.L(H);
 YFREP(F,SIM,YR)      = YF.L(F);
 YHFREP(H,SIM,YR)     = YHF.L(H);
 YGREP(SIM,YR)        = SUM(H,ty(H)*YH.L(H))+SUM(F, tf(F)*YF.L(F))+SUM(C,
tm(C)*PWM.L(C)*QM.L(C))*EXR.L
                 +SUM(A,ta(A)*PA.L(A)*QA.L(A))+SUM(C,
te(C)*PWE.L(C)*QE.L(C))*EXR.L
                 +SUM(C, tq(C)*PQ.L(C)*QQ.L(C))+trnsfr('govt','rest')*EXR.L;
 YHREP(H,SIM,YR)      =
YHF.L(H)+trnsfr(H,'govt')*CPI.L+trnsfr(H,'rest')*EXR.L+trnshh(H)*CPI.L;
 SHREP(H,SIM,YR)      = MPS.L(H)*((1-ty(H))*YH.L(H));
 IREP(SIM,YR)         = SUM(H,SH.L(H))+GSAV.L+FSAV.L;
 IREP(SIM,YR)         = SUM(C,QINV.L(C)*PQ.L(C));
 WALRASREP(SIM,YR)    = WALRAS.L;
 EVREP(H,SIM,YR)      = YH.L(H)*PROD(C,((PQ0(C)/PQ.L(C))**bshr(C,H)))-YH0(H);

**GDP data
 GDPREP('PRVCON',SIM,YR) = SUM((C,H), PQ.L(C)*QH.L(C,H)) ;
 GDPREP('GOVCON',SIM,YR) = SUM(C, PQ.L(C)*QG.L(C));
 GDPREP('INVEST',SIM,YR) = SUM(C, PQ.L(C)*QINV.L(C));
 GDPREP('EXP',SIM,YR)    = SUM(C, EXR.L*PWE.L(C)*QE.L(C));
 GDPREP('IMP',SIM,YR)    = - SUM(C, EXR.L*PWM.L(C)*QM.L(C));
 GDPREP('GDPFC',SIM,YR ) = SUM(F,YF.L(F));
```

```
 GDPREP('NITAX',SIM,YR)
  = SUM(C, tq(C)*(PD.L(C)*QD.L(C) + (PM.L(C)*QM.L(C))$CM(C)))
  + SUM(C$CM(C), tm(C)*EXR.L*PWM.L(C)*QM.L(C))
  + SUM(C$CE(C), te(C)*EXR.L*PWE.L(C)*QE.L(C));

) ;

*Processing GDP data
* GDPREP('GDPMP1',SIM,YR)= SUM(ACGDP1, GDPREP(ACGDP1,SIM,YR));

GDPREP('GDPMP1',SIM,YR)=GDPREP('PRVCON',SIM,YR)+GDPREP('GOVCON',SIM,Y
R)
                 +GDPREP('INVEST',SIM,YR)+GDPREP('EXP',SIM,YR)
                 +GDPREP('IMP',SIM,YR)+ GDPREP('NITAX',SIM,YR);

 GDPREP('GDPMP2',SIM,YR)= GDPREP('GDPFC',SIM,YR)+GDPREP('NITAX',SIM,YR);
 GDPREP('GDPGAP',SIM,YR)  = GDPREP('GDPMP1',SIM,YR) -
GDPREP('GDPMP2',SIM,YR);

*ALPHAVAREP(A,SIM,YR)=ALPHAVAREP(A,SIM,YR)/ALPHAVAREP(A,'BASE',YR);
QXREP(C,SIM,YR)=QXREP(C,SIM,YR)/QXREP(C,'BASE',YR);
QEREP(CE,SIM,YR)=QEREP(CE,SIM,YR)/QEREP(CE,'BASE',YR);
QMREP(CM,SIM,YR)=QMREP(CM,SIM,YR)/QMREP(CM,'BASE',YR);
EVREP(H,SIM,YR)=EVREP(H,SIM,YR)/EVREP(H,'BASE',YR);
GDPREP('GDPFC',SIM,YR)=GDPREP('GDPFC',SIM,YR)/GDPREP('GDPFC','BASE',YR);
ALPHAVAREP(A,SIM,YR)=ALPHAVAREP(A,SIM,YR)/ALPHAVAREP(A,'BASE',YR);

OPTION  GDPREP:3:1:1,QHREP:3:1:1, QINTREP:3:1:1,  YFREP:3:1:1
QFREP:3:1:1,QFSREP:3:1:1,WFREP:3:1:1, WFDISTREP:3:1:1
;
DISPLAY
ALPHAVAREP,GAMAREP,QGREP,APRREP,WFAREP,WFDISTREP,QFREP,KSHRREP,
QFSREP,PWEREP,PWMREP,FSAVREP,GSAVREP,CPIREP,PRKREP,QKREP,QINVREP,
YHREP,YGREP,EHREP,YFREP,QQREP,EGREP,QINTREP,QHREP,QDREP,QAREP,
GDPREP,EXRREP,PXREP,PVAREP,PQREP,PEREP,PDREP,PMREP,PAREP,QXREP,
SHREP,EVREP,EXRREP,GDPREP,QMREP,QEREP,WALRASREP,GDPREP,TRNSHHRE
P,TRNSHGREP,TRNSHRREP,TRNSGRREP,TRNSRGREP
;
```