Impact of Climate Variables on Revenue of Major Food Crops in Ghana: Ricardian Cross-Sectional Analysis

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Abstract

This study analyzes the impact of climate on net revenues of five major food crops in Ghana using 2005 national survey data. A multinomial logit regression is used to correct for crop selection bias in estimation of net revenue per hectare. Results of a multinomial logit regression show that farmers are likely to switch from the cultivation of maize, sorghum and rice to cassava and yam with marginal warming. Marginal increase in rainfall prompts farmers to switch from cassava and yam to the cultivation of maize, sorghum and rice. After incorporating selectivity bias, it was found that warming raises revenues from cassava, maize and sorghum but reduces that of rice and yam; additional rainfall reduces revenues of all crops except rice. With the exception of maize and sorghum, the choice of food crops to grow is motivated by higher net revenues per hectare obtainable from the cultivation of those crops. Marginal warming tends to increase expected net revenue in all ecological zones in Ghana but with much higher positive effect if farmers adapt to changing climate by switching crops. Marginal decrease in rainfall reduces expected net revenue in all ecological zones but reverses the losses into positive returns if farmers switch crops as a way of adapting to climate. This study suggests public investment in research on high yielding, heat and drought tolerant varieties of the above mentioned food crops in order to make crop switching a more beneficial exercise for farmers.

1. Introduction

The importance of agriculture to the economies of most developing countries cannot be overemphasized. The agricultural sector has a high share in national output while at the same time employs the largest share of the labor force in many developing countries. 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 region as a whole (UNECA, 2005). The agricultural sector remains the primary source of employment in sub-Saharan Africa, accounting for approximately 70% of the total employment in the late 1990s (Delgado, 1995). Evidence consistently shows that agricultural growth is highly effective in reducing poverty. Gallup and Warner (1997) report from a cross-country study that every 1% increase in per capita agricultural output led to a 1.61% increase in the incomes of the poorest 20% of the population.

Despite visible contribution 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

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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 percent 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 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 others 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 paper uses national survey data to assess the impact of climate on major food crops using structural Ricardian model. This approach incorporates efficient adaptive response 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.

The rest of this paper is structured as follows: next section describes climate and crop production in Ghana; section three discusses the empirical strategy for this research; section four presents and discusses model results; section five discusses climate impact on expected net revenue; and section six concludes the paper.

2. Climate and crop production in Ghana

Agriculture engages about 57% of the economically active population in Ghana (GSS, 2005) and contributes about 30% to Gross Domestic Product (GDP). 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 and to a lesser extent, rice, maize and pineapples. 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 in Ghana varies by agro-ecological zones. Broadly speaking, there are four ecological zones: Guinea savanna, transition, forest and coastal savanna zones (see Appendix 1). The guinea savanna zone covers northern, upper east and upper west regions, where climate, soils and other physical conditions, are 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. The forest zone covers greater part of 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 where crops like maize is cultivated twice a year. The coastal savanna covers Greater Accra and Central regions and crops like maize and vegetables can be grown in this zone. The transition zone covers greater part of the Volta and Brong-Ahafo regions, known for cultivation of cereals and cocoa (see Figure 1). In all ecological zones, mean annual temperature is generally high ranging from 24 °C to 30 °C. The wettest area is the extreme southwest in the forest zone where annual rainfall is about 2000 millimeters. The driest area is wedge-like strip in the coastal savanna zone where the annual rainfall is about 750 millimeters.

This paper focuses on five major food crops only of cassava, maize, sorghum, 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 and grown in those regions of the country predicted to be adversely affected by climate change. They constitute about 80% of food crops contribution to agricultural GDP) and feature prominently in the diet of most Ghanaians (Breisinger and Duncan, 2007). Supply of rice has a high import component. Ghana is currently self-sufficient in the production of the above-mentioned crops except rice.

Figure 1. Political and relief map of Ghana
Source: http://www.vidiani.com

3. 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, 2008). 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 (1) and (2) below are econometric specification of net revenue and crop choice equations respectively.

$$\pi_i = X_i\beta_j + U_j \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$\pi_{ji} = Z_j\gamma_j + \epsilon_j \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

Z_j is a vector of explanatory variables for crop choice equation; X_i is a vector of independent variables for the revenue equation; π is net revenue per hectare, β and γ vector of coefficients for revenue and crop choice equations respectively; U_j and ϵ_j are the error terms for revenue and crop choice equations respectively.

Efficient and consistent estimates of equation (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 $\in_j$ is independently and identically Gumbel distributed, logistic specification of equation (2) as in equation (3) below, indicating the probability (P_{ji}) that a farmer chooses a particular crop, is estimated by multinomial logistic regression at the first stage.

$$P_{ji} = \frac{exp(Z\gamma)}{\sum_{k=1}^{k} exp(Z\gamma)} \quad \ldots\ldots\ldots\ldots\ldots \quad (3)$$

At the second stage, equation (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 (4) below is the selection bias corrected (conditional) revenue regression based on equation (1):

$$\ln \pi_j = X_j \varphi_j + \sigma \sum_{i \neq j}^{J} r_i \left(\frac{P_i \, lnP_i}{1-P_i} + lnP_i \right) + w_i \quad \ldots\ldots\ldots\ldots\ldots \quad (4)$$

$\ln \pi_i$ is the logarithm of net revenue per hectare; the second term on the right-hand side is the selection bias correction term; X_j is a vector of independent variables including climate variables; φ_j is a vector of parameters; and w_i is the error term. $\ln P_i$ is logarithm of crop probability (P_i); σ stands for standard deviation of error term in equation (2); and r_i is the correlation coefficient between error terms in equations (1) and (2). The above correction of selection bias provides fairly good estimation of net crop revenue even if crop choices are not completely independent of each other (Bourguignon 2007).

In this study, the above technique is implemented using 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 (see crops growing calendar in Appendix 1). The climate data is, then, matched with the farming households in the GLSS V.

Description and summary statistics of model variables can be found in Appendix 2. Log of net revenue per hectare is calculated as the logarithmic transformation of the difference of the 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 farmland. The vector of independent variables X_j 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 logarithm of farm size. The independent variable for the crop choice equation, Z_j, includes all explanatory variables for the revenue equation in X_j above and the prices of the crops in question(cassava, maize, sorghum, rice and yam). The inclusion of variables for crop prices in crop choice equation but not in the revenue equation is to ensure model identification.

Having estimated equations (3) and (4), expected revenue of a typical farm W_i is calculated as the sum of the probabilities of each crop choice times the conditional net revenue of that crop choice as follows:

$$W_i = \sum_{j=1}^{J} P_j \left(Z_{ji}\right) . \pi_j \left(Z_{ji}\right). \quad \ldots\ldots\ldots\ldots\ldots \quad (5)$$

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) is differentiated with respect to climate variables to obtain equation (6) below:

$$\frac{\partial W}{Z_c} = \frac{\partial P_j}{\partial Z_c} \cdot \pi_j + \frac{\partial \pi_j}{\partial Z_c} \cdot P_j \quad \ldots\ldots\ldots\ldots\ldots \quad (6)$$

Marginal effect of climate variables on probability of crop selection, $\partial P_j / Z_c$, is estimated by differentiating equation (3) as follows:

$$\frac{\partial P_j}{\partial Z_c} = P_j \left[\gamma_j - \sum_{k=1}^{J} P_k \gamma_k \right] \quad \ldots\ldots\ldots\ldots\ldots \quad (7)$$

The marginal effect of climate variables on conditional net revenue, $\partial\pi_j/Z_c$, can also be estimated by differentiating equation (4) as shown below:

$$\frac{\delta\pi_j}{\delta z_c} = \varphi_j\pi_j \quad \ldots\ldots\ldots\ldots\ldots \quad (8)$$

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, 2008).

The approach was first applied in the United States (U.S.) 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, 2006). Seo and Mendelsohn (2008) 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.

4. Presentation of results and discussion

This study estimates a model for farmers' choice of which crops to grow and then a model of net revenue per hectare conditional on those choices. This model is estimated in a two stage process. At the first stage, equation (3) is estimated using multinomial logit method. At the second stage, equation (4) is estimated using Ordinary Least Squares (OLS) method. In the ensuing sections, the results of these two equations are presented and discussed.

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 as in Table 1 below. The dependent variable is crop choice variable, indicating five major food crops grown in Ghana (cassava, maize, sorghum, rice and yam). Mean monthly temperatures 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 the price variables for the selected crops.

Table 1 above presents the regression results of the multinomial logit model. There are 19,861 observed plots in the regression. The coefficients on household size are negative and significant indicating maize, sorghum and yam but insignificant for rice. This implies that maize, sorghum and yam are less often chosen in smaller households but the omitted choice, cassava, is often chosen in larger households. The coefficients on age of heads household head have significant positive effect on maize but not on other crops, meaning that older household heads tend to select maize while younger heads choose the omitted choice, cassava. Coefficients on female household heads and household education are positive for maize, sorghum and yam but not significant for rice, implying that these crops are often grown by female heads while, the omitted crop, cassava are often grown by males. Coefficients on log of farm size are negative for all crops indicating that cassava is often grown on large farms while smaller farms grow the other crops. Own prices tend to have negative effect on crops. That is, price per kilogram of maize reduces selection of maize and this is true for all other crops. This is so because higher prices are often as a result of higher input prices thereby negatively affecting crop selection. In terms of cross-price effects, price per kilogram of maize, sorghum, rice and yam has no significant effect on the probability of selecting other crops. Price per kilogram of cassava, however, influences positively on the probability of selecting other crops except rice. The positive coefficient on cross-price terms indicates substitutability in crop selection between crops. Cassava price reduces selection of cassava while increasing the probability of selecting maize, sorghum and yam.

Table 1. Multinomial logit crop choice regressions in Ghana

Variables	Maize	Sorghum	Rice	Yam
constant term	38.0128***	30.1371***	78.3215***	-82.3334***
	(2.0644)	(1.7649)	(1.9569)	(2.8760)
temperature (°C)	-1.5605***	-1.1935***	-3.0931***	3.0609***
	(0.0819)	(0.0706)	(0.0783)	(0.1094)
rainfall (cm)	0.1496***	0.1090***	0.1754***	0.0217
	(0.0112)	(0.0111)	(0.0111)	(0.0156)
Household size	-0.0407***	-0.0363***	0.0140	-0.1512***
	(0.0132)	(0.0105)	(0.0113)	(0.0155)
Age of household head	0.0095***	0.0026	0.0017	0.0019
	(0.0026))	(0.0021)	(0.0023)	(0.0028)
female household head	0.2872***	0.4700***	-0.0340	1.4097***
	(0.1071)	(0.0901)	(0.0968)	(0.1112)
Education of household head	0.0170*	0.0676***	0.0098	0.1829***
	(0.0096)	(0.0079)	(0.0083)	(0.0097)
Log of farm size	-0.1743***	-0.1565***	-0.0641*	-0.3836***
	(0.0372)	(0.0302)	(0.0330)	(0.0390)
Log of cassava price	9.6763***	9.6225***	9.7046	10.2971***
	(0.5720)	(0.4339)	(0.3850)	(1.6126)
Log of maize price	-6.3672***	-0.0324	0.0016	-0.0268
	(0.3679)	(0.3567)	(0.3556)	(0.7955)
Log of sorghum price	0.1279	-6.8150***	0.3374	0.1329
	(0.9167)	(0.6370)	(0.9495)	(0.5235)
Log of rice price	-0.8695	-0.0306	-9.3485***	0.6175
	(1.6297)	(0.9962)	(1.1070)	(1.3603)
Log of yam price	-0.1088	-0.0923	-0.0696	-5.3340***
	(0.7239)	(0.5269)	(0.6832)	(0.5524)

Notes: *** means significant at 1%, ** means significant at 5% and * means significant at 10%; number of observations=19,861; LR chi2 (48) =36889.31***, Pseudo R^2=0.6789 and Log likelihood=-13520.389; This model correctly predicts 67.03% for cassava, 71.03% for maize, 57.87% 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.
Source: authors' calculations

Climate variables have statistically significant effect on the probability of selecting most crops. The coefficients on temperature are negative for maize, sorghum and rice but positive for yam. This means that higher temperature decreases the probability of selecting maize, sorghum and rice but increases the selection of yam and cassava. The coefficients on rainfall are significantly positive for maize, sorghum and rice but statistically insignificant for yam, indicating higher rains increase the likelihood of selecting maize, sorghum and rice but reduces the probability of selecting, the omitted choice, cassava. Since coefficients in Table 1 are maximum likelihood estimates, they cannot be used to assess average impact of climate variables on crop choice. Average impact of climate variables on the probability of selecting crops in Ghana is presented in Table 2 below:

Table 2. Marginal effects of climate variables on the Probability of selecting crops

Crop	Base	temperature (°C)	rainfall (cm)
Cassava	32.93%	30.55%	-2.87%
Maize	24.81%	-15.70%	1.55%
Sorghum	26.78%	-7.12%	0.59%
Rice	11.29%	-24.45%	1.00%
Yam	4.19%	16.72%	-0.27%

Notes: The marginal change denotes 1 °C increase in temperature and 1cm increase in rainfall
Source: calculated using multinomial logit regression coefficients

From Table 2 above, the probability of selecting cassava, maize, sorghum, rice and yam are 32.93%, 24.81%, 26.79%, 11.46% and 4.19% respectively. Marginal increase in temperature is likely to prompt farmers to switch from maize, sorghum and rice to cultivation of cassava and yam, which are more tolerant to heat. The marginal increase in rainfall reduces the selection of the tuber crops (cassava and yam) and increase the selection of the water loving cereals (maize, sorghum and rice). That is, in warm and dry places, cassava and yam are likely to be selected while in cooler and wet locations, maize, sorghum and rice will be more preferable.

4.2 Climate impact on conditional crop revenue

The impact of climate variables on revenues from major food crops is assessed using selection bias corrected (conditional) revenue equation (equation 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 3 below shows the results of conditional net revenue regressions with selection bias correction terms of the five major crop species cultivated in Ghana. Household size has significant positive effect on net revenues of cassava, maize and yam and no

Table 3. Conditional revenue regressions of major food crops in Ghana

Variables	Cassava	Maize	Sorghum	Rice	Yam
Intercept	-4.7480*	-15.4082***	5.3134	22.2116***	17.0505**
	(3.0052)	(1.6496)	(5.0001)	(5.2682)	(2.8608)
temperature (°C)	0.3863***	0.8161***	0.1970***	-0.7177***	-0.0489
	(0.1189)	(0.0669)	(0.1684)	(0.2049)	(0.0833)
rainfall (cm)	-0.0614***	-0.0889***	-0.3996***	0.0036*	-0.0650*
	(0.0105)	(0.0126)	(0.1347)	(0.0036)	(0.0402)
household size	0.0668***	0.0777***	0.0762	0.0418	0.0509***
	(0.0103)	(0.0092)	(0.0224)	(0.0248)	(0.0138)
age of household head	0.0029	-0.0025	0.0012	-0.0053	0.0010
	(0.0027)	(0.0023)	(0.0041)	(0.0047)	(0.0038)
Female household head	-0.0256	-0.2407**	-0.3585	-0.3480	0.0248
	(0.0766)	(0.1216)	(0.3237)	(0.04347)	(0.1272)
Education of household head	-0.0068	-0.0037	-0.0036	0.0430	-0.0400***
	(0.0087)	(0.0078)	(0.0272)	(0.0252)	(0.0125)
Log of farm size	-0.9733***	-0.7488***	-1.0396***	-0.7951***	-0.7329***
	(0.0274)	(0.0277)	(0.0555)	(0.0893)	(0.0725)
Cassava selection		-0.2392	2.9103**	-4.5334*	6.4662
		(1.6184)	(4.3125)	(2.2265)	(26.7830)
Maize selection	4.9308**		1.6545	1.3782	16.0761
	(2.3772)		(12.4737)	(2.1884)	(148.4792)
Sorghum selection	-3.3822***	0.4824		3.8372*	-14.6135
	(1.0398)	(0.9598)		(1.3378)	(25.0608)
Rice selection	-0.6834	-0.0084	-0.7181		-6.6597
	(0.8289)	(0.9054)	(5.1579)		(128.2462)
Yam selection	-0.9599	-0.2568	-3.9643***	-0.8925	
	(1.1183)	(0.9599)	(2.6049)	(2.0686)	
R-squared	0.3727	0.2736	0.4105	0.2688	0.1747
F-statistic	78.43***	62.74***	34.69***	9.29***	15.69***
N	1464	1844	560	290	827

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

significant effect on other crops. Positive effect of household size on some of the crops is not surprising because family labor support farmers during planting, weeding and harvesting periods especially in a developing country such as Ghana. Age of household head has no significant effect on revenues of all crops. There is no significant difference in net revenue between male- and female-headed families except maize. Male heads receive higher revenues from the cultivation of maize as compared to their female counterparts. Educational attainment of the household head has not significant influence on all crops except yam. Less educated heads have higher revenues from growing yam. 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 results if this model were to be estimated using unadjusted OLS regression. 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. Farmers for whom the selection model predicts would select maize but actually selects cassava earn higher net revenue. Farmers, who the selection model predicts would select sorghum, will earn lower net revenue if they actually choose cassava and higher revenue if they actually select rice. Farmers, who the selection model predicts would select yam but actually select sorghum, earn lower net revenue.

Most climate variables have statistically significant impact on net revenues of crops. Mean monthly temperature has significant positive effect on net revenues of cassava, maize and sorghum but negative effect on rice revenue. Marginal increase in temperature significantly increases cassava, maize and sorghum revenues by 38.63%, 81.61% and 19.70% respectively whereas rice and yam revenues significantly reduce by 71.77%. Temperature has no significant effect on yam revenue. Rainfall has negative influence on revenues from cassava, maize, sorghum and yam but predictably positive effect on rice revenue. Marginal increase in rainfall significantly reduces cassava, maize, sorghum and yam revenue by 6.14%, 8.89%, 39.39% and 6.507% respectively but significantly increases rice net revenue by 0.36%. This implies that rainfall during the growing seasons of most crops is adequate and any marginal increase in rainfall is likely to be less beneficial to all crops in Ghana except rice.

Results of the crop revenue regressions in Table 3 are partly consistent with that of the crop selection equation in Table 2. For instance, marginal increase in temperature increases the probability of selecting cassava and this is informed by increase in cassava revenue. Reduced selection for rice resulting from warming is matched by decrease in rice revenue. Similarly, increase in rainfall reduces net revenues of cassava and yam and this is matched by increased probability of selecting these crops. Marginal increase in rainfall also increases revenue from rice resulting in increased likelihood of selecting rice. The direction of impact of climate variables on the probability of selecting maize and sorghum is not matched by that of net revenue. This 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.

5. Impact of climate variables on expected net revenue

This section assesses the impact of climate on expected net revenue (long term net revenue) across the three major ecological zones 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. From equations (5) and (6), climate impact on expected net revenue can be estimated.

It can be seen from Table 4 below that expected revenue per hectare for the five major crops is about GHS 450.99 with significant variations across ecological zones. The highest expected revenue is observed in the coastal zone and lowest in the savanna zone. Marginal warming increases expected net revenue by 42.61%, 60.87% and 50.93% for coastal, forest and savanna ecological zones respectively as shown in the fourth column. If farmers adapted to change in climate by switching among crops, warming would raise expected net revenue by 64.57%, 78.18% and 74.93% for coastal, forest and savanna zones respectively as in the third column. In the case of rainfall, marginal drying increases expected net revenue by 18.18%, 12.48% and 9.97% for coastal, forest and savanna zones respectively if there is crop switching as shown in the fifth column. Expected net revenue, however, reduces by 3.35%, 4.55% and 4.25% for coastal, forest and savanna zones respectively if there is not crop switching as can be seen in the sixth column.

Table 4. Impact of climate on expected net revenue in Ghana

Ecological zones	expected revenue	temperature (switching)	temperature (no switching)	rainfall (switching)	Rainfall (no switching)
Coastal	562.08	362.95 (64.57)	239.53 (42.61)	103.80 (18.18)	-18.83 (3.35)
Forest	457.66	357.79 (78.18)	278.59 (60.87)	57.11 (12.48)	-20.81 (4.55)
Savanna	381.36	285.76 (74.93)	193.73 (50.80)	38.04 (9.97)	-16.20 (4.25)
Ghana	450.99	334.15 (74.09)	242.36 (53.74)	59.27 (13.14)	18.88 (4.18)

Notes: increase in temperature by 1 °C and a decrease in rainfall by 1 cm; all figures are in Ghana Cedis (GHS), monetary currency of Ghana. As of 2005, 1GHS=0.92 United States Dollars. The figures in parenthesis are in percentages.

6. Conclusion and recommendation

This study analyzes the impact of climate on selection and on revenues of five major food crops in Ghana in a two-stage process. At the first stage, a multinomial logit regression is used to analyze the effect of climate variables on choice of crops by farmers 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. Using national survey data, it is found that marginal warming during the growing season is likely to prompt farmers to switch from maize, sorghum and rice to the cultivation of cassava and yam. Marginal increase in rainfall can compel farmers to switch from cassava and yam to the cultivation of maize, sorghum and rice. Farmers' choice of crops is partly consistent with revenue predictions. Marginal warming increases (decreases) the probability of selecting cassava (rice), and this is matched by increase (decrease) in cassava (rice) revenue. Additional rainfall reduces net revenues of cassava and yam and this is matched by increased probability of selecting these crops. Marginal increase in rainfall also increases revenue from rice resulting in increased likelihood of rice selection. The direction of impact of climate variables on the probability of selecting maize and sorghum is not, however, explained by net revenue, implying 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 better explain the irrational choice of these crops.

Changing climate will not have same effect across space. Even without adaptation through crop switching, marginal warming will raise expected net revenue across all ecological zones in Ghana but the positive effects will be enhanced through appropriate adaptation through crop switching. Marginal drying without crop switching reduces expected net revenue across all ecological zones but the negative effects will be reversed through damage reducing effects of 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 switch to others crops can use only the available varieties. In this regard, public investment in research on high yielding, heat and drought tolerant varieties of the above mentioned food crops is suggested in order to make crop switching a beneficial exercise for farmers.

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Appendix 1. Cropping calendar for major food crops in Ghana

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Guinea savanna zone												
Cassava												
Maize												
Sorghum												
Rice												
Yam												
Rainforest zone												
Maize												
Maize												
Rice												
Cassava												
Transition zone												
Maize												
Maize												
Sorghum												
Rice												
Cassava												
Yam												
Coastal savanna zone												
Cassava												
Maize												
Maize												
Yam												

Legend
Plantingperiod Growingperiod Harvestingperiod

Source: Food and Agriculture Organization (http://www.fao.org/agriculture/seed/cropcalendar/searchbycountry.do)

Appendix 2. Description and summary statistics of model variables

Variables	Description	Cassava	Maize	Sorghum	Rice	Yam
Log of net revenue per hectare (GHS)	log of gross crop revenue minus costs of inputs including fertilizer, irrigation, hired labor and pesticide	5.0392 (1.7411)	4.4175 (1.6164)	3.9189 (1.7347)	3.2539 (1.6623)	4.6942 (1.6687)
temperature (°C)	monthly mean maximum temperature (°C) from 1961 to 2010 in effective growing seasons for crops	25.9420 (0.6968)	25.9523 (0.4079)	26.1945 (0.5855)	25.7124 (0.8577)	27.7005 (1.2890)
rainfall (cm)	monthly mean rainfall (cm) from 1961 to 2010 in the effective growing seasons for crops	13.2717 (3.3811)	16.1344 (3.2120)	14.7792 (3.2505)	28.0656 (46.3065)	14.5713 (3.0632)
Household size	number of individuals living in a household	4.7496 (2.8507)	5.2810 (3.2020)	6.1012 (3.3475)	5.9284 (3.5159)	5.5827 (3.2332)
Age of household head	age in years of the head of household	46.7608 (14.7051)	45.8503 (14.7515)	46.1108 (14.4565)	45.4189 (14.1823)	46.3183 (14.5928)
Gender of household head	dummy variable (0=male; 1=female)	0.2470 (0.4313)	0.1690 (0.3749)	0.0896 (0.2857)	0.1189 (0.3239)	0.1398 (0.3469)
Education of household head	number of years spent in attending school by household head	4.0628 (4.8727)	3.3435 (4.7580)	1.6792 (3.8341)	2.2919 (4.2673)	2.9294 (4.5378)
Log of farm size		-0.1076 (1.0571)	0.2203 (1.1045)	0.5406 (0.9020)	0.5280 (0.9160)	0.4627 (0.9949)
Log of cassava price	log of price per kilogram of maize in 2005	-1.1518 (0.7220)				
Log of maize price	log of price per kilogram of maize in 2005		-1.2094 (0.6540)			
Log of sorghum price	log of price per kilogram of millet in 2005			-0.7738 (0.6618)		
Log of rice price	log of price per kilogram of sorghum in 2005				-0.4479 (0.5704)	
Log of yam price	log of price per kilogram of rice in 2005					-1.7910 (0.8608)
Observations		1464	1844	560	290	827

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