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Assessing the impact of climate change on smallholder farmers' crop net revenue in Togo

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Abstract: This study employs a Ricardian modelling approach to measure the impact of climate change variables such as temperature and rainfalls on smallholder famers' crop net revenue in Togo. The obtained results show that climate has a nonlinear effect on crop net revenue. In rainy season, the marginal impact of temperature on revenue shows that if the temperature increases by 1°C, the net crop revenue may fall by US$340.33/ha. On the other hand, if rainfalls increase by 10 mm, the net revenue may increase by US$35.5/ha. A warming of 2°C will lead to a decrease by 62.02% in the net revenue in 2050. Also, a decrease in rainfalls by 2.5% in 2025 will lead to 0.82% fall in the net revenue, while 7.85% fall in the net revenue are expected with 10% decrease in rainfalls in 2050. Similarly, an increase of 2°C in the temperature and a decrease of 10% in rainfalls will lead to 80.75% fall in the net revenue in 2050 in Togo. Other variables such as educational attainment, access to extension services and livestock ownership are found to have positive impact on farmers' crop net revenue. Consequently, policies aimed at improving those factors could improve smallholder farmers' wellbeing.

Keywords: Climate change, revenue, Ricardian approach, Togo

Introduction

Climate change may well force large regions of marginal agriculture out of production in Africa, given the extreme vulnerability of agriculture to climate change (IPCC, 2001). The agriculture sector in Africa will be particularly sensitive to future climate change and any increase in climate variability. Besides, with the rapid population growth– especially in developing countries-food insecurity has become a major threat to people that are already poor. Globally, countries in West Africa are among the most vulnerable to the effects of climate change because of the reliance of the population on rain-fed agriculture. The vulnerabilities are worsened by a host of biophysical and human-related factors including soil degradation, low input farming systems, decreased fallow period, deforestation, frequent bush fires, and overgrazing (USAID, 2011). The Intergovernmental Panel on Climate Change (IPCC, 2007) defines climate change as statistically significant variations in climate that persist for an extended period, typically a decade or longer. It includes shifts in the frequency and magnitude of sporadic weather events as well as the slow but continuous rise in global mean surface temperature. Climate change has become a new reality. It brings changes in weather patterns that can have serious repercussions, modifying seasonal cycles, harming ecosystems and water supply, affecting agricultural farming systems and food production, causing sea-levels to rise. The phenomenon is expected to be more severe in Africa, where current information is the poorest, technological change the slowest, and the domestic economies depend heavily on agriculture (Mendelsohn *et al.*, 2000).

According to the Togolese Minister of the Environment and Forestry (MERF, 2001), 70% of the Togolese population practice agriculture as their main activity, making agriculture the most important sector of the economy. Agriculture accounts for about 38% of the country's gross domestic product (GDP). In addition, agriculture represents more than 20% of export receipts (MERF, 2010). Despite its high contribution to the overall economy, the Togolese agriculture is predominantly rain-fed and fundamentally dependent on weather fluctuations. Less than 1% of cultivated areas in Togo are under irrigation (FAO, 2005). Therefore, changes in rainfalls conditions may impact both the performance of agricultural sector and the country's total gross domestic product. The mean annual temperature has increased by 1.1˚C since 1960 with an average of 0.24˚C increase per decade in Togo whereas annual rainfalls are highly variable on inter-annual and inter-decadal timescale (McSweeney et al., 2009). Rainfalls were particularly high in the 1960s and decreased to particularly low levels in the late 1970s and early 1980s causing an overall decreasing trend in the period from 1960 to 2006. In addition, the 2008 flooding in Togo destroyed 24,956 hectares of crops, representing 56% of cultivated areas (MERF, 2010). Maize and sorghum are the mostly consumed staple crops and are particularly vulnerable to climate change because of their strong sensitivity to water stress especially at flowering stage. Based on Global Circulation Models (GCMs), the mean annual temperature is projected to increase from 1.0 to 3.1˚C by the 2060, and 1.5 to 5.3˚C by the 2090 in Togo (McSweeney *et al.*, 2009). Precipitation-wise, a wide range of changes is projected (McSweeney *et al.*, 2009). In addition, the IPCC's 2025, 2050 and 2100 scenarios have projected decreasing production of major crops at 5%, 7% and 10%, respectively (MERF 2010).

To the best of our knowledge, there are few studies to date which have investigated climate change impacts on farmers' revenue using cross-sectional data distributed across a representative sample of farmers' population in Togo. The objective of the present study is to assess the impacts of climate change on smallholder farmers' crop production-based revenue in Togo using the Ricardian modelling approach. Specifically, the study will (1) analyse the relationship between farmers' net revenue and climate variables such as rainfall and temperature, (2) identify factors explaining significantly farmers' net revenue, (3) determine the marginal impact of temperature and rainfalls on farmers' crop revenues and (4) evaluate the effects of climate change on farmers' revenue on the basis of specific climate change scenarios for Togo (RCP8.5). The study is organized as follows. The next section presents a brief background on climate change effects on agriculture drawing on the assessments observed in the recent literature. Subsequently, the materials and the methods used are presented to stress the importance of the Ricardian approach in the climate change impacts studies and the interest of the specific dataset used for this study. The results of the econometric estimations and their meanings are given in section four. The conclusion and recommendations drawn from this study are offered in the last section.

Background on climate change impact on agriculture assessments based on Ricardian approach

Originally developed by Mendelson *et al.* (1994) to measure the value of climate in the United States' agriculture, the Ricardian model is a cross-sectional analysis of the impact of climate on land value and farm revenue. The technique has been named "Ricardian method" because it is based on the observation made by Ricardo (1817) that land value would reflect its productivity under perfect competition. Generally using cross-sectional data, the Ricardian analysis aims at studying the land value and net revenues on climatic, agronomic and input variables to quantify the impact of climate change. Mendelson *et al.* (1994) found that under a scenario of 5°F temperature rise and 8% increase in precipitation, farm land values are expected to decrease by an amount between US$119 billion and US$141 billion. This represents an annual decrease of about 5% in 1982 gross farm income. However, when using the crop-revenue model, farm land values rise by an amount between US$20 billion and US$35 billion which represents an annual increase in gross revenues of about 1%. The discrepancies in these results are attributed to the differences in weights on different geographic areas and different crops across models. It is assumed that farmers choose agricultural activities in order to maximise revenue, given the environmental conditions (Blanc, 2011).

Ouedraogo *et al.* (2006) used the Ricardian cross-sectional approach to measure the relationship between climate and net revenue from growing crops in Burkina Faso. This study looked at the impact of several variables including climate, soil, relevant hydrologic and socio-economic indicators on the net revenue of crops. Three models were tested (one without adaptation, one with adaptation and one with a dummy zone variable). The data for the analysis is based on cross-sectional data on household and district level. These include farm household, climate, soils and hydrology data. The authors found that a temperature increase of 1°C results in a revenue decline of 19.9 US$/ha. If precipitation increases by 1 mm/month, net revenue will increase by 2.7 US$/ha. In addition, the study revealed that some variables used in the regression can be effective as adaptation options. Extension service and irrigation are significant, and positively affect net revenue. Furthermore, they show that a 5°C increase in the temperature correspond to farmers losing 93% of their net revenues obtained from crops. Farmers would also lose their entire net revenue from crops if precipitations decrease by 14%. Similar studies undertaken in Cameroon by Molua and Lambi (2006) employed a Ricardian cross-sectional approach to measure the relationship between climate and the net revenue from crops. Net revenue is regressed on climate, water flow, soil and economic variables. The farm-level and household information was collected and climate data including satellite data (temperature and soil moisture) were used. They found that 5°C increase in the temperature would cause net revenues to fall by $1.7 billion and 14% decrease in precipitation would cause net revenues to fall by $3.8 billion.

Kumar and Parikh (1998) as well as Sanghi *et al*. (1998) employed the net revenue approach and used pooled observations from 1966 to 1986 for India. Kumar and Parikh (1998) found that the effect of temperature (increase) is negative. The impact of precipitation (increase) is positive but is smaller in magnitude than the temperature effect, so the global effect is negative. They estimated a 8.7% decrease in net revenues when considering a uniform climate scenario of +2°C and +7% mean precipitation change. Under the same scenario, Sanghi et al. (1998) estimated a larger decrease in farmers' net revenues (12.3%). Under no change in precipitation and a slight temperature increase (+1°C) scenario, Sanghi *et al*. (1998) estimated revenue effect (-8.8%) is also larger than those of Kumar and Parikh (1998) (-3.2%).

Conversely, a study realized by the economic commission for Latin America and the Caribbean (ECLAC, 2011) used crop yield in Jamaica instead of land value or net revenue as the dependent variable. This study justifies the procedure by the fact that Jamaica has underdeveloped property markets rendering land value difficult to determine and hence makes the original Ricardian model inapplicable. Therefore, it uses a modified version of the Ricardian model where crop yield is the dependent variable. The data on price of sugarcane, output of sugarcane per hectare, cost of production, soil types, and monthly rainfalls and temperature for the major estates were used. The results showed that a unit increase in the ratio of price to production will lead to 0.12 increase in sugarcane output per hectare. According to the model, for sugarcane production to be maximized, rain in the growing season (April to July) must be greater than or equal to the optimal minimum of 189.93 mm per month. And, the increase in temperature above the average temperature of 29.43 °C has a negative impact on sugarcane yield.

Several other studies applied the Ricardian analyses to assess climate change impact on agriculture in Africa. These studies were published as discussion papers by the Centre for Environmental Economics and Policy in Africa (CEEPA).

They include studies in Kenya (Kabubo-Mariara and Karanja, 2006), Egypt (Eid *et al.*, 2006), South Africa (Benhin, 2006 and Gbetibouo and Hassan, 2005), Senegal (Sene *et al.*, 2006), Zambia (Jain, 2006), Zimbabwe (Mano and Nhemachena, 2006), and Ethiopia (Deressa, 2006). In detail, Kabubo-Mariara and Karanja (2006) showed that increased winter temperatures are associated with higher crop revenue, but increased summer temperatures have a negative impact. Increase in rainfall is positively correlated with net crop yield. They also established that andosols, irrigation and household size are positively correlated with revenue, but livestock ownership, farm size and wage rates are inversely correlated with crop revenue. While Mano and Nhemachena (2006) estimated that Zimbabwean farm net revenues will decrease by 31% and 36% relative to the mean of the sample when temperature increases by 2.5°C and 5°C, respectively.

UNDP (2011) has undertaken the econometric analysis of climate change effect on households in Togo by using the Ricardian approach. In addition to climate variables such as temperature and rainfalls, UNDP (2011) has also considered the number of agricultural machines, fertiliser consumption, percentage of agricultural population, percentage of irrigated area and arable lands as other variables. Time series data were used in the study which covered 1960 to 2010. It was found that climate variables explained up to 33.8% the variation of the agricultural added value in Togo. Moreover, UNDP (2011) disclosed that in short term, an increase of temperature and rainfalls will affect positively the agricultural added value while a quadratic increase of the same climate variables will have a negative impact on the latter. These results mirrored those found by Molua (2009) for Cameroun and Kabuko-Mariana and Karanja (2006) for Kenya. Mikémina (2013) used the Ricardian approach to measure the effect of climate change on agriculture performance in Togo, applying time series data from the period 1971-2004. He found that there exists a nonlinear relationship between agricultural added value and recorded rainfalls during the cropping period. This is a confirmation of the results of Ouedraogo *et al.* (2006) in Burkina Faso and Kabubo-Mariara and Karanja (2006), who suggested a non-linear relationship between temperature and revenue, on the one hand, and between rainfalls and revenue, on the other. In addition, Mikémina (2013) pointed out that marginal impacts are mostly in line with the Ricardian model, showing that marginally increasing rainfalls during rainy season would increase net farm income, but reduce by the square terms of this season. Furthermore, he argued that other variables, such as ratio of irrigated farm land and farm labor, are found to have positive impact on net farm value.

Instead of ad hoc adjustments of parameters that are characteristic of traditional approach, the Ricardian approach is preferred to the traditional estimation methods, because it automatically incorporates efficient adaptations by farmers to climate change (World Bank, 2003). In addition, applying this model is cost effective, since secondary data on cross-sectional sites can be easily collected on climate, production and socio-economic factors (Deressa and Hassan, 2009). Besides, the Ricardian model is used for a comparative assessment of with and without adaptation scenarios in agriculture (Ouedraogo et al, 2006; Benhin, 2006).

Despite the popularity of the Ricardian approach it has several limitations. Early Ricardian studies on agriculture (Mendelsohn *et al*., 1994; 1996) have been criticized because they did not include irrigation and other sources of water in the analysis (Darwin, 1999). Another criticism of the method is that it treats price as constant (Cline, 1996) - because the inclusion of price effects is problematic and the Ricardian approach is weaker for it (Mendelsohn *et al*., 1994). By holding prices constant, the Ricardian model underestimates damages and overestimates benefits. Furthermore, the Ricardian method, as a cross-section analysis, does not account for dynamic transition costs which can occur as farms move between two states. For example, if a farmer has crop failures for a year or two as he learns about a new crop, this transition cost is not reflected in the analysis. Similarly, if the farmer makes the decision to move to a new crop suddenly, the model does not capture the cost of decommissioning capital equipment prematurely (Kurukulasuriya and Mendelsohn, 2008). However, these problems are significant but not fatal (Mendelsohn *et al*., 2000).

Therefore, the Ricardian model is the methodological approach which is used in the present study. This research differs from the existing literature in two noteworthy ways; (1) it uses cross section dataset that covers all the regions of the country's districts, (2) for the future climate impact assessment on crop production in Togo, it uses the results of climate models for specific scenarios downscaled to West Africa (Representative Concentration Pathway 8.5) released by IPCC in 2013, instead of using uniform scenarios found in the existing literature.

Materials and Methods

Study Area

This study, which focuses on the economic impact of climate change on farmers' revenues, covers all the 35 prefectures of Togo (See Appendix figure 1). At latitudes of

6-12˚N, the climate of Togo is tropical; it is strongly influenced by the West African Monsoon. According to McSweeney *et al.* (2009), the rainy seasons of Togo are controlled by the movement of the tropical rain belt (also known as the Inter-Tropical Conversion Zone, ITCZ), which oscillates between the northern and southern tropics over the course of a year. The dominant wind direction in regions south of the ITCZ is south-west, blowing moisture from the Atlantic onto the continent, but the prevailing winds north of the ITCZ come from the north-east, bringing hot and dusty air from the Sahara desert (known as the Harmattan). As the ITCZ migrates between its northernmost and southernmost positions over the course of the year, the regions between these northernmost and southernmost positions of the ITCZ experience a shift between the two opposing prevailing wind directions. This pattern is referred to as the West African Monsoon.

In northern Togo, there is a single rainy season occurring between May and November, when the ITCZ is in its northern position and the prevailing wind is south-west, and a dry season between December and March, when the Harmattan wind blows from north to east. The northern and central regions receive between 200-300mm per month in the peak months of the rainy season (July to September). The southern regions of Togo have two rainy seasons, one from March to July, and a shorter rainy season from September to November, corresponding to the northern and southern passages of the ITCZ across the region. In Togo, arable lands represent approximately 3.6 million of hectares, accounting for 60% of the total area of the country. However, the cultivated area is estimated at 1.4 million hectares, which represents 41% of the arable lands (Koffi-Tessio, 2013).

Approach and methods of the study

Given the market price P_i for good *i*, and assuming that farmers are profit maximising agents, operating under perfect competition, land market will drive profits to zero. That is, the land rental value per hectare will be equal to the discounted sum of future net revenue per hectare P_L. Consequently land value (V) will reflect the present value of future net productivity (Mendelsohn and Dinar, 2003) such that

$$V = \int_0^\infty p_L \, e^{-\delta t} dt \qquad (1)$$

$$V = \int_0^\infty \left[\sum_i \frac{(P_i Q_i(K_i,E) - C_i(\,Q_i,W,E))}{L_i}\right] \; e^{-\delta t} dt \qquad (2)$$

Where Q_i is the quantity produced of good *i* and K_i is a vector of all purchased inputs in the production of good *i*. *E* is a vector of exogenous environmental variables such as climate factors (temperature, rainfalls, etc.), soil types and economic factors (market, credit access, etc.), which are common to any farm. p_L is the annual cost or rent of land and L_i is the area of land under the production of good *i*. Bearing in mind that c_i is the cost function for all purchased inputs other than land and w is the vector of inputs' prices. δ is the discount rate and t represents time. The interest of this analysis is to measure the impact of exogenous changes in environmental variables (E) on land value as captured by changes in land values across various environmental conditions. By regressing farm values on climate, soil and other control variables, the method enables measuring the marginal contribution of each variable to land value.

The empirical estimation of the Ricardian model for Togo is an extended version of the standard model in order to capture the distinctiveness of the climate in Togo. Therefore, zone dummy variables were introduced in the empirical model for Togo to capture the climate impact across regions. Some variables such as latitude, altitude, flood-prone and wetland included in the original model (Mendelsohn *et al.*, 1994) were not taken into account in the present study because of lack of data. Some socio-economic variables–household size, education attainment, access to extension services and livestock ownership–which were not included in the original model are part of the present study in order to capture farmers' adaptation effect to climate change.

$$V = \beta_0 + \beta_1 T_r + + \beta_2 (T_r)^2 + \beta_3 T_d + \beta_4 (T_d)^2 + \beta_5 R_r + \beta_6 (R_r)^2 + \beta_7 R_d + \beta_8 (R_d)^2 + \sum_{i=1}^{n} b_i \, Soil_i + \sum_{j=1}^{n} c_j \, Z_j + D_z + u_i \quad (3)$$

The dependent variable V is crop net revenue per hectare whereas the variables T and R represent respectively vectors of temperature and rainfalls. The index represents rainy season and dry season, while D_z are regional dummies (for the 5 administrative regions in Togo). Z_j is a set of socio-economic characteristics of the farms, while β_i, b_i and c_j are coefficients to be estimated, β_0 is a constant term and u_i is an error term. In orde to capture the potential nonlinear relationship between net revenue and climate change, quadratic terms of temperature and rainfalls are introduced in the model.

Based on this model, the change in the revenue from a marginal change in temperature or precipitation evaluated at a particular vector of seasonal temperatures T or rainfalls R in rainy season, for example, is:

$$\frac{\partial V_i}{\partial T} = \beta_1 + 2\beta_2 \bar{T} \quad (4)$$

$$\frac{\partial V_i}{\partial R} = \beta_3 + 2\beta_4 \bar{R} \quad (5)$$

The dependent variable of the model is net farm revenue per hectare, while independent variables are rainfalls, temperature, soil and other socio-economic characteristics. The net farm revenue is calculated for each agricultural household and is defined as being the value of the gross crop revenue minus the associated production costs. The cost elements include expenditure on transport, fertilizer, pesticide, seeds and hired labor. Other costs include farmland rent, interest paid on loans and household labor; but these were excluded from the estimation of the costs. The gross revenue per hectare is the product of total harvest and price of the crop divided by the area in hectares.

The temperature and rainfalls variables are estimated in degree Celsius and mm/month, respectively. In Togo, the climate varies according to the southern or northern regions. Globally, the southern regions (Maritime and Plateaux) include four seasons: the long dry season from mid-November to March, the long rainy season from March or April to July, the short dry season from August to September and the short rainy season from September to mid-November. The central and the northern regions (Kara and Savannah) are subject to two seasons: the rainy season from May to October and the dry season from November to April. The temperature and rainfalls are computed based on the various seasons mentioned above

Until 1992, studies on soil were undertaken mainly by two institutions namely ORSTOM (Office de la Recherche Scientifique et Technique d'Outre-Mer) and the National Institute of Soil (INS) of Togo. The researchers of ORSTOM : Lamouroux (1969), Vieillefon et al, (1969), Levêque (1979), Faure (1985), Le Coq (1986), Poss (1996) have made soil maps on various scales ranging from 1/100 000 to 1/50 000. When putting them side by side, they cover the entire national territory of Togo. The National Institute of Soil unlike ORSTOM, has made soil maps on scales 1/50 000 to 1/2000 or 1/1 000. According to them, the dominant soils in Togo are Ferruginous soils, Ferralsol and hydromorphic soils. Based on the World Reference Base for Soil Resources, FAO/ISRIC/ISSS (1998) disclosed that the dominant soils in Togo are Luvisols, Arénosols, Ferralsols and Gleysols. The present study takes into account five major types of soils found in Togo. The main one is Lixisols (LX): Soils with subsurface accumulation of low activity clays and high base saturation; these represent 50% of all the soils in the country, according to Soklou (2000). The other important ones are: Leptosols (LP): very shallow soils over hard rock or in unconsolidated very gravelly material; Nitisols (NT): deep, dark red, brown or yellow clayey soils having a pronounced shiny, nut-shaped structure; Plinthosols (PT): wet soils with an irreversibly hardening mixture of iron, clay and quartz in the subsoil; and Vertisols (VR): dark-coloured cracking and swelling clays (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2012).

Factors that explain the variability of agricultural incomes are the type of agricultural equipment used and the level of production intensification (land, work). Animal traction and tractor variables are used to represent the level of equipment. For the production factors, we use the total area farmed, the household size and the use of hired labor. These two last variables serve as proxy to the household labor. The expected effect of these variables is positive. The impact of extension services on net revenue is measured by including a variable on extension. Extension services promote the use of agricultural inputs (fertilizers, pesticides and improved seeds) in order to increase crop yield. The expected effect of this variable is positive. In addition, socio-economic characteristics such as age, gender and education level of the household head–are included in the model, because these variables do matter in agricultural productivity. For instance, the age of the household is often used as a proxy variable for farm experience and its expected effect is positive.

The regressions are done stage by stage using STATA software. Climate variables, soils variables and zone dummies are integrated in the first place. This process helps in defining the model without adaptation that relies only on biophysical factors (climate and soils). Next, characteristics of the farms such as socio-economic variables are integrated into the model without adaptation. This permits to take farmers' adaptations into consideration and to assess their effects on agricultural income. And then, it is called the model with adaptation in this study.

Data

Farm household data are obtained from a survey conducted in the 35 districts of Togo in the framework of the National Agricultural Census (RNA) 2012/2013. The nine crops included are maize, sorghum, millet, rice, yam, cassava, potato, bean and groundnut. Socio-economic characteristics of agricultural households, farm characteristics, factors of production and socio-institutional environment of the farmers are taken from this database.

Climate data are collected from the National Meteorological Service. These data include monthly average rainfalls and mean temperature from 1961 to 2013 recorded in the following weather stations: Lomé and Tabligbo in Maritime region; Kouma-Konda and Atakpamé in the Plateaux region; Sokodé in the Central region; Kara and Niamtougou in the Kara region; Mango and Dapaong in the Savannah region (Figure 1). Prefecture level climate data was not available but, it was necessary to estimate the climatic conditions for each district. To achieve that goal, we did a spatial interpolation using Geographical Information System (GIS). Kriging methods which are based on statistical models that include autocorrelation—that is, the statistical relationships among the measured points were used.

Soil data were obtained from Harmonized World Soil Database (HWSD), version 1.2 (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2012) and National Institute for Agricultural Research (ITRA) in Togo.

The summary statistics of the data set used is in the Table 1 in the appendix.

Results and discussions

Table 1 presents the regressions (without and with adaptation strategies) on net farm revenue per hectare for Togolese farms. The F-test shows that the coefficients of the variables in the regression of the model without adaptation are not all zero at 1% level. However, this model explains only 09 % ($R^2 = 0.09$) of the total variation observed in the net revenue. A large part of the variation in the agricultural income remains unexplained by the variables under consideration. However, this model remains satisfactory regarding the results obtained in the framework of similar studies (Kurukulasuriya *et al.*, 2006 and Ouedraogo *et al.*, 2006). The results of the model without adaptation show that the sign of quadratic terms is opposite to the sign of linear terms for the temperature and rainfalls. Therefore, a nonlinear relationship is detected between the net revenue and temperature on one hand and the rainfalls on the other hand. Similarly, the squared terms for most of the climate variables are significant, implying that the observed relationships are nonlinear. This means that temperature or rainfalls affects the net revenue positively up to a certain level, above which it causes damage to the crops. However, some of the squared terms are positive especially rainfalls in dry season, meaning that there is a threshold above which this variable has positive effect on the production. This implies that there is a minimum productive level of rainfalls under which agricultural production is not profitable to farmers. This minimum of rainfalls in dry season is needed, because crops like bean and groundnut are grown in dry season in Togo. The temperature variable in rainy season also shows that there is a threshold above which it has positive effect on the production. The negative quadratic coefficient implies that there is an optimal level of the variable above which the value function decreases. This is the case of rainfalls in rainy season and temperature in dry season which show that there is a threshold above which they have negative effect on the production. The effects of Leptosols and Vertisols are negative for the model without adaptation, which can be explained by the low fertility level and low water retention capacity of these types of soils compared to the Lixisols which was the reference type of soil in the comparisons.

Regarding the model with adaptation, the F-test shows that the coefficients of the variables in the model are not all zero at 1% level. However, the coefficient of determination (R^2) shows that only 11% of the total variation of the dependent variable is explained. Like the model without adaptation, the regression of the model with adaptation shows that the sign of quadratic terms is opposite to the sign of linear terms for the temperature and rainfalls. Also, the squared terms for most of the climate variables are significant, implying that the observed relationships are non-linear. Like in the model without adaptation, the temperature variable in rainy season for the model with adaptation also shows that there is a threshold above which it has positive effect on the production. Note also that like in the model without adaptation, rainfalls in rainy season and temperature in dry season for the model with adaptation show that there is a threshold above which climate variables have negative effect on production. Like in the model without adaptation, the effects of Leptosols and Vertisols are negative.

Farm area has positive effects on farmers' net revenue; because most farmers in Togo have small area under crops and an increase in the cultivated area combined with utilization of fertilizers contribute to increase yields generally. Also, farmers

Table 1 - Regression results

Variables	Model Without Adaptation Net Revenues (per hectare)	Model With Adaptation Net Revenues (per hectare)
	Coefficients	
Rainy season rainfalls	87.78 (3.14)**	36.84 (1.23)
Rainy season rainfalls squared	-0.28 (3.07)**	-0.14 (-1.44)
Dry season rainfalls	-40.82 (3.82)**	-58.42 (-3.22)***
Dry season rainfalls squared	0.32 (4.04)**	0.49 (3.84)***
Rainy season temperature	-3,977.09 (1.12)	-5,079 (-1.40)
Rainy season temperature squared	67.34 (1.00)	83.01(1.21)
Dry season temperature	9,707.55 (2.90)**	12,378 (3.38)***
Dry season temperature squared	-171.22 (2.81)**	-217.7 (-3.27)***
Nitisols (NT)	49.205 (0.55)	114.4 (1.23)
Leptosols (LP)	-3.09 (0.03)	-176.4 (-1.32)
Vertisols (VR)	-104.53 (0.98)	-113.4 (-1.04)
Plinthosols (PT)	290.08 (1.52)	318.0 (1.67)*
Plateaux region zone	-185.56 (1.18)	-231.2 (-1.35)
Central region zone	96.51 (0.50)	56.01 (0.28)
Kara region zone	-671.77 (2.40)*	-772.5 (-2.70)***
Savannah region zone	-1,107.08 (2.96)**	-920.3 (-2.45)**
Sex of household head		-97.01 (-1.80)*
Age of household head		3.13 (1.88)*
Marital status of household head		-47.24 (-0.50)
Size of household		-4.45 (-0.69)
Education level of household head		33.34 (1.87)*
Livestock ownership		90.47 (1.89)*
Access to extension services		7.63 (0.14)
Population density		-5.62 (-4.98)***
Population density squared		0.01 (4.35)***
Crop land area		22.43 (1.29)
Constant	-84,107.61 (4.47)**	-99,096 (-5.19)***
F statistic	6.77	5.88
R^2	0.09	0.11
N	1,337	1,337

* p<0.05; ** p<0.01 Values in parenthesis are robust t-statistics.

tend not to invest in their farming activities when they have a small area under crops. This result is similar to that of Eid *et al.* (2006) but contradicts that of Ouedraogo *et al.* (2006). However, this strategy helps increase the total output. As expected *a priori*, livestock ownership is found to be positively and significantly related to net revenue because manure improves soil productivity and animals are used as means of transport.

The current methods of cultivation are characterized by marginal use of machinery and animal traction. Most farmers continue using traditional agricultural methods based on human labour. Most farmers do not use improved seeds even though government policies have made available some climate resistant seeds. Storage methods are mostly traditional but new government policies are being put in place to modernise the agricultural storage system in the country. Market access is still limited due to the lack of transportation infrastructure and limited information on prices.

The regressions also show that the household size affects negatively net revenue, probably because children, elderly and sick household members may negatively affect its labor supply. Also, large families might possess small pieces of land, leading to underemployment. These results mirror Deressa's (2006) findings. As expected, education level and access to extension services have positive effect on farm revenues. This means that better access to extension services and education are likely to help farmers develop, gather, and digest intelligence on farming activities. Regarding the zone dummy variables, the Maritime region is used as reference region to which the comparisons are made. The results show that Kara and Savannah regions are significant with a negative sign. This means that on the average, the net revenue is lower is these regions than in the Maritime region by while the net revenues in Central and Plateaux regions are not significantly different from the Maritime region. This can also be explained by the fact that market organization is more developed in the southern part of the country than in the northern one. Farmers in the Maritime, Plateaux and Central regions suffer less the harsh climatic conditions than those in the northern regions of Togo (Kara and Savannah).

Marginal Impacts of Climate on Agricultural Revenue

The marginal impact of the temperature is calculated on the basis of the average temperature of the sample in the rainy season and in the dry season, whereas the marginal impact of rainfalls is calculated on the basis of the average annual rainfalls of the sample in the rainy season and in the dry season. In order to allow easy comparison of marginal impacts with similar studies undertaken in other countries, the values are converted from FCFA to 2014 US$ using exchange rate of 485 FCFA/US$.

The model without adaptation reveals that the net revenue per hectare will increase to an average of US$35.5 per 10 mm increase in rainfalls in rainy season (Table 2). This increase in net revenue is similar to what Ouedraogo *et al*. (2006) found in Burkina Faso (US$3.51 per 1mm). In addition, in rainy season, the marginal impact of temperature on revenue shows that if the temperature increases by 1°C, the net crop revenue falls by US$340.33/ha (Table 2). Comparatively, Togo is more

Table 2 - Marginal impacts of climate on farmers' revenue (US$/ha) in Togo

		Model Without Adaptation Net Revenues (per hectare)	Model With Adaptation Net Revenues (per hectare)
Rainfalls	Rainy season	3.55	-4.35
	Dry season	-7.08	-9.27
Temperature	Rainy season	-340.33	-652.67
	Dry season	333.14	490.16

sensitive to the variation of rainfalls than 11 African countries taken together (South Africa, Burkina Faso, Cameroon, Egypt, Ethiopia, Ghana, Kenya, Niger, Senegal, Zambia and Zimbabwe) for which 1mm decrease in rainfalls leads to a fall of US$1.6 on average (Kurukulasuriya *et al.*, 2006). Also, Togo is more affected by the changes in the temperature than the above mentioned countries taken together where 1°C increase in the temperature leads to a decrease of US$27 in the farmers' net revenue (Kurukulasuriya *et al.*, 2006).

Forecasts of Climate Impacts on Agriculture in Togo

Simulations based on scenarios specific to Togo are done to estimate the impact of climate change on the agricultural income. The consequences of these climate change scenarios on net revenue in 2025 and 2050 are examined using the estimated models in table 3. Based on the results of climate models for specific scenarios downscaled to West Africa (Representative Concentration Pathway 8.5) released by the IPCC in 2013, the following parameters are taken into account: an increase temperature of 1 °C in 2025 and 2°C in 2050 and a fall in rainfalls of 2.5% in 2025 and 10% in 2050 in Togo (IPCC, 2013).

A warming of 2°C will lead to a decrease of 62.02% in the net revenue in 2050. Also, a decrease in rainfalls by 2.5% in 2025 will lead to 0.82% fall in the net revenue, while 7.85% fall in the net revenue are expected with 10% decrease in rainfalls in 2050. Similarly, an increase of 2°C in the temperature and a decrease of 10% in rainfalls will lead to 80.75% fall in the net revenue in 2050 in Togo. These results are in line with the expectation that increasing temperature and decreasing rainfalls are damaging to African agriculture (Deressa, 2006).

Conclusions and implications

This study is an attempt to assess the economic impact of climate change on crop production in Togo using the Ricardian model. It tests two models: a model without adaptation and a model with adaptation. Annual net revenue per hectare is regressed on climate, socioeconomic and soil variables. The regression results are then applied

Table 3 - Impacts from climate scenarios on farmers' revenue in Togo

Scenarios	Model Without Adaptation	Model With Adaptation
	Net Revenues (per hectare)	Net Revenues (per hectare)
Temperature warming (1 °C)	-179.25	-339.41
	(-19.63)	(-32.25)
Temperature warming (2°C)	-566.27	-945.09
	(-62.02)	(-89.81)
Rainfalls decreasing (2.5%)	-7.44	27.28
	(-0.82)	(2.59)
Rainfalls decreasing (10%)	-71.65	95.28
	(-7.85)	(9.05)
Temperature warming (1 °C) and Rainfalls decreasing (2.5%)	-186.69	-312.13
	(-20.45)	(-29.66)
Temperature warming (2°C) and Rainfalls decreasing (10%)	-637.91	-849.82
	(-69.87)	(-80.75)

to possible future Representative Concentration Pathways (RCP8.5) scenarios for Togo on temperature and rainfalls.

The empirical results from this study provide some evidence that climate change will affect net crop revenue in Togo. Results also suggest that climate has a nonlinear effect on net revenue from crop production. In rainy season, the marginal impact of temperature on revenue shows that if the temperature increases by 1°C, the net crop revenue may fall by US$340.33/ha. On the other hand, if rainfalls increase by 10 mm, the net revenue may increase by US$35.5/ha. The results of Representative Concentration Pathways (RCP8.5) scenarios indicate that an increasing temperature as well as the simultaneous effects of reducing rainfalls and increasing temperature may reduce crop revenue very substantially. The study reveals that some variables used in the regression are significant and have positive effects on the net revenue. For instance, livestock ownership is significant and has a positive effect, while education levels, access to extension services and farm size have positive but not significant effect on the net revenue.

There are a number of caveats that readers should keep in mind when interpreting the results of this study. First, the cross sectional analyses are vulnerable to omitted variables; second, the analyses do not consider carbon fertilization which is predicted to increase future crop productivity; third, the analyses do not include changes in prices; and fourth, the analyses do not take into account future technological changes. Then, the study considers technology to be constant and the prediction of climate change impacts does not take into account all the farmers' ongoing adaptations strategies. The study looks at crops overall and does not examine the impact crop by crop. Future studies should take an interest in the mono-crop models. This would permit researchers to target those crops that are most important for the country like maize and sorghum. Finally, irrigation is not included in our model because of the lack of statistical information. Future irrigation data simulations may be necessary to improve our understanding of the impact of irrigation as an adaptation measure on crop production.

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Appendix

Table 1 - Summary statistics

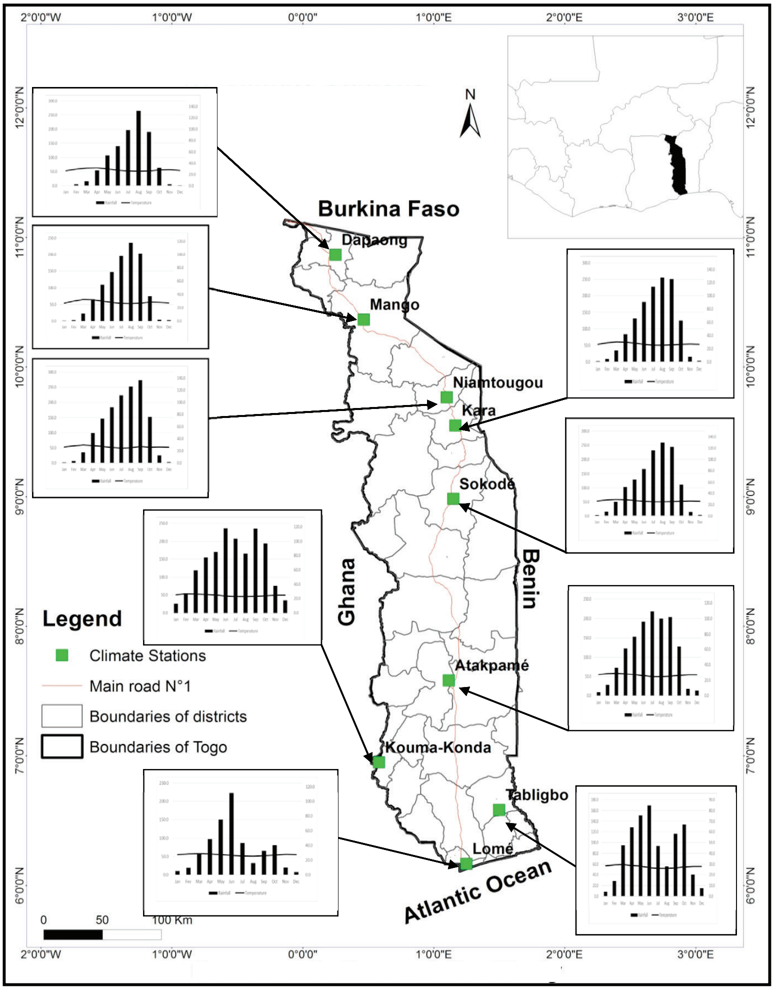

Figure 1 - Geographical Situation of Togo. *Source: Authors of the Study*

VARIABLE	MEAN	STD. DEV.	MIN.	MAX.
National production of maize (tons)	825710	-	-	-
National production of sorghum (tons)	250892	-	-	-
National production of millet (tons)	27703	-	-	-
National production of white rice (tons)	99781	-	-	-
National production of yam (tons)	864408	-	-	-
National production of cassava (tons)	959889	-	-	-
National production of potato (tons)	19957	-	-	-
National production of bean (tons)	132636	-	-	-
National production of groundnut (tons)	43636	-	-	-
Price of maize (US$/tons)	330	-	-	-
Price of sorghum (US$/ tons)	410	-	-	-
Price of millet (US$/ tons)	430	-	-	-
Price of white rice (US$/ tons)	770	-	-	-
Price of yam (US$/ tons)	430	-	-	-
Price of cassava (US$/ tons)	220	-	-	-
Price of potato (US$/ tons)	370	-	-	-
Price of bean (US$/ tons)	960	-	-	-
Price of groundnut (US$/ tons)	1370	-	-	-
Crop Net revenues (US$)	511.152	781.49	-568.54	4097.01
Rainy season precipitation (mm)	152.00	25.97	111.82	205.30
Rainy season precipitation squared (mm)	23777.95	7961.97	12503.49	42147.57
Dry season precipitation (mm)	49.39	25.74	13.42	105.75
Dry season precipitation squared (mm)	3101.33	2867.74	180.01	11183.66
Rainy season temperature (°C)	26.63	0.62	23.98	27.71
Rainy season temperature squared (°C)	709.65	32.41	575.10	768.07
Dry season temperature (°C)	27.43	0.95	24.45	29.48
Dry season temperature squared (°C)	753.22	51.79	597.99	869.09
Nitisols (0/1)	0.37	0.48	0	1
Lixisols (0/1)	0.51	0.50	0	1
Leptosols (0/1)	0.04	0.19	0	1
Vertisols (0/1)	0.04	0.21	0	1
Plinthosols (0/1)	0.03	0.17	0	1
Sex of household head (0/1)	0.80	0.40	0	1
Age of household head (Years)	46.65	14.78	15	99
Marital status of household head (0/1)	0.96	0.19	0	1
Size of household	5.18	3.42	1	15
Education level of household head	1.52	1.39	0	6
Livestock ownership (0/1)	0.73	0.44	0	1
Access to extension services (0/1)	0.21	0.41	0	1
Population density per km^2	124.30	91.40	28.13	376.69
Population density squared	23796.42	34533.42	791.22	141896.50
Crop land area (ha)	0.50	1.19	0.01	4.58