Impact of climate change on rice income: case study of four West African countries

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Abstract.

This study aimed to assess the impact of climate change on rice income in four West African countries. The paper used the Ricardian approach to measure the relationship between the net income and climate variables (temperature and precipitation), soil characteristics, and socio-economic variables. Two models (with climate variables interaction and without climate variables interaction) were used under two growing environments (rain-fed and irrigated systems). We relaxed the assumption of additively separable climatic effects by including an interaction term in Ricardian equation to allow the effect of precipitation and temperature to be mutually dependent like in agronomic experiments. Data from 22,556 rice farmers across four countries were used. Results showed that if the average temperature increases by 1°C the net income of rice decreases by US$ 1,198. Results showed that irrigation can be applied as adaptation measure to climate change.

Keywords: Climate Change, Ricardian Analysis, Rice, Impact, West Africa.

JEL codes: D24; Q54

1. Introduction

There is growing concerned about the effect of climate change on human life. Indeed, there is an increasing scientific consensus that significant climate change is very likely to occur over the 21st century (Christensen and Hewitson, 2007). Climate change can have both direct and indirect negative impact on the general well-being of the people especially those who depend highly on the natural resources such as agriculture and forest for their livelihoods. The climate change at the regional level, especially the increase in temperature, has already seriously affected the physical and biological systems as well as the agriculture systems. In developing countries, the challenge of climate change and global warming is more important due to poverty and prevailing of rain-fed agriculture. Developing countries are more likely to be negatively affected by climate change than developed (IPCC, 1996). Although climate change is a threat to economic development, agricultural production activities are generally more vulnerable to climate change than other sectors (IPCC, 1990; Derresa *et al.,* 2005; Mendelsohn, R., 2007). The general consensus is that changes in temperature and precipitation will result in changes in land and water regimes that will subsequently affect agricultural productivity (World Bank, 2003). The impact of climate change on agricultural sector is therefore a crucial issue, particularly in the low income countries where a majority of people are living in rural areas. The Intergovernmental Panel on Climate Change's report on climate change provides strong evidence that accumulating greenhouse gases are leading to a warming world and predicts increased droughts for the African continent (IPCC, 2007). If these greenhouse gases and global warming continue, they are predicted to impose serious costs to agricultural farms in developing countries (Kurukulasuriya *et al.*, 2006; Seo *et al.*, 2006; Seo and Mendelsohn, 2008). In addition, since most of the African agriculture is rain-fed, climate change will have negative consequences on crop yields such as rice.

Rice is a tropical crop and can grow under high temperatures, but unfortunately has its limits. During the vegetative stage, rice can resist to night temperatures of 25°C and day temperatures of 35°C (AfricaRice, 2011). However, high temperatures will result in reduced photosynthesis. In addition, high daily temperatures can result to heat stress. Heat stress causes spikelet sterility which can lead to high yield loss. Rice is particularly sensitive to heat stress at the flowering stage, which may occur when the temperature rises above 35°C. Drastic changes in rainfall patterns and rise in temperature could reduce the rice productivity. We need to anticipate such changes and provide alternatives or measures for farmers to adapt to lower and erratic rainfall, higher demand for water, higher temperature, and so on.

So far, there has not been any study to address the economic impacts of climate change on rice farming. The main objective of this study therefore is to analyze the economic impact of climate change on rice production in West African zone. The study estimated a Ricardian model to assess the potential impact of climate change on rice farmers in four West Africa countries (Benin, Ghana, Cote d'Ivoire and Togo). This paper differs from the earlier economic research on African agriculture in the two ways. First, it quantifies climate change impacts on rice income for four main rice producer countries in West Africa zone. Second, this paper relaxes the assumption of additively separable climatic effects by including an interaction term in Ricardian equation to allow the effect of precipitation and temperature to be mutually dependent.

In the next section, we discuss the Ricardian approach adopted including specification of the empirical model. The third section describes the data followed by empirical results in the fourth section. The paper concludes with a discussion of the results and policy implications.

2. Methodology

2.1. Model specification

To assess economic impacts of climate change and to evaluate effect of adaptations measures, the econometric approach used in this study is based on the Ricardian method. The Ricardian model assumes that each farmer aimed to maximize income subject to the exogenous conditions of his farm. It is based on land rent which is seen as the net income from the best use of land. Land rent is given by:

$$V = \int [\sum PQ(I,C,X,Z) - RI] \; e^{-\delta t} dt \qquad (1)$$

Where V is net income per hectare, P is market price of rice, Q refers to the output of crop, I is the vector of purchased inputs (other than land), C is a vector of climate variables, X is a set of socio-economic characteristics such as household size, Z is a vector of soil variables, R is a vector of input prices, t is the time and δ refers to the discount rate.

We assume that farms are atomistic, and input demand is small enough to not influence input prices. Similarly weather shocks don't influence the exogenous output prices if the quantity of rice produced in each country is not large enough to affect the global market. Under these hypotheses, the reduced form of the model where V is strictly a function of the exogenous variables such as socio-economic variables (X), soil variables (Z) and climate variables (C) is:

$$V = f(X, Z, C) \qquad (2)$$

Following Schlenker *et al.* (2006), we used log-linear Ricardian model. Indeed, Schlenker *et al.* (2006) suggest that a log transformation of dependent variable (net rice income) if the distribution of land value is not negative and typically highly skewed. In addition, Van Passel *et al.* (2012) found the log-linear model has a more uniform predictive power compared to the linear model. Under hypothesis of non-interaction of climatic variables, the empirical model (Model A) is presented as followed:

$$\ln rev_{m,t} = \beta_0 + \beta_1 Temp_{m,t} + \beta_2 Temp_{m,t}^2 + \beta_3 Prec_{m,t} + \beta_4 Prec_{m,t}^2 + \sum_{i=1}^{m} \alpha_i Z_{m,t} + \sum_{j=1}^{n} \mu_j X_{m,t} + \mu_{m,t} \qquad (3)$$

Where $rev_{m,t}$ is net rice income, $Temp_{m,t}$ is the temperature variable, $Prec_{m,t}$ is the precipitation variable, m indicates the rice producer, t indicates the time period, $\beta_0, \ldots, \beta_4$, α_i and μ_j are the parameters to be estimated and $\mu_{m,t}$ is a residual component. $Z_{c,t}$ includes soil fertility (*solrich)* and rice growing environment (*ecolog*). $X_{m,t}$ includes household size (*hldsiz*), irrigation system used (*irrig*) and fertilizer used (*engmi*).

In this specification, climatic effects are multiplicative. For example, the marginal effect of temperature is:

$$\frac{\partial rev_m}{\partial temp_m} = rev_m(\beta_1 + 2\beta_2 Temp) \qquad (4)$$

In equation (4), the marginal effect depends only the temperature itself, and none other climatic variables. This is in contrast to agronomic experiences which shown that warmer conditions typically lead to an increase in crop requirements for water.

To account for the additively effects of climatic variables, we include interaction terms to regression (3). Therefore, the new specification (Model B) can be estimated as followed:

$$\ln rev_{m,t} = \beta_0 + \beta_1 Temp_{m,t} + \beta_2 Temp_{m,t}^2 + \beta_3 Prec_{m,t} + \beta_4 Prec_{m,t}^2 + \beta_5 Temp * Prec_{m,t} + \sum_{i=1}^{m} \alpha_i Z_{m,t} + \sum_{j=1}^{n} \mu_j X_{m,t} + \mu_{m,t}$$

Where $Temp * Prec$ is the interaction between temperature and precipitation, and all others symbols are the same as defined in equation (3).

In this specification, the marginal effect of temperature can be derived as:

$$\frac{\partial rev_m}{\partial temp_m} = rev_m(\beta_1 + 2\beta_2 Temp_m + \beta_5 prec_m) \quad (5)$$

In equation (5), the marginal effect of temperature on income depends on both the temperature and precipitation.

2.2. Data collection

The data used for this study was collected by national partners of Africa Rice Center (AfricaRice) in Benin, Togo, Ghana and Cote d'Ivoire. Household data on income, household and production characteristics were collected from 22,556 rice framers randomly selected in 4 countries (Benin, Togo, Ghana and Cote d'Ivoire). These countries are amongst the major rice producing countries in West Africa and are all in the same agro-ecological zones. In total, the survey was conducted in 577 districts across the four countries. In each country, districts were chosen to get a wide representation of farms across climate conditions. In each selected district, survey was conducted on randomly selected rice farming households. The number of surveyed households varied from country to country. A sample of 6420 households were randomly chosen in Benin, 4194 in Togo, 7644 and 4298 in Cote d'Ivoire and Ghana, respectively. The number of surveyed households per growing environment and per country is shown in Table 1. The data collected at farm-level was for the season 2008-2009. The data include:

- the socio-economic characteristics of the agricultural households;
- the characteristics of the farms;
- the quantity of inputs;
- the value of outputs; and
- the environment of the farmer.

Temperature and precipitation were obtained from the dataset produced by the Climatic Research Unit (CRU) of University of East Anglia (UEA). Climate data were accessed through the portal of the World Bank Group on Climate Change Knowledge (World Bank 2014). This site allowed obtaining mean monthly temperature and rainfall for each district of country during the time period 1990-2009. The temperatures and precipitations for each country are shown in Table 2.

2.3.Data analysis

Two models (without interaction of climatic variables and with interaction of climatic variables) were used. At the first stage, we introduce the climatic variables, then the soil variables and finally the socio-economic variables. This first model (Model A) is without interaction of climatic variables. At the second stage, we integrated into the first model with an interaction of temperature and precipitation. For each of these models, we also estimated separately for irrigated systems, rain-fed systems and all farms.

The dependent variable is the rice net income (*rev*). This was calculated for each rice farming household during the period 2008-2009. The net income was measured as the gross income minus the cost of the inputs such as: fertilizer, insecticide, herbicide, labor, depreciation on machineries and other farming cost. Table 3 presented the mean net rice income for rain-fed and irrigated farmers in each country. On the average, the net income for both irrigated rice and rain-fed were US$ 534.07 and US$424.31 respectively. As expected, irrigated rice system incomes were generally higher than rain-fed systems in all countries (Table 3).

The explanatory variables used are: climatic variables, soil variables and farmers' characteristics. Climatic variables are temperature (temp) in degrees Celsius and precipitation (prec) in millimeter. Temperature variable corresponds to the average of the temperature of each district during the period 1990-2009. Similarly, the precipitation variable corresponds to the average of the precipitation of each district during the period 1990-2009.

Soil variables refer to soil characteristics. We include the soil type through 5 dummy variables identifying very fertile, average fertile, fertile, poor, and very poor. We also, include growing environment through 3 dummy variables: irrigated, lowland, and upland. Farm characteristics refer to socioeconomic factors that can explain the variability of rice income: farm area, household size, use of fertilizer, use of pesticide and access of seed of the rice variety (Table 4).

3. Results

Table 5 presents the result of the estimated parameters for model A (without interaction of climatic variables) for irrigated system, rain-fed system and pooled. F test showed that the three regressions are all significant at the 1% level. The coefficients for irrigated and rain-fed farmers are different, suggesting they have different relationships with the independent variables. The estimated coefficient of temperature is positive for all farmers and for, irrigated and rain-fed systems. But it is only significant at 10% level for the rain-fed. Contrarily, the estimated coefficient of precipitation is negative for rain-fed farm and positive for irrigated rice farm. The sign of quadratic terms is opposite to the sign of linear terms for the temperature and the precipitation in all of cases. The relationship between income and temperature or precipitation is therefore non-linear. The household size coefficient is positive and highly significant at 1%. This means that the size of household influence the rice income. Indeed, this can be explained by the importance of family labor in rice production in West Africa. Irrigation coefficient is positive and significant. As a mean of adaptation to climate change, irrigation can help to alleviate rainfall hazards and ensure stable production. The use of pesticide coefficient is also positive and significant at 10%.

Results of Model B (with interaction of climatic variables) are presented in Table 6. In this model, both the quadratic term of temperature and the interaction is significant. This interaction is positive which is consistent with the agronomic literature showing that increase in precipitation can reduce the negative effect of increase of temperature.

In order to interpret the climate coefficients, we calculated the marginal effects of each climatic variable. Table 7 showed that the marginal impact of climate variables on rice household income for Model B (with interaction of climate variables).

Results showed that if the average temperatures increase by 1°C, the net rice income will drop by US$1198 for all farmers and US$8691 for irrigated farmers. The drop will reach US$9437 for rain-fed system. The temperature had a less harmful effect on irrigated rice farm because irrigation can reduce the negative effect of increase of temperature.

On the other hand, the marginal effects of precipitation on net income varied also across production systems. If the average of precipitation decreases by 1mm, rice income will reduce by US$306 for all rice farmers and US$1049 for rain-fed rice farm. The decrease will be US$221 for irrigated system.

4. Conclusion

This study assessed the impact of climate change on net rice income in four West African countries. It uses the Ricardian approach to measure the relationship between the net crop income and climate variables (temperature and precipitation), soil variables, and socio-economic variables. Two models (without interaction of climatic variables and with interaction of climatic variables) were used under two growing environments (rain-fed and irrigated systems).

Results showed a significant impact of climate on net rice income across West African rural households. They indicated negative impact of decreasing precipitation and increasing temperature. With interaction of climatic variables, marginal impacts are US$1198 and US$306 for temperature and precipitation, respectively, if temperature increases by 1°C and precipitation decrease by 1 mm on average.

The study showed that some variables used in the regression are significant and have a positive effect on net income. The irrigation variable is significant and has a positive effect and can be applied as adaptation options.

References

Africa Rice Center (AfricaRice). 2011. *Boosting Africa's Rice Sector: A Research for Development Strategy 2011–2020*. Cotonou, Benin: Africa Rice Center.

Christensen, J. H., Hewitson, B., 2007. "Regional climate projections". In *Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, chapter 11, pages 847-940. Cambridge University Press.

Deressa, T., Hassan, R., Poonyth, D., 2005. Measuring the economic impact of climate change on South Africa's sugarcane growing regions. *Agrekon* 44(4): 524–542.

Intergovernmental Panel on Climate Change, 1990. *Scientific assessment of climate change*. Report prepared by Working Group 1, World Metrological Organization and United Nations Environmental Program, New York.

Intergovernmental Panel on Climate Change, 1996. *Climate change 1995*. The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the IPCC. Press. Cavelli, California, 572p.

Intergovernmental Panel on Climate Change, 2007. *Synthesis report (Eds: A. Allali, R. Bojariu, S. Diaz, I. Elgizouli, D. Griggs, D. Hawkins, O. Hohmeyer, B.P. Jallow, L. Kajfez-Bogataj, N. Leary, H. Lee, D. Wratt),* published by the Intergovernmental Panel on Climate Change, Geneva.

Kurukulasuriya, P., Mendelsohn R., Hassan R., Benhin J., Deressa, T., Diop M., Eid H.M., Fosu, K.Y., Gbetibouo, G., Jain, S., Mano, R., Kabubo-Mariara, J., El-Marsafawy, S., Molua, E., Ouda, S., Ouedraogo, M., Sene, I., Maddison, D., Seo, S. N., Dinar, A., 2006. "Will African agriculture survive climate change?" *The World Bank Economic Review* 20 (3), 367–388.

Mendelsohn, R., 2007. Measuring climate impacts with cross sectional analysis. *Climate Change* 18, 1-7.

Schlenker, W., Hanemann, M., Fisher A. C., 2006. The impact of global warming on U.S. agriculture: an econometric analysis of optimal growing conditions. *Review of Economics and Statistics* 88, 113-125.

Seo, N., Mendelsohn R., 2008. A Ricardian analysis of the impact of climate change on South American farms. *Chilean Journal of Agricultural Research* 68, 69-79.

Seo, S. N., Mendelsohn R. Munasinghe M., 2006. Climate change and agriculture in Sri Lanka: a Ricardian valuation. *Environment and Development Economics* 10, 581-596.

Van Passel, S., Massetti E., Mendelsohn, R., 2012. A Ricardian Analysis of the of climate change on European Agriculture. *Climate Change and Sustainable Development Series* 83, 27p.

World Bank, 2003. *Africa rainfall and temperature evaluation system (ARTES).* World Bank, Washington DC.

World Bank, 2014. Climate data. World Bank Group on Climate Change Knowledge (http://sdwebx.worldbank.org/climateportal/index.cfm?page=country_historical_climate&ThisRegion=Africa&ThisRCode=AF#). Accessed May 2014.

Table 1: Sample size per growing environment and per country

Countries	Growing environments		All farmers
	Rain-fed	Irrigated	
Benin	5008	1412	6420
Togo	3226	968	4194
Cote d’Ivoire	6665	979	7644
Ghana	4256	42	4298
Total	19155	3401	22556

Table 2: Temperatures (°C) and precipitations (mm) per country

Countries	Minimum temperature	Average temperature	Maximum temperature	Average Precipitation
Benin	25.06	27.30	30.70	1025.01
Togo	24.64	27.22	28.60	1245.56
Cote d’Ivoire	25.02	26.96	28.60	1274.76
Ghana	25.76	28.09	31.60	906.67
Africa-wide	25.11	27.31	29.74	1132.32

Source: World Bank, 2014

Table 3: Average net income of rice per country (in US$)

Countries	Growing environments		All farmers
	Rain-fed	Irrigated	
Benin	410.88	645.25	457.37
Togo	419.88	453.47	425.92
Cote d’Ivoire	389.92	454.14	398.28
Ghana	426.32	479.27	416.30
Average	409.72	534.07	424.31

Table 4: Descriptive Statistics of variable used in regression

Variable		All farmers		Irrigated farmers		Rain-fed farmers	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Log of Net rice income		5.28	1.46	5.27	1.84	5.30	1.38
Temperature		27.31	0.50	27.34	0.3021	27.19	0.53
Precipitation		1132.33	152.16	1122.48	122.59	1158.18	155.36
Ecology type	Irrigated	0.15	0.36	1	0	0	0
	Upland	0.35	0.47	0	0	0.41	0.49
	Lowland	0.44	0.49	0	0	0.52	0.49
Soil type	Very fertile	0.06	0.24	0.07	0.27	0.05	0.21
	fertile	0.28	0.45	0.33	0.47	0.28	0.44
	Average fertile	0.47	0.49	0.44	0.49	0.47	0.49
	Poor	0.16	0.37	0.14	0.34	0.17	0.38
	Very poor	0.01	0.12	0.01	0.08	0.02	0.13
Farm area		1.97	9.26	1.76	7.53	2.05	9.85
Household size		6.63	4.08	6.53	4.38	6.68	4.05
Irrigated		0.15	0.36	1	0	0	0
Use of fertilizer		0.73	0.44	0.79	0.40	0.71	0.45
Use of pesticide		0.66	0.472	0.68	0.46	0.64	0.47
Cropping method	Manual cropping	0.51	0.49	0.59	0.49	0.48	0.49
	Use of animal for cultivation	0.16	0.36	0.09	0.29	0.17	0.38
	Other cropping method	0.14	0.35	0.09	0.29	0.15	0.36
Access to rice seed		0.74	0.44	0.73	0.44	0.74	0.43

Table 5: Parameter estimates for model A: farm-level no climatic interaction

Variable		All farmers		Irrigated farmers		Rain-fed farmers	
		Coeff.	t-value	Coeff.	t-value	Coeff.	t-value
Temperature		91.99	1.95	1435.46	1.25	134.81**	2.71
Temperature squared		-1.64	-1.90	-26.44	-1.25	-2.45**	-2.68
Precipitation		-0.01	-0.48	0.22*	2.23	-0.07	-1.72
Precipitation squared		9.92E-06	0.55	-0.02*	-2.20	0.01	1.76
Ecology type	Upland	0.82***	3.67	-	-	0.57*	2.53
	Lowland	1.15***	5.15	-	-	0.90***	3.95
Soil type	Very rich	-0.31	-0.84	1.36	1.61	-0.96*	-2.31
	Rich	1.32***	3.86	2.03*	2.48	1.19**	3.26
	Averagely rich	1.21***	3.55	2.37**	2.88	0.92*	2.50
	Poor	0.31	0.89	0.31	0.36	0.37	1.00
Farm area		0.01	0.79	-2.93	7.53	0.01	1.06
Household size		0.04***	3.64	-0.03	-1.79	0.08***	5.48
Irrigation		1.35***	5.67	--	--	--	--
Use of fertilizer		0.13	0.91	-0.95	-2.16	0.19	1.20
Use of pesticide		0.38**	2.67	0.14	0.37	0.50**	3.25
Cropping method	Manual cropping	-0.01	-0.04	0.73*	2.60	-0.02	-0.24
	Animal draught cultivation	0.52**	2.88	0.34	0.72	0.73***	3.68
Access to rice seed		-0.13	-1.19	-0.05	-0.29	-0.13	-1.08
Constant		-1273.74	-2.05	-19601	-1.26	-1814**	-2.78
Adjusted R^2		0.22		0.34		0.26	
F-statistic		16.99***		8.53***		18.10***	

* significant at 10%; ** significant at 5%; *** significant at 1%.

Table 6: Parameter estimates for model B: farm-level with climatic interaction

Variable		All farms		Irrigated farms		Rain-fed farms	
		Coeff.	t-value	Coeff.	t-value	Coeff.	t-value
Temperature		-18.27*	-2.11	961.31	0.78	-23.92**	-2.63
Temperature squared		-0.02**	-2.89	-18.68	-0.83	-0.01**	-3.07
Precipitation		-0.64*	-2.25	-1.28	-0.90	-0.84**	-2.76
Precipitation squared		0.01	1.85	-0.01	0.26	0.01*	2.39
Temperature and precipitation		0.01*	2.40	-0.04	-1.06	0.02**	2.90
Ecology type	Upland	0.78***	3.48	-	-	0.53*	2.36
	Lowland	1.10***	4.85	-	-	0.84***	3.67
Soil type	Very rich	-0.29	-0.79	1.42	1.67	-0.92*	-2.22
	Rich	1.33***	3.91	2.05*	2.50	1.21***	3.32
	Averagely rich	1.20***	3.54	2.39**	2.90	0.91*	2.50
	Poor	0.31	0.89	0.34	0.40	0.38	1.01
Farm area		0.01	1.14	-0.23**	-3.00	0.01	1.38
Household size		0.04***	3.83	-0.03	-1.67	0.08***	5.64
Irrigation		0.38**	5.32	-	-	-	-
Use of fertilizer		0.13	0.90	-0.95	-2.21	0.19	1.20
Use of pesticide		0.38**	2.64	0.14	0.37	0.49**	3.19
Cropping method	Manual cropping	-0.01	-0.11	0.72*	2.55	-0.01	-0.28
	Animal draught cultivation	0.54**	2.96	0.37	0.77	0.74***	3.74
Access to rice seed		-0.13	-1.17	-0.06	-0.34	-0.13	-1.05
Constant		598.29*	-2.09	-12276.61	-0.72	787.29**	2.62
Adjusted R^2		0.22	0.34	0.26	0.22	0.34	0.26
F-statistic		16.25***		8.07***		17.17***	

* significant at 10%; ** significant at 5%; *** significant at 1%.

Table 7: Marginal effect of climate variables on rice income

		Model B: farm-level, with interaction of climatic variables
	All farmers	-1198.99
Temperature	Irrigated	-8691.34
	Rain-fed	-9437.67
	All farmers	-306.61
Precipitation	Irrigated	-221.76
	Rain-fed	-1049.72