Impact of Climate Change on Grain Yield and Variability in Nigeria: A Stochastic Production Model Approach

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Abstract

This paper analyses the impact of climate change on Nigeria's cereal grain yields, variance and covariance. Maize and rice were selected based on their distinct production in almost all the States in Nigeria. A panel data stochastic production model with heteroscedasticity was employed in analysing the data. The data consists of a panel of eight States and 18 time periods. The eight states spans across the six geopolitical zones. The cereal grains considered are rice and maize. The simulation results show that there would be an increase in rice yield whereas its variance would increase. The contrary holds for maize. The covariance of the two crops would reduce in future due to climate change. The results have implications for allocations of agricultural land among crops, for crop production mix, and for adaptation and mitigation policies.

Introduction

It has now been widely accepted that the earth is warming and will continue to warm as the concentration of greenhouse gases rise in the future (Mendelsohn, 2009). These greenhouse gases such as carbon dioxide (CO2) have been shown to lead to changes in climate conditions such as temperature, precipitation, soil moisture, and sea level (Houghton et al., 1996; Schimmelpfennig and Yohe, 1999). Climatic change could have adverse effects on ecological systems, agriculture, human health, and the economy. However, how harmful climate change will actually be is still an ongoing debate (Intergovernmental Panel on Climate Change (IPCC), 2007a). Though climate change is a threat to agricultural and socioeconomic development, agricultural production activities are generally more vulnerable to climate change than other sectors (IPCC, 1990). Hence, substantial attention has been devoted to agricultural effects of climate change (Bryant et al., 2000; McCarthy et al., 2001; Polsky and Easterling, 2001; Isik and Devadoss, 2006; Deressa et al., 2005; Ajetomobi et al., 2011; Fonta et al., 2011). Climatic conditions and water availability may influence the mix of crop and livestock productions. As climatic conditions vary, crop production patterns could change since different crops could react differently to the alterations in climatic conditions. The timing and level of precipitation will impact the seeding and other field operations, and changes in the temperature level will affect the length of growing season and crop evapo-transpiration. These changes could also increase the need for more irrigation and decrease water supplies that are crucial for natural ecosystems, urban population, industry, and other users (Adams et al., 1998; Isik and Devadoss, 2006). Therefore, agriculture would have to compete for the scarce water with various users of water. Consequently, agricultural production patterns need to be adjusted to suit the ever changing climatic conditions.

Nigerian agriculture is a key sector in the economy employing over 60% of the labour force and contributing about 41% of the nation's GDP. The sector is also the source of raw materials used in several processing industries as well as a source of foreign exchange earnings for the country. However, agricultural productivity growth has been below expectation. How much one can hold climate change responsible for changes in agricultural productivity in Nigeria remains a subject of research. Hence, its vulnerability to climate change is of particular interest to both researchers and policy makers. Attempts to analyze the effects of climate change on crop productivity globally have basically focused on mean crop yields. Majority of these studies employed either a crop simulation model or regression techniques. Only a few studies have analysed the impact of climate change on yield variability (Chen et al., 2004; Isik and Devadoss, 2006; Finger and Schmid, 2007, Baubacar, 2010). To the best of my knowledge, there has not been a similar study on Nigerian agriculture. Hence, this study intends to fill this gap by using historical data to elicit the response of crop yield and variability to climate change in Nigeria. A stochastic production function with multiplicative heteroscedasticity is employed. This is selected to ensure that consistent estimates of both the mean and variance of the production function are obtained.

Data

Maize and Rice were selected for analysis as these are the only cereal crops that are planted in all the geopolitical zones in Nigeria. The data description is presented in Table 1. These include maize output in tons, rice output in tons, area under maize and or rice cultivation in hectares, total annual precipitation in millimeters and average monthly temperature in degree Celsius. Output data are sourced from National Bureau of Statistics (NBS). Monthly Climate data are sourced from World Weather Records, GHCN v.3 (2011) and NBS Abstract of Statistics (2009). The explanatory variables used for the estimations include a constant, precipitation and temperature levels, and trend. The trend variable is a proxy for technological progress. Although aware that maize yields are driven by numerous factors, only climate factors are considered, specifically temperature and precipitation. Other factor inputs such as fertilizer, seed, herbicides could have been included but these are not available on a crop by crop basis. The data spans the period 1991 to 2008 for eight States namely Enugu, Borno, Kano, Lagos, Niger, Ondo, Plateau and Rivers.

Table 1: *Variable Description*

Variables	N	Mean	Standard Deviation	Minimum	Maximum
Maize(Tons/ha)	N	1.731	0.310	1.000	2.500
Rice (Tons/ha)	144	1.909	0.930	0.147	8.756
Precipitation (Millimetres)	144	1445.302	518.442	426.600	2710.800
Temperature (Degree Celsius)	144	26.205	1.967	20.400	29.100

Prior to fitting the functions, IPS panel unit root was conducted to determine the stationarity or otherwise of all the variables used in the analysis. Results are presented in Table 2. In all cases the null hypothesis of panel unit root is rejected. All the variables are therefore integrated of order zero, in other words, they are stationary.

Table 2: *IPS Panel Unit Root Test*

	Maize	Rice	T	P
Statistic	-5.1022	-4.3194	-3.5836	-6.9658
P-value	0.0000	0.0000	0.0002	0.0000

H_0: All panels contain unit roots

Empirical model

In this paper, the stochastic production function with multiplicative heteroscedasticity is employed following Harvey 1976 and Just and Pope, 1978. The model is implemented in a panel data frame work by taking into account State specific effects. The model is specified as:

$$y_{it} = f(x_{it}) + u_{it} \quad (1)$$

$$u_{it} = h(x_{it}, \alpha)\varepsilon_{it} \quad (2)$$

where y_{it} denotes maize (or rice) output for State i at time t, x_{it} is a vector of climate variables for State i at time t, β and α are the corresponding parameter vectors, ε is a random variable distributed with zero mean and variance: $V(y_{it}) \equiv \sigma_{it}{}^2 = h(x_{it}, \alpha)^2$ $f(\cdot)$ and $h(\cdot)$ could be linear or nonlinear functions. The idea behind the above specification is that the effects of inputs on output should not a priori be tied to the effects of inputs on the variability of output. The first argument of equation (1) specifies the effects of inputs on the mean of output and the second argument expresses the effects of inputs on the variance of output. Thus, $E(y) = f(x)$, and $V(y) = h(x)$ and the two effects are independent. The Just–Pope function does not impose a priori restriction on the risk effects of inputs and therefore it accommodates both increasing and decreasing risk effects of inputs on output. The sign of α indicates whether a climate variable increases or decreases crop yield variability. An input is said to be risk increasing (decreasing) if it increases (decreases) the variance of crop yields (i.e. α >(<)0) under uncertainty.

Feasible generalized least squares (FGLS) has been widely used since the Just and Pope (1979) paper. However, Saha, et al. (1997) Monte Carlo experiment results show that, unless the error distribution departs significantly from normality, the maximum likelihood estimator (MLE) is substantially more efficient with a considerably smaller mean squared error than FGLS. Hence, in this study, the MLE is employed. The maximum likelihood function is given as:

$$\ln L = -\frac{1}{2}\left[n\ln(2\pi) + \sum_{i=1}^{n}\ln(h(x,\alpha)^2 + \sum_{i=1}^{n}\frac{y_{it} - f(x_{it},\beta))^2}{h(x_{it},\alpha)^2} \right] \quad (3)$$

Maximization of $\ln L$ with respect to α and β provides ML estimates. Three functional forms are considered namely, the linear, quadratic and square root functional forms. However, the discussion is limited to the quadratic form as this was selected based on AIC for the mean and variance model.

Using the estimated production function parameters from Equation 3, we estimate the covariance of crop k and crop j by running the regression of $\hat{u}_{kit}\hat{u}_{jit}$ on the same set of explanatory variables as in the mean yield and variance functions. Also, the functional form for the covariance function is selected based on the RMSE and R^2.

The future impacts of climate change on the mean grain yields and yield variability were examined using the climate scenarios from the Special Report on Emission Scenarios (SRES). Predictions from two climate models namely CGM2 and HADCM3 for the period 2060 and 2100 were used.

Results and Discussion

First, the correct panel data model for the estimation of production functions was ascertained. Panel data models take two alternative forms: random effects and fixed effects (Baltagi, 1995). The correct panel data model was determined by testing the random effects model versus the fixed effects model using the Hausman test statistics. The Hausman test statistic is distributed asymptotically as chi-squared with m (explanatory variable) degrees of freedom under the null hypothesis that the random effects estimator is consistent and more efficient. The Hausman test statistics rejected the null hypothesis that the random effects estimator is consistent and efficient for rice and maize estimations. Thus, the fixed effects model is more appropriate than the random effects model for two estimated yield equations. The fixed effect models are estimated using the maximum likelihood estimation method. The estimated equations showing the effects of climatic variables on the mean and variance of maize and rice yields for the three alternative functional forms are presented in Table 3 and 4 respectively. Based on the AIC, the quadratic functional form is selected for discussion.

Precipitation has a negative impact on the mean maize yield. However, only the square of temperature is statistically significant. Whereas temperature is positively and significantly related to the mean maize yield, its square is negatively and significantly related to mean maize yield. The interaction term between the precipitation and the temperature in the quadratic mean yield function for maize is positive and statistically significant. This implies that temperature and precipitation are not independent. The estimated coefficients in the variance function indicate that increases in the rainfall and temperature tend to respectively reduce and increase the variability of maize yields. These results imply that rainfall and temperature are respectively risk-decreasing and risk-increasing inputs in maize production. The trend has a positive impact on both the mean yield and variance though only significant in the mean maize yield function. This implies that as crop yields rise over time because of the technological progress, yield variance rises as well. These results also confirm the findings of Anderson and Hazell (1987) and Isik and Devadoss (2006) who found that the improved technology augments both the mean and variability of crop yields.

The estimated equations for rice show that the precipitation and temperature have negative effects on the mean rice yield but a positive effect on the variance of rice yield. With exception of the square of temperature in the mean function and precipitation in the variance yield function, all other climate terms are statistically significant.

Table 3: *Impact of Climate Change on Mean and Variance of Maize in Nigeria*

Model	Variable	Linear		Quadratic		Square root	
Mean :							
		Coeff.	S.E	Coeff.	S.E	Coeff.	S.E
	P	0.0001**	0.0001	-0.0015	0.0012	-0.0008*	0.0004
	T	-0.0594***	0.0073	0.8901***	0.3267	-2.0826***	0.7024
	P^2			-0.0000***	0.000		
	T^2			-0.0213***	0.0069		
	PT			0.0009*	0.0005		
	$P^{1/2}$					-0.1801	0.1632
	$T^{1/2}$					18.3744***	6.7417
	$(PT)^{1/2}$					0.0462	0.0319
	Trend	0.0066*	0.0037	0.0061*	0.0036	0.006	0.0037
	Constant	3.0316***	0.1622	7.2629	3.8366	38.7489**	16.4452
Variance:							
	P	0.0004	0.0006	-0.0002	0.0004	-0.0002	0.0004
	T	0.1851**	0.0828	0.2158***	0.0778	0.2129***	0.0796
	Trend	0.0471**	0.0226	0.0333	0.0247	0.0355	0.0246
	Constant	8.5435***	2.1889	8.5487***	2.1641	8.4639***	2.174
	R^2	0.332		0.3785		0.3635	
	Log Likelihood	-7.2166		4.0637		2.4631	
	AIC	30.4333		13.8727		17.0737	

, **, *, denotes significance at 10%, 5% and 1% respectively; S.E = Standard error*

The interaction term in the quadratic mean yield function is positive and statistically significant. The positive coefficients of the precipitation and temperature in the variance function imply that the temperature and the precipitation are risk-increasing inputs in the rice production. However, only the coefficient of temperature is significant. The coefficient of the trend variable is positive in the mean yield function and the variance function, indicating that the technological progress brings higher yield and larger variability though this is only significant in the mean rice yield function.

Table 4: *Impact of Climate Change on Mean and Variance of Rice in Nigeria*

Model	Variable	Linear		Quadratic		Square root	
Mean :							
		Coeff.	S.E	Coeff.	S.E	Coeff.	S.E
	P	0.0006***	0.0001	-0.0028*	0.0021	-0.0013	0.0009
	T	-0.077***	0.0208	-1.3568*	0.7767	2.2593	1.5354
	P^2			-0.0001**	0.0000		
	T^2			0.0226	0.0151		
	PT			0.0021**	0.001		
	$P^{1/2}$					-0.4205	0.268

	$T^{1/2}$					-26.4436*	15.9643
	$(PT)^{1/2}$					0.1089**	0.0488
	Trend	0.0256**	0.0129	0.0258*	0.0132	0.0263**	0.0133
	Constant	2.8672***	0.5024	20.0503***	9.9456	74.5008	41.8504
Variance:							
	P	0.0004	0.0004	0.0006	0.0005	0.0006	0.0005
	T	0.2266**	0.1099	0.2368*	0.1214	0.2374*	0.1213
	Trend	0.0756	0.0479	0.0737	0.0469	0.0732	0.0468
	Constant	7.6898***	2.9688	8.2365**	3.353	8.2359**	3.3422
	R^2	0.1935		0.2547		0.2528	
	Log Likelihood	-1.70E+02		-1.70E+02		-1.70E+02	
	AIC	356.8258		354.9872		355.0794	

*, **, ***, denotes significance at 10%, 5% and 1% respectively; S.E = Standard error

The impacts of the precipitation and temperature on the covariance between maize and rice are reported in Table 5. The estimated coefficients of the precipitation and temperature terms are negative and statistically significant. This indicates that increases in the precipitation and temperature levels initially reduce the covariance between maize and rice. However, the square of temperature and the interaction term has positive and significant coefficients. The trend term is positive and significant implying that technological progress increases the covariance between maize and rice.

Table 5: *Impact of Climate Change on Covariance of Maize and Rice in Nigeria*

Variable	Linear		Quadratic		Square root	
	Coeff.	S.E	Coeff.	S.E	Coeff.	S.E
P	-0.0013***	0.0001	-0.0061***	0.002	-0.0017***	0.0003
T	-0.8929***	0.0325	-4.8769***	0.4468	6.6689***	0.9266
P^2			-0.0000	0.0000		
T^2			0.0746***	0.0094		
PT			0.0022***	0.0008		
$P^{1/2}$					-0.5946**	0.2736
$T^{1/2}$					-79.794***	8.7859
$(PT)^{1/2}$					0.1204**	0.0497
Trend	0.2273***	0.0076	0.2334***	0.0052	0.2306***	0.0051
Constant	29.1074***	0.9328	82.2523***	5.4365	239.079***	21.486
R^2	0.9732		0.9918		0.9917	
RMSE	0.386		0.2367		0.2355	

*, **, ***, denotes significance at 10%, 5% and 1% respectively; S.E = Standard error

The estimated production function parameters are employed to examine the implications of the climate change scenarios (CGM2 and HADCM3) for crop yields and variability. The percentage changes in the mean crop yields, variance, and covariance are calculated for the four climate change scenarios and the results are presented in Table 6. The results from the CGM2 and HADCM3 indicate that both temperature and precipitation would increase maize by about 4.1%-13.7% and 1.2%-2.1% respectively in the four scenarios. However, temperature and precipitation would cause a decrease in maize yield variance by about 1.5%-3.0%. For rice, temperature and rainfall would in general decrease the yield for rice and increase its variance in all four scenarios. Table 6 also summarizes the potential impacts of the four climate change projections on the yield covariance of maize and rice. The results indicate that the covariance of maize and rice would decrease in all cases except for the CGM2 precipitation scenarios where precipitation would cause an increase in the covariance of the two crops.

Table 6: *Percentage Change in Mean, Variance and Covariance of Maize and Rice under Climate Change Scenario*

Model	CGM3		HADGM3	
	2060	2100	2060	2100
Maize				
Mean				
Temperature	4.1288	7.2446	13.7431	7.5116
Precipitation	1.8740	2.1009	1.2083	1.1931
Variance				
Temperature	-2.3127	-1.5574	0.0181	-1.4926
Precipitation	2.8734	-2.8404	-2.9701	-2.9723
Rice				
Mean				
Temperature	-1.7296	-6.4789	-16.3844	-6.8860
Precipitation	-2.1973	2.6226	-0.9499	-0.9216
Variance				
Temperature	0.1126	0.9412	2.6696	1.0123
Precipitation	-0.5786	0.6623	0.3332	0.3276
Covariance				
Temperature	-11.3768	-28.4459	-64.0472	-29.9090
Precipitation	2.3487	3.2659	-0.3417	-0.4028

Conclusions and Policy Implications

This paper uses an econometric model to estimate a stochastic production functions and quantify the impacts of temperature and precipitation on the mean, variance, and covariance for maize and rice yields in Nigeria. The estimated production functions are then used to draw inferences about the future impacts of climate change for Nigerian agriculture.

The results from the econometric model that employs the historical climate and yield data show that the impacts of the temperature and precipitation on grain yields vary between maize and rice. The impact of precipitation is very minimal and sometimes insignificant compared to that of temperature. In general temperature and precipitation decreases maize and rice yields and reduces their variability. Simulation results however indicate that the mean yields of maize will increase substantially in the future while its variance would decrease because of the projected increases in both the temperature and precipitation levels. For rice, climate change will reduce its yield and increase its variance in future. The climate change will likely have significant impacts on the covariance of grain yields. The covariance of maize and rice yields is declined significantly except for the CGM2 precipitation scenario.

These results have important implications. First, there is need to learn the consequences of global warming for agriculture in order to prepare for the possible changes in climate conditions. Global climate change could have significant effects on Nigerian Agriculture. Hence, mitigation and adaptation strategies to curb these effects are necessary especially for rice production in Nigeria. If these are not tackled appropriately, Nigeria would continue to spend huge money on rice importation. Second the results have important implications for allocations of agricultural land among crops and the mix of crop production in the future. Allocations of agricultural land among various crops could change because of the changes in climate conditions. Changes in the variance and covariance of crops affect producers' land allocations among various crops by impacting the variability of profits. Because the climate change projections have differential impacts on the mean crop yields, yield variability, and covariance, the future mix of crop production and the extent of the acreage allocated to each crop are expected to change. Farmers will likely expand the acreage of crops whose mean yield increases and/or variability decreases in response to the projected climate change. Ceteris paribus, production of maize will likely increase and productions of rice will likely decrease in Nigeria. The reason for this result is that a risk-averse farmer is more likely to plant crops with low variability. Although, these results appear to support the current ongoing doubling of maize production in Nigeria, this however has long term implication for Nigeria's foreign reserve as rice continues to be imported.

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