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Climate Change and Agriculture: Modeling the Impact of Carbon Dioxide Emission on Cereal Yield in Ghana

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Abstract

The objective of the paper is to contribute to the body of knowledge in the area of climate change and agriculture by examining the effect of carbon dioxide concentration (CO_2) on cereal yield using autoregressive distributed lag models (ARDL). The research is based on quantitative, descriptive and cross-sectional research using secondary data obtained from World Bank data base for the period of 1961-2010. The co-integration test indicates the series are co-integrated. The results on the long run and shorts run elastically co-efficient indicate that there is significant negative link between CO_2 and cereal yield. There significant positive long run and short run link between cereal yield and income (proxied by real gross domestic product). Policy makers and agriculture scientists and environmental scientists should put in place policies to reduce atmospheric temperature increase and pollution to benefit from CO_2 fertilization in order to ensure food security. The findings indicate that income (proxied by real gross domestic product) positively affect cereal yield. The link between CO_2 and cereal production should be examine in future studies current study considered cereal yield.

Keyword: Climate change, CO_2, Real gross product, Cereal yield.
Jel Classification: Q54, Q56, Q57, Q58.

Contents

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1. Introduction

The significant impact of changes in climatic conditions (an increased frequency of climate extreme events; altered precipitation and transportation regimes; higher temperatures; elevated CO_2 Concentration) agricultural production systems now and years to come in developed and developing economies [1]. The role of climate change in agriculture productivity is of much concern to researchers and policy makers [2]. This increased attention results from the fact that crop yield as well as the type of crops to grow is the function of climate change [2-4].

The role of agricultural sector in an economy such as job creation [5] provision of food security; provision of raw material for the industrial sector and supply of export product to generate foreign exchange makes research and policy makers spend a lots of resources in examining the effects of climate change on agriculture. Researchers [6] have reported that there is slower growth rate of agricultural sector over the years due to climate change and this becomes more worrisome given the current nature of urbanization and population growth rate. Since in the developing economies, such as Ghana, agricultural is based largely on the climatic condition [6, 7] there is the need to empirically examine the effect of climate change on agriculture so that the right adaptation measure could be put in place to ensure food security.

Carbon dioxide (CO_2) is among the influential climatic factors the influence crop yield and which has empirically attracted attention in the literature. According to researchers [8-12] CO_2 acts as a fertilizing element (carbon dioxide fertilization) in the growth of crops classified as C3 and C4 crops. CO_2 is reported to have both direct and indirect effect of plant growth by enhancing photosynthesis processes and changing the climate through greenhouse effect.

According to Blanc [8] “greater CO_2 concentration enhances CO_2 assimilation by crops. This results in faster stomata closures and ultimately lower transpiration rates (i.e. crops loose less water). Therefore, CO_2 Concentration increases are most beneficial in sudano-sahel, which has a warm and arid climate”. The implication for these theoretical frameworks is that crop yield is expected to have positive link with carbon dioxide emissions, especially C4 plants, which is a subject of empirical verification such as the current study.

The empirical findings on the effects of the link between climate change and agricultural productivity are found in the works of various researchers [6, 8, 12-25]. Alaim [6] state that, rising concentration of CO_2 may cause decline in agricultural productivity and “will act as a fuel to the higher prices of goods and services in the economy”.

Blanc [8] reported that CO_2 emissions have significant long run and short run impact on millet yield but not on cassava and maize yields. The results indicate that 1ppm CO_2 increase in CO_2 concentration leads to about 4.75% millet yields increase. At the regional level, a1ppm increase CO_2 concentration leads to about 11.9% increase in millet yields. The results indicated that CO_2 concentration insignificant impact on sorghum yields.

In the study by Wang, et al. [26] the results indicate that without the direct effect of CO_2 the estimated model indicated that all three climate change scenario examined significantly increase biomass production compared to the baseline scenarios whereas the combined effect (climate and CO_2) increased biomass production much more, increased CO_2 concentration of 220 and 120 ppm resulted in increased biomass production of 43-45% and 25%, respectively in the study.

Other researchers such as Lobell and Field [14] used regression analysis and reported of positive plant responses to responses to CO_2 fertilization in the 20 largest producing countries of the Northern Hemisphere. Adams [9] established positive plant yields results from CO_2 fertilization. In a study by De Tafur, et al. [27] negative link was reported between CO_2 and cassava yields. Fuhrer [28] states that “ Warning accelerate plant development and reduce grain-fill, reduces nutrients use efficiency, and favors C4 weeds over C3 crops… and that warming again reduces the positive CO_2 effect”. Cure and Acock [12] used experimental research to report of a positive relationship between maize yields and CO_2 fertilization.

1.1. The Agriculture Sector of Ghanaian Economy

According to The State of Ghanaian Economy [29] the contribution of the agriculture sector to the Ghanaian economy in recent past has been low in relation to other sectors. For examples in 2011 the agriculture sector (25.65%) contributed least to the economic growth of the country followed by the industrial sectors (25.9%) and then the service sector (48.5%). The sector is still dominated by the peasant economy without any significant change since independent. Statistics indicate that growth rate of the sectors has been falling. For example in 2011 the growth rate was 5.3% but fell to 0.8% in 2011.

The sector even experienced negative growth rate in 2007. The contribution to the positive growth rate in 2011 after the rebounce in 2008 and 2009 are the subsectors such as cocoa (14%); livestock (5.1%) and the crop subsector (3.7%). Some of the subsectors (forestry and fisheries) have registered negative growth rate. The main cereal crops in Ghana are maize; sorghum; millet and rice. The performance of the cereals over the years has not been impressive. In 2011 the total output of the cereal crops did not attain positive growth. In 2011 the output was 186,000 tonnes whereas in 2010 the output was 218,000 tonnes. Maize has been the leading subsectors of the cereal crops in terms of yields and cultivated hectares of land.

The review of the literature and the agricultural sector indicates that the agricultural sector is important in relation to the economic development of any economy especially in small but open economy such as Ghana. Examination of factors that are responsible for the growth agricultural sectors in the empirical study is worth doing. The current paper models the long run and short run relationship between cereal yields and CO_2. The review of the literature indicates mixed findings of the effects of CO_2 on crop yield. Few econometrics studies exist in relation to developing economies such as Ghana. The finding on cereal yields and CO_2 has also been mixed in the literature [8]. The current paper fills the literature gap. Policy makers are provided with policy documents in order to adapt to the changes of climate change and to ensure food security. Theories of fertilization and climate change are provided with further understanding.

The general objective of the study is to contribute to the body of knowledge in the area of climate change and agriculture by modeling the stable long run relationship between carbon dioxide emissions and cereals yields empirically. Specifically, the paper examines; (a) The unit root properties of carbon dioxide emissions and cereal yields, (b) The co-integration relationship between carbon emission and cereals yield, (c) The long run and short run parameter estimate of the effect of carbon emission on cereal yield.

The study is based on the following research questions; (a) What is the effect of carbon dioxide emissions on cereal yield? (b) What is the nature of long run and short run relationship between carbon dioxide emissions and cereals? The assumptions tested in the current research are; (a) Carbon dioxide emissions and cereals yield are co-integrated, (b) Carbon emissions are key influential factors explaining cereal yield.

Data for the study was obtained from World Bank database. The estimated model might suffer from errors in variables and data massaging. The study is descriptive in nature and as such, causality issues are not the focus of the current study. The period for the study is between 1961-2010. Structural breaks in unit root are not considered in the study. Other influential factors such as temperature and precipitation are not considered for non-availability of data. The rest of the study deals with the methods, empirical results conclusions and policy implications.
The rest of the paper looks at the methodology, empirical results, discussion, and conclusion

2 Research Methodology

2.1. Design/Format/Strategy

The study modeled the link between CO2 and cereal yield in a trivariate, quantitative, descriptive and cross-sectional research format. Annual time series data for Ghana for the period 1961-2011 was used. The period was chosen for availability of data. The data used are CO_2; cereal yield and economic growth (proxied by real gross domestic product).

2.2. Unit root Test

The examination of unit roots is based on the Kwiatkowski, et al. [30] (KPSS) and Augmented [31] (ADF) test models. The ADF model is based on the null assumption (H0) that there is a unit root in the levels of the series. The alternative hypothesis (H1) is that the series are stationary in levels. The KPSS model is based on the null assumption (H0) that there is no unit root (stationary) in the levels of the series. The alternatives hypothesis (H1) is that the series are unit root (stationary) in levels.

2.3. Bound Testing Approach to Cointegration Model

The cointegration test is based on the Autoregressive distributed lag model (ARDL) developed by Pesaran and Shin [32]. Series variables in a model are considered to be cointegrated if they are integrated of order one, 1(1) in the presence of non-zero vector which is integrated of order zero, 1(0). The non- stationary series with the same order of integration may be cointegrated if there exist some linear combination of the series that can be tested for stationarity.

The cointegration analysis is based on the null hypothesis (Ho) that there is no cointegration among the series variables in the models against the alternatives hypothesis (Ha) that the variables are cointegrated. H0: b1=b2-b3=… =b k=0. The alternative hypothesis (Ha) is not Ho. The ARDL model estimated is assess for goodness of fit using various diagnostic test such as J-B Normality test. Breusch-Godfred LM test, ARCH LM test, white Heteroskedastically test, Ramsey RESET. The stability of the model parameters are examined using the cumulative sum of recursive residuals (CUSUM) and the cumulative sum of squares of recursive residuals (CUSUMSQ).

2.4. The Model

The conceptual model for the study state that cereal yield (CY) is a function of carbon dioxide emission (CO_2) with real gross domestic product (RGDP) as the control variable. That is InCY= f ($lnCO_2$, lnRGDP). The model is estimated in natural log form.

3. Empirical Results

The results are ADK; KPSS unit roots test results; cointegration test results; long run results; short run results; diagnostic test results and the stability test results.

3.1. Time Series Plots of the Series Variables

The plots of the series variables in levels and in first difference are shown in figures 1to6. The plot of the series in levels indicate the series are not stationary in levels but become stationary in first difference. This calls for formal examination of the stationary properties using the ADF test and the KPSS test. The results are presented in tables.

3.2. The ADF Model

The unit root results based on the ADF test are reported in Table 1and Table 2. The result of the ADF test for unit root in logarithm show that the series are non- stationary in intercept and trend. The null hypothesis of unit root was accepted for the series variables.

Table-1. ADF stationary test results with a constant and time trend

Variables (logarithm)	T-ratio	ADF P-value	Results
CO_2	-0.523027	0.9826	Not stationary
CY	-1.74441	0.7315	Not stationary
RGDP	0.0578461	0.9969	Not stationary

Source: Author's computation, 2014

Taking logarithm of the first difference of the series and testing these with intercept and time trend does make the series stationary. That is, the null hypothesis of unit root was rejected. The series become stationary after first difference. These results indicate that the series exhibit unit root processes and are integrated of order one, 1(1) and order zero, 1(0). The results are reported in Table 3

Table-2. ADF stationary test result with constant and time trend

Variables(1st diff. of Logarithm)	T-ratio	ADF P-value	Results
ΔlnCO_2	-6.01131	1.89e-006	stationary
ΔlnCY	-4.83595	0.0003711	stationary
ΔlnRGDP	-4.7488	0.0005364	stationary

Source: Author computation, 2014

3.3. The KPSS Model

The KPSS test results are presented in table 4. The KPSS is a reversed test for unit root. It is used in the current study for confirmation of the stationary properties of the series. The series were examined in their logarithm form. The results confirm that of the ADF test results.

Table-3. KPSS stationary test results with a constant and time trend

Variables (logarithm)	T-stats	Results
CO_2	0.28804(<0.01)	Not stationary
CY	0.232247(<0.01)	Not stationary
RGDP	0.306493(<0.01)	Not stationary

Source: Author computation, 2014
Note: 1%; 5% and 10% Critical values are 0.213, 0.149 and 0.121 respectively

Table-4. KPSS stationary test results with constant and trend

Variables(1st diff. of Logarithm	T-stats	Results
ΔlnCO_2	0.065819(>0.1)	stationary
ΔlnCY	0.0478982(>0.1)	stationary
ΔlnRGDP	0.100559(>0.1)	stationary

Source: Author computation, 2014
Note: 1%; 5% and 10% Critical values are 0.212, 0.149 and 0.122 respectively

In summary, the test results from the ADF and the KPSS indicate that the series exhibit unit root processes and are integrated of order one, 1(1) and order zero, 1(0). The detection of unit roots in the series indicate that shocks to the series will have permanent effects and not transitory effects. The results indicate that cointegration can be performed.

3.4. Cointegration Analysis using Autoregressive Distributed Lag (ARDL) Model/Bound Approach to Cointegration

In this section of the paper the results of the relationship between carbon dioxide emissions, infant mortality and real gross domestic product ate presented. The dependent is variable is infant mortality whereas dioxide emission and real gross domestic products are the independent variables. The results on the bound test, long run and short run parameters are presented in table 5, table 6 and table 7.

3.4.1. Bound Approach to Cointegration for Infant Mortality (FM)

The results presented reported in table 5 indicate significant cointegration between carbon dioxide emissions (CO_2); cereal yield (CY) and real gross domestic product (RGDP) in Models 1, 2 and 3. In model 1, the F- statistics value of 11.0045 is greater than the critical value of the upper bounds at the 90%, 95%, and 99% levels of significance, which is an indication of cointegration between carbon dioxide emissions, cereals yields, and real gross domestic product with carbon emissions as the dependent variable. In model2, the F-calculated value of 4.4938 is greater than the critical values of the upper bounds at the 90% and 95% levels of significance, which are indication of cointegration between carbon dioxide emissions, cereals yield, and real gross domestic product with carbon emissions as the dependent variable. In Model 3, the F-calculated value of 8.9438 is greater than the critical values of the upper bounds at the 90%, 95%, and 99% levels of significance, which is indication of cointegration between carbon dioxide emissions, cereal yields, and real gross domestic product with real gross domestic product as the dependent variable. The null assumption of no cointegration is rejected in models 1, 2 and 3. Models 1 are estimated for long run and short run parameters (elasticity coefficient).

Table-5. Test for cointegration relationship

Critical bounds of the *F*-statistic: intercept			
Models	90% level	95% level	99% level
	1(0) 1(1)	1(0) 1(1)	1(0) 1(1)
	2.915 3.695	3.538 4.428	5.155 6.265
	Computed F-stats	decision	
1.F_{lnCY}(lnCY/lnCO_2, lnRGDP	11.0045[0.001***]	cointegrated	
2.F_{lnCO2}(lnCO2/lnCY, lnRGDP)	4.4938[0.034**]	cointegrated	
3.F_{lnRGDP}(lnRGDP/lnCO2, lnCY	8.9438[0.003***]	cointegrated	

Source: Author computation, 2014: Note: critical value are obtained from Pesaran, et al. [33] and Narayan [34]:
Note*** and** denote significance at 1% and 5% levels of significance.

3.4.2. Results of Long- Run Elasticities of ARDL Model

The long-run relation between carbon dioxide emissions, cereals yields and real gross domestic product was estimated with cereal yield as the dependent variable. The results are reported in table 6. The results indicated that carbon dioxide concentration is significant (at 10% level) explanatory variable of cereal yield in the long run. The results indicate that increase in carbon dioxide emissions (CO_2) by 1% will lead to a decrease in cereal yields by about 54.67%. There is positive significant long run relationship between cereal yield (CY) and real gross domestic product (RGDP) in the model estimated. The results indicate that increase in real gross domestic (RGDP) by 1% will lead to an increase in cereal yield by about 76.41%.

Table-6. Estimated Long run Coefficients. Dependent variable is lnFM

Variable	Coefficient	Std.Error	T-ratio	P-value
Constant	6.2748	1.8826	3.3330	0.002***
Trend	0.035723	0.011348	3.1479	0.003***
InCO2	-0.54665	0.29027	-1.8833	0.066*
InRGDP	0.76406	0.23174	3.29711	0.002***

Author's computation, 2014: ARDL (1) selected based on Akaike Information criterion.
Note: *** and * denotes statistical significance at the 1% and 10% levels significantly.

3.4.3. Result of Short-Run Elasticities of ARDL Model

The results of the short-run dynamic equilibrium relationship coefficients estimated with trend and error correction term (ecm) are reported in table 7. The results on the nature of the short run coefficient are not different from that of the long run parameters. The results indicate that carbon dioxide concentration is statistically significant determinants of cereal crop yields in the short run. The results indicate that increase in carbon dioxide emissions (CO_2) by 1% will lead to a decrease in cereal yield by about 31.03%. There is significant positive short run relationship between cereal yield (CY) and real gross domestic product (RGDP) by 1%will lead to an increase in cereal yield by about 43.37%. The error correction term is statistically significant and does have theoretical expected sign which is negative. The coefficient of -0.56767 indicate that, after 1 percent deviation or shock to the system, the long run equilibrium relationship of infant mortality is quickly re-established at the rate of about 56.77% per annum. The value does indicate moderate adjustment rate.

Table-7. Short-run representation of ARDL model. ARDL (1) selected based on Akaike Information criterion. Dependent variable: ΔlnFM

Variable	Coefficient	Std.Error	T-ratio	P-value
Trend	0.020279	0.0059051	3.4341	0.001***
$\Delta InCO_2$	-0.310331	0.14638	-2.1199	0.040**
ΔInRGDP	0.43373	0.14503	2.9906	0.005***
Ecm(-1)	-0.56767	0.13033	-4.3557	0.000***

Source: Author's computation, 2014.
Note: *** and* denotes statistical significance at the 1% and 10% levels significantly.

3.4.4. Results of Diagnostic Tests

The diagnostic tests of the short-run estimation to examine the reliability of the results of the error correction model are reported in table 8. The null hypothesis of no serial correlation is not rejected using the Lagrange multiplier test and F-statistics. The reset test showed evidence of incorrect functional specification of the model. The estimated model did not passed the normality test. The model passed Heteroscadasticity test indicating the variances are constant over time. The R^2(0.81733) and the adjusted R^2(0.80034) in the Table are an indication of very well behave model. The coefficient indicate approximately 81.73% of the variations in cereal yield are attributed to carbon dioxide emissions and real gross domestic product.

Table-8. Short run diagnostic tests of ARDL model

Test statistics	LM Version	F Version
A: Serial correlation	CHSQ(1)=.15519[0.694]	F(1, 42) =0.13623[0.714]
B: Functional form	CHSQ(1)= 5.5570[0.018]	F(1, 42)=5.4990[0.024]
C: Normality	CHSQ(2)=12.1834[0.002]	Not applicable
D: Heteroscedasticity	CHSQ(1)=1.4482[0.222]	F(1, 46)= 1.4718[0.23]
A: Language multiplier test of residual serial correlation		
B: Ramsey's RESET test using the square of the fitted value		
C: Based on a test of test skewness and kurtosis of residuals		
D: Based on the regression of squared residual on squared fitted values		

Source: Author's computation, 2014

The stability of the long run estimates was determine by employing the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMG) procedures. This was determined using the residual of the error-correction model indicate by equation (1). The CUSUM test of stability determines the methodological arrangements of the estimate and its null hypothesis states the coefficients are stable. The null assumption is rejected when the CUSUM surpasses the given critical boundaries, which demonstrate unstable nature of the estimates. The CUSUMG determines the stability of the variance. Both tests indicate that the estimate and the variance were stable as the residuals and the squared residuals fall within the various 5% critical boundaries. The null assumptions are rejected in both tests.

4. Conclusions and Policy Recommendations

The objectives of the paper have been achieved. The long run link between CO_2 and cereal yield has been examined. The series variables in the estimated model are cointegrated. The long run and short run elasticities are statistically significant but do not have the expected signs. The CO_2 elasticity of cereal yields is negative in the long run and short run. The findings of the current study are in support of the findings of previous studies reported in the literature [6, 8, 27, 35-37].

Blanc [8] reported of insignificant effect of CO_2 concentration on maize yield. Fuhrer [28] indicate that the benefits of CO2 may be lost in warmer climate. According to J., et al. [37] crop yield (wheat and rice) is decreased as a results of high temperature (Above 32) and that higher temperature offset an increase in yield resulting increase atmospheric CO_2 concentration. Amthor [36] indicated benefits of CO_2 fertilization is largely offsets by pollutants and nutrients limitation. De Tafur, et al. [27] reported of negative link between CO2 concentration and cassava yields. The findings are in consistent with the findings of researchers [12, 14, 26] who reported of positive significant link between CO_2 concentration and crop yield.

Policy makers, agriculture scientists, and environmental scientists should put in place policies to reduce atmospheric temperature increase and pollution to benefits from CO_2 fertilization in order to ensure food security. Agriculture practices should ensure there is no issue of limiting nutrient crop farming. There should by intensive agriculture that will save the potential to adapt to changing climate conditions. Farmers should adapt policies such as providing irrigation or increasing its efficiency, maintaining or improving flood control, encouraging agronomic research. The findings indicate that income (proxies by real gross domestic product) positively affect cereal yield. Economic policy makers should put in place policies to ensure economic growth so as to be able to attain increase cereal yield. Future studies should examine causality issues since the current study is descriptive in nature. The link between CO_2 and cereal production should be examined in future studies since the current study considered cereal yields.

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