Between Climate Reliance and Climate Resilience: Empirical Analysis of Climate Variability and Impact on Nigerian Agricultural Production

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1 Introduction

Climate change is now a global phenomenon that portends significant developmental challenges. The agricultural sector is no exception to the impact of climate change (Choptiany et al. 2015). The potential and predicted impacts of climate change are resulting in increased frequency and intensity of rainfall, floods and droughts (IPCC 2015). Rain-fed agricultural production system is vulnerable to seasonal variability which affects the livelihood outcomes of farmers and landless laborers who depend on such system of agricultural production. (Choptiany et al. 2015; Vermeulen et al. 2012). Climate change affect agriculture through rainfall variability (IPCC 2015). This situation, therefore, makes climate change an important consideration for sustainable agricultural production (Easterling et al. 2007). In the events of erratic rainfall, irrigated land area is insurance to rain-fed agriculture and a predictor of resilience of agriculture to rainfall-induced vagaries (including, droughts and heat waves) and impact of climate change (Cassman and Grassini 2013). Hence, the need for the empirical analysis of the impacts of rainfall and irrigation on agricultural production in Nigeria.

The agricultural sector is increasingly showing high level of vulnerability and impact. Climate change across Africa is exacerbated by low level of adaptation and mitigation (IPCC 2015; Montpellier Panel Report 2015). Further, literature suggests that farmers are now adapting to climate change and building resilience to vagaries of climate change (Choptiany et al. 2015; Wood et al. 2014; Kristjanson et al. 2012).

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The agricultural production risk imposed by rainfall variability may be a motivation or hindrance to investment in improved agricultural technology and climate resilient agriculture. Besides, farmers who are unable to adapt to changing climate may find alternative livelihoods or remain impoverished. Others may become resilient by developing alternative systems of production that help them to cope with changing climate. There is, therefore, pseudo choice-making process that is constrained by initial endowment or capacity to innovate so as to overcome vulnerability by becoming climate-resilient through appropriate adaptation and mitigation strategies (Montpellier Panel Report 2015; Wood et al. 2014). It has been noted that any strategy to adapt agriculture and food systems to a changing climate must, therefore, exploit the diversified means of climate resilient strategies. (Vermeulen et al. 2012).

Variability and extreme rainfall events have the potential to transform agricultural production system (rain-fed or irrigated) and diversifications of agricultural production (Liverman and Kapadia 2010; Nelson et al. 2009). The ability to circumvent the negative impact of climate and weather variability in agricultural production is an important consideration for climate adaptation and resilient agriculture for maximizing its benefits agricultural livelihoods and economic development.

The paper builds on emerging literature on the impact of climate variability on agricultural production (Ajetomobi et al. 2015; Craparo et al. 2015; Gourdji et al. 2015). It reveals the reliance and/or resilience of agricultural production to climate change and variability (Schlenker and Lobell 2010; Schlenker and Roberts 2009; Guiteras 2009; Kurukulasuriya et al. 2006). The study also underscores the contexts of vulnerability, impact and adaptation to climate change (Metternicht et al. 2014), including productivity, food security and livelihoods (Carandang et al. 2015; Arumugam et al. 2015).

2 Materials and Methods

2.1 Type, Measurement and Sources of Data

Time series data were extracted from harmonized databases of the Central Bank of Nigeria (CBN), National Bureau of Statistics (NBS), Nigerian Meteorological Agency (NIMET) and the Food and Agriculture Organization (FAO) of the United Nations in the Statistical Bulletin of the NBS (NBS 2013). Supplementary data on occurrence of flooding of the magnitude of national emergency situation were obtained from various publications. The specific data extracted included: agricultural production index, incidences or occurrence of flooding in a specific year, mean annual rainfall in millilitres, and value of agricultural (food) imports in million US dollars. The index of agricultural production is the relative level of the aggregate/composite volume of agricultural production (base year = 1990) (http://faostat.fao.org/site/362/DesktopDefault.aspx?PageID=362).

Since the impact of climate change is considered over a long period time (usually more than 30 years), this paper analysed times series dataset that spanned a period of 43 years (1970–2012) to estimate the impact of rainfall and irrigation on aggregate agricultural production in Nigeria. This criterion of sufficient time period also satisfies the econometric properties of large sample size (or observations) of the generalised methods of moment (GMM) estimation (Craparo et al. 2015; Gourdji et al. 2015; Hansen 2012), and consequently the estimation of the impact of rainfall and irrigation on agricultural production.

2.2 Analytical Methods

Descriptive analyses (means and standard deviations) were used to analyse the dataset to elaborate the variables. The GMM econometric technique was employed in estimating the impact of rainfall and irrigation on agricultural production. The choice of GMM was informed because the ordinary least squares estimation technique (regression) might result in biased estimation which is particularly linked to spurious regression and endogeneity problems (Fan et al. 2008). The issue that may cause spurious regressions is the possible existence of unit roots or non-stationarity of variables in the time series data analysis. This problem was handled by differencing while the problem of endogeneity of correlated independent variable (Fan et al. 2008) was resolved with the use of instrumental variables in the GMM estimation procedures.

Following Fan et al. (2008), and Arellano and Bond (1991), a GMM estimator as an estimation method was stated as:

$$\Delta y_{it} = \sum_{e=1}^{m} a_e \Delta y_{it-e} + \sum_{e=1}^{n} \beta_e \Delta x_{it-e} + \Delta \eta_{it} + \Delta u_{it} \quad (1)$$

where y is the dependent variable; x is a set of independent variables, i = 1, …, N; m and n are the lag (Δ) lengths sufficient to ensure that u_{it} is a stochastic error and η_i are instrumental variables. Blundell and Bond (1998) suggest that if the simple autoregressive AR(1) model is mean-stationary, the first differences Δy_{it} will be uncorrelated with individual effects.

The procedure for examining the nature of dataset for stationarity is to establish whether or not there exists a long-run relationship between the dependent variables and the independent variables. According to Engel and Granger (1987), homogenous non-stationary time series, which can be transformed to a stationary time series by differencing d times, is said to be integrated of order d. Thus, Y, (a time series variable) is integrated of order d [$Y \sim I(d)$] if differencing d times induces stationarity in Y_t. If $Y_t \sim I(0)$, then no differencing is required as Y is stationary (Jefferis and Okeahalam 2000). The test proposed by Dickey-Fuller to determine the stationarity properties of a time series is called the Unit Root test denoted by DF. The regression equation for the DF class of unit root test is:

$$\Delta Y_t = \varphi Y_{t-1} + \varepsilon_t;\ \varepsilon_t \sim N\left(0, \sigma^2\right), Y_0 = 0 \tag{2}$$

The unit root test above is valid only if the series is an autoregressive, AR(1) process. The Augmented Dickey-Fuller (ADF) tests use a difference method to control for higher-order serial correction in the time series. Another alternative test for stationarity is the Phillips-Perron (PP) test. The PP test allows for individual unit root process so that the autoregressive coefficient can vary across units (Olayide and Ikpi 2013; Ajetomobi 2008). The stationarity tests make a parametric correction for higher-order correlation by assuming that the Y series follows an AR(p) process and adjusting the test methodology. The ADF is identical to the standard DF regression, but augmented by k lags of the first difference of the series as follows:

$$\Delta Y_t = \alpha Y_{t-1} + \sum_{i=1}^{k} \omega i \Delta Y_{t-1} + \varepsilon_t \tag{3}$$

where the lag k is set so as to ensure that any autocorrelation in Y_t is absorbed and that a reasonable degree of freedom is preserved, while the error term is white noise or stationary.

The GMM is widely preferred and used in applied econometric research for empirical impact analysis. Zhang and Fan (2004) applied a GMM method to empirically test the causal relationship between productivity growth and infrastructure development using India district-level data, while Fan et al. (2008) assessed the impact of public expenditure in developing countries.

2.3 Variables Used for the Estimation of the GMM

In estimating the GMM model, aggregate agricultural production index was specified as the dependent variables while annual mean rainfall (in millilitres) and proportion of arable land under irrigation were the independent variables. The instrumental variables were incidence of flooding and annual total value of agricultural (food) imports (in million US dollars) (Quian and Schmidt 1999). These variables are predicted to have impact on aggregate agricultural production in Nigeria. The estimations were carried with E-Views 7 econometric computer software package.

3 Results and Discussion

3.1 Description of Variables

Results in Table 1 show the description of variable used in the analysis. The results reveal that the index of aggregate agricultural production was above the average for the base year (1990 = 100). This result indicates that agricultural production

Table 1 Description of variables used in estimating the generalized method of moment model

Variable and measurement	Mean	Std. deviation
Index of aggregate agricultural production	119.48	67.87
Mean rainfall in mm	355.39	64.24
Proportion of arable land under irrigation	0.80	0.10
Flood occurrence (dummy)	0.42	0.50
Total agricultural (food) imports in million US dollars	2236.47	1971.98

increased above the base year period. The mean rainfall for the study period was 355.39 (± 64.24) mm. The average proportion of arable land under irrigation was less than one percent (0.80 ± 0.10). Flooding incidence of national catastrophe magnitude was recorded for average of 42% of the study period. The total agricultural (food) imports in million US dollars were worth 2236.47 (±1971.98). The implications of the results in the context of the Nigeria agricultural policy call for concern. In that, the national agricultural policy agenda seek to promote food self-sufficiency by gradual reduction in the share of food imports that have comparative and competitive advantages. However, the country still spends a lot of foreign exchange on food imports (Olayide et al. 2011), and therefore, not self-sufficient in food production. For the country to move progressively towards self-sufficient in food production and food security (availability, access and stability), it should ensure increased food production under climatic changes which would have implications for rainfall and irrigation under the current agricultural production system.

3.2 Results of the Stationarity Tests

As a necessarily steps for estimating times series econometric models, we examined the variables used for the GMM model for stationarity or unit roots using comparable standard test statistic recommended in literature (Breitung 2002). The natural logarithms of the variables (except incidence of flooding which is a dummy variable) were tested for stationarity/unit root using comparable test methodologies of Augmented Dickey-Fuller and the Philips-Perron. Both tests yielded similar results (see Table 2). Only average annual rainfall and value of total agricultural (food) imports were stationary (white-noised) at level. All the variables (including, average annual rainfall and value of total agricultural (food) imports) were, however, stationary at first difference which suggests that they were auto-regressive of order I (ARI) variables (Breitung 2002), and they are co-integrated with their past values. This result also informed the estimation of the GMM by suggesting the incorporation of appropriate lag length (first difference) in the model estimation (Fan et al. 2008).

Further, the stationarity tests of the variables suggest that the interdependence with one-year lag or past values. For instance, this result has implications for

Table 2 Results of unit roots tests

Variable	At level (test statistic)		At first difference (test statistic)	
	Augmented Dickey-Fuller	Philips-Perron	Augmented Dickey-Fuller	Philips-Perron
Index of aggregate production	−1.0242 (0.7359)	−1.2427 (0.6469)	−5.9026*** (0.0000)	−5.9026*** (0.0000)
Mean annual rainfall	−4.9653*** (0.0002)	−4.9871*** (0.0002)	−8.9894*** (0.0000)	−23.0233*** (0.0001)
Proportion of arable land under irrigation	−1.1104 (0.7030)	−1.3873 (0.5794)	−5.9871*** (0.0000)	−5.9955*** (0.0000)
Value of total agricultural (food) imports	−3.5210** (0.0122)	−3.4116** (0.0161)	−6.5873*** (0.0000)	−7.8971*** (0.0000)

*** indicates 1% level of significance while
** indicates 5% level of significance

availability or retention rainfall from past year in the current year, all things being equal. But we know that soil water retention/availability is affected by many factors (Brooksbank et al. 2011), which are not captured in the present study. However, it is instructive that rainfall is required in current agricultural production system in Nigeria, almost on year-to-year basis. Again, the result supports the fact that the Nigerian agricultural production system is predominantly rain-fed. This result has implications for climate adaptation and resilient agriculture in Nigeria because with the climate change predictions of variability in rainfall, drought in previous year would have negative impact on agricultural production and food security (availability, access and stability) in Nigeria.

4 Impacts of Rainfall and Irrigation on Agricultural Production

4.1 Evidence for Promoting Climate Change Adaptation and Climate Resilient Agriculture in Nigeria

The results in Table 3 revealed that irrigation had positive and significant impact on aggregate agricultural production. The diagnostic statistic (R-squared) of the aggregate agricultural production model showed that the independent variables explained 74% of the variation in agriculture production. The impact of irrigation on aggregate agricultural production showed that a unit change in arable land under would lead to 4.3% in aggregate agricultural production. This result also revealed that rainfall has positive but insignificant impact on aggregate agricultural production. The results implies that irrigation system of production, rather than the current reliance on rain-fed agriculture, holds the key to sustainable agricultural production in Nigeria, especially the face of climate change and variability.

Table 3 Impacts of rainfall and irrigation on agricultural production

Variable	Coefficient	*t*-value	Probability	R-squared
Constant	1.0265	0.1951	0.8463	0.7455
Rainfall	0.7843	0.8877	0.3802	
Proportion of arable land under irrigation	4.3260***	9.6783	0.0000	

*** indicates 1% level of significance

Irrigation agriculture is a climate change adaptation strategy for managing extreme rainfall events (including, drought) and for promoting climate resilient agriculture. Irrigation agriculture could also ensure all-year round and sustainable agricultural production, afforestation and development of ranches and pasturelands for livestock production, including aquaculture. The pasturelands could also contribute to reduced greenhouse gas emission and enhance carbon sequestration in grazing lands through grazing intensity, increased productivity, nutrient management, fire management, and species introduction (O'Mara 2012).

It should be noted that irrigation agriculture is expensive to maintain, and a long-term investment (Mulangu and Kraybill 2015). However, the cost of irrigation system could be recouped through the production of high agricultural value commodities, especially in the dry season farming. The irrigation technology could also involve the combination of drainages and channeling of flood water to reservoirs to mitigate flooding. Irrigation practices should be encouraged at both small-holder famers' level and community level. Overall, the social and economic costs of irrigation agriculture (Connor et al. 2008) are often lower than the benefits that could accrue in terms of increased agricultural productivity and diversification, economic profitability, environmental amelioration and reduction of agricultural production risks.

5 Conclusion

This paper assessed the impacts of rainfall and irrigation on agricultural Production in Nigeria with a view to determining the level of reliance or resilience in the face of climate change. We found evidence for the impact of irrigation as a tool for promoting climate change adaptation and resilient agriculture in Nigeria. Irrigation had positive and significant impact on aggregate agricultural production. The findings suggest the need for the minimization of the impact of climate-induced production risks through the climate resilient agriculture in order to bring about the much-desired sustainable agricultural production in Nigeria. Expanding the area under irrigation in Nigeria would ensure sustainable agricultural production and food security in the country. It would also enhance the development of all subsectors of agriculture. It would not only be beneficial to the crop production subsector only (Ajetomobi et al. 2015), but it would inclusive and broad-based development of the agricultural economy (World Bank 2008) in Nigeria.

Therefore, there is the need for policy shift from the predominantly rain-fed agricultural production to irrigation system of agricultural production. Such policy shift would involve progressive expansion of arable areas under irrigation in Nigeria. The irrigation system of agricultural production is consistent with climate change adaptation and resilient agriculture. The irrigation system of agricultural production would enhance long-term sustainability of food production and food security. It is important to consider the cost on investment in irrigation and sustainability dimensions (social, economic and environmental) of irrigation agriculture. Although the issue of investments on irrigation agriculture was not considered by the present study, past studies (Mulangu and Kraybill 2015) have established that the initial costs of irrigation system of agricultural production (either at farm-level or landscape level), are huge but recoverable over a long-term investment period. Notwithstanding, the overall social, economic and environmental beneficial impacts of irrigation agriculture provide the guarantee for food security and sustainable agricultural production in the face of climate change and variability.

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