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Full Length Research Paper

Interrupted Time Series Analysis on maize production in Ghana: The case of Planting for Food and Jobs program

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Abstract

The Planting for Food and Jobs program was a government policy implemented in 2017 with the aim of improving the production of major food crops such as maize in Ghana. In this paper, we used Interrupted Time Series Analysis to investigate whether there was any structural change in the mean level of Ghana's maize production. To this end, we developed an interrupted time series model with a set of pulse functions to evaluate any possible structural change in the production of maize in Ghana. The data we used for the analysis in this paper were secondary data representing Ghana's annual maize production from 1960 to 2020. Estimation results of the interrupted time series model revealed that significant improvements in maize production were realized in 2017, 2018, 2019 and 2020. Overall, the study was concluded by indicating that the significant improvements in the maize production could be attributed to the Planting for Food and Jobs program as well as other possible underlying factors.

Keywords: Interrupted Time Series Analysis, pulse functions, extension services.

INTRODUCTION

Maize (Zea mays), also called corn, is a cereal crop and is believed to have originated in central Mexico 7000 years ago from a wild grass, and Native Americans transformed maize into a better source of food. Maize contains approximately 72% starch, 10% protein, and 4% fat, supplying an energy density of 365 Kcal/100 g and is grown throughout the world (Dula, 2019; Ranum et al., 2014).

Maize is Ghana's number one staple food crop and accounts for more than 50 percent of the country's total cereal production and contributes significantly to consumer diets. Additionally, maize represents the second largest commodity crop in the country after cocoa. Thus, maize is one of the most important crops for Ghana's agricultural sector and for food security. Despite the enormous importance and benefits of maize production, yield in Ghana's maize farms was indicated to be one of the lowest worldwide (Wongnaa et al., 2019). Thus, the government of Ghana with the aim of increasing food production and ensuring food security introduced an intervention program (a flagship policy called Planting for Food and Jobs) in the country in 2017 (Tanko et al., 2019).

As the aim of the program was to help increase production thereby causing a possible structural change in maize production, the extent of any structural change in maize production is being investigated as the main focus of this work. To this end, the study sought to

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develop an interrupted time series model to address the following research questions: that is, during the years in which the intervention program was implemented in the country,

1. Was there any change in maize production (such as an improvement in production) in Ghana?
2. And if so, how much was the level of improvement in the production?

The Intervention Program (Planting for Food and Jobs)

The Planting for Food and Jobs Program is an intervention program that was implemented by the government of Ghana in 2017. The program implemented was geared towards increasing food productivity and ensuring food security for the country as well as reducing food import bills to the barest minimum (Ministry of Food and Agriculture, 2017).The intervention program involved: supply of improved seeds to farmers at subsidized prices (50% subsidy), supply of fertilizers to farmers at subsidized prices (50% price cut), free extension services to farmers, creating marketing opportunities for produce after harvest (arrangements have been made to offer ready markets for farmers who will be participating in the campaign) and E-Agriculture (a technological platform to monitor and track activities and progress of farmers through a database system) (Ministry of Food and Agriculture, 2017).

Review of Literature

The use of improved seeds is revealed to be one key to rapid increase in crop production and productivity (Abebe and Alemu, 2017). However, most farmers, especially of developing countries, are unable to use such seeds due to their unavailability and ignorance (Basnyat, 2017). In Ghana for example, it is revealed that only 11% of maize farmers used improved seeds for farming before the start of the intervention program (Ghana News Agency, 2017). As a result, the Ghana government sought to supply improved seeds at a subsidized price through the implementation of the intervention program. It is indicated that inorganic fertilizers and improved maize varieties significantly increase maize yields when adopted as a package, rather than as individual elements (Nyangena and Juma, 2014). Thus, the supply of improved seeds and fertilizers both at subsidized prices as captured in the intervention program in Ghana was crucial in contributing to an improvement in maize production. Agricultural extension (also known as agricultural advisory services) plays a crucial role in promoting agricultural productivity and increasing food security among others (Hameed and Sawicka, 2016). Access to agricultural extension is revealed to result to higher productivity and higher food security (Ragasaand Mazunda 2018). Despite the significant importance of agricultural extension service, its availability remained inadequate in Ghana as indicated by Ababio (2017). Agricultural extension was therefore captured as one key component of the intervention (planting for food and Jobs) to provide the needed help to farmers in order to ensure improvement in crop production.

Time series is defined as a sequence of observations ordered in time which are mostly collected at equally spaced, discrete time intervals (Schaffer et al., 2021; Zamanah 2016; Agrawal et al. 2012). Time series are frequently affected by certain external events such as holidays, strikes, sales promotions and other policy changes. These external events are referred to as interventions. Thus, interrupted time series analysis also called intervention analysis is a technique that is used to evaluate the effects of these external events (Schaffer et al., 2021; Wei, 2006). Interrupted time series analysis was developed by Box and Tiao (1975) and has been successfully applied in various fields of study (Wei, 2006). For example, Henry et al. (1993) applied the concept of Time-Series Analysis to assess the interrupted effect of government policies on the U.S. Beef Cattle Industry.

Ledolter and Chan (1996) also used Time Series Intervention Analysis to study the effect of speed limit change on the number of fatal and major-injury accidents in Iowa rural interstates. Findings from their study revealed a 20% increase in the number of state-wide fatal accidents to the speed limit change. However, there was no significant impact of the speed limit change on the number of major-injury accidents.

Zamanah (2016) successfully used Time Series Intervention Analysis to study the effect of a fertilizer subsidy program on maize production in Ghana. The study findings revealed that, significant improvements in maize production were realized in some of the years during which the subsidy program was implemented.

Schaffer et al. (2021) applied the concept of Interrupted Time Series Analysis to assess the impact of a change in subsidy on Australian medicine dispensing claims. The findings from the study showed that the change in the subsidy was associated with a decrease in dispensing claims by 3285.

MATERIALS AND METHODS

Time Series Intervention Analysis is adopted to evaluate possible interrupted effect of the intervention program (Planting for Food and Jobs) on maize production in Ghana. Annual maize production (measured in 1000 metric tons) from 1960 to 2020 representing a time series was used as the data in this work. The data were obtained from a secondary source (Index Mundi, 2021). SAS was used as the statistical software in the data analysis.

Interrupted Time Series Analysis

Interrupted Time Series Analysis is a method used in evaluating the effect of external events on a time series (Schaffer et al., 2021; Wei, 2006). The effects of external events are determined using time series intervention models. An interrupted time series model also called intervention model is an Autoregressive Integrated Moving Average (ARIMA) model with an input series. In an intervention model, the input series is an indicator variable that contains discrete values that flag the occurrence of an external event affecting the response series. An ARIMA model is a combination of Autoregressive (AR) and Moving Average (MA) models with a differencing factor. The autoregressive model shows the relationship between the present value and past values of the series plus a random value whiles the moving average model describes the relationship between the present value of the series and past residuals. An ARIMA model of order (*p*, *d*, *q*) denoted by ARIMA(*p*, *d*, *q*) is defined according to Wei (2006) as follows;

$$\emptyset_p(B)(1-B)^d Y_t = \theta_0 + \theta_q(B)a_t \ldots\ldots\ldots\ldots (1)$$

Where

Y_t =theobserved series (Annual maize production for this study)

θ_0 = Mean of Y_t

$$\emptyset_p(B) = 1 - \varphi_1 B - \ldots - \varphi_p B^p$$
$$\theta_q(B) = 1 - \theta_1 B - \ldots - \theta_q B^q$$

φ_i = The i^{th} autoregressive parameter,θ_i = The i^{th} moving average parameter,p, q and $d$denote the autoregressive, moving average and differenced orders respectively,$B$is the backward shift operator and $\{a_t\}$ is a zero mean white noise process with constant variance σ_a^2.

Analyzing the Interruption Effect

Toevaluatethe interrupted effects of possible external events,we divided the modeling process into two phases. The first phase of the modeling process was the pre-intervention analysis which consisted of: model identification and diagnostic checking for the period before the intervention was introduced. This period is referred to as the noise season with the series called noise series (Wei, 2006).

Model Identification

The model identification involved determining a tentative ARIMA model referred to as a noise model. This was achieved by identifying the proper values for the orders of the AR and MA components. The respective orders of the MA and AR components (p, q) can be determined by using sample Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) respectively (Schaffer et al. 2021; Wei 2006). A nonstationary series can be made stationary by differencing the data. The number of times the series is differenced is defined by d. For a stationary series therefore, $d = 0$ and ARIMA (p, d, q) can be written as ARMA (p, q).

In modeling the noise series, we used order identification diagnostic technique which involved the use of extended sample autocorrelation function (ESACF) and the smallest canonical (SCAN) correlation method where final tentative model orders were determined at 5% significance level.

The SCAN method used a SCAN table from which tentative orders were identified by finding a (maximal) rectangular pattern in which the smallest canonical correlations were insignificant for all test orders $m \geq p + d$ and $j \geq q$ where m is autoregressive test order, j is moving-average test order,$p + d$ is a true autoregressive order with a true moving-average order of q (Tsay and Tiao,1985).

In the ESACF method, an ESACF table was used from which tentative orders were identified by finding a right (maximal) triangular pattern with vertices located at $(p + d, q)$ and $(p + d, q_{max})$ and in which all elements (extended sample autocorrelations) were insignificant (based on asymptotic normality of the autocorrelation function) where q_{max} represents maximum moving average test order (Tsay andTiao, 1984).

Diagnostic checking

After identifying the model, the parameters are estimated and the model checked for adequacy through a residual analysis. That is, the residuals are checked to see if the model assumptions are satisfied. The basic assumption is that the residuals are white noise (Wei, 2006). We tested this assumption by using the modified Box-Pierce Q statistic $\tilde{Q}(\hat{r})$, which is defined below according to Ljung and Box (1978).

$$\tilde{Q}(\hat{r}) = n(n+2)\sum_{k=1}^{h}(n-k)^{-1}\hat{r}_k^2 \ldots\ldots\ldots\ldots (2)$$

Where

$\hat{r}_k$ = The residuals autocorrelation at lag k

n = The number of residuals

h = The number of time lags included in the test

When the p-values are large for the chi-square statistics at various lags, the model is considered adequate, otherwise a new model is used and the process repeated (Wei, 2006). In this study, we performed all tests at a significance level of 5%.

In the second phase of the modeling process, we used the noise model identified in the first phase to hypothesize the interrupted effect of the intervention by using a set of pulse functions for the intervention variable.

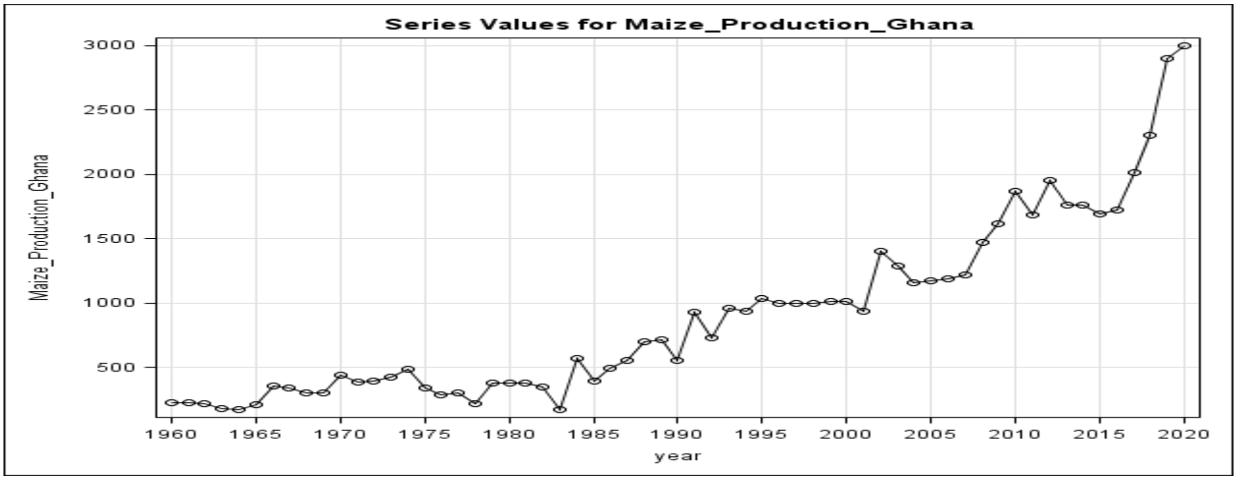

Figure 1.Time series plot of Ghana maize production.

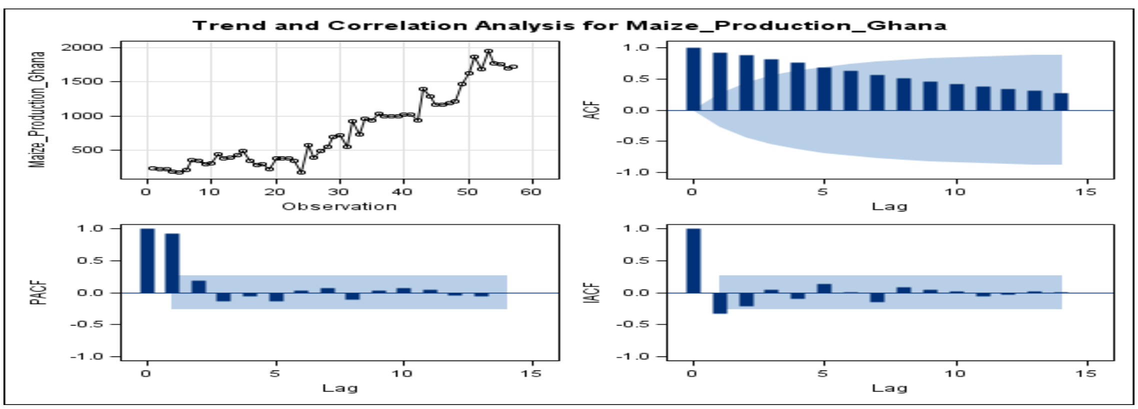

Figure 2.Trend and Correlation Analysis for the maize production.

A pulse function represents an intervention that occurs at only one time period, T. It is defined according to Wei (2006) as,

$$I_t = \begin{cases} 1, & t = T, \\ 0, & t \neq \text{T}. \end{cases} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

The general response function for the intervention variable used is given as follows according to Wei (2006).

$$\frac{\omega(B)B^b}{\delta(B)}\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

where $\omega(B) = \omega_0 - \omega_1 B - \ldots - \omega_s B^s$, $\delta(B) = 1 - \delta_1 B - \ldots - \delta_r B^r$, b is the time delay for the intervention effect and ω_j's represent the expected initial effects of the intervention and $\delta(B)$ measuresthe behavior of the permanent effect of the intervention with s and r being non negative integers.

Thus, the general form of the intervention model using the response function is given as,

$$Z_t = \theta_0 + \sum_{j=1}^{k} \frac{\omega_j(B)B^{bj}}{\delta_j(B)} I_{jt} + \frac{\theta(B)}{\psi(B)} a_t \ldots\ldots\ldots(5)$$

where I_{jt}, j= $1, 2, \ldots, k$ are intervention variables, $\omega_j(B)B^{bj}/\delta_j(B)$ represents the jth intervention response form,$[\theta(B)/\psi(B)]\, a_t$is the noise modeland $Z_t$is the response of the original series as a result of the introduction of an intervention (Wei, 2006).

The intervention program (Planting for Food and Jobs) was implemented in 2017 and continued to 2020. The intervention program as an external event was expected to have an effect of improving/increasing maize production thereby causing a structural change in maize production levels in Ghana. Thus, the intervention program in 2017, 2018, 2019 and 2020 were represented by the pulse variables I_{1t}, I_{2t}, I_{3t} and I_{4t}respectively. The

Table 1. ADF test results of original data (Augmented Dickey-Fuller Unit Root Tests)							
Type	Lags	Rho	Pr< Rho	Tau	Pr< Tau	F	Pr > F
Single Mean	1	0.2327	0.9652	0.18	0.9686	2.39	0.4696
	2	0.1907	0.9634	0.14	0.966	2.20	0.5172
	3	0.2024	0.9638	0.15	0.9669	2.30	0.4918
Trend	1	-8.3965	0.5219	-2.15	0.5083	2.80	0.6228
	2	-9.1126	0.4639	-2.13	0.5204	2.69	0.6430
	3	-8.8073	0.4873	-1.96	0.6075	2.32	0.7167

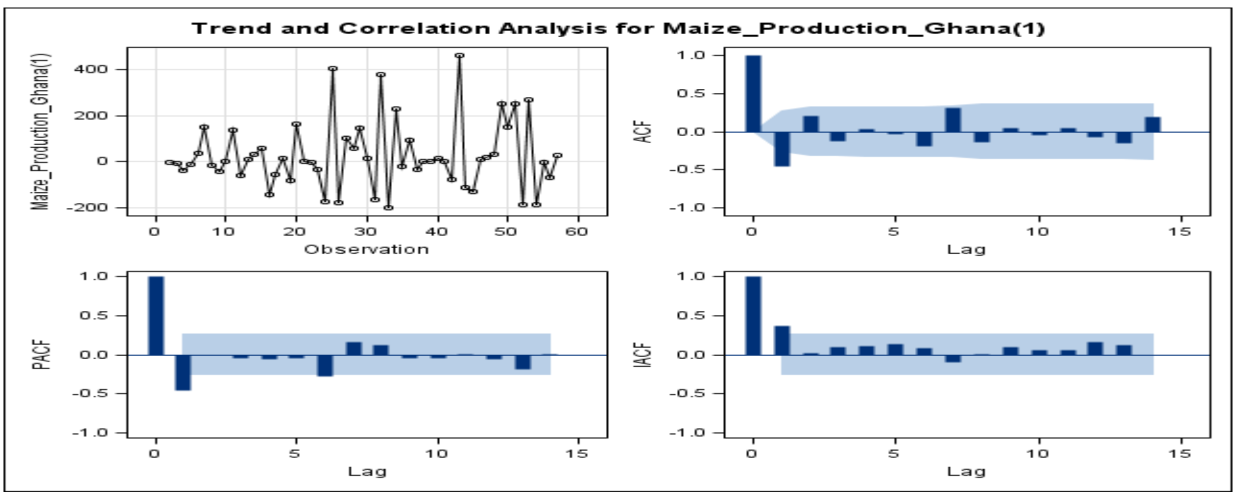

Figure 3. Trend and Correlation Analysis for the Differenced Series.

intervention was then incorporated in the noise model thereby resulting in the proposed intervention model for the study given as follows.

$$Z_t = \omega_1 I_{1t} + \omega_2 I_{2t} + \omega_3 I_{3t} + \omega_4 I_{4t} + \frac{\theta(B)}{\psi(B)} a_t \quad \text{........(6)}$$

where

$$I_{1t} = \begin{cases} 1 & t = 2017 \\ 0, & t \neq 2017 \end{cases}$$
$$I_{2t} = \begin{cases} 1 & t = 2018 \\ 0, & t \neq 2018 \end{cases}$$
$$I_{3t} = \begin{cases} 1 & t = 2019 \\ 0, & t \neq 2019 \end{cases}$$
$$I_{4t} = \begin{cases} 1 & t = 2020 \\ 0, & t \neq 2020 \end{cases}$$

and ω_1, ω_2, ω_3, ω_4 represent the coefficients of the pulse functions for 2017, 2018, 2019 and 2020 respectively. The method of maximum likelihood was used to estimate parameters of the model.

RESULTS

In Figure 1, plot of the original series (maize production) showed a generally increasing trend from the mid-1980s with some irregular fluctuations. The ACF plot in Figure 2 showed a slow decay which suggested nonstationarity in the series. The Augmented Dickey Fuller (ADF) test also produced large p-values as shown in Table 1 which suggested that the series was not stationary.

Table 2. ADF test results of differenced series (Augmented Dickey-Fuller Unit Root Tests)							
Type	**Lags**	**Rho**	**Pr< Rho**	**Tau**	**Pr< Tau**	**F**	**Pr > F**
Single Mean	1	-80.4551	0.0005	-6.15	0.0001	18.93	0.001
	2	-96.621	0.0005	-4.83	0.0003	11.66	0.001
	3	-157.708	0.0001	-4.12	0.002	8.47	0.001
Trend	1	-84.4255	<.0001	-6.2	<.0001	19.27	0.001
	2	-111.505	0.0001	-4.87	0.0012	11.96	0.001
	3	-314.409	0.0001	-4.16	0.0095	8.86	0.001

Table 3. Results of SCAN and ESACF methods						
SCAN Chi-Square[1] Probability Values						
Lags	**MA 0**	**MA 1**	**MA 2**	**MA 3**	**MA 4**	**MA 5**
AR 0	0.0003	0.2004	0.4352	0.857	0.8521	0.2267
AR 1	0.942	0.7083	0.6335	0.8549	0.8547	0.1731
AR 2	0.7064	0.8872	0.9731	0.7187	0.5625	0.4464
AR 3	0.647	0.9758	0.9762	0.8486	0.2049	0.3261
AR 4	0.7458	0.7442	0.8488	0.9752	0.4078	0.9122
AR 5	0.0301	0.1114	0.2338	0.4184	0.5561	0.3758
ESACF Probability Values						
Lags	**MA 0**	**MA 1**	**MA 2**	**MA 3**	**MA 4**	**MA 5**
AR 0	0.0006	0.2016	0.4306	0.8566	0.854	0.2451
AR 1	0.8731	0.4215	0.4767	0.5352	0.9664	0.4177
AR 2	0.1635	0.8301	0.8089	0.907	0.9966	0.7123
AR 3	0.0004	0.216	0.9572	0.9333	0.7273	0.7248
AR 4	0.0007	0.7263	0.3686	0.8821	0.2475	0.9469
AR 5	0.2652	0.2152	0.621	0.6913	0.0968	0.8131
	ARMA(p+d,q) Tentative Order Selection Tests					
	SCAN			**ESACF**		
	p+d	**q**	**BIC**	**p+d**	**q**	**BIC**
	0	1	9.818359	1	0	9.727669
				2	0	9.790565
				0	1	9.818359
				4	1	9.973372
				5	0	9.981555
(5% Significance Level)						

To obtain stationarity, the original series was then differenced.

In Figure3, the ACF plot of the differenced series cut off after lag 1 indicating a condition of stationarity. The ADF test results of the differenced series shown in Table 2 provided small p-values (<0.05) thereby giving a confirmation of stationarity, hence no higher differencing or transformation was needed. Results from the SCAN and ESACF methods provided tentative noise models at 5% significance level.

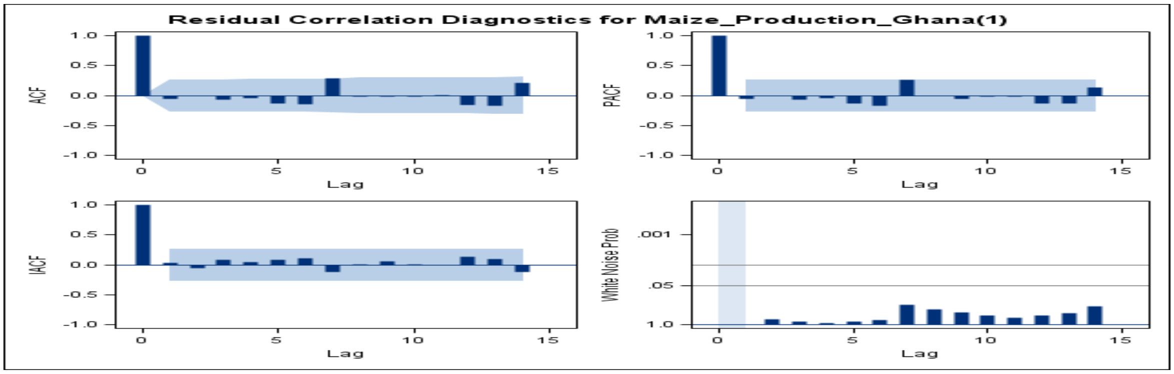

Figure 4. Residual Analysis of ARIMA (1, 1, 0): Correlation.

Table 4. Ljung-Box Test for ARIMA (1, 1, 0).

Model	**p-values**			
	lag6	**lag 12**	**lag18**	**lag24**
ARIMA(1, 1, 0)	0.9690	0.5489	0.1924	0.1164

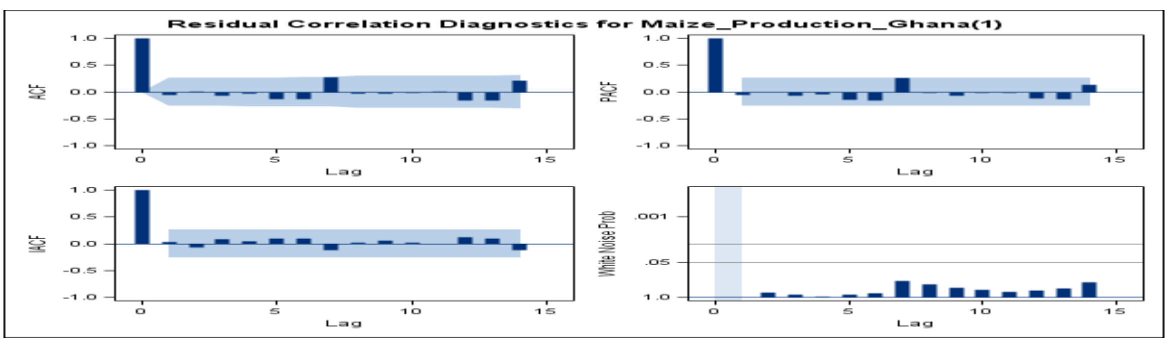

Figure 5. Residual Analysis of intervention model: Correlation.

The results in Table 3 above showed ARIMA (1, 1, 0) with least BIC. Thus, ARIMA (1, 1, 0) was considered as the best tentative model. Residual analysis of ARIMA(1, 1, 0) revealed insignificant spikes of the ACF and PACF plots shown in Figure 4. The Ljung-Box test also produced large p-values at all lags as shown in Table 4. These results of the residual analysis showed that the residuals are uncorrelated and therefore form a white noise process. ARIMA (1, 1, 0) was therefore considered the adequate noise model.

In the second phase of the modeling process, we used the noise model identified to hypothesize the effect of any interruptions by using a transfer function of intervention variables and the resultant intervention model given as follows.

$$Z_t = \omega_1 I_{1t} + \omega_2 I_{2t} + \omega_3 I_{3t} + \omega_4 I_{4t} + \frac{a_t}{(1-B)(1-\varphi_1 B)} \quad \ldots\ldots (7)$$

The intervention model in equation (7) was then fitted and the residual analysis produced insignificant spikes for the ACF and PACF plots as shown in Figure 5. The Ljung-Box test also produced large p-values at all lags as shown in Table 5. These results revealed that the residuals are uncorrelated and therefore form a white noise process.

Overall, the residual analysis results confirmed that the intervention model was adequate for evaluating the nature of any structural change in the production of maize.

Table 5: Ljung-Box Test for the fitted intervention model

	p-values			
	lag 6	**lag 12**	**lag18**	**lag24**
Model	0.9646	0.4974	0.1528	0.0880

Table 6. Estimation results of the intervention model in equation (7)

Parameter	**Estimate**	**Standard Error**	**t Value**	**Approx Pr> |t|**	**Variable**	**Year**
φ_1	-0.40387	0.12283	-3.29	0.001	Z_t	
ω_1	301.11614	133.75714	2.25	0.0244	I_{1t}	2017
ω_2	591.22278	155.67383	3.8	0.0001	I_{2t}	2018
ω_3	1187.2	185.86643	6.39	<.0001	I_{3t}	2019
ω_4	1286.4	207.70099	6.19	<.0001	I_{4t}	2020

Maximum Likelihood parameter estimates of the intervention model in Table 6 showed a significant improvement in maize production from 2017 to 2020.
The significant improvements in maize production were evidenced by small p-values (<0.05) for all theIntervention variables $I_{1t},\ I_{2t},\ I_{3t}$ and I_{4t}.

DISCUSSION

To examine possible structural change in maize production following the implementation of Planting for Food and Jobs program in Ghana, we used an intervention model with a set of pulse functions in this work. The residuals of the intervention model did not show any form of departure from white noise thereby indicating that the model was appropriate and adequate. The estimation results from of the intervention model showed evidence of significant improvements in maize production in 2017, 2018, 2019 and 2020. The significant improvements in maize production were evidenced by small p-values (< 0.05) in Table 6. For 2017, maize production increased by 301, 116 metric tons corresponding to a 17.49% improvement in production.
For 2018, 2019 and 2020, maize production increased by 591, 223 metric tons, 1, 187, 200 metric tons and 1, 286, 400 metric tons respectively. These increments in production for 2018, 2019 and 2020 corresponded to an improvement in maize production by 34.33%, 68.94% and 74.70% respectively during the years in which the Planting for Food and Jobs program was implemented.

CONCLUSION

In this study, we used an intervention model to evaluate the possible structural change in maize production in Ghana following the implementation of the planting for Food and Jobs program. The intervention model was found to be appropriate and adequate.
The results from the analysis of the data revealed a structural change in maize production in Ghana. The structural change was associated with a significant improvement in maize production during the years that the Planting for Food and Jobs program was implemented. Specifically, significant improvements in maize production were realized in 2017, 2018, 2019 and 2020.
Our analysis showed that maize production increased by 17.49%, 34.33%, 68.94% and 74.70% for 2017, 2018, 2019 and 2020 respectively.
Overall, it is worth noting that the significant improvements in maize production realized in 2017, 2018, 2019 and 2020 could be attributed to the Planting for Food and Jobs program and other possible underlying factors affecting maize production in Ghana. On the whole, the Planting for Food and Jobs program was useful in contributing to the improvement of maize production in Ghana.

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