Modeling Annual Coffee Production in Ghana Using ARIMA Time Series Model

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ABSTRACT

In the international commodity trade, coffee, which represents the world's most valuable tropical agricultural commodity, comes next to oil. Indeed, it is estimated that about 40 million people in the major producing countries in Africa derive their livelihood from coffee, with Africa accounting for about 12 per cent of global production. The paper applied Autoregressive Integrated Moving Average (ARIMA) time series model to study the behavior of Ghana's annual coffee production as well as make five years forecasts. Annual coffee production data from 1990 to 2010 was obtained from Ghana cocoa board and analyzed using ARIMA. The results showed that in general, the trend of Ghana's total coffee production follows an upward and downward movement. The best model arrived at on the basis of various diagnostics, selection and an evaluation criterion was ARIMA (0,3,1). Finally, the forecast figures base on Box- Jenkins method showed that Ghana's annual coffee production will decrease continuously in the next five (5) years, all things being equal

Keywords: Coffee, Annual Production, Autoregressive (AR), Moving Average (MA) and ARIMA

1. Introduction

In the international commodity trade, coffee, which represents the world's most valuable tropical agricultural commodity, comes next to oil. Indeed, it is estimated that about 40 million people in the major producing countries in Africa derive their livelihood from coffee, with Africa accounting for about 12 per cent of global production. Though coffee cultivation in Ghana dates as far back as the latter part of the 18th century, about the same time that cocoa was introduced into the country, the development of coffee has been overtaken by cocoa (Zaney, 2011).

Unlike cocoa, coffee has generally been grown in small holdings, scattered throughout the cocoa-growing areas, with only a few large plantations. In 2007 and 2008, for example, Ghana received modest earnings of US$1,331,308.36 and US$2,767,378.00, respectively, from coffee exports. This implies that coffee production, if boosted, can generate substantial income to supplement revenue generated by government from other sources – and Government, of course, is not unaware of this fact and has, in fact, embarked on efforts in this direction. Government, through the Ghana Cocoa Board, has been funding coffee research at the Cocoa Research Institute of Ghana (CRIG). Government has also supported activities aimed at enhancing the coffee industry in Ghana (Zaney, 2011).

Ghana's hosting of 49th Annual General Assembly (AGA) of the International African Coffee Organization (IACO) in November 2009 was also part of efforts to revamp coffee production and marketing for the realization of the full potential of the sector. The IACO is an inter-governmental organization, made up of 25 African coffee-producing countries. It was formed in 1960 by coffee-producing countries in Africa, namely Angola, Cameroon, The Central African Republic, The Democratic Republic of Congo, Cote d'Ivoire, Benin, Gabon, Kenya, Madagascar, Uganda and Tanzania. IACO's membership increased to 25 when 14 other countries joined. These are Burundi, Congo, Equatorial Guinea, Ethiopia, Ghana, Guinea, Liberia, Malawi, Nigeria, Rwanda, Sierra Leone, Togo, Zambia and Zimbabwe. IACO's objective is to take up the challenges associated with the world coffee sector through regional and international co-operation so as to protect the interests of African coffee producers and economies. The Annual General Assembly of the IACO, therefore, serves as a platform for discussion and exchange of information between the various members over issues pertaining to the coffee industry (Zaney, 2011).

Coffee production has not really thrived in Ghana even though it is believed to have been the first crop exported in Ghana before the arrival of cocoa. Due to the low yield of coffee in Ghana, most farmers are diverting from coffee farming to other farming especially cocoa farming, since it has become the major source of foreign exchange for the country. Farmers are not willing to cultivate coffee since at the end of the day there would not be any government interventions in the sales of their produce. Farmers are forced to bargain for the price that suits buyers, at a price that does not favor them; therefore making them run into loses.

To apply ARIMA time series in modeling the behavior of coffee production in Ghana as well as forecast the total production of coffee in Ghana for few years ahead excluding external factors such as climatic change, pest and diseases etc.

Coffee growers in developing countries receive a notoriously small share of the export price of green coffee, which often is explained with excessive government regulation of the domestic markets and market inefficiency. Producer price shares vary substantially across countries, even when comparing countries with seemingly similar exporting systems. For example, producers in Tanzania received only 42% of the export price of arabica coffee and 30% of the price for robusta in 1998/99 (Baffes, 2003), while in Uganda the share of export price accruing to growers of robusta at the same time was 75% (ITF, 2002b).

Coffee is economically more (nearly three times) profitable in the present context among the farmers as compared to other cereal crops in the hill region (Bajracharya, 2003). Mostly, coffee production is organic by default and some parts of production are certified as organic. It could be an important means for the soil conservation; biodiversity maintenance and watershed balance in the mid-hills of Nepal (Nepal, 2006). Coffee industry is in rudimentary stage and still unable to yield extra economic leverage and excess production. However, it has been a livelihood support for many rural and marginal people in mid-hill region.

Ponte (2002) stated the importance of coffee quality rather than the quantity with respect to the producers of coffee. He argued that producers should keep in mind, the final consumers' preferences and the characteristics of the coffee for which consumers would be willing to pay more. Quality coffee provides more revenue to producers and it is a better strategy to earn more revenue for same quantity of coffee compared to low quality coffee.

Various attempts have been made to determine the importance of numerous factors that affect growth and bean quality in coffee agro ecosystems, including climatic conditions, shade management, fertilization regimes, and adequate pruning. (Wintgens, 2004; Steiman, 2008; Bosselmann et al., 2009; valos-Sartorio and Blackman, 2010).

Shade management ranges from coffee systems under natural unmodified forest cover over scattered multipurpose trees to highly controlled shade in commercial agroforestry systems (Perfecto et al., 2005; Siles et al., 2010). Some work has been done to document the relationship between shade and coffee yield, e.g. Beer (1987) and DaMatta (2004) found positive effects in suboptimal locations, whereas Soto-Pinto et al. (2000) and Elevitch et al. (2009) found negative effects when shade level was above 50%. Lin (2009) found that high shade (60-80%) coffee flowers equally well to the medium-shade (30-50%) in low-input coffee farms of Chiapas, Mexico. Results differ because the environmental factors and the coffee varieties examined vary among the studies, and issues of exact environmental needs are difficult to quantify because of the variation (Carr, 2001).

Coffee (*Coffea Arabica* L.) production in agroforestry systems can offer many advantages to farmers interested in environmental services such as increasing local biodiversity, erosion reduction (Donald, 2004), improvement of water storage in soils (Lin and Richards, 2007), and mitigation of climatic extremes (Lin, 2007; Morais et al., 2006). It can also result in economic advantage by the generation of extra products and by the opportunity to explore alternative markets (Donald, 2004) and reduce the biennial pattern of coffee yield (Da Matta, 2004). Nevertheless, despite those potential benefits, the complex interactions between the abiotic components and species in agroforestry systems result in extremely variable coffee tree performance. In Costa Rica, under high rainfall and high soil organic matter, coffee trees intercropped with *Eucaliptus deglupta* trees showed similar (Schaller et al., 2003) or higher (van Kanten et al., 2004) production than coffee trees intercropped with *Terminalia ivorensis* or *Erythrina poeppigiana*. Intercropping robusta and arabica coffee with food crops such as beans, groundnuts, soyabeans, rice, yams and maize have been reported elsewhere (Okelana, 1982; Snoeck, 1988; Wrigley, 1988; Njoroge, Waithaka & Chweya, 1993). However, the conflicting reports of Okelan a (1982) and Snoeck (1988) on the suitability of maize as an intercrop for coffee indicate that the success of any intercropping system could be influenced by the type of crops used and location specific factors.

Most coffee farmers in Brazil choose full-sun production. One of the reasons for this choice is the growth and yield reduction observed in shaded coffee trees compared with coffee trees under full sun (Campanha et al., 2004; Morais et al., 2006). In particular, under conditions of restricted water and nutrient availability the negative effect of low radiation on production becomes more evident (Da Matta, 2004).

Intercropping robusta and arabica coffee with food crops such as beans, groundnuts, soyabeans, rice, yams and maize have been reported elsewhere (Okelana, 1982; Snoeck, 1988; Wrigley, 1988; Njoroge, Waithaka & Chweya, 1993). However, the conflicting reports of Okelana (1982) and Snoeck (1988) on the suitability of maize as an intercrop for coffee indicate that the success of any intercropping system could be influenced by the type of crops used and location specific factors. Osei-Bonsu (1998) also asserted that a temporary shade of plantain should be provided in the cultivation of coffee.

In the international commodity trade, coffee, which represents the world's most valuable tropical agricultural commodity, comes next to oil. Indeed, it is estimated that about 40 million people in the major producing countries in Africa derive their livelihood from coffee, with Africa accounting for about 12 per cent of global production. Though coffee cultivation in Ghana dates as far back as the latter part of the 18th century, about the same time that cocoa was introduced into the country, the development of coffee has been overtaken by cocoa (Zaney, 2012).

2. Materials and Methods

2.1 Model Specification, Estimation and Tests

ARIMA is the method first introduced by Box and Jenkins (1976) and until now become the most popular models for forecasting univariate time series data. This model has been originated from the Autoregressive model (AR), the Moving Average model (MA) and the combination of the AR and MA, the ARMA models.

2.1.1 Stationarity

A key concept underlying time series processes is that of stationarity. A time series is covariance stationarity when it has the following three characteristics:
(a) exhibits mean reversion in that it fluctuates around a constant long-run mean;
(b) has a finite variance that is time-invariant;
(c) has a theoretical correlogram that diminishes as the lag length increases.

In its simplest terms a time series Yt is said to be stationary if;
(a) $E(Y_t)$=constant for all t;
(b) $Var(Y_t)$=constant for all t;
(c) $Cov(Y_t,T_{t+k})$=constant for all t,
or if it is mean, its variance and its covariances remain constant over time. Stationarity is important because if the series is non-stationary then all the typical results of the classical regression analysis are not valid.

2.1.2 Integrated processes and the ARIMA models

An integrated series
The ARMA (*p, q*) model can only be made on time series Y_t that stationary.
In order to avoid this problem, and in order to induce stationarity, we need to detrend the raw data through a process called **differencing**.

$$\Delta Y_t = Y_t - Y_{t-1}$$

(13.39)

As most economic and financial time series show trends to some degree, we nearly always end up taking **first differences** of the input series. If, after **first differencing**, a series is stationary then the series is also called **integrated to order one**, and denoted **I (1)**.

2.1.3 ARIMA models

If a process Y_t has an ARIMA (*p, d, q*) representation, the has an ARMA (*p ,q*) representation as presented by the equation below:

$$\Delta^d Y_t(1-\phi_1 L-\phi_2 L^2-\ldots-\phi_p L^p)=(1-\theta_1 L-\theta_2 L^2-\ldots-\theta_p L^q)u_t$$

(13.41)

Writing $W_t = \nabla^d Y_t = (1-B)^d Y_t$

The general ARIMA process is of the form

$$W_t = \sum_{i=1}^{p} \emptyset_i W_{t-i} + \sum_{i=1}^{q} \theta_i \varepsilon_{t-i} + \mu + \varepsilon_t$$

ARIMA (1, 1, 1) Process

An example of ARIMA (p, d, q) is the ARIMA (1, 1, 1) which has one autoregressive parameter, one level of differencing and one MA parameter is given by

$$W_t = \emptyset_1 W_{t-1} + \theta_1 e_{t-1} + \mu + \varepsilon_t$$

$$(1-B)Y_{t-1} = \emptyset_1 (1-B)Y_{t-1} + \theta_1 \varepsilon_{t-1} + \mu + \varepsilon_t$$

Which can be simplified further as

$$Y_t - Y_{t-1} = \emptyset_1 Y_{t-1} - \emptyset_1 Y_{t-2} + \theta_1 \varepsilon_{t-1} + \mu + \varepsilon_t$$

$$Y_t - Y_{t-1} = \emptyset_1 (Y_{t-1} - Y_{t-2}) + \theta_1 \varepsilon_{t-1} + \mu + \varepsilon_t$$

2.1.4 Box-Jenkins model selection

In general Box-Jenkins popularized a three-stage method aimed at selecting an appropriate (parsimonious) ARIMA model for the purpose of estimating and forecasting a univariate time series.

Three stages are: (a) identification, (b) estimation, and (c) diagnostic checking.

2.1.5 Identification

A comparison of the sample ACF and PACF to those of various theoretical ARIMA processes may suggest several plausible models. If the series is non-stationary the ACF of the series will not die down or show signs of decay at all.

A common stationarity-inducing transformation is to **take logarithms** and then **first differences** of the series.

Once we have achieved stationarity, the next step is identify the p and q orders of the ARIMA model

Table 1: Identifying p and q orders of ARIMA models

Model	ACF	PACF
Pure white noise	All autocorrelation are zero	All partial autocorrelation are zero
MA(1)	Single positive spike at lag 1	Damped sinewave or exponential decay
AR(1)	Damped sinewave or exponential decay	Single positive spike at lag 1
ARMA(1,1)	Decay (exp. or sinewave) beginning at lag 1	Decay (exp. or sinewave) beginning at lag 1
ARMA(p,q)	Decay (exp. or sinewave) beginning at lag q	Decay (exp. or sinewave) beginning at lag p

2.1.6 Estimation

In this second stage, the estimated models are compared using AIC and BIC.

2.1.7 Diagnostic checking

In the diagnostic checking stage we examine the goodness of fit of model.

We must be careful here to avoid over fitting (the procedure of adding another coefficient is appropriate).

The special statistic that we use here are the Box-Piece statistic (BP) and the Ljung-Box (LB) Q statistic, which serve to test for autocorrelations of the residual (*eshare.stut.edu.tw/EshareFile/2010_4/2010_4_ea775b08.doc).*

3. Analysis and Results

3.1 Preliminary Analysis

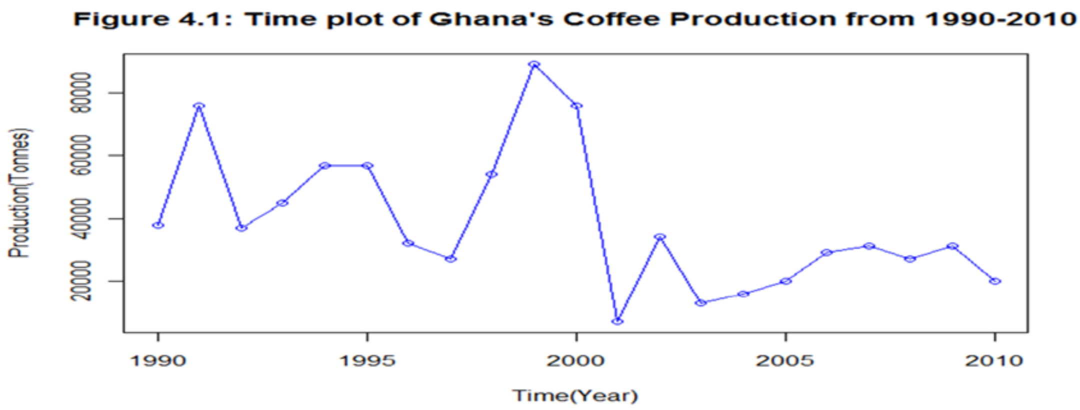

Figure 1: The time series plot of the total coffee production of Ghana from 1990 to 2010.

There is a systematic change in the time plot in Fig. 1 which is not periodic. This indicates that the pattern of Ghana's total coffee production is either decreasing or not. Total production was low after 1991 and we could attribute this to the liberalization of the coffee sector by the government in 1991/1992, where the government no longer engaged in the buying and selling of the coffee beans, hence farmers were left to bargain their prices at the will of the buyers.

There was a sharp rise in production from 1997 to 1999, after which it drastically declined. In general, the trend of Ghana's total coffee production follows an upward and downward movement. The figure exhibits a moving trend, hence there is the need to apply the method of differencing to attain stationarity since the trend describing the data shows non stationarity.

The time series analysis of the coffee data is conducted using R. First, we examine the behavior of the ACF for the time series.

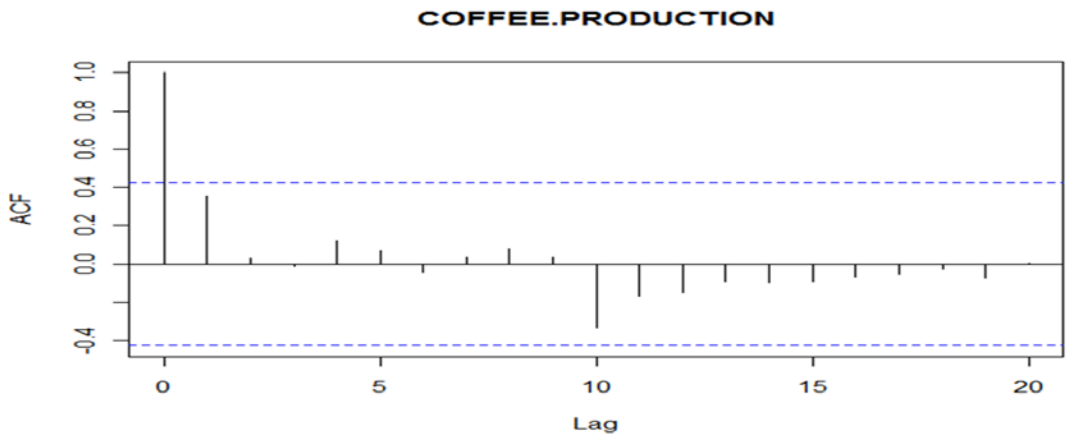

Figure 2: Autocorrelation function (ACF) of Ghana's Total Coffee Production.

The autocorrelation function of Ghana's total coffee production is shown in Fig. 2. The plot of the ACF function against the lag is called the correlogram. A trend in the data shows in the correlogram as a slow decay in the autocorrelation which depicts a downward slopping due to the exponential nature of the plot. It describes the correlation between values of Ghana's total coffee production at different points in time, as a function of the time difference. The autocorrelation function is decreasing and that shows there is a trend in Ghana's total coffee production data.

3.2 Differencing

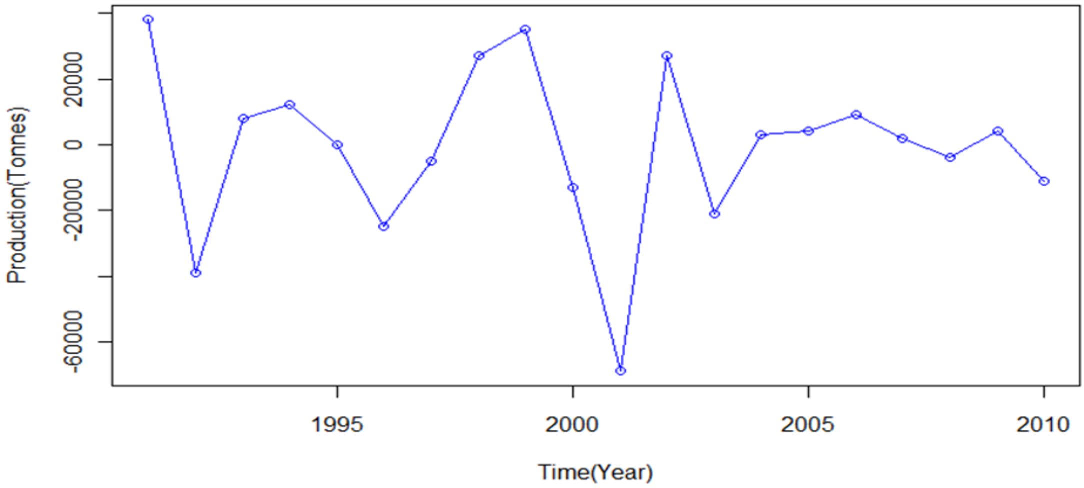

Figure 3: First differencing of Ghana's coffee production from 1990 to 2010

To remove the trend component from the data, we difference the data. The Fig. 3 above is a transformation of Ghana's Total Coffee production using first differencing method. The observation does not revert to its mean value. The transformation of the data with the first differencing displays characteristics that suggest non stationary. Due to this it is necessary to make another transformation so as to produce a new series that is more compatible with the assumption of stationarity. In general, the first difference plot in figure 4.2 reveal a little bit of variability. Hence the second differencing is employed.

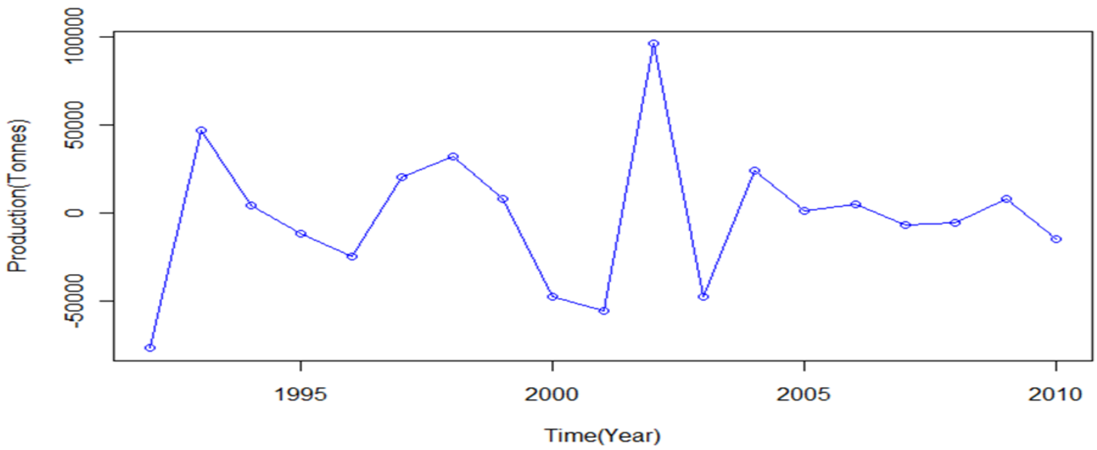

Figure 4: Second differencing of Ghana's coffee production from 1990 to 2010

Differencing the data the second time shows some variability and hence the data is still not stationary Therefore we apply the third differencing to the data.

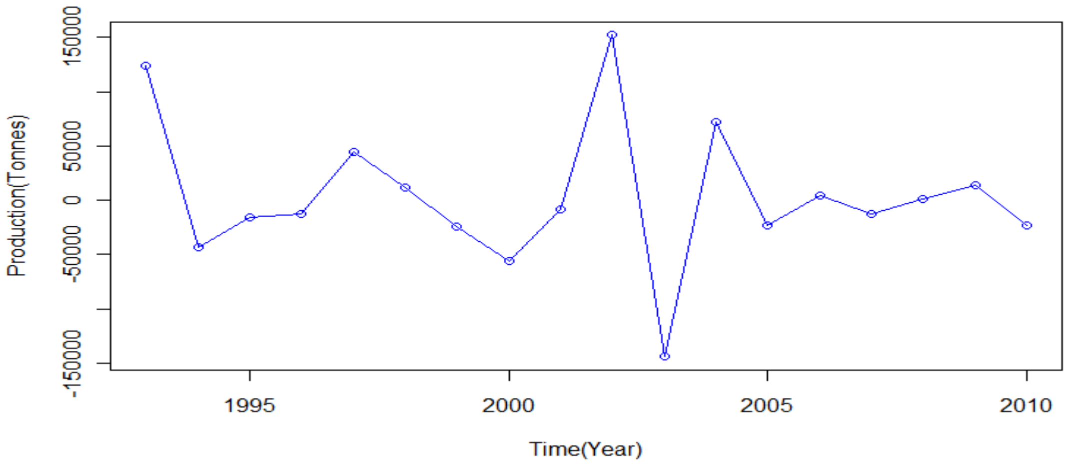

Figure 5: Third differencing of Ghana's coffee production from 1990 to 2010

A transformation is performed on Ghana's total coffee production data using the third differencing method to remove the trend component in the original data, as shown in Fig. 4. The observations move irregularly but revert to its mean value and the variability is also approximately constant. The data of Ghana's total coffee production now looks to be approximately stable.

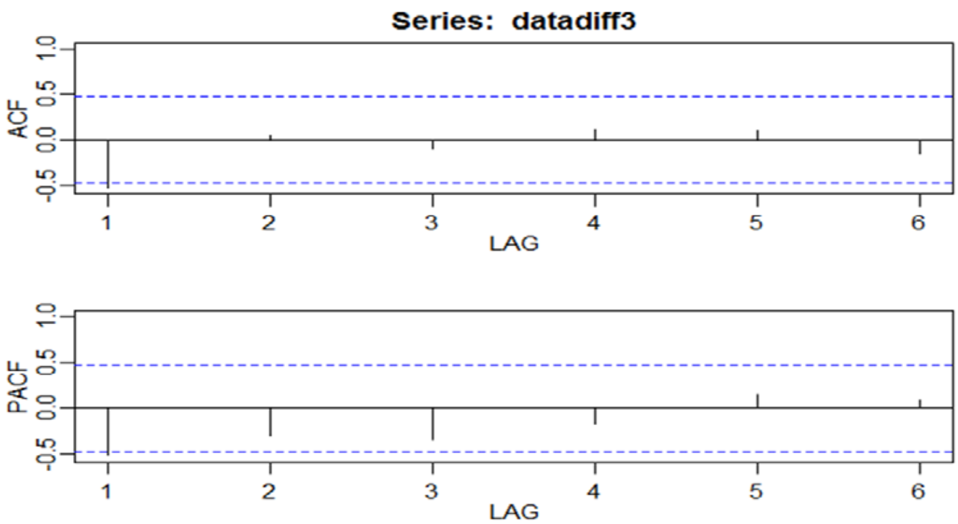

Figure 6: ACF and PACF of the third differencing of Ghana's coffee production (1990-2010)

ACF and PACF of the third differencing of Ghana's coffee production (1990-2010)
The Fig. 6 above shows both the autocorrelation function and the partial autocorrelation function of the third differencing of Ghana's coffee production at various lags. Inspecting both the ACF and the PACF of the third differencing of the Ghana's coffee production, the following models are suggested;

- *ARIMA(1,3,0)*
- *ARIMA(0,3,1)*
- *ARIMA(1,3,1)*

In order to select the best model for forecasting into the future, each model is assessed based on its parameter estimates, the corresponding diagnostics of the residuals and the AIC, BIC and $AICc$.

3.3 Parameter Estimation

ARIMA (1, 3, 0) MODEL

Coeff	Estimate	Std error	t-value	AIC	BIC
ar1	-0.616	0.200	3.08	22.93659	22.03552
xmean	1362.992	7748.801			

sigma^2 estimated as 2.694e+09: log likelihood = -221.21, aic= 448.42

The parameter based on the t-value test is statistically significant.

ARIMA (0, 3, 1) MODEL

Coeff	Estimate	Std error	t-value	AIC	BIC
ma1	-1.0000	0.1417	7.0572	22.39	21.48893
xmean	505.2666	1654.6015			

sigma^2 estimated as 1.56e+09: log likelihood = -217.52, aic = 441.05

The parameter based on the t-value test is statistically significant.

ARIMA (1, 3, 1) MODEL

Coeff	Estimate	Std error	t-value	AIC	BIC
ar1	-0.4542	0.2288	1.985	22.26478	21.41318
ma1	-1.0000	0.1479	6.761		
xmean	194.7241	1069.6642			

sigma^2 estimated as 1.231e+09: log likelihood = -215.87, aic = 439.74

The t-value for ma1 is statistically significant while that of ar1 is not statistically significant since the t-value is less than 2 in absolute terms.

3.4 Model Diagnostics

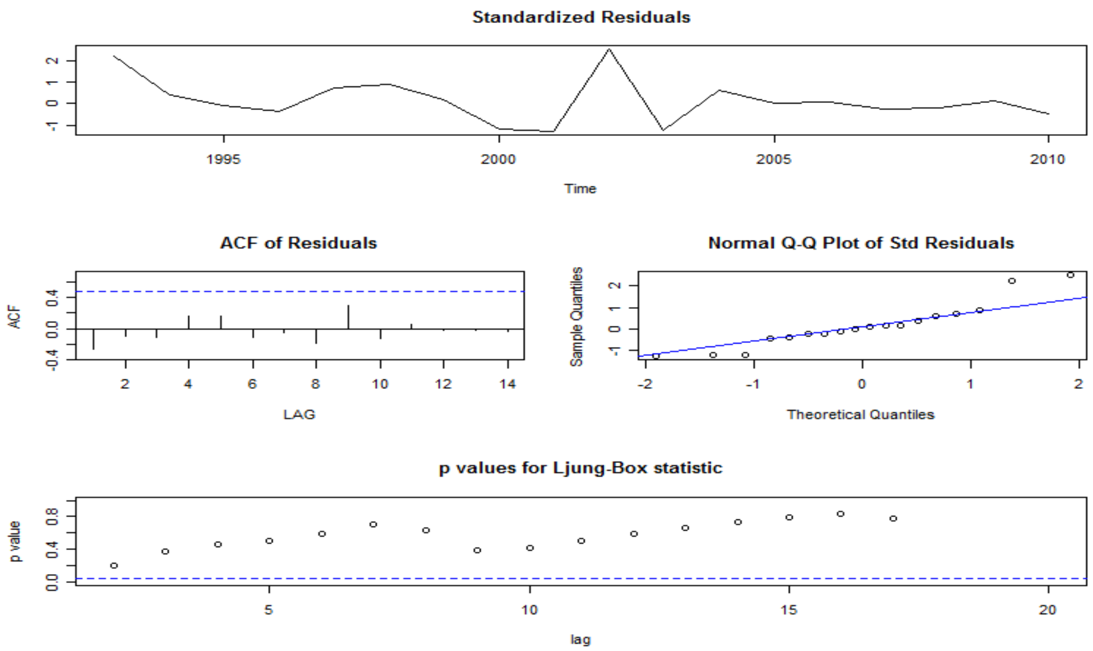

Figure 7: Diagnostics of ARIMA (0, 3, 1)

It can be seen from $ARIMA(0,3,1)$ in Fig. 7 above that the standardized residuals plot shows no obvious pattern and look like an i.i.d. sequence of mean zero with some few outliers. The middle part of the Diagnostics is the plot of the ACF of the residuals. There is no evidence of significant correlation in the residuals at any positive lag. At the right side of the middle of the Diagnostics is the normal Q-Q plot of the standardized residuals. Most of the residuals are located on the straight line except some few residuals deviating from normality. Therefore, the normality assumption look satisfied and so the residuals appear to be normally distributed. The bottom part of the Diagnostics is the time plot of the Ljung-Box statistics. It can be observed that the Ljung-Box statistics plot is not significant at any positive lag.

It was also observed that, ARIMA (1, 3, 0) and ARIMA (1, 3, 1) models exhibited similar diagnostic characteristics as ARIMA (0, 3, 1) model shown in Fig. 7.

3.5 Selection of Best Model for Forecasting

The standardized residual plots of all the models are independently and identically distributed with mean zero and some few outliers. There is no evidence of significance in the autocorrelation functions of the residuals of all the models except one model and the residuals appear to be normally distributed in all the models. The Ljung-Box statistics are not significant at any positive lag for all the models.

The AR parameter in the $ARIMA(1,3,1)$ model is not significant at 5% level of significance which could have a negative effect on the forecast if used for prediction but the MA parameter is significant at 5% level of significance. The parameters in the $ARIMA(0,3,1)$ and $ARIMA(1,3,0)$ models are significant.

The AIC, $AICc$ and the BIC are good for all the models but they favor $ARIMA(0,3,1)$ model.
From the above discussion it is clear that $ARIMA(0,3,1)$ model is the best model for forecasting.

$\nabla^3 Y_t = \nabla^3 (w_t - w_{t-1}) + 505.2666$

Where $\nabla Y_t = Y_t - Y_{t-1}$

$$Y_t = Y_{t-3} - 3Y_{t-2} + 3Y_{t-1} + w_{t-4} - 3w_{t-3} - 3w_{t-2} - w_{t-1} - w_t + 505.2666$$

Hence our model for forecasting is MA (1) with the equation:

$$Y_t = -\varepsilon_{t-1} + 505.2666$$

With a variance δ_e^2 estimated as 1654.6015

3.6 Forecasting

5 steps forecast into the future;

[1] 6421.089 -9736.733 -28473.467 -49789.111 -73683.667
[1] 40623.99 92636.94 157859.59 235128.29 323719.85

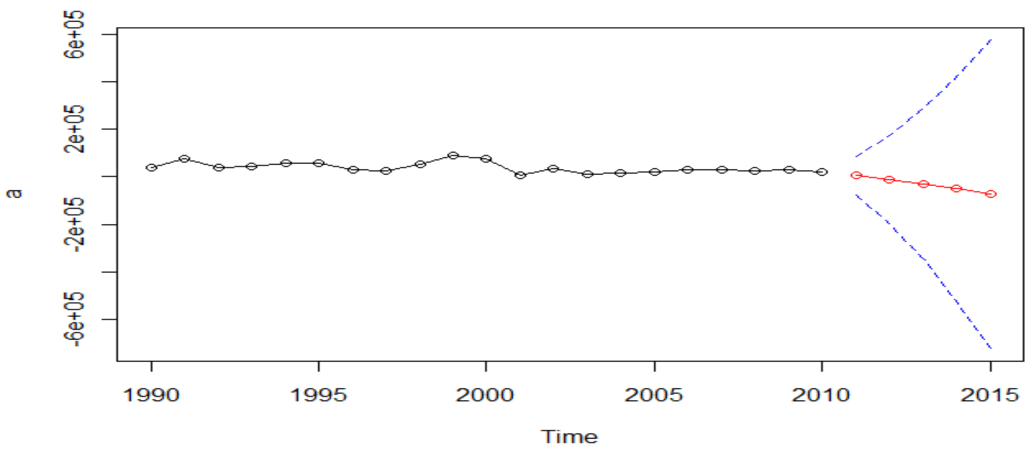

Figure 10: Ghana's total coffee production, its forecasts and confidence interval

Figure 4.9 shows the original Ghana's total coffee production data in black line, its 5 years forecasts in red line and the confidence interval in short blue dashes lines.

4. Conclusion

The study showed that total production was low after 1991. There was a sharp rise in production from 1997 to 1999, after which it drastically declined. In general, the trend of Ghana's total coffee production follows an upward and downward movement. The best model arrived at on the basis of various diagnostics, selection and an evaluation criterion was ARIMA (0, 3, 1). The framework for ARIMA forecasting drawn up base on Box- Jenkins method shows that Ghana's annual coffee production will continue to decrease in the next 5 years, all things being equal.

These following interventions are recommended. Government could support farmers by providing them with high yielding seedlings of the crop and other modern equipments as well as logistics. Also, farmers should be educated to enhance their knowledge and skills in the cultivation of the crop. Companies that buy coffee from farmers should register with the COCOBOD, similar to the cocoa industry's system of licensed buyers. Farmers must be encouraged to grow the other types of coffee, like the Arabica, which is less labor intensive.

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