Modeling the co-movement of Inflation and exchange rate

Nelson Christopher Dzupire[1, *]

[1]University of Malawi, Chancellor College

[*]Email: ndzupire@cc.ac.mw

Abstract

Inflation and exchange rates have great influence on consumer prices especially on imports and exports. Exchange rate fluctuations create inefficiency and distort world prices whereas changes in inflation rates have a direct impact on consumer goods prices which incidentally include exchange rates. There is a direct interdependence between inflation and exchange rates and this paper is aimed at investigating this relationship in dynamic context. It tries to find out how changes in inflation and exchange rates impact on another by adopting the econometric and copula approaches. Both inflation and exchange rates data are susceptible to volatility clustering, possess fat tails and are skewed coupled with conditional heteroskedasticity. Hence we model the univariate distributions by using ARMA(p, q)-GARCH(x, y) so as to capture the most important stylized features of inflation and exchange rates. A bivariate model is then constructed by coupling the marginal distributions of inflation and exchange rates using the survival Clayton copula. Empirical results from monthly inflation and exchange rates data show positive correlation between the two based on Kendall τ test which confirms that a change in inflation results in change of exchange rates an vice versa hence there is co-movement. Furthermore, by the Granger causality test, exchange rates spikes cause changes in inflation rates. The results of the study have implications on economic policy design and hedging strategies for traders on imports and exports.

Keywords: *inflation, exchange rates, heteroskedasticity, Granger causality, copula, bivariate, volatility clustering*

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1 Introduction

Inflation measures the relative price changes of commodities and affects every consumer, businesspersons and investors in some way or the other. It is an economic indicator that has direct influence on the state of the economy as it influences interest rates, consumer prices, financial markets including stocks, bonds and foreign exchange (Abdurehman and Hacilar, 2016). Inflation measures the effectiveness of government economic policy and hence acts as a guide on price changes in the country's economy as in most countries the central bank takes into account the rate of inflation to achieve for stable prices. The main source of inflation in developing countries is the devaluation of local currency necessitated by the rising level of imports (Ahmad and Ali, 1999). The most common way of measuring inflation is by use of consumer price index over a period of time like monthly, quarterly or yearly. The consumer price index measures the weighted average of prices of several consumer goods and services taking into account changes of prices of each item.

Another important factor that has a great influence on consumer prices especially on imports and exports is the foreign exchange rate. Exchange rate fluctuations can create inefficiency and distort world prices hence affecting consumers worl wide. Volatility in exchange rates is very significant in financial markets as both imports and exports of goods and services are affected, in addition it affects the capital flow, inflation and overall economic welfare. The depreciation of exchange rates could also have inflationary effects on the economy (Maana, Mwita, and Odhiambo, 2010) with Holmes (2002) concluding that exchange rate depreciation was inflationary although the impact was overshadowed the gains from external forces.

Several studies have been undertaken to study the impact of exchange rate on inflation especially in the perspective of the country's economy. Several such studies have concentrated on modeling inflation and exchange rate by assuming constant variance assumption. However, this approach is unrealistic in that time series data areheteroskedastic hence the assumption of constant variance does not reflect much truth from the data. For the studies that embrace GARCH models the focus is on the headline inflation to determine its effects on other macroeconomic variables. In many instances where conditional variance is assumed like (Nortey, Ngoh, Doku-Amponsah, and Ofori-Boateng, 2015), most studies use the multivariate GARCH to model the correlation which does not take into account the interdependence between inflation and exchange rates. Based on the studies the key findings on inflation collaborate as follows: inflationary pressures in sub-Saharan Africa emanate from rainfall, large swings in commodity prices, public spending, exchange rate fluctuations, foreign inflation and excessive

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money growth (Oulatta, 2018).

In Abdurehman and Hacilar (2016), the study investigated the relationship between inflation and foreign exchange rates in Turkey with empirical data based on United Kingdom pound. The authors employ ordinary least square and a single GARCH method. Since time series data areserially correlated and not normally distributed ordinary least square may not be a best approach to find the correlation as it assumes normality of the data. Ahmad and Ali (1999) studied a simultaneous determination of general price level and exchange rate in Pakistan. It was observed that the speed of adjustment in price level and exchange rates to domestic impulse is slow. The main objective was to determine policies that influence both inflation and exchange rates and hence applied the Granger causality test to find the causal effect. However, the Granger causality test has no sound economic theory hence the results of the test can best be used to lend support to the evidence from proper economic analysis. Uddin (2018) examined the causality between exchange rate and consumer prices, exchange rate and short-term interest. The study uses Granger test just like in (Ahmad and Ali, 1999) and a forecast based on causality measure by Dufour and Taamouti (2010).

Nguyen, Dridi, Unsal, and Williams (2017) investigated the drivers of inflation in Sub Saharan Africa and observed that the main drivers in the past 25 years are domestic supply shocks, monetary variables and shocks to the exchange rate. The authors quantitatively analyzed inflation dynamics using the global vector autoregressive model which incorporated linkages among economies as well as the role of regional and global demand and inflationary spillovers. In a related study Barnichon and Peiris (2008)explored the sources of inflation by examining the relationship between inflation, output gap and real money gap. It was concluded that both gaps contain significant information regarding the evolution of inflation where the money gap plays a big role.

Nortey et al. (2015) investigated the volatility and conditional relationship among inflation rates, exchange rates and interest rates by constructing a multi-variate model . It is observed that the fact the inflation rate is stable does not mean exchange and interest rates are expected to be stable as well. Besides the rates of inflation as well as interest rates are likely to react in the long run to the expected volatility in exchange rate.

Do inflation and exchange rate co-move? The rate of inflation in a country significantly affect the value of the country's currency and the corresponding rates of foreign exchange with other currencies. Abdurehman and Hacilar (2016) observed that inflation is more likely to have a significant negative effect on foreign exchange rates. However, foreign exchange is affected by several other factors like rate of economic growth, balance of trade, interest rates

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and a country's debt level it can be argued that a very low inflation rate does not guarantee a favourable exchange rate for a country.

It can also be observed that foreign exchange rate is simply the price of one currency when expressed in another currency, hence it is one of the prices that changes as inflation rises. Since foreign exchange rates change, domestic prices are also affected, the inflation rates get volatile. From this perspective, one may conclude that inflation is also affected by foreign exchange.

The study aims at investigating the nature of relationship between inflation rate and exchange rate volatility in dynamic context. It tries to find out how the change in inflation rate impacts on exchange rate and vice versa by adopting econometric and copula methodologies. In between we also explore the cause and effects between the two by applying the Granger causality test. The study is very important as policy makers need to understand the dynamics of both inflation and exchange rate, and how change in the other affects the other to design proper monetary policies that can mitigate adverse effects of foreign exchange rate volatility on important economic indicators like inflation. The study provides a theoretical underpins by developing a mathematical model that simultaneously determines inflation and exchange rate movement. Both inflation and exchange rate data are susceptible to volatility clustering hence they can ably be modeled by using stochastic processes to capture the time dependent structure embedded in the data justifying why the econometric methods are suitable for the study.

The paper is structured as follows: in Section 2 we look at the methodologies in modeling the univariate distributions as well as the constructing of the bivariate model using the copula approach. Section 3 presents results and discussion where we tackle data analysis and the coupling of the univariate models to realise the bivariate model. Finally, we conclude the paper in section 4.

2 Methodology

2.1 Marginal Distributions for inflation and exchange rates

Both inflation and exchange rate data exhibit conditional heteroskedasticity, skewed and have fat tails (Maana et al., 2010; Okeyo, Ivivi, and Ngare, 2016; Fasanya and Adekoya, 2017). As such the study models the marginal distributions for both inflation and exchange rate as an ARMA(p, q)-GARCH(x, y) model which are able to model the stylized features of both inflation and exchange rate volatility. ARMA models the conditional mean of the inflation and exchange rate data whereas the GARCH models the volatility as it is fitted to the ARMA residuals once its heteroscedastic behavior is confirmed. The presence of volatility clusters as well as significant autocorrelation in the vector of squared residuals indicates conditional heteroscedasticity. Furthermore, fitting an ARMA in the mean equation of the GARCH model, helps to correct the problem of serial correlation in the residuals.

Therefore, the univariate model for both inflation and exchange rate has the form

$$f_t = \varphi_0 + \sum_{j=1}^{p} \varphi_j f_{t-j} + \xi_t + \sum_{1=1}^{q} \theta_i \xi_{t-i} \tag{1}$$

where

$$\xi_t = \delta_t Z_t \quad Z_t \sim N(0,1) \tag{2}$$

and

$$\delta_t^2 = \alpha_0 + \sum_{i=1}^{x} \alpha_i \xi_{t-i}^2 + \sum_{i=1}^{y} \beta_i \delta_{t-1}^2 \tag{3}$$

In equation (1), p and q are non-negative integers and, φ and θ are the autoregressive (AR) and moving average (MA) parameters respectively with order of the AR and MA terms p and q respectively, are empirically determined by identifying the optimal model among alternative values for p and q using the Akaike Information Criterion (AIC) (Reboredo, 2012).

Based on the GARCH model in equation (2), δ_t^2 is the conditional variance of ξ_t that evolves according to equation (3) where $\alpha_0 > 0$, $\alpha_i \leq 0 \quad \forall i = 1, 2, \ldots x$ and $\beta_i \leq 0, \quad \forall i = 1, 2, \ldots, y$.

In this model the magnitudes of α_i and β_i explain the short dynamics of the resulting volatility process (Maana et al., 2010). Large error coefficients α_i means volatility reacts significantly to changes in inflation and exchange rates whereas large coeficients in terms of β_i imply that shocks to the conditional variance take long time to die hence persistent volatility. AIC is used to determine the appropriate lag lengths in the GARCH model just like in the ARMA model. The ARMA(p, q)-GARCH(x, y) model used here has a further advantage in that it is able to differentiate the impact of positive or negative innovations in volatility for both inflation and exchange rates.

2.2 Modeling the co-movement of inflation and exchange rates

To analyze the co-movement of inflation and exchange rates requires knowledge of their joint distribution and the interdependence between the two. As such we employ the copula function

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to construct a bivariate distribution for inflation and exchange rates data and model the interdependence between them as a concordance measure of the copula function. The bivariate distribution enables us to assess the movement of both inflation and exchange rates across.

Let X and Y be continuous random variables representing inflation and exchange rates respectively with marginal cumulative distributions $F_X(x)$ and $F_Y(y)$ then based on Skalr's theorem (Nelsen, 2007) $F_{XY}(xy)$ is a bivariate distribution characterized by a copula function C such that

$$F_{X,Y}(x,y) = C(F_X(x), F_Y(y)) \tag{4}$$

A bivariate distribution constructed in this way can be recovered from univariate distributions using a copula even though the dependence structure is not contained in the univariate distributions. Furthermore, using copulas allows us to eliminate the need for both marginal distributions to be Gaussian which we know is not correct as most time series data have shown that the conditional distribution of returns series exhibit several stylized features such as excess kurtosis, negative skewed, and temporal persistence in conditional movements (Gyamerah, 2019). In addition, copula function provides information on both the degree and structure of dependence between inflation and exchange rates unlike simple linear correlation which only look at how inflation and exchange rate move together on average across the marginal distribution assuming multivariate normality (Embrechts, 2009). This is achieved because some measure of concordance between random variables like Spearman ρ and Kendall τ are properties of copulas.

There are many parametric copula families available, which usually have parameters that control the strength of dependence. As such, it is not an easy task to select an appropriate copula that suits a particular case. Therefore, a reasonable strategy is to consider different copulas and evaluate their goodness of fit based on AIC and BIC. First, all available copulas are fitted using maximum likelihood estimation and then the AIC and BIC are calculated and compared. Parameter estimation would be done using inference function for margins as described in (Cherubini, Luciano, and Vecchiato, 2004; Joe, 1997).

3 Results and Discussion

3.1 Descriptive Statistics

The data used to investigate the dependence between inflation and exchange rates consists of monthly rate of inflation and monthly exchange rates on Malawi kwacha against the US

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dollar spanning the period from January 2001 to May 2019. The monthly exchange rate was an average of buying and selling rates of commercial banks spot exchange rates as recorded by the Reserve Bank of Malawi.

Figure 1 shows the inflation and exchange rate dynamics during the sampling period. The exchange rate data has been scaled down by 10 so that it becomes compatible for a single plot of both variables.

It can be observed that there is a weak positive relationship between the two until the year 2012 when Malawi adopted the floating point regime in terms of exchange rate. Under floating exchange rates, the rate is determined by the demand and supply of foreign currencies in every period. Any internal and/or external shock will be reflected in the exchange rate in a rather short period of time, if not instantaneously. Wu (2017) found out that during this floating regime period the pass through exchange rate to headline inflation jumped from 0 to 11% holding other factors constant.

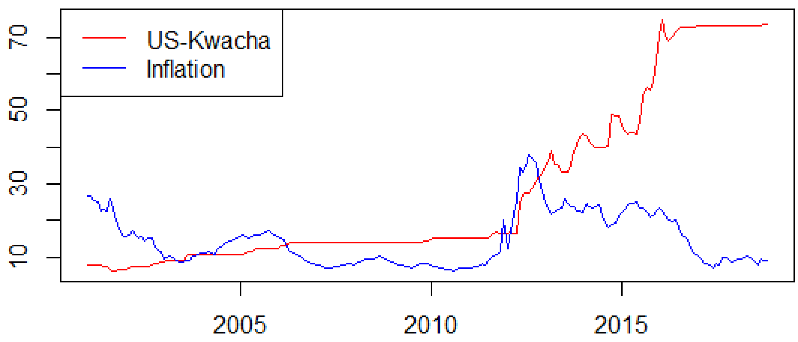

Figure 1: Inflation and Exchange rate dynamics since 2001

The descriptive statistics for both inflation and exchange rate are provided in Table 1

Clearly, both inflation and exchange rate are relatively skewed and leptokurtic. The normality test just confirms that the time series data are not normally distributed and hence we need to model with appropriate distribution other than the Gaussian for both cases of inflation and exchange rate. However it can be observed from the graph (Figure 1) that both inflation and exchange rates are not stationary as both inflation and exchange rate shows some form of trend. We carried out an argumented Dickey Fuller (ADF) t-statistic test to find out if any of inflation or exchange rate has unit root(s).

Based on the results of the test as seen in Tables 2 and 3 it can be observed both inflation

	Inflation	Exchange Rate
Maximum	503	751.09
Minimum	62.23	101
Mean	216.1	291.5
Skewness	0.83	0.95
Kurtosis	3.76	2.30
ADT*	$A = 2.34$	$A = 22.45$

Table 1: Descritpive Statistics for Inflation and Exchange rates

ADT is the Anderson-Darling Test for normality

* indicates rejecting the null hypothesis at 1%

Inflation
Augmented Dickey-Fuller Test data: x1 Dickey-Fuller = -1.4074, Lag order = 6, p-value = 0.8247 alternative hypothesis: stationary

Table 2: Root test for Inflation

Exchange Rate
Augmented Dickey-Fuller Test data: x2 Dickey-Fuller = -2.6613, Lag order = 6, p-value = 0.2984 alternative hypothesis: stationary

Table 3: Root test for Exchange rate

and exchange rate are in $I(1)$ as we fail to reject the null hypothesis, implying they have unit roots and hence confirms our observation that the two are not stationary. This means that we can not model the data using the ARIMA-GARCH in that state hence we need to make it stationary.

Hence, we opt to use log returns of both inflation and exchange rate, which automatically detrends the data, so that it becomes stationary. Figure 2 shows a plot of the log returns for both inflation and exchange rates.

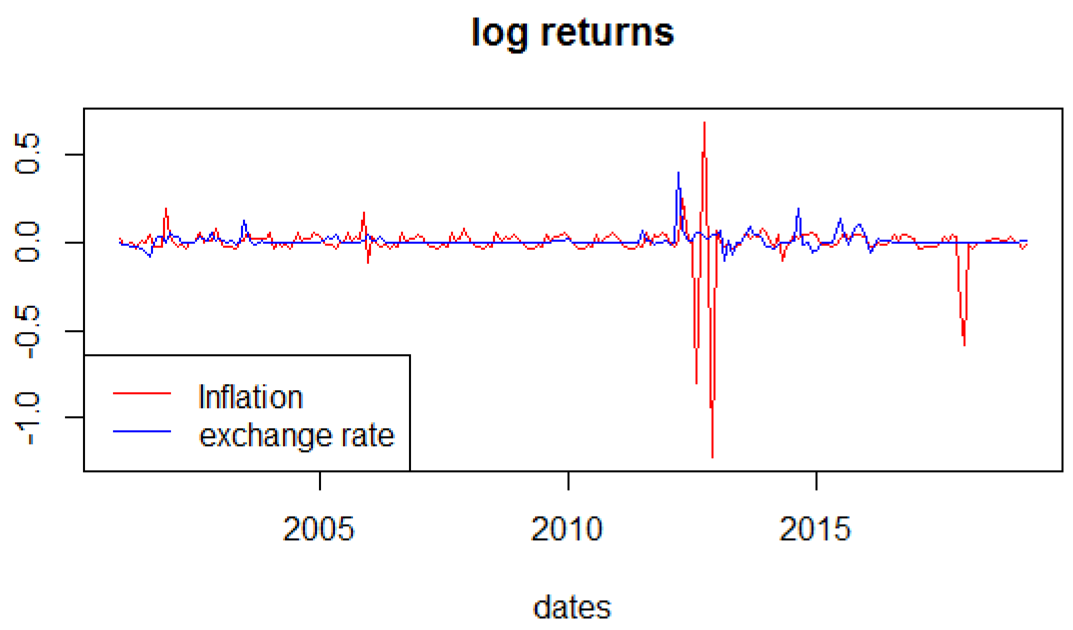

Figure 2: The log returns plot

The evident spikes in both graphs, Figures 1 and 2, show the unsteady patterns of inflation and foreign exchange rates. The upward spikes can be as a result of fiscal expansion and monetary growth whereas the downward spikes are a result of government's intervention to strengthen stabilizing measures through monetary contraction, exchange rate stability and fiscal surplus as response to the inflationary pressures.

3.2 The Cause and effect Relationship between Inflation and Exchange rates

In this study the Granger causality test is used to identify the cause and effect relationship between inflation and exchange rates. It is determined on the basis of potential lag response in each variable to the change in the other variable (Ahmad and Ali, 1999). The test involves the estimation of the following I_t as inflation and E_t as exchange rates such that

$$\log I_t = a_0 + \sum_{i=1}^{p} a_i \log(I_{t-1}) + \sum_{j=1}^{q} b_j \log(E_{t-j}) + U_t \tag{5}$$

$$\log E_t = \alpha_0 + \sum_{i=1}^{p} \alpha_i \log(E_{t-1}) + \sum_{j=1}^{q} \log(I_{t-j}) + V_t \tag{6}$$

The test is applied to the log returns of inflation and exchange rate data as plotted in Figure 2. This will help us understand if either inflation or exchange rate can be predicted by lags of one another.

```
grangertest(xx1, xx2 , order = 1)
Granger causality test

Model 1: xx2 ~ Lags(xx2, 1:1) + Lags(xx1, 1:1)
Model 2: xx2 ~ Lags(xx2, 1:1)
  Res.Df Df      F  Pr(>F)
1    216
2    217 -1 5.1113 0.02477 *
---
Signif. codes:  0 *** 0.001 ** 0.01 * 0.05 . 0.1   1
> grangertest(xx2, xx1, order = 1)
Granger causality test

Model 1: xx1 ~ Lags(xx1, 1:1) + Lags(xx2, 1:1)
Model 2: xx1 ~ Lags(xx1, 1:1)
  Res.Df Df      F Pr(>F)
1    216
2    217 -1 0.3091 0.5788
```

Table 4: Unit Root test Results

Based on this test, at 1% significant level, it can be concluded that fluctuations in inflation result in changes in exchange rates but it is inconclusive on whether exchange rates spikes causes change in inflation. This tells us that there is a possibility of predicting exchange rates based on observed changes in inflation. This agrees with Monfared and Akın (2017) who also found out that there is a direct relationship between inflation and exchange rate for the case of Iran in their study where they analyzed the relationship between exchange rate and inflation based on the Hendry general to specific method and vector autoregressive model. However, as it is observed (Ahmad and Ali, 1999) the Granger causality test has no sound economic theory so the results are just a catalyst for further exploring so that we can confirm with evidence from the proper econometric analysis.

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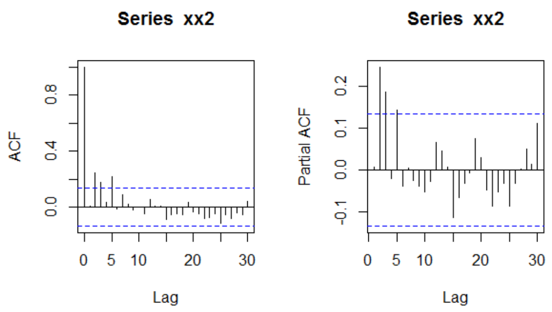
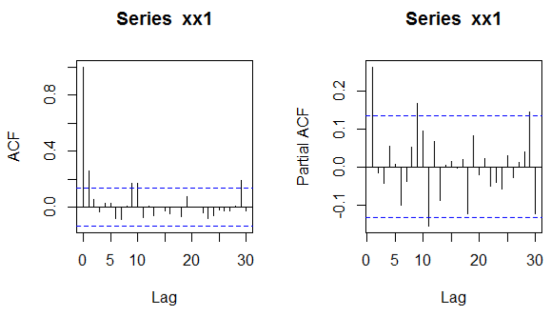
3.3 ARIMA-GARCH Modeling for Inflation and Exchange rate

3.3.1 Mean Models (ARIMA) for Inflation and Exchange rate

In the study we first estimate the mean equations for the log returns of inflation and exchange rate by fitting the data to ARIMA models. The ARIMA models for inflation and exchange rates described by ARMA(p, q) were estimated by considering different combinations of the parameters p, q based on lags on ACF and PACF where the most appropriate model is selected based on AIC values. Based on the combination of significant lags for both the ACF and PACF of inflation the suitbale model is ARMA$(1, 2)$ with an AIC of -441.2 whereas for exchange rate a suitable mean model is AR(1) with an AIC of -768.42.



(a) ACF and PACF of Inflation



(b) ACF and PACF of Exchange Rate

3.3.2 Testing ARCH Effects

The residuals of each mean model of inflation and exchange rates are tested for serial correlation using the Ljung Box test. The Ljung Box test (Gyamerah, 2019) is a method used in testing the absence of serial autocorrelation up to a specified lag k. The null hypothesis is that the first k lags of ACF of the time series data are zero.

It is found, at 10 degrees of freedom, that the p-values for exchange rates and inflation rates under the Ljung box test are 0.0001979 and $1.126e - 08$, respectively. Therefore, we reject the null hypothesis with much evidence from the data sets. This entails presence of serial correlation in the data. Figures 4 and 5 show the ACF and PACF of the residuals where lags can be observed indicating significant correlation hence agreeing with the test results that there is ARCH effects in the data. This tells us about the presence of dependency in the squared returns of both inflation and exchange rate series. As such, in both data the volatility ARCH effect is very much present hence we can model the residuals using the GARCH model. This volatility can cause among other things balance of payment disequilibrium which has the tendency of bringing in inflation in case of depreciation or unemployment in case of appreciation within the economy (Timothy, Mbah, and Chigozie, 2016).

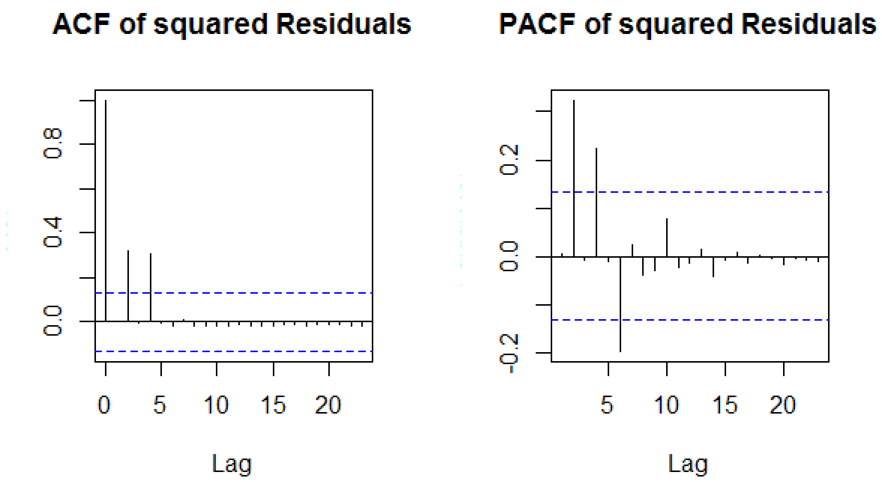


Figure 4: ACF and PACF for inflation rate data

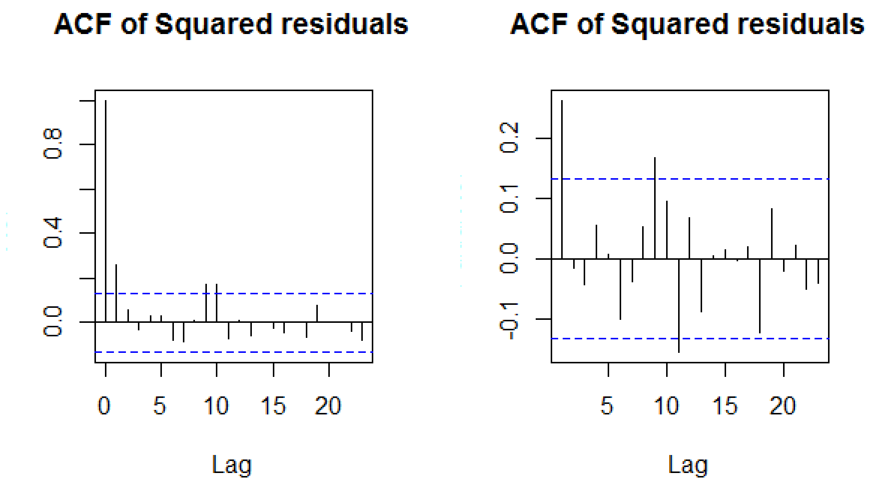


Figure 5: ACF and PACF for Exchange rate data

3.3.3 GARCH modeling

In terms of volatility both models are being modeled by GARCH(1, 1) based on empirical evidence in (Bollerslev, Chou, and Kroner, 1992) that such a model is adequate in describing volatility in many time series data.

Table 5 and 6 shows estimates of parameters for both marginal distributions in terms of inflation an exchange rate and inflation respectively.

Hence the AR(1)-GARCH(1, 1) for foreign exchange is expressed as follows:

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	Estimate	Std. Error	t-value	$Pr(>\|t\|)$
mu	9.573885	2.195782	4.360125676	$1.299878e-05$
ar1	0.378930	0.053634	7.065083	0.00000
omega	9.709400	$6.080197e-01$	15.96889122	0.0000000
alpha1	0.656474	0.100865	6.508419	0.00000
beta1	0.302124	0.042552	7.100080	0.00000
shape	2.704624	0.130396	20.741672	0.00000

Table 5: Parameter estimates of the GARCH model for exchange rate

let r_t be exchange rate at time t then

$$r_t = 9.574 + 0.379r_{t-1} + a_t \tag{7}$$

$$a_t = \sigma_t \xi_t \tag{8}$$

$$\sigma^2 = 9.709 + 0.656a_{t-1}^2 + 0.302\sigma_{t-1}^2 \tag{9}$$

$$\xi_t \sim i.i.d(1, 0, 2.07) \tag{10}$$

	Estimate	Std. Error	t value	$Pr(>\|t\|)$
mu	0.574653	0.243896	2.35600	0.018500
ar1	0.599896	0.198240	3.02612	0.002477
ma1	−0.188353	0.207899	−0.90599	0.364944
ma2	0.083370	0.120098	6.94183	0.007570
omega	6.450000	0.498001	12.9518	0.000241
alpha1	0.346739	0.171885	2.01727	0.016603
beta1	0.652261	0.133322	4.89238	0.000001
shape	2.802691	0.464119	6.03874	0.000000

Table 6: Parameter estimates of the GARCH model for inflation

Based on the estimates in Table 6 for inflation, we observe that $ma1$ is not significant and so can not be included in the ARMA-GARCH model. Hence the ARMA$(1,2)$-GARCH$(1,1)$ model for inflation is expressed as

$$f_t = 0.575 + 0.66 f_{t-1} + a_t + 0.834 a_{t-2} \tag{11}$$

$$a_t = \sigma_t \xi_t \tag{12}$$

$$\sigma_t^2 = 6.45 + 0.347 a_{t-1}^2 + 0.652 \sigma_{t-1}^2 \tag{13}$$

$$\xi \sim i.i.d(0, 1, 2.8) \tag{14}$$

where f_t is inflation on t time.

3.4 Empirical Copula Results

In this research, based on historical data for inflation and exchange rate, we used R software based function called *BiCopSelect* which compares the AIC and BIC, to identify the suitable copula as the survival Clayton copula which is from the Archimedean Copula. Using *BiCopSelect*, all available copulas are fitted using maximum likelihood estimation and then the AIC and BIC are calculated and compared to select the suitable copula for the data.

The survival Clayton copula which has the form

$$\bar{C} = \left(u_1^{-\theta} + u_2^{-\theta}\right)^{-\frac{1}{\theta}} \tag{15}$$

and its inverse generator function is

$$\varphi_\theta = \frac{w^{-\theta} - 1}{\theta}, \quad \theta \in [0, \infty) \tag{16}$$

The estimated parameter θ for the survival clayton copula based on historical data and using the inference for margins is $\tilde{\theta} = 0.21$ based on goodness of fit.

We simulated the pdf and cdf of the bivariate model based on the empirical data and the survival clayton copula seen in Figures 6 and 7.

The Kendall τ correlation is estimated as 0.1072 implying that there is positive interdependence between inflation and exchange rates. It can be observed that inflation and exchange rate co-move though the correlation is weak. One can then conclude that any fluctuation in either inflation or exchange rate directly makes the other to fluctuate as well. The exchange rate regime whether fixed or floating plays a key role in reducing the risk of fluctuations in the real Exchange rate which will affect the rate of inflation and vice versa (Timothy et al., 2016). The weak interdependence can also be attributed to the exchange rate being correlated with other macroeconomic factors including economic growth, that influences the expected high level of commodity prices.

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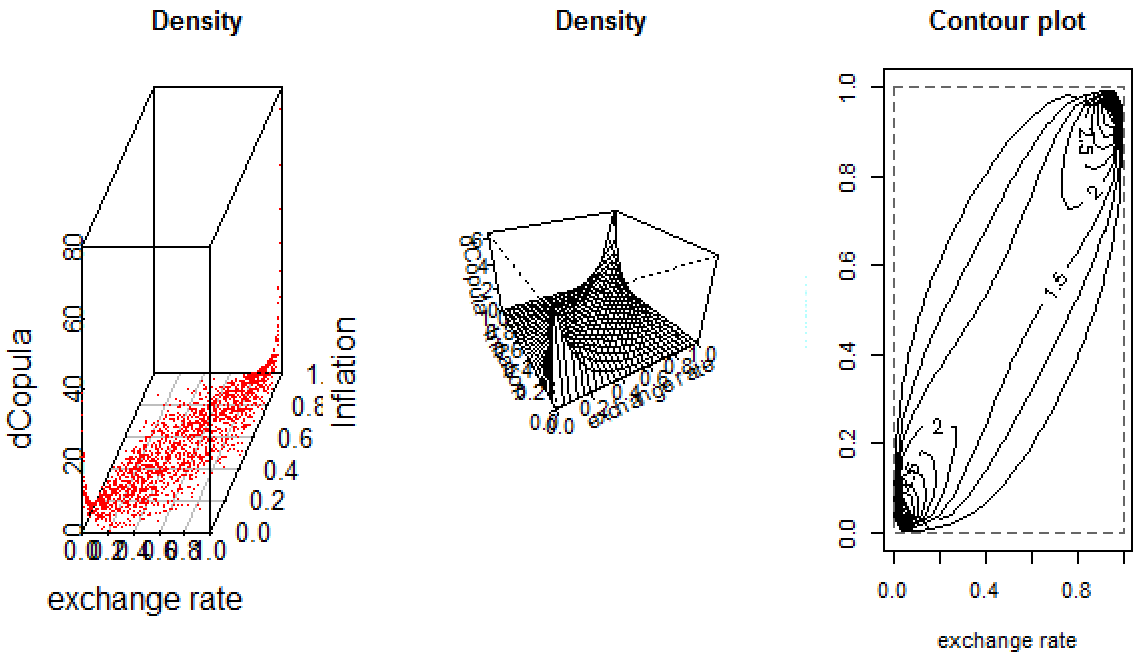

Figure 6: The probability density function

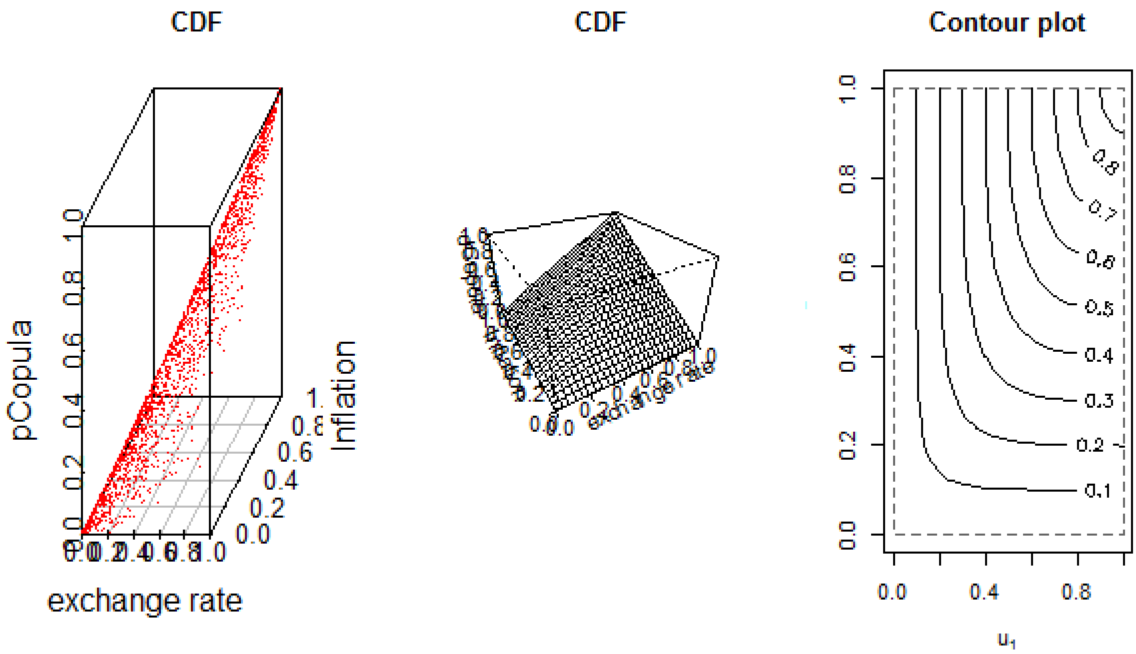

Figure 7: The cumulative density function

4 Conclusion

The fluctuation in the exchange rate can further be threatened if there is an already existing high level of inflation in the system coming from both the demand and the supply sides (Timothy et al., 2016). A rise in money supply is always believed by the monetarists to cause a proportionate rise in price level and as the rise in the price level persists, the tendency is that the domestic goods and services produced within the country will become less competitive both within and outside the country when compared with other countries' output, hence, loosing market both within and outside the country.

The study has found a remarkable correlation between inflation and exchange rate which entails that the interdependence between the two is positive and hence there is co-movement as the either of them fluctuates or depreciates. Our empirical findings also agree with the Granger causality test which pointed at a dependence between inflation and exchange rate. Furthermore, movements in the exchange rate have undulating effects on other macro-economic variables such as interest rate, inflation rate, unemployment, and money supply hence the weak interdependence is explained. Therefore, in terms of economic policies, if any of them affects inflation or foreign exchange then it directly affects both. The research can be expanded by looking at the tail dependence between the two as that would tell whether there is systematic risk in times of extreme changes in either inflation or exchange rate especially for Malawi as it has adopted the floating point regime.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Data Availability

Data for this work are available from the author upon request.

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