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Granger Causality and Error Correction Models in Economics: A Case study of Kenyan Market

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Abstract

The U.S. Dollar exchange rate and the interbank lending rate in Kenya are analyzed. An Error Correction Model (ECM) is used to establish if there exists any short term relationship between the lending and the exchange rates. A linear ECM is fitted and there is evidence that a short-term relationship exists between these two rates. A high threshold value exists at the second lag, an indication of simple smoothing in the data. The residual deviance is greater than the degrees of freedom confirming that the model perfectly fit to the data. This is supported by the high R^2 value of 0.9308. A Granger Causality model is also built to demonstrate all the long term relationships. Contrary to hypothesis of the study, only the exchange rate granger caused interbank lending rate. This can be explained by the instability in the exchange market. It can be attributed to the economic crisis experienced in recent years; that is, an unexpected and sudden attainment of economic stability. The study concludes that Error Correction Models and Granger Causality models are significantly appropriate in analysing time series. It is suggested that a close track of exchange rates may lead to prediction of interbank lending rate movements. Further research is recommended on the factors influencing exchange rate movements and analysis of tail clustering.

Keywords: Granger Causality, Error Correction Model, Economics

1. Introduction

Escalation of interest rates and exchange rates in Kenya has been a common phenomenon. Its random inter-data movements lead to the subject of volatility. It has formed the basis of most research in time series analysis, with several scholars building various models in an attempt to exhaustively examine the sources of these volatilities and their predictions. Unfortunately, no particular scholar has been able to exhaustively determine the sources of volatilities. Neither have they settled on any particular optimum model. Nevertheless, Leykam (2008), Zhongjian (2009), Musyoki et al (2012), amongst others, concur that modelling of these volatilities are vital for the health of an economy. It has been pointed out that the most important aspect in any volatility analysis, including others, are to be able to; predict the future volatility behaviour[1] at some level of significance, and at least establish the risk attached to these movements.

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Volatility can be defined as the periodic displacement of a time series from its long-term mean-level. Forces that displace these time series from its mean-level is of great importance. The displacements as well occur in phases, as suggested by the definition; the short term and the long term. Most scholars have not done concurrent short term and long term analysis. However, there is a great need to analyze these shocks in two phases, the short and long-term, in order to capture the movements exhaustively; where imputation of the two relationships can be analyzed. Granger (1986) first proposed a procedure, called granger causality, which analyses the long-term movements. On the other hand, an ECM, introduced by Granger (1986) in his work which analysed a short-term relation in existence. He analyzed a balance in an ECM and realized that there was an imbalance in *I(0*[2]*)* and *I(1)*[3], (Granger, 2010).

Earlier, Fung and Hsieh (2004) had used co-integration on their study on hedge funds. They criticized the conventional approaches of model constructions for asset-class indices to be applied in hedging. Seven factors were identified from which a model was built. On analysis of parameter stability, Fung and Hsieh (2004) apply the cumulative recursive residual method and plots on a time scale to investigate the reversion of the model parameter in the risk factor model. The factors are co-integrated and hence influence each others' performance. Fung and Hsieh (2004) finally proposed a seven factor model to be applied for hedging.

Later, Leykam (2008) in his work on cointegration and volatility in the European natural gas spot markets tests the Granger causality in volatility markets. Four markets were identified from which spot prices were obtained. Granger causality tests were done for different pairs of the markets. Of the four markets, one (Bunde) market indicated no association with the other three markets. All the hypotheses that the other three markets can be used in predicting volatility in Bunde were rejected at 1% significance level. This meant that Bunde could not be considered a price setter in the European gas spot market.

The study by Fung and Hsieh (2004) was further extrapolated by Zhongjian (2009) who analyzed the same hedge funds in view of further examining the validity of the method used in deriving the seven factors which had been suggested by Fung and Hsieh (2004) for the inclusion in a hedging portfolio. In his research, he highlights that Fung and Hsieh (2004) did not provide enough evidence to proof that the procedure used in choosing the factors is quite different from the Sharpe and Fama-French which only relies on one characteristics of the entire market. Contrary to Fung and Hsieh (2004), Zhongjian (2009) bases his parameter stability on the adjusted R^2 statistic. Zhongjian (2009) does not mention the reason for his selection of R^2 statistic instead of the cumulative recursive residual. He identifies nine hedge indices which can be included in the hedging strategy. A full rank co-integration in the industry was as well established, and an eight factor model to be used for hedging strategies as the most powerful model, is proposed.

Initially, Rashid (2005) had applied granger causality in agriculture in a study on spatial integration of maize markets undertaken in the post-liberalized Uganda. Different markets were identified. Causality tests were conducted on different pairs of markets, and the results indicated that all pairs which included Kampala and Jinja failed to reject the causality null. This was an indication of uni-directional causality, implying that the regional maize prices Granger caused the prices in these two large cities. Also, a two directional causality effect was established between Mbale and Hoima indicating dependence behaviour; that is, all deviances in one market affect the other.

Huang and Neftci (2004) investigated co-integration relationship that existed between the swap spreads and various rates such as the LIBOR[4], US corporate credit spreads and the treasury yield curve; which found evidence of co-integration existence. In their study, they showed that under the ECM framework, the daily swap spreads reacted to the corrective long-run forces except from the short-term fluctuations in the variables. They concluded that the swap spread had a negative effect only on one measure, the treasury yield curve, but positive in all the other rates.

Later on, Petrov (2011) applies ECM in evaluating a pair wise co-integration strategy between the South African equity market and other emerging and developed markets; using the price indices rather than MSCI[5], as used by Biekpe and Adjasi. He gives two reasons; one, that price index is raw and two, it enabled comparisons across different markets. Petrov (2011) shows that all the markets were responding slowly to any long term disequilibrium. The integration proved to be high between most markets and hence portfolio selection was the most sensitive task to undertake. Petrov (2011) applies an ECM to analyze different portfolios of different sizes. He finds out that USA dominated in all the portfolios in which it was introduced. It was then recommended that such portfolios should be considered the most favourable for investors.

Credit risk is one of the most important types of risk which a bank will be keen to assess to ensure that it remains in business. On the other hand, most of the bank advances are made on a collateral basis. Karumba and Wafula (2012) study this collateral lending characteristic of the lending institutions[6] and their implication on the general financial equilibrium. They investigated its implication on the level of credit risk faced by the banks. Karumba and Wafula (2012) apply co-integration and error correction techniques to investigate long-run relationship. The study found over-reliance on collateral in institutional lending. A negative ECM adjustment coefficient was found indicating that advances in loans and collaterals had a short-term adjustment. With the introduction of credit referencing, the study concludes a general reduction in credit risk.

In Basel III accord, the main challenge is addressing rates volatility. Its evolution over time makes credit risk analysis more complex. In this research, we contribute to the bank of literature by investigating existence of short-term and long-term relation between lending and interest rates. This contributes to mitigation of credit risk analyzed by Karumba and Wafula (2012). A procedure for modelling interbank lending rates can be seen as a milestone to the mitigation strategy. It will make the work proposed in Basel III accord much easier.

1.1. Organization of the paper

The rest of this paper is organized as follows; In the section that follow, a review of some important definitions on the various tests which will be used in section *(3)* is given. Foremost is a review of definitions on granger causality in sub-section *(2.1);* followed by a review on ECM in sub-section *(2.2)*, and finally a definition of some tests in sub-section *(2.3)*, which are fundamental in the study. Empirical results are discussed in section *(3)* which is concluded by discussion of the results and recommendations for further study.

2. **Some Theoretical Review**

2.1. Granger Causality

Granger (2004), proposed a procedure of investigating causality using lagged series and residuals. Suppose that there is a series or vector y_t from which one wants to obtain k ahead predictions, y_{t+k}, from an information matrix Λ. Let Λ be a vector of random variables/series $(a_t, b_t, a_{t-1}, b_{t-1}, \cdots, a_1, b_1)$. Obtaining the y_{t+k} using least squares involves calculation of the conditional mean$E[y_y/\Lambda]$. In time series, it involves regressing y_t on Λ where Λ in this case have the variables$(y_{t,} y_{t-1,} y_{t-2,} \cdots y_1)$. This is rather complex. An easier procedure is to consider its causality.

Theoretical Representation of Granger Causality

Let X_t and Y_t be two series. X_t is said to Granger cause Y_t if the lagged values of X_t has statistically important information about the future values of Y_t . It is calculated for stationary series. An appropriate procedure is chosen to determine the lag to be used, to obtain optimum results. Regression is used for estimation. T-tests are used to retain the significant variables in the regression and F-test determines jointly significant variables to be retained.

The procedure involves fitting a regression of lagged values of y_t such that;

$$y_t = \lambda_0 + \lambda_1 y_{t-1} + \lambda_2 y_{t-2} + \cdots + \lambda_k y_{t-k} + \varepsilon_t \tag{1.1.1}$$

where ε_t are the residuals. The k statistically significant lags of y_t is augmented with lagged values of X_t such that;

$$y_t = \lambda_0 + \lambda_1 y_{t-1} + \lambda_2 y_{t-2} + \cdots + \lambda_k y_{t-k} + \mu_a x_{t-a} + \cdots + \mu_b x_{t-b} \tag{1.1.2}$$

The lagged values of X_t in Equation (1.1.2) are retained if it adds an explanatory power to the regression equation. F-tests are used to determine the retained lagged values ofX_t. The shortest possible regression has a values where longest has b values. The null hypothesis of no Granger causality is rejected if and only if there exists at least one lagged value of X_t retained in Equation (1.1.2).

2.2. Error Correction Model

When estimating a granger causality relationship, the requirement is to ensure the series is $I(1)$. Making a series $I(1)$ implies differencing. Differencing removes trend and hence loss of some important information about the time series behaviour in the short-run. Also, a cointegration relationship assumes a linear relationship; which might not be always the case due to random shocks. A displacement from the equilibrium relation implies a response from one of the variables to attain the equilibrium. The rate at which either variables re-attains equilibrium is modelled by an ECM. Simply, an ECM is a model which gives an estimated response behaviour of a variable upon dis-equilibrium. An ECM can be estimated as

$$\triangle A_t + \lambda \triangle B_t = \Omega + \beta(\Lambda) + \varepsilon_t \tag{1.2.1}$$

where λ and β are coefficients, Ω an intercept which may or may not be included; ε_t random noise; and Λ an 'error correction component'.

2.3. Empirical Unit Root tests

In this section, definitions of some tests which are fundamental to the empirical analysis in section (3) is given.

Review of Augmented Dickey Fuller test

This is a generalized form of the Dickey Fuller test, (Dickey and Fuller (1979)). It relies on the assumption that the residuals are independent and identically distributed. For a series Y_t, ADF uses the model

$$\Delta y_t = \alpha + \lambda t + \eta y_{t-1} + \delta_1 \triangle y_{t-1} + \cdots + \delta_{p-1} \Delta y_{t-p+1} + \varepsilon_t \tag{1.3.1}$$

which reduces to a random walk when $\alpha = 0$ and $\lambda = 0$; and a random walk with a drift when $\lambda = 0$. The ADF[7] test thus detrends the series before testing for unit root. It uses lagged difference terms to address serial correlation. The ADF test clearly depends on differenced series. This thus possess a need for another validating test.

An inspection of the p-value also determines whether the null hypothesis of non-stationarity will be accepted. A small p-value[§] leads to the acceptance of the null hypothesis. An inspection of the Dickey-Fuller value is as well important as this indicates the mean-reverting property. It is normally a negative value. The larger its absolute value, the lower the chance of occurrence of mean-reverting property.

Review of Kwiatkowski Philips Schmidt Shin test

Contrary to ADF test, the KPSS[8] tests (Kwiatkowski D. *et al* (1992)) for the null hypothesis of level or trend stationarity. It gives a way to specify whether to test with a trend or without, in its test statistic. A regression model with linear combination of a deterministic trend[**] , a random walk and a stationary residual series

$$Y_t = \alpha + \beta t + \lambda \sum_{i=1}^{t} \varepsilon_i + \delta_t \tag{1.3.2}$$

is used where $\delta_t$is stationary, βt is the trend component while $\sum_{i=1}^{t} \varepsilon_i$ is the random walk. $\beta t = 0$ if we assume a without-trend regression. The series in Equation (1.3.2) will be stationary if $\lambda = 0$. Regression is used to obtain the estimate of δ_t, that is $\widehat{\delta}_t$, from which we compute

$$\Omega_{resid} = \sum_{i=1}^{t} \widehat{\delta}_i \tag{1.3.3}$$

The test statistic for KPSS test is then calculated as

$$R = \frac{\sum_{i=1}^{n} \Omega_i^2}{n^2 \widehat{\theta}_T^2} \tag{1.3.4}$$

where the spectral density function estimator

$$\widehat{\theta}_T^2 = \widehat{\sigma}_\delta^2 + 2 \sum_{k=1}^{T} \left(1 - \frac{k}{T-1}\right) \widehat{\omega}_t \tag{1.3.5}$$

§ less than 0.05 or 0.01 depending on the statistician

** if test statistic is with a trend

is a linear combination of the variance estimator $\widehat{\sigma}_{\delta}^{2}$ and covariance estimator

$$\widehat{\omega}_t = \frac{\sum_{t=k+1}^{n} \delta_t \delta_{t-k}}{n} \tag{1.3.6}$$

The test turns to a prudential choice of T in Equation (1.3.5) above.

Review of Phillip Perron test

The Phillips Perron approach (Phillips and Perron (1988)) applies a nonparametric correction to the standard ADF test statistic, allowing for more general dependence in the errors, including conditional heteroskedasticity. If there were strong concerns over heteroskedasticity in the ADF residuals this might influence an analyst to go for PP[9]. If the addition of lagged differences in ADF did not remove serial correlation then this again might suggest PP as an alternative.

3. Empirical Results

Daily data on exchange rate of the Kenyan shilling against the dollar and the interbank lending rates are analysed in this section. The main aim is to establish if there exists any causality between the two rates. Granger causality is investigated in sub-section (3.1) while an ECM is built in sub-section (3.2) as follows:

3.1. Granger Causality

The first step in granger causality analysis is to establish stationarity of the time series. A basic investigation of this property is by visual inspection of time plot. A time plot is plotted, represented in Figure (1) below, and by inspection the series is non stationary.

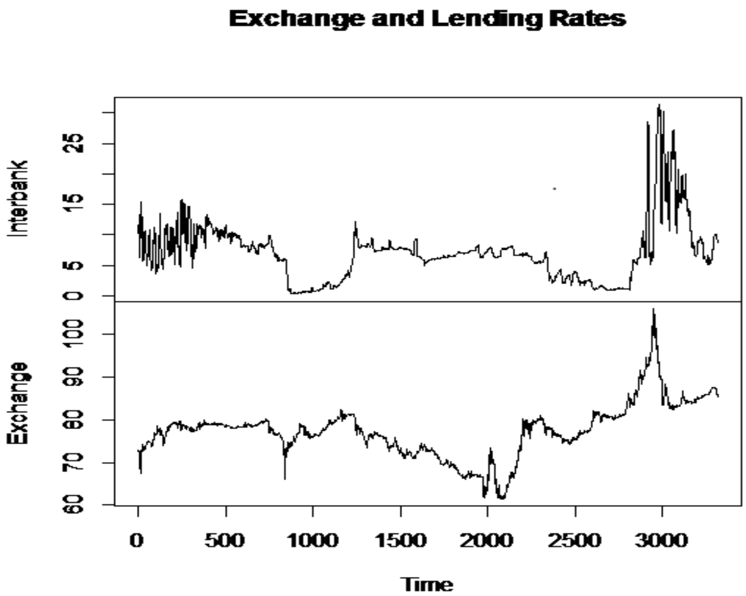

Figure 1: Time Plots of the Two Series, Dollar Exchange Rate and Interbank Lending Rate

ACF[10] is conventionally used in time series analysis to inspect for stationarity. If the spikes tend to be constantly high close to a value of 1, the series is non stationary. The Figure below represents the respective ACFs of the two rates.

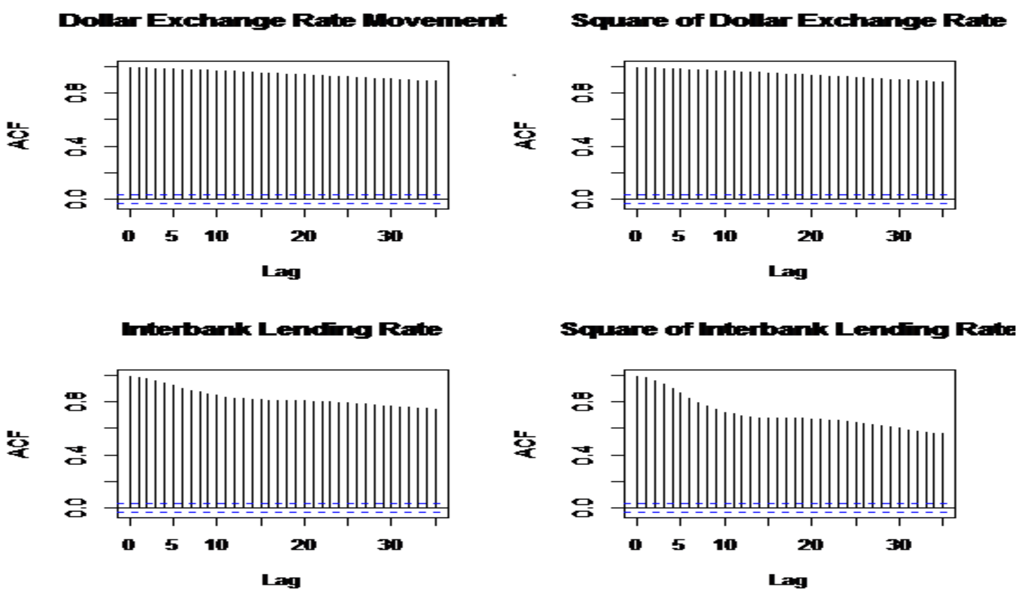

Figure 2: ACFs of the Exchange and Lending Rates

An inspection of the ACFs suggests non stationarity. The respective squares of the two series helps in the analysis of heteroskedasticity, which will determine the method used to investigate for causality. Nevertheless, mathematical tests such as KPSS, ADF and PP tests are necessary to ascertain non stationarity.

ADF test output of the two series is presented in the Table below.

Table 1: ADF Test Output for Exchange and Interbank Lending Rates

Data	Dickey-Fuller	Lag	P-value
Exchange Rate	-2.1937	14	0.4963
Interbank Rate	-3.6382	14	0.02897

The ADF test tests the null of non stationarity. From the ADF test output above, an inspection of the p-values indicates that the null hypothesis is not rejected at 5% level of significance for the Dollar exchange rate. We reject the null hypothesis at 5% level of significance for the Interbank lending rate. Conventionally, p-value indicates the amount of evidence we have against the null. It is therefore concluded that the exchange rate is non stationary while the interbank lending rate might be stationary. However, the ADF test has two weaknesses, namely;

i. The model for an ADF test uses the differenced series.
ii. It assumes that the residuals are independent and identically distributed.

These weakness calls for the use of KPSS test. The KPSS test uses the series to test for non stationarity without differencing. The assumption on the distribution of the residuals is not required in this test. It is therefore a tentative alternative for stationarity test.

Table 2 :KPSS Test Output for Exchange and Interbank Lending Rates

Data	KPSS Level	Lag	P-value
Exchange Rate	5.0182	13	0.01
Interbank Rate	1.3153	13	0.01

Contrary to the ADF test, the KPSS test tests for the null of stationarity. Therefore, from the output presented in Table (2) above, an inspection of the p-value calls for the rejection of the null hypothesis at 5% level of significance and conclude that the two series are not stationary. This is not in line with the results obtained from the ADF output in Table (1) above, where the interbank lending rate was established to be stationary.

To ascertain these results, we apply the PP test. The results of this test are presented in the Table below.

Table 3 :PP Test Output for Exchange and Interbank Lending Rates

Data	Dickey-Fuller	Lag	P-value
Exchange Rate	-7.3937	9	0.6974
Interbank Rate	-48.5564	9	0.01

Just like the ADF, the PP test tests the null of non stationarity. An inspection of the p-values indicates that the Interbank lending rate is stationary while the exchange rate is non stationary. This result is contrary to the results from KPSS test in Table (2) above, but in line with the results obtained from Table (1). This therefore calls for an informed judgement on whether to assume stationarity of the interbank lending rates. In this study, we will assume that the interbank lending rates are stationary and its only the exchange rate which is non stationary. This is because two of the three tests performed support this judgement.

Following the above results, it is necessary to inspect whether the two series might be having a causal relationship. This can be investigated by superimposing the two series onto each other and checking whether their movements are similar.

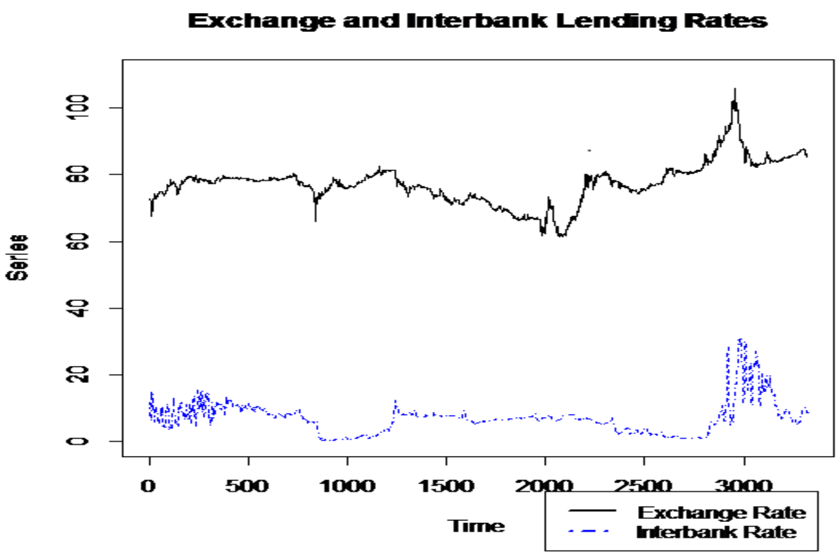

Figure 3: Superimposed Series of Exchange and Interbank Lending Rates

Clearly from Figure (3) above, the two series have causal relationship. The exchange rate series is thus differenced and checked for stationarity. The same tests are applied.

Table 4: Test Output for the Differenced Series of the Exchange Rate

Test	Test Statistic Value	Lag	P-value
ADF	-14.2119	14	0.01
KPSS	0.0153	13	0.1
PP	-1300.176	9	0.01

The null hypothesis is rejected at 5% level of significance. The exchange rate series is now stationary. Because of the weaknesses of the ADF test discussed above, KPSS test is done and the results presented in same table as below. The results are same as for ADF test. We fail to reject the null hypothesis at 5% level of significance and conclude that the series is stationary. To ascertain these results, the PP test is done and results presented in the same table.

This test wraps up the unit root tests and we infer that the differenced series is stationary. It is therefore concluded that the exchange rate is *I(1).*

Estimation of lag value to be used in the estimation of causal relation between the two series follows. AIC is the commonly used procedure in the estimation. The output of the estimation is presented in the following Table.

Table 5: Results for the AIC lag Estimation

	Degrees of Freedom	Sum of Squares	RSS	AIC
Null			74156	10319
Differenced Exchange Rate	1	247.4	74403	10328

NB : $rank = 2$

From the output, the second lag is the most appropriate for estimation. The model effects are therefore investigated and from Figure (4), it is clear that the model has a level effect except for tail values.

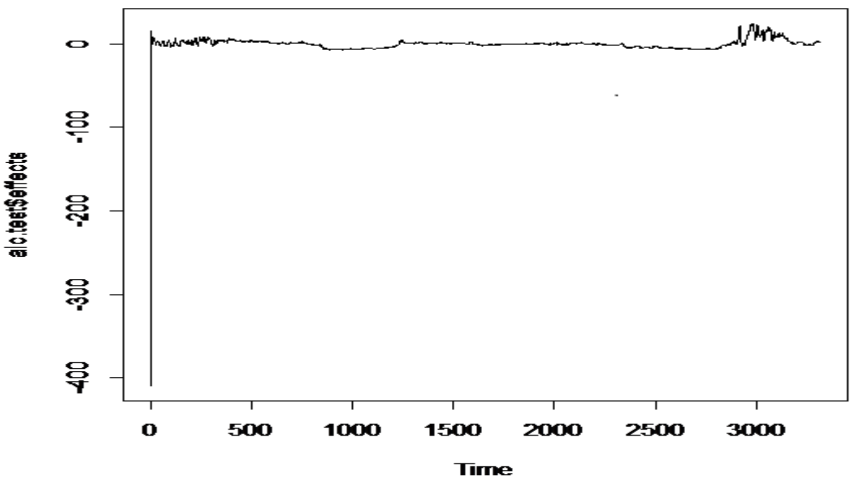

Figure 4: Exchange- Rate- verses Interbank Lending Rate Model Effects

Since the model effects are level within the mean, the necessity of lag inclusion in the model is investigated. The results of this test are as shown in Table (6) below.

Table 6: Statistical Test Output on Lag Inclusion in the Model

Model	Inclusion	Residual Df	F-value	$pr(>F)$
One	$Lags(Y, 1:1) + Lags(X, 1:1)$	3317		
Two	$Lags(Y, 1:1)$	3318	-1	4.264×10^{-7}

Y[††] and X[‡‡] represents the interbank lending rate and the exchange rate, respectively. The null hypothesis of the saturated model is not rejected. Therefore, $\exists$ sufficient evidence that the inclusion of the lagged values in causality estimation leads to the overall improvement in the model predictive ability. The coefficients for the granger causality model are presented in the table below.

Table 7: Granger Causality Model Coefficients

Intercept	X11	X12	X13
-7.9150651	0.1942408	0.1574291	-0.8701337

The third variable[§§] is found to be insignificant in the model, at 5% level of significance. The variable is dropped. A linear model is thus fit with the series itself and its second lagged value as follows;

Table 8 : A Linear Model with Significant Lagged Values

Intercept	X11	X13
-7.9123922	0.1942063	-0.7914011

All the model parameters were found to be statistically significant at 5% level. From the output above, the granger causality model therefore becomes:

$$Y_t + 7.91239 = 0.19421X_t - 0.79140X_{t-2} \tag{2.1.1}$$

where Y_t represents the interbank lending rate while X_t is the dollar exchange rate.

It therefore remains to check on the direction of the causality. The output is presented below.

Table 9 : Direction of the Causality

	F-statistic	p-value
Exchange $\rightarrow$ Interbank	6.473963	0.00156268
Interbank $\rightarrow$ Exchange	2.992947	0.05027497

It is clear that exchange rates granger causes the interbanking lending rates. Therefore, movements in interbank lending rates are more likely to be caused by the movements in the exchange rates. However, interbank lending rate does not granger cause the exchange rate, as could have been expected.

[††] interbank lending rate
[‡‡] exchange rate
[§§] first lag of the exchange rate

3.2. Error Correction Model

Once the granger causality model in sub-section (3.1) above has been built[***], an ECM is easily built by considering the residuals of the model in Equation (2.1.1) above. ECM involves fitting a regression equation of the differenced series and the residuals of the fitted granger causality model. Due to the inclusion of the residuals, dynamic linear modelling is used. The fitted model will involve two main parts; the residual part which might be considered more stable than the differenced series part, hence the use of a dynamic linear model. The output of an estimated ECM is as shown in Table (10) below.

Table 10 :An Estimation of an ECM for Exchange and Interbank Lending Rates

	Estimate	Std. Error	t value	$pr(>\lvert t\rvert)$
Intercept	7.108730	0.021622	328.78	2.0×10^{-16}
Differenced Exchange Rate	-0.775746	0.055974	-13.86	2.0×10^{-16}
Residual	1.000388	0.004744	210.85	2.0×10^{-16}
Residual Standard Error : 1.246 on 3317 df				
Multiple R^2 : 0.9308				
Adjusted R^2 : 0.9308				
P-value = 2.2×10^{-16}				

All the parameters from the model are significant at 5% level. R^2 value of 0.9308 shows that the overall model fits well to the data. The fitted ECM therefore becomes;

$$Y_t = 7.108730 - 0.775746 \triangle X_t + 1.000388\Lambda \qquad (2.2.1)$$

where Y_t represents the interbank lending rate, X_t the exchange rate while Λ denotes the error correction component.

4. **Conclusion and Discussion**

Contrary to time series theory, tests on interbank lending rates return stationarity. Nevertheless, the exchange rates seem to be consistently non stationary. The stationarity of the interbank lending rate can be attributed to the fact that;

- The interbank lending rates are controlled locally and are mainly set following fluctuation of worldwide economic performance. The stability of interbank lending rates is mainly determined by the central bank.
- The exchange rate is normally controlled by the overall worldwide economic performance. Its fluctuation is thus not influence locally by any country, i.e., it is not controlled monopolistically.

From the above arguments, we expect the interbank lending rates to be more stable of the two.

Results of the granger causality indicate that the exchange rates granger causes the interbank lending rates. Movements in exchange rates can be used as an indication of the most probable movement in interbank lending rate. The residual sum of squares from the granger causality model is very low, an indication that the model optimally explains the variations in the data. From the superimposed plot of the two series in Figure (3), it is expected that the exchange rate and the interbank lending rate granger

[***] Equation (2.1.1)

causes each other. However, contrary to this intuition, the interbank lending rate does not granger cause the exchange rate. This can as well be attributed to the local nature of the interbank lending rate.

Finally, an ECM model is built and results presented in Table (10) in sub-section (3.2). The model is presented in Equation (2.2.1). From the output, the R^2 value is 0.9308, an indication that the model well fits to the data. Further, the adjusted R^2 value is 0.9308, same as the R^2 value, meaning the model can as well perfectly fit to any other data with similar characteristics. Therefore, the model can be used for predictive purposes. This argument is ascertained by the very small sum of squared residuals. The model can therefore be used to analyse data with similar characteristics as those used in the study. It can as well be adopted by institutions for their internal hedging and as a liquidity guard.

Recommendations

It is recommended that the same study be conducted with interbank lending rates being differenced to investigate whether there will be any change in the overall model. Also, an investigation on the stationarity of the interbank lending rates should be done to establish its cause and why it occurs. Further, a study on the tail values should be done to examine the cause of the tail clustering and its impact on the overall model. Given the granger causality model, it is recommended that a cointegration model be built to examine whether the two models differ from each other; and if so, examine the reasons for the difference.

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[1] at some level of significance
[2] Integration of Order 0 or stationarity
[3] Integration of Order 1
[4] London Interbank Offered Rate rates
[5] Morgan Stanley Capital International index
[6] Banks
[7] Augmented Dickey Fuller test
[8] Kwiatkowski Philips Schmidt Shin test
[9] Phillip Perron test
[10] Auto Correlation Function