Multivariate Modeling and Forecasting of the Stock Price Index in the Nairobi Stock Market

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Abstract*: Stock price index has been used as a statistical measure of the stock market based on the performance of certain stocks. Stock prices in capital markets of developing nations, Kenya included, depends on the investors' potential in buying and selling at a given time. Imperfect market information has thus brought about uncertainty and stock price fluctuations. It has further caused drastic volatility in share prices hence leading to reduced returns for investors. Therefore, the study focused on the past influence of inflation and interest rates on Kenyan stock price indices by establishing a multivariate model which was used to predict future stock price index. The study examined long run and short run relationship between the Kenyan stock price index and the selected macroeconomic variables using a VEC model, estimated parameters of multivariate GARCH model, and finally, forecasted the stock price index using multivariate GARCH model. The study found a long run relationship between stock price index and both the interest and inflation rates. Further, a DCC GARCH model was fitted and its parameters estimated. There was an upward trend in the correlation between the NSE 20 share index and both interest and inflation rates across the twelve years-period. Declines were found in times of economic crisis, that is, 2013 and 2017 when there was a general election. The forecast showed an expected decrease in the strength of the correlation between stock price index and the selected macroeconomic factors in the long run. The forecast seemed stable.

***Keywords*: VEC model, Cointegration, DCC-GARCH, Stock Price Index, NSE 20 Share Index.**

1. Introduction

Stock price index has been a perfect indicator of the market performance in terms of economic, social and political performances across the world [1]. A country with a well-thriving economy experiences a very settled and good political environment; again, the stock price index is high, which make the investors highly depend on it as they can freely enter and exit the market. An index is a portfolio of stocks representing the entire stock market. A stock price index is the assessment tool for an efficient market. In an efficient market, stock prices fully reflect the available information about the market thus helping to close any opportunity to gain excess profit [2]. Stock price index forecasting has currently gained more attention, especially to the investors and regulators as it guides the future market direction and investments. Besides, the regulators take better corrective measures. In Africa, stock market exchange has improved the wealth and the long-term capital required for development hence reducing poverty. It also creates jobs and trading opportunities.

In Kenya, shares are traded in the Nairobi stock exchange (NSE), which has been used to determine the stock's performance of the country. The NSE 20 Share Index is a price-weighted index where members are selected based on weighted market performance for a 12-month period. This index is based on a geometric mean of average prices of the constituent companies which are equally weighted and is reviewed periodically to ensure an accurate reflection of the stock's performance. The weights are allocated as follows: Market Capitalization 40%, Shares Traded 30%, Number of deals 20%, and Turnover 10% [3]. In 2008, all companies were considered in order to get a more broad-based NSE All-Share Index (NASI) which captures the market capitalization of all the NSE's listed equities traded in a day.

NSE has experienced a downward trend in the stock's performance from the year 2015. The years 2013 and 2017 performed worse which might have been affected largely by the general election [3]. This indicates that there has been drastic volatility in share prices. This has attracted much research using different methods to understand the volatility and determinants of stocks performance. Time series methods have been applied seeking to establish a relationship between stocks performance and macroeconomic variables and more so to predict the future.

The contribution of this study is that it uses macroeconomic variables namely; the interest rate and inflation rate, to explain and forecast the stock price index of the Nairobi stock market in a multivariate framework. Particularly, the study examines the long run and short run relationship between the stock price index and selected macroeconomic variables, use MGARCH to estimate the parameter of the model and then use the model to forecast the stock price index.

2. Literature review

A. Stock market performance

Many studies have been done at global, regional and local levels with most of them finding a significant relationship between stock market and macroeconomic variables such as Gross Domestic Product (GDP), inflation, money supply and interest rates among others. These macroeconomic variable acts as indicators of the market performance and thus helping in making perfect future market speculation. A recent study conducted by Gasheja, Mung'atu, Ingabire, Ndakaza, Napoleon, and Hagenimana applied Vector Error Correction in Modeling the Rwanda Exports [4]. The study used data dated from 1976 to 2013 of gross domestic production (GDP), foreign direct investment (FDI), and industrial value added (IVA) and savings (SAV). The study tested the stationarity of the data, cointegration to examine a long run relationship between exports and the macroeconomic variables and lastly examined the existence of a dynamic relationship between export and hypothesized determinant. The results found that the series was of I(1), and the existence of a long-run relationship between exports, GDP, FDI, and IVA & SAV. Also, GDP, FDI, IVA were statistically significant in a short run relationship while savings was found not statistically significant.

Additionally, focusing on the Kenyan stock market, Njenga studied the effect of stock market development on economic growth in Kenya [5]. The study used the Harrod-Domar growth model, Ordinary Least squares (OLS) Method and Vector Error Correction Model (VECM) to estimates the parameters. The VECM estimated both the short run and long run dynamics. The study found that the market capitalization, investments, and equity turnover had a short run relationship with Kenyan economic growth. On the other hand, the university enrollment, the total value of shares traded and the equity turnover had a long run relationship with the Kenyan economic growth. Therefore, the study revealed that it was relevant to improve investment within the economy due to the short run relationship with the most sensitive microeconomic variables.

Njehu studied the effect of the Nairobi stock exchange market capitalization on the economy of Kenya [6]. The study identified a gap emerging when listing companies through market capitalization yet there was no any realized economic growth and instead, fluctuations were rampant. A sampling method was used and the sample composed of 16 companies from the industrial and allied sector, 12 from finance and investment, 9 from commercial and services sector, 8 from alternative investment segment and 3 from the agricultural sector. The study found that the Nairobi stock exchange has not significantly promoted the Kenyan economic growth due to the strict measures input by the government towards the companies' licensing. Therefore, the study recommended the government to revise the company listing terms to encourage the permitting of more companies to allow expansion and economic growth.

B. Nairobi security exchange

Nairobi Securities Exchange is a voluntary association of stockbrokers that deal with shares and stocks. It started in 1954 and is registered under the Societies Act. By the year 1966, the association had already started measuring daily trading activity through NSE Index computation of the daily average price change in 17 most active companies in the market [7]. Since then, many companies have come on board and NSE index is now calculated daily using the best 20 well-performing companies, hence the name 'NSE 20 share index.'

Currently, the NSE has two market indices; the NSE 20 Share Index, which is price-weighted and an all-inclusive NSE All-Share Index (NASI), which is market capitalization weighted. Price weighted indices are based on a geometric mean of average prices of the constituent companies which are equally weighted [7]. The stock price indices are revised periodically to make sure they reflect the exact representation of the performance of the stock market.

Occasionally, NSE has experienced drastic volatility in share prices. In March 2004, there was a realized decline in market capitalization from Kshs.375.10 billion to Kshs.286.27 billion, depicting a loss of 23.7% [7]. Between January and March 2007, it again dropped from Kshs.845.97 billion to Kshs.696.92 billion, a loss of 17.6% [7]. Also, between June 2008 and February 2009, it dropped from Kshs.1.22 trillion to Kshs.611.77 billion, a loss of 49.86% [7]. Further, the most recent crash was witnessed in 2011 when it dropped from Kshs.1.205 trillion in January 2011 to Kshs.864.15 billion in December 2011 [7].

C. Previous studies on modeling stock indices

Many studies have been conducted and applied different models to the stocks indices data from time to time. Kiragu and Mung'atu conducted a model of the extreme values of Nairobi stocks using the peak-over-threshold (POT) method [8]. The study focused on the Generalized Pareto distribution to model the empirical distribution's tail in the NSE-All Share Index (NASI), and the extreme value theory to examine the extreme values in the NASI. A time series plot was used to demonstrate a fat-tailed data through a histogram of returns. The histogram was right skewed, which consistently followed a positive kurtosis. The returns were found to be stationary, and ARCH effects present. The study concluded that the data was well fitted for both the right and left tail, although the left tail fitted better than the right. Also, through the risk measures of VaR and ES, the probability of losses was moderate compared to that of profit for an investor in the NSE.

Additionally, the study by Abaenewe, Ogbulu and Nnamocha examined the behavior of the stock market price given the selected macroeconomic variables as industrial production, exchange rate and interest rates in Nigeria [9]. They used the co-integration and error correction model (ECM), impulse response function(IRF) and the variance decomposition(VDC) test. The study found a co-integration existing between Nigerian share prices and the selected macroeconomic variables. There was a long run relationship between stock prices and the macroeconomic variables. Also, the study found an insignificant negative relationship between the Nigerian Stocks Exchange and industrial production. The study recommended for resolutions of the emanating problems in the sector of energy generation and distribution hence anticipating in cost reduction of industrial production hence support investment in other sectors.

In addition, Olweny modeled the volatility of short-term interest rates in Kenya [10]. The study used GARCH model, ARCH models and the specifications of the Stochastic Differential Equation (SDE) to test the specification for the stochastic behavior. The study found the GARCH model as good for modeling short-rate volatilities compared to ARCH models. Further, the study established the characteristics of GARCH model on volatility clustering phenomena which is realized in many financial time series data. The study recommended the use of modified GARCH models such as EGARCH and FIGARCH to model financial time series data.

Lastly, Rousseau and Wachtel investigated the relationship between inflation, output and stock performance for the developing markets of Peru and Chile [1]. The study used a co-integration test and Barro regression model, which was a suitable empirical multivariate model in macroeconomic variables to study the effect of financial deepening on economic growth. The study found an association between the financial crises with the dampening of the impact on the growth of the financial. Further, extreme financial deepening or rapid credit growth might have caused both weakened banking systems and inflation hence causing financial crises to rise. The study also found a weak long run equilibrium between stock prices and general price levels. Additionally, the extensive financial liberalizations in the late 1980s and early 1990s in Peru and Chile might have led to excessive financial deepening due to poor legal or regulatory infrastructure that is necessary to conduct financial development successfully.

3. Methodology

A. Unit root test

Most macro-economic variables appear to be non-stationary and behave as random walks [11]. Therefore, they have to be differenced once in order to become stationary, which is represented as I (1). Notably, when a series need not be integrated so as to become stationary, it is represented as I(0) meaning it is integrated zero times to become stationary as illustrated below:

x level = x_t (1)

x 1st differencing = $x_t - x_{t-1}$ (2)

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x nth differencing = $x_t - x_{t-n}$ (3)

The study performed the Dickey-Fuller test for the series stationarity test as illustrated below [12]. Consider an AR(1) process;

$$\Delta x_t = (\rho - 1)\, x_{t-1} + \varepsilon_t \quad (4)$$

Where x_t is the time series of the stock price index, and ε_t is a sequence of interest rate and inflation rate, with $\mu=0$ and variance σ^2. The general dickey-fuller test has its hypothesis stated as follows:

H_0: $\rho = 1$ (unit root)

H_1: $\rho < 1$ (stationary)

B. Test for co-integration

Two series become cointegrated once they are integrated of the same order and are linearly combined hence giving a stationary series [13]. The study used the Johansen test to analyze any co-integration relationship between the series. As a result, the procedure applied two tests namely, the Maximum Eigenvalue test and Trace test and the number of the cointegrating equations. Through the Maximum Eigenvalue test, the null hypothesis is; there are r cointegrating equations against the alternative hypothesis states; that there are r+1 cointegrating equations. Similarly, through the Trace test; the null hypothesis is; there are r cointegrating equations against the alternative hypothesis that states; there are r+1 cointegrating equations.

The two test statistic are given as illustrated below:

$$LR_{max}(r/n+1) - (-T^*\log(1 - \hat{\lambda})) \quad (5)$$

$$LR_{trace}(r/n) - (-T^*\textstyle\sum \log(1 - \hat{\lambda})) \quad (6)$$

Where r = 0, 1, 2, …, n-1, T = number of observations, and λ = Maximum Eigenvalue.

The Trace test is usually preferred whenever its output gives different outcomes from the Maximum Eigenvalue test. An existence of cointegration between the time series prompt to a conclusion that there exists a long-run relationship.

C. Vector error correction (VEC) model

Vector Error Correction Model (VECM) is a special case of the vector autoregressive model for variables that attains stationarity upon their differencing and the variables are co-integrated. The model is used only if the series are co-integrated. The cointegration term is called the error correction term as the deviation from long-run equilibrium is corrected gradually in a series of partial short-run changes. The co-integration equation (Error Correction Model) is corrected steadily within a series of partial short-term changes.

The study used VECM to examine the existence of both short-run and long-run relationship between the selected macroeconomic variables as illustrated below:

$$\Delta y_t = \beta_0 + \sum_{i=1}^{n} \beta_i \Delta y_{t-i} + \sum_{i=o}^{n} \delta_i \Delta x_{t-i} + \varphi Z_{t-1} + \mu_t \quad (7)$$

Where y_t is the time series of the dependent variable, μ_t is innovations series, φ coefficient of ECT that show the speed adjustment, Z is the ECT and is the OLS residual from the long-run cointegration equation.

D. Diagnostics tests

1) Serial correlation test

For a good model, there should be no serial correction. This is determined using the p-value such that whenever the p-value is less than 5% significant level, we reject the null hypothesis in favor of the null hypothesis. If otherwise, we do not reject the null hypothesis. The study, in this case, used the P-value to test for the presence of serial correlation.

2) Dynamic stability test

The test examines whether the model is dynamically stable. For a dynamically stable model, the blue trend line where the model lay should be between the red lines which is discovered through inspection and hence concluding the model is good. If otherwise, the model is not good. In this study, a plot was used to reveal whether the model was dynamically stable.

E. Univariate GARCH model

A univariate GARCH model is introduced before elaborating further on a multivariate GARCH model. A GARCH model of orders p and q as defined by Bollerslev is given as [14]:

$$r_t = \mu + a_t \quad (8)$$

$$a_t = \sigma_t^2 \epsilon_t \quad (9)$$

$$\sigma_t^2 = \alpha_0 + \sum_{i=1}^{p} \alpha_i a_{t-i}^2 + \sum_{j=1}^{q} \beta_j \sigma_{t-j}^2 \quad (10)$$

Where r_t is the log return at a given time t, μ is the average return, a_t mean-corrected return of an asset at time t, σ_t^2 is conditional variance at time t, ϵ_t is standardized residual returns (i.e. iid random variable with mean $\mu = 0$ and $\sigma^2 = 1$), α and β are parameters and are such that $\alpha_0 > 0$, α_i, $\beta_j \geq 0$ and $\sum_{i=1}^{\max(p,q)} (\alpha_i + \beta_i) < 1$. The simplest model of the GARCH model specification is the GARCH (1,1) given as:

$$\sigma_t^2 = \alpha_0 + \alpha_1 \alpha_{t-1}^2 + \beta_1 \sigma_{t-1}^2 \quad (11)$$

Where $\alpha_0 > 0$, and $\alpha_1, \beta_1 \geq 0$, $\alpha_1 + \beta_1 < 1$

F. Model selection

The information criteria used for model selection are the AIC, BIC and HQC as illustrated below:

$$AIC = 2k - 2\log(L) = 2k - n\log(\frac{RSS}{n})$$

$$BIC = \log(\sigma_e^2) + \frac{k}{n}\log(n)$$

$$HQC = -2L_{\max} + 2k\log(\log(n))$$

Where k is the number of parameters, RSS is the residual sum of the square for the estimated model, n is the number of observations, σ_e^2 is the variance of residuals and $L_{\max}$ is the maximized log-likelihood value.

The model with the smallest value of the information criteria was considered.

G. Multivariate GARCH models

The use of multivariate model leads to better empirical models as compared to univariate models. It also leads to better decision tools in financial econometrics and prediction of the dependence in the co-movements of the asset [15].

1) Dynamic conditional correlation (DCC-) GARCH model

The model falls under the category of conditional variances and correlations models. The concept of (DCC-) GARCH was first introduced by Engle and Sheppard [16]. In this model, the covariance matrix H_t is decomposed into conditional standard deviations D_t and a correlation matrix R_t. Supposing that there are a_t returns from n assets with an $\mu = 0$ and covariance matrix H_t, then a Dynamic Conditional Correlation (DCC-) GARCH model is defined as:

$$r = u + a_t \quad (12)$$

$$a_t = H_t^{1/2} z_t \quad (13)$$

$$H_t = D_t R_t D_t \quad (14)$$

Where, r_t is $n \ x\ 1$ vector of log returns of n assets at time t,

a_t is $n \ x\ 1$ vector of mean-corrected returns of n assets at time t,

u_t is $n \ x\ 1$ vector of the expected value of the conditional r_t,

H_t is $n \ x\ n$ matrix of conditional variances at time t,

$H_t^{1/2}$ is any $n \ x\ n$ matrix at time t such that H_t is the conditional variance matrix of a_t,

D_t is $n \ x\ n$ diagonal matrix of conditional standard deviations of a_t at time t,

R_t is $n \ x\ n$ conditional correlation matrix of a_t at time t, and

z_t is $n \ x\ 1$ vector of iid errors such that $E[z_t] = 0$, and $E[z_t z^T] = I$

Therefore, R_t is decomposed to give $R_t = Q_t^{*-1} Q_t Q_t^{*-1}$ hence giving the correlation structure for the general DCC(M, N)-GARCH model as:

$$Q_t = (1 - \sum_{m=1}^{M} a_m - \sum_{n=1}^{N} b_n)\bar{Q}_t + \sum_{m=1}^{M} a_m a_{t-1} a_{t-1}^T + \sum_{n=1}^{N} b_n Q_{t-1} \quad (15)$$

The study used DCC-(1,1) GARCH model given as:

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$$Q_t = (1-a-b)\bar{Q}_t + a \in_{t-1}\in_{t-1}^T + b_n Q_{t-1} \quad (16)$$

Where,

$\bar{Q} = Cov(\in_t \in_t) = E(\in_t \in_t^T)$ is the unconditional covariance matrix of the standardized error $\in_t$, error $\in_t = D_t^{-1/2} a_t$, the parameters a and b are scalars, $\bar{Q}_t = E(\in_t \in_t^T)$ and Q_t^* is a diagonal matrix with the square root of the diagonal elements of Q_t. The diagonal $\bar{Q}$ is estimated as $\bar{Q} = \frac{1}{T}\sum_{t=1}^{T} \in_t \in_t^T$

2) Estimation of DCC-GARCH

The parameters are estimated using Quasi-Maximum Likelihood Estimator (QMLE) method, introduced by [17]. This vectors of the parameters are made of:

i. The $\alpha's$ and $\beta's$ which belong to the univariate GARCH model part, and

ii. The a and b parameters which belong to the correlation structure of the DCC-GARCH model.

Under the Gaussian assumption:

- the log-likelihood of the $\alpha's$ and $\beta's$ estimators is given as:

$$\ln(L(\alpha,\beta)) = \sum_{i=1}^{n}(-\frac{1}{2}\sum_{t=1}^{T}[\ln(h_{it}) + \frac{a_{it}}{h_{it}}] + const \quad (17)$$

Where h_{it} is the conditional variance for $i = 1,..., n$, and

- the log-likelihood of the a and b estimators is given as:

$$\ln(L(a,b)) = -\frac{1}{2}\sum_{t=1}^{T}(\ln(|R_t|) + \in_t^T R_t^{-1} \in_t) \quad (18)$$

3) Forecasting using DCC-GARCH

After the estimation of the model's parameters, the study proceeds to forecast the conditional covariance matrix $H_{t+k} = D_{t+k}R_{t+k}D_{t+k}$ at a time $t = t + k$ when the history up to time t is unknown.

4. Data description

The study used data from three variables namely: NSE 20 share index which was the variable of interest to indicate the stock price index, and the other variables were some selected macroeconomic variables affecting the stock price index namely: interest rate and inflation rate.

The data was collected on a monthly basis from June 2006 to June 2018. It was obtained from the Nairobi Stock Exchange (NSE) and Central Bank of Kenya (CBK). For the exchange rates, the currency was transformed into daily log returns as demonstrated by the formulae below:

$$R_t = \log(\frac{P_t}{P_{t-1}}) \quad (19)$$

5. Empirical result

A. Descriptive statistics

The results presented in Table 1 and Figure 1 shows the mean, median, standard deviation, skewness, and kurtosis as well as the time series plots for the three variable respectively.

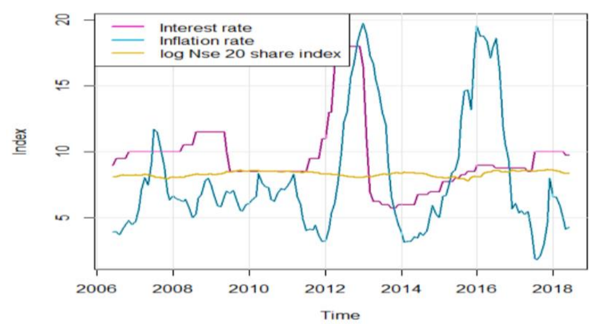

Fig. 1. Time series plots of the three variables

The results indicated that the NSE 20 share Index for the last 12 years was 4196.81 on average with a standard deviation of 784.06; hence, the market deviation varied over time.

Table 1
Descriptive statistics for the three series

	NSE 20 Share Index	Interest Rate	Inflation Rate
Mean	4196.81	9.53	7.98
Sd	784.06	2.67	4.52
Median	4143.35	9.00	6.55
Min	2474.75	5.75	1.85
Max	5774.27	18.00	19.72
Jarque bera	7.6949	138.27	38.457
Prob.	0.0213	0.0001	0.0001
N	145	145	145

Jarque Bera test indicated that the data was not normally distributed at 5% significance level just as most financial time series data do.

B. Stationary test

The results presented in Table 2 applied Augmented Dickey-Fuller (ADF) approach to test for stationarity of the three variables.

Table 2
Stationarity test for the three series

Variable	Level		Differenced	
	ADF Statistics	P-value	ADF Statistics	P-value
NSE 20 share Index	-2.6437	0.3084	-3.8839	0.01693
Interest Rate	-3.4380	0.05602	-4.0141	0.01056
Inflation Rate	-2.0599	0.2613	-6.2652	0.0001

The results illustrated that NSE 20 share index, interest rate and inflation rate were not stationary at level. However, they proofed stationary upon first differencing, i.e., I (1).

C. Lag selection

The results presented in table 3 show the AIC, SC and HQ lag order selection criteria.

Table 3
Lag Order Selection Criteria

Lag	AIC	BIC	HQC
0	0 26.67814	26.74118	26.70376
1	18.97670	19.22884	19.07916
2	18.63603*	19.07728*	18.81534*
3	18.69842	19.32877	18.95457
4	18.67301	19.49247	19.00601
5	18.67505	19.68361	19.08490

*indicates lag order selected by the criterion
The output showed that 2 lags were the optimal lag order selected for the study.

D. Johansen Cointegration Test

The study proceeded to test the cointegrating equations and the results for both the trace and maximum eigenvalue presented in Tables 4 and Table 5 respectively.

Table 4
Johansen cointegration test (Trace test)

Trace test				
Null hypothesis (H_0)	Eigenvalue	statistics	95% C.V	*p*
None *	0.130594	41.41938	29.79707	0.0015
At most 1 *	0.099652	21.54722	15.49471	0.0054
At most 2 *	0.045691	6.640988	3.841466	0.0100

Table 5
Johansen cointegration test (Maximum Eigenvalue)

Trace test				
Null hypothesis (H_0)	Eigenvalue	statistics	95% C.V	*p*
None *	0.130594	19.87216	21.13162	0.0443
At most 1 *	0.099652	14.90623	14.26460	0.0395
At most 2 *	0.045691	6.640988	3.841466	0.0100

*Denotes rejection of the hypothesis at 5% significance level
*Denotes rejection of the hypothesis at 5% significance level
The outcome showed that p-values in both cases were less than 5% significance level. Therefore, there were cointegrating equations indicating a long-run relationship between the stock price index as indicated by the NSE 20 share index, and both the interest rate and inflation rate.

E. Vector Error Correction model

The presence of a cointegrating equation (long-run model) resulted in a VEC model as given below:

$$ect_{t-1} = 1.000 Nse_{t-1} + -463.7898 \text{int}_{t-1} + 299.4817 \inf_{t-1} - 2201.316 \quad (20)$$

Where ect is the error correction term, Nse is the NSE 20 share index indicating stock price index, int is the interest rate and $\inf$ is the inflation rate.

Next, the estimated VEC model with the NSE 20 share index as the dependent variables are demonstrated in table 6.

Table 6
Parameter estimates of Vector Error Correction Model

	Coefficient	Std. Error	t-statistics	Prob.
CointEq1	-0.001114	0.013299	-4.362919	0.0000
nse (-1)	0.070714	0.086641	3.528687	0.0006
nse (-2)	0.138596	0.089461	2.549225	0.0237
int (-1)	19.90559	28.73258	0.692788	0.4896
int (-2)	-31.14121	29.51570	-1.055073	0.2933
inf (-1)	-40.26304	18.36778	-1.192047	0.1301
inf (-2)	14.66353	17.86849	0.820637	0.4133
C	2.212591	18.96747	0.116652	0.9073
R-squared				0.372575
Adjusted R-squared				0.339799
F-statistics				11.36734
P-value				0.000000
AIC				2.886710

The estimated VECM equation extracted from table 6 with the NSE 20 share index as the dependent variable was given as:

$$\Delta NSE_t = -0.001114 ect_{t-1} + 0.070714 NSE_{t-1} + 0.138596 NSE_{t-2} + 19.90559 \text{int}_{t-1} - 31.14121 \text{int}_{t-2} - 40.26304 \inf_{t-1} + 14.66353 \inf_{t-2} + 2.212591 \quad (21)$$

Where ect_{t-1} indicated the speed of adjustment.

The previous month's deviation from the long run equilibrium is corrected at a speed of 0.1114%. There was no relationship between the interest rate and inflation rates with stock price index in the short-run as shown by the p-values associated with the coefficients.

F. Diagnostic Tests

1) Serial Correlation

Table 7 applied Breusch-Godfrey Serial Correlation LM Test to test for serial correlation.

Table 7
Breusch-Godfrey Serial Correlation LM Test for the VECM

F-statistics	0.483786	Prob. F(2,132)	0.6175
Obs*R-squared	1.033299	Prob. Chi-Square(2)	0.5965

The results through a p-value greater than 5% significance level indicated that there was no serial correlation, and hence a good VEC model.

2) Model Dynamic Stability

Figure 2 was used to test the dynamic stability of the model. The plot indicated that the model was dynamically stable as the blue trend line lay within the red boundary.

G. Log returns

Figure 3 presented the log returns of the data, and figure 4 and 5 the distributions of monthly log-returns.

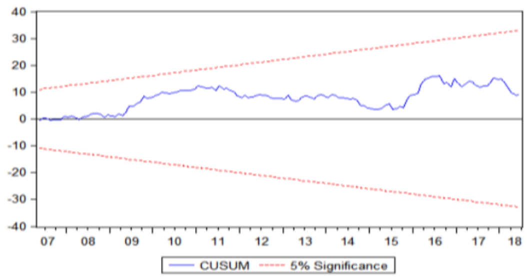

Fig. 2. Dynamic stability test for the VECM

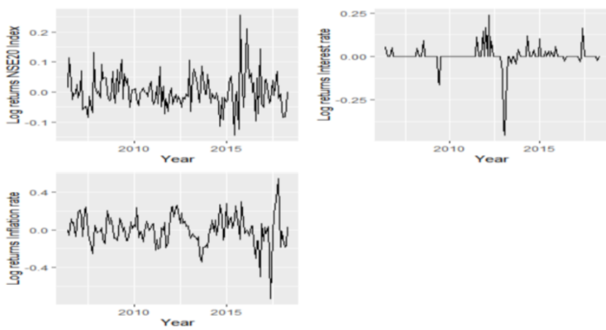

Fig. 3. Time plots of Monthly Log returns of the three series

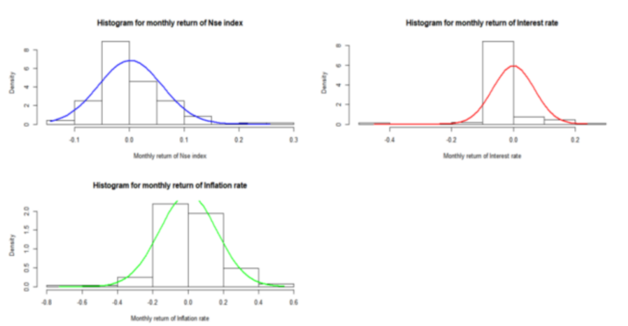

Fig. 4. Log returns plots of NSE 20 share index, inflation and interest rates

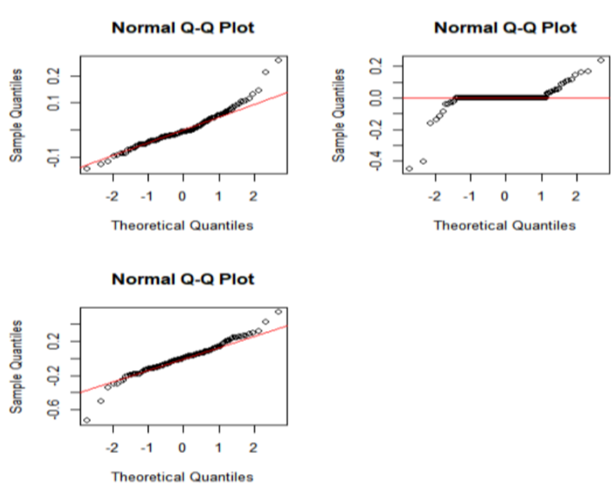

Fig. 5. Log returns plots of NSE 20 share index, inflation and interest rates

The log returns of stock price index as indicated by NSE 20 share index, the interest rate and inflation rate were stationary. The three variables were skewed with NSE 20 share index exhibiting positive skewness hence implying that it was not normally distributed.

H. Multivariate DCC-GARCH Model

logr1=log returns of NSE 20 share index, logr2=log returns of Interest rate and logr3=log returns of the inflation rate.

The results in Table 8 shows a joint significance of the coefficients alpha 1 and beta 1 for each series and joint significance of the conditional correlation coefficients dcca1 and dccb1. The findings for alpha 1 and beta 1 were jointly significant for each series indicating that GARCH (1,1) "make sense" for the given series. Similarly, dcca1 and dccb1 were jointly significant indicating that the DCC-GARCH model "makes sense" for the system of series. Therefore, the findings imply that the DCC-GARCH specification is valid for modeling the stock price index in the Nairobi Stock Market.
The output gives a Multivariate DCC (1,1)-GARCH as shown below:

$$Q_t = (1 - 0.0129080 - 0.6194270)\bar{Q} + 0.0129080\,\epsilon_{t-1}\epsilon_{t-1}^{T} + 0.6194270\,Q_{t-1} \quad (22)$$

I. Conditional Correlation Plots

Figure 6 presents a time series plots of the conditional correlation from June 2006 to June 2018.

Table 8
Parameter estimates of the DCC-GARCH Model

	Estimate	Std. Error	t value	Pr(>|t|)
[logr1]. mu	0.001161	0.005153	0.225394	0.821673
[logr1]. omega	0.000365	0.000223	1.635968	0.101846
[logr1]. alpha1	0.268467	0.120334	1.799994	0.011515
[logr1]. beta1	0.726459	0.114081	6.367918	0.000010
[logr2]. mu	0.010092	0.003954	2.552691	0.010689
[logr2]. omega	0.000923	0.000322	2.866273	0.004153
[logr2]. alpha1	0.824872	0.503670	2.637724	0.021479
[logr2]. beta1	0.174128	0.089360	1.948610	0.031342
[logr3]. mu	0.008789	0.013394	0.656179	0.511709
[logr3]. omega	0.012611	0.002967	4.251211	0.000021
[logr3]. alpha1	0.618787	0.248466	2.490427	0.012759
[logr3]. beta1	0.043686	0.018424	2.200034	0.041454
[Joint]dcca1	0.0120080	0.0230005	2.00452	0.019940
[Joint]dccb1	0.619427	0.136113	6.754869	0.000000
Akaike				-7.1314
Bayes				-6.7808
Shibata				-7.1556
Hannan-Quinn				-6.9890

The general indication from figure 6 is that the correlation between the NSE 20 share index and both the interest rate and inflation rate tends to have an upward trend across the twelve-year period. However, there are tendencies of declines in correlations particularly when there are crises in the economy, mostly observed in 2013 and 2017 during general elections.

J. Multivariate DCC-GARCH Forecast

Figure 7 and figure 8. shows (both in a separate and joined plot) correlation forecasts between NSE 20 share index and interest rate, NSE 20 share index and inflation rate, and interest rate and inflation rate. The prediction was set two-years ahead throughout the entire period.

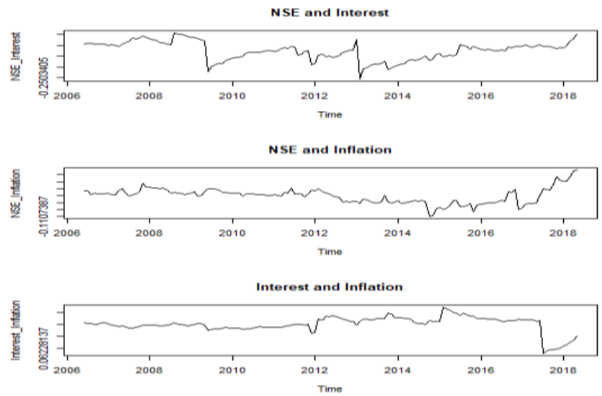

Fig. 6. Estimated dynamic conditional correlation of the three variables

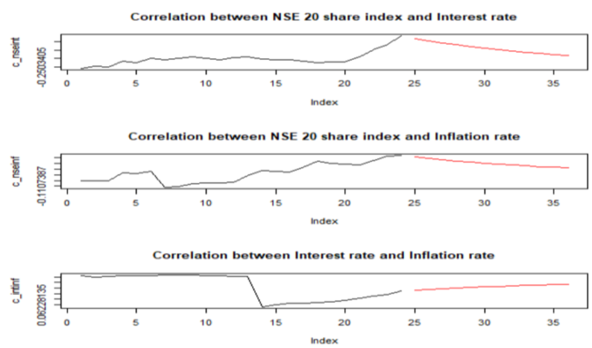

Fig. 7. Forecasts of dynamic conditional correlation of the three variable separately

The results of figure 7 indicated that there was an expected decrease in the strength of the correlation between the NSE 20 share index and both the inflation rate and interest rate in the long run. However, the correlation between the interest rate and the inflation rate is expected to rise. From figure 8, it can be observed that the DCC-GARCH forecasts seem to be stable.

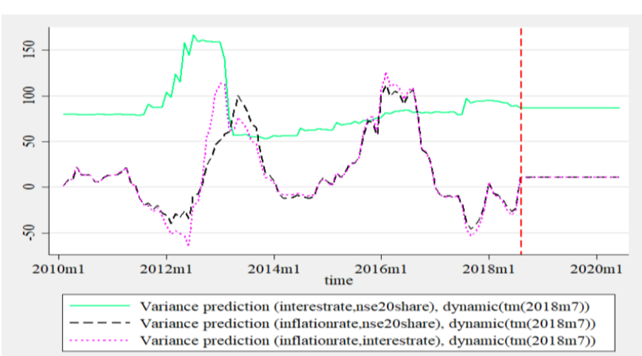

Fig. 8. Forecast of correlations among NSE20 share index, interest rate and inflation rate using the DCC-GARCH Model

6. Conclusion

The study aimed at modeling and forecasting the stock price index in the Nairobi stock market using a Multivariate framework. The first objective was to model short run and long run relationships between the Kenyan stock price index and both the interest rate and inflation rate. The Johansen cointegration test found a long run relationship between the stock price index and both the inflation rate and interest rate; however, there was no short run relationship. The second objective aimed at estimating the parameters of the multivariate GARCH model by fitting a DCC-GARCH model. The study found an upward trend in the correlation between the NSE 20 share index and both interest and inflation rates across the 12 years-period. There were declines found in times of economic crises such as in 2013 and 2017 during the general election. Finally, the third objective aimed at the forecast using the DCC-GARCH multivariate model. The study found an expected decline in the strength of the correlation between the stock price index and interest rate and inflation rate in the long run but the correlation between the interest rate and the inflation rate was expected to rise. Again, the forecast seemed stable. Generally, the use of VECM and DCC-GARCH models lead to better market decision making and understanding of financial co-movement among stock markets investors, market policy maker and government. Therefore, efforts should be put in place to reduce the interest rate through proper negotiations between the government and the banks to stabilize the inflation rate.

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