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Determinants of exchange rate volatility in Ghana: GARCH and VAR analyses

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In recent times, many developing economies have experienced volatility in their exchange rates which has been attributed to some factors or determinants and Ghana is no exception to this. This study examines the determinants of exchange rate volatility in Ghana using the GARCH models and vector autoregression (VAR) model based on quarterly dataset from 1990Q1-2022Q4. The study reveals the persistent existence of volatility in exchange rates in Ghana using the GARCH models. The study reveals that in the long run, money supply and FDI have positive effects on the exchange rate volatility while public debt, inflation, interest rate, and remittances have negative effects. In the short run, FDI, and remittances inflows have positive effects on the exchange rate volatility while inflation, interest rate, money supply, public debt, and the dummy variable have negative effects. In conclusion, exchange rate volatility is strongly influenced by the behaviour of macroeconomic variables in Ghana.

Keywords: exchange rate volatility, GARCH models, Vector Autoregression (VAR) model

It has been indicated in the economic literature that the exchange rate serves as a vital component in determining both short-run and long-run growth and development *(Olamide et al., 2022; Ehikioya, 2019)*. Thus, for the countries and their economies, the exchange rate has been crucial and has significant effects *(Fatima et al., 2022)*. It is undeniable that it plays a vital role in determining the competing strength of nations. Exchange rates, however, have become extraordinarily sensitive to even little changes in local or global conditions since several nations adopted flexible exchange rate regimes *(Fatima et al., 2022)*. For this reason, analysis of exchange rate volatility has become a major concern in recent times to both developed and developing countries due to its effects on economic activities *(Hung et al., 2022; Boateng et al., 2020; Alagidede–Ibrahim, 2017)*. According to *Bahmani-Oskooee and Hajilee (2013)*, the majority of large economies today use a floating exchange rate system, which naturally leads to currency fluctuations.

Moreover, Ghana still faces numerous economic challenges, one of which is the recent global financial crisis and the pandemic. These shocks have tremendously affected the economy, partly through the exchange rate market. The country's currency has been depreciating against the currencies of its trading partners until recently, when the Cedi gained some momentum, causing researchers to investigate further to examine the determinants of the exchange rate's volatility. It can be emphasised that the volatility of the exchange rate is influenced by various fundamental and technical factors *(Hung et al., 2022; Boateng et al., 2020; Zerihun et al., 2020; Ramli, 2020)*. Ghana's currency has experienced fluctuations against major currencies, impacting various sectors of the economy *(Essilfie, 2018)*.

Furthermore, the majority of these factors are explained by different exchange rate economic theories *(Zerihun et al., 2020)*. For instance, as cited by *Zerihun et al. (2020)*, the literature on the optimal currency area identifies trade openness and economic size as the two main long-term determinants of exchange rates *(McKinnon, 1963; Mundell, 1961)*. While the fundamental equilibrium theory recognizes the necessity of both internal and external balance in the economy *(Hausmann et al., 2001; Berger et al., 2000)*, the exchange misalignments literature, on the other hand, emphasises the significance of relative productivity *(Bhagwati, 1984; Balassa, 1964)*.

In general, certain exchange rates are more vulnerable to variations in these factors than others. Because of this, currencies are often classified as strong (highly appreciated or revalued) or weak (extremely depreciated or devalued) based on how susceptible they are to these influences *(Zerihun et al., 2020)*. Despite the concern for this phenomenon, limited studies have been done in this area, especially in the context of Ghana *(Mohammed et al., 2021; Boateng et al., 2020; Adjei, 2019; Alagidede–Ibrahim, 2017; Akumbobe, 2015)*, and this study tries to fill in the gap. This study contributes to the literature in many ways. First, understanding the determinants of exchange rate volatility in Ghana can help policymakers and central banks develop effective strategies to manage and stabilise the exchange rate, thereby promoting economic stability and growth. Second, examining the determinants of exchange rate volatility in Ghana, policymakers and businesses can gain insights into the factors influencing currency fluctuations, enabling them to make informed decisions and mitigate risk.

Third, by identifying the determinants of exchange rate volatility, policymakers and regulators can implement measures to enhance financial market stability and reduce systemic risks. Fourth, the study provides valuable insights into the interplay between the factors determining exchange rate volatility and exchange rate movements, allowing policymakers to design effective macroeconomic policies and promote sustainable economic growth. The rest of the study is organized as follows. Section 1 presents a literature review on the subject matter, section 2 presents the data and methods, section 3 indicates the results, section 4 presents the discussion concerning the results and section 5 presents the conclusion and policy recommendations.

1. Literature review

1.1 Theoretical underpinning

This section provides theories that underpin the current study. The study employs the purchasing power parity theory (PPP) to examine the exchange rate volatility in the context of Ghana. This is important to link the study to the existing literature. The purchasing power parity (PPP) theory is a concept that relates to exchange rate volatility and the determination of exchange rates. It suggests that in the long run, exchange rates should adjust to equalize the purchasing power of different currencies *(Rogoff, 1996)*. Thus, the theory is based on the idea that goods should have the same price when expressed in a common currency. According to the theory, if there is a persistent difference in the price levels between two countries, the exchange rate should adjust to reflect this difference *(Taylor 2003)*.

In other words, if one country has a higher inflation rate than another, its currency should depreciate to maintain parity in purchasing power. This adjustment is expected to occur over time as prices and inflation rates change. Concerning exchange rate volatility, the PPP theory implies that deviations from purchasing power parity can lead to fluctuations in exchange rates. Thus, if the actual exchange rate deviates from the rate implied by the PPP, there may be a tendency for the exchange rate to revert to the PPP-based equilibrium rate, resulting in volatility *(Krugman et al., 2014)*. However, it can be emphasized that PPP theory has limitations and may not hold perfectly in practice. For instance, factors such as market imperfections, transportation costs, trade barriers, and non-tradable goods can prevent immediate arbitrage and hinder the adjustment of exchange rates to PPP. Additionally, short-term factors such as investor sentiment, speculative activities, and macroeconomic shocks can lead to deviations from PPP and contribute to exchange rate volatility *(Isard, 2007)*.

Moreover, despite the limitations of PPP, it remains significant in examining exchange rate volatility. Thus, this is in the sense that it provides a benchmark for understanding long-run exchange rate movements and the link between relative price levels and exchange rates *(Krugman et al., 2014)*. Further, by examining deviations from PPP, policymakers can gain insights into the factors driving exchange rate volatility and assess whether exchange rates are overvalued or undervalued. Moreover, the PPP theory has implications for international trade, investment decisions, and policy formulation. It helps businesses and investors assess the relative competitiveness of different countries and make informed decisions based on the expected purchasing power of currencies. For policymakers, understanding the implications of PPP deviations can guide decisions related to monetary policy, trade policy, and exchange rate management.

1.2 Empirical review

This section tries to link the previous studies to the current study, which helps to shape its focus. Exchange rate volatility plays a crucial role in shaping the economic landscape of a country, affecting trade, investment, and overall macroeconomic stability. This literature review aims to provide a brief overview of the determinants of exchange rate volatility, specifically in the context of Ghana. By examining relevant studies, some relevant insights can be gained into the factors that influence exchange rate fluctuations in the country. Further, this study is integrated into the body of literature to provide it with a solid foundation for the purpose of shaping its focus. Moreover, some empirical studies have been conducted in this area of research, especially in the context of Ghana. However, studies are limited in this area of research.

Between 1981 and 2019, *Dung and Okereke (2022)* looked at factors influencing exchange rates in sub-Saharan African nations such as Sierra Leone, Ghana, The Gambia, Liberia, Nigeria, and Ghana. The data was analyzed for the study using Panel Least Square (PLS) estimate techniques in addition to descriptive statistics. The study found that in African sub-Saharan countries, particularly Anglophone West African countries, the exchange rate (EXCR) is depreciated by the following factors: terms of trade (TMTR), current account balance (CABL), inflation rate (INFL), and interest rate (INTR).

Exchange rate volatility clustering among a subset of WAMZ countries was examined by *Eregha et al. (2020)* for the years 1980–2016. The Maximum Likelihood Estimation Technique was used in conjunction with the univariate symmetric and asymmetric ARCH/GARCH modeling technique in this work. The study was carried out using a causal research approach, and the findings demonstrated that there is a leverage effect and that exchange rate volatility clustered in all of the nations.

Ramli (2020) used secondary data from the Central Bank of Indonesia from 2004 to 2015 to analyze currency rate volatility in Indonesia. Based on 143 data observations using GARCH 1.1, the study's conclusions showed that exchange rate volatility was negatively and strongly influenced by reserve assets, trade openness, and the stock market index. Additionally, productivity has a favorable and large impact on the volatility of exchange rates. In contrast, inflation was negatively but not substantially correlated with exchange rate volatility, while bank intervention had a positive but not statistically significant correlation.

Kilicarslan (2018) investigated the factors that contributed to Turkey's exchange rate volatility between 1974 and 2016. The study used the PP (Phillips-Perron test) unit root test and the Augmented Dickey–Fuller Test (ADF) to conduct the stationary analysis. Real effective exchange rate volatility was determined by the study using the GARCH model and the Johansen cointegration test. The FMOLS approach was used for estimation. The investigation revealed a long-term association between the analysis's variables. The FMOLS results showed that while real effective exchange rate volatility is reduced by rising foreign direct investment, production, and government spending, it is increased by rising domestic investment, money supply, and trade openness.

Enu (2017) employed time series data to identify the critical factors behind Ghana's periodic depreciation of its currency between 1980 and 2015. Stepwise Regression, Backward Elimination, and the natural logarithm were used to scale the data. The study's conclusions showed that during the years under consideration, exports, industrial output, services output, and agricultural output were the variables that had the biggest impact on the Ghana Cedi's exchange rate against the US dollar.

Three African Economies including South Africa, Nigeria, and Ghana had their series of exchange rate returns simulated by *Ajibola et al. (2017)* between 2002 and 2015. Here, to investigate the fundamental characteristics of these developing FOREX markets, the analysis took into account seasonal breaks under the premise of a student-t distribution. The three markets were found to have serial correlations and significant tails. Because of this, the study used a battery of GARCH models to simulate these properties. As a result, it was found that the three markets exhibit volatility clustering, January effects, and both GARCH and ARCH effects. Leverage effects, however, are supported by the EGARCH but rejected by the GJR model.

Using monthly exchange rate data from 1990 to 2013, *Akumbobe (2015)* investigated exchange rate volatility using GARCH models. The exchange rate volatility was modelled in the study using a basic rate of return. Both symmetric and asymmetric models that represent the most widely used stylized facts about returns, like volatility persistence and leverage effect, were included in the models.

EGARCH (2, 2) was found to be the overall best-fitted model by the results. Different diagnostic tests of the model residuals using the ARCH-LM test, the Ljung–Box test, and the ACF plots showed that the models are independent of conditional heteroscedasticity and higher-order autocorrelation. The research also demonstrated that leverage effects do not exist and that volatility persists.

Russ (2012) looked into the dynamic relationships between FDI inflows and exchange rate volatility for 28 OECD nations between 1980 and 2005. Panel data analysis with the OLS, FGLS, and GMM approaches was used in the study. The findings demonstrated that the impact of exchange rate risk on the admission of both new and seasoned foreign enterprises differed depending on whether domestic or foreign interest volatility was higher. Exchange rate volatility and interest rate volatility from the source and host countries correlated positively.

2. Methodology

This section presents the methodology for carrying out the study. This involves the data and source of data, the statistical tool employed, and the specification of the model.

2.1 Data and methods

The study used time series quarterly data spanning from 1990Q1 to 2022Q4. All the data used were extracted from secondary sources. Data on the dependent variable; exchange rate and independent variables, relative inflation rate, interest rate, money supply, foreign direct investment inflows, public debt, and remittances inflows were extracted from the World Bank World Development Indicators (WDI) and database of the central bank of Ghana from1990 to 2022. These variables were selected based on the body of literature *(Dung–Okereke, 2022; Eregha et al., 2020; Ramli, 2020; Kilicarslan, 2018)*. The study employed the Vector Autoregressive (VAR) model to analyze the variables understudy. The measurements of the variables are presented in Table 3. In terms of the estimation procedure, the study starts by inspecting the time series properties of the variables based on the aforementioned tests, of which the results are presented in Table 1. The volatility of the exchange rate was examined using the GARCH models and the cointegration and short-run dynamics were done using the VAR and Vector Error Correction Model (VECM).

2.2 Theoretical model

This paper tries to analyze the determinants of the exchange rate volatility in Ghana. Exchange rate volatility is defined as the persistent fluctuation of a currency rate *(Alagidede–Ibrahim, 2017)*. To examine the determinants of the volatility of the exchange rate, following *Hung et al. (2022), Boateng et al. (2020), Eregha et al. (2020), Alagidede and Ibrahim (2017)*, the following theoretical model can be developed:

$$EXR\_VOL_t = \beta_0 + \beta_1 INF_t + \beta_2 INT_t + \beta_3 MS_t + \beta_4 FDI_t + \beta_5 PD_t + \beta_6 RMT_t + \\ +\beta_7\ Dummy\_SB_t + \varepsilon_t \quad (1)$$

where EXR_VOL_t is the exchange rate volatility at time t, INF_t is the relative inflation rate at time t, INT_t is the interest rate at time t, MS_t is the money supply at time t, FDI_t is the foreign direct investment inflows at time t, PD_t is the public debt at time t, RMT_t is the remittances inflows at time t and $Dummy\_SB_t$ is a dummy variable representing a shock to the series (1 = a shock; 0 otherwise). ε_t is the error term, at time t, β_0 is the constant term, $\beta_1 ... \beta_7$ are the parameters to be determined and t is the time period.

Apriori expected signs of the variables

β_1<0, β_2<0, β_3<0, β_4>0, β_5<0, β_6 >0 and β_7>0, <0

The above signs are based on the standard literature indicating the effects independent or exogenous variables (inflation rate, interest rate, money supply, foreign direct investment, public debt, remittances inflows, and the dummy variable) have on the dependent variable (exchange rate volatility). These variables (exogenous variables) were further analyzed to determine their significance on the exchange rate using the Vector Autoregression (VAR) model. Also, the volatility of the exchange rate was determined using GARCH models. Thus, Different GARCH models were fitted to the data to analyze patterns of volatility persistence, following *Cappiello et al. (2006)* and *Kiss (2023)*. Here, in the study, the applied GARCH(p,q), GJR GARCH(p,o,q), TARCH(p,o,q), and APARCH(p,o,q) (1–5) models were useful to capture volatility developments and their clustering in time (heteroscedasticity) *(Kiss, 2023*). The measurements of the variables understudy are presented in Table 1.

Table 1

Measurement of variables and source of data

Variable	Explanation	Data source
Exchange rate	This is measured using the log of the real effective exchange rates.	World Development Indicators 1990–2022
Inflation	Measured as using the consumer price index (Annual percentage).	World Development Indicators 1990–2022
Money supply	This is measured using the broad money as a percentage of GDP.	World Development Indicators 1990–2022
Interest rate	This is the interest rate differential measured as the difference between domestic and foreign rates	World Development Indicators and Central Bank' Database 1990–2022
Foreign direct investment	This is measured using the FDI inflows as a percentage of GDP.	World Development Indicators 1990–2022
Public debt	This is measured as the public debt as a percentage of GDP.	World Development Indicators 1990–2022
Remittances	This is measured using remittances inflows as a percentage of GDP.	World Development Indicators 1990–2022

Source: author's computation.

2.3 GARCH models

To determine the volatility of the exchange rate, the GARCH models are employed. The following are the representations of the models:

GARCH (p,q): $\sigma_t^2 = \omega + \sum_{i=1}^{p} \alpha_i \, \varepsilon_{t-i}^2 + \sum_{j=1}^{q} \beta_i \, \sigma_{t-j}^2.$ (2)

where σ_t^2 represents present variance, ω is a constant term, p denotes the lag number of squared past ε_{t-i}^2 innovations with α_i parameters, while q denotes the lag number of past σ_{t-j}^2.variances with β_i parameters to represent volatility persistence. Here, asymmetric GARCH models can be introduced through the following conditions *(Kiss, 2023)*:

$\begin{cases} S_{t-i}^- = 1, if \, \varepsilon_{t-i} < 0 \\ S_{t-i}^- = 0, if \, \varepsilon_{t-i} \geq 0 \end{cases}$ as a sign asymmetric reaction to decreasing returns. (3)

GJR GARCH (p,o,q): $\sigma_t = \omega + \sum_{i=1}^{p} \alpha_i |\varepsilon_{t-i}| + \sum_{i=1}^{o} \gamma_i S_{t-i}^- \, |\varepsilon_{t-i}| + \sum_{j=1}^{q} \beta_i \, \sigma_{t-j},$ (4)

Under the GARCH analysis, model, the selection was made with a focus on homoscedastic residuals (using a 2-lagged ARCH-LM test), searching for the lowest Alkaike Information Criterion and Bayesian Information Criteria (BIC).

2.4 VAR model

The Vector autoregressive (VAR) processes can describe the data generation process of a small set of time series variables, where all of them are treated as being a priori endogenous, and allowance is made for rich dynamics *(Kiss, 2023)*. This procedure captures the dynamic interactions for a set of K time series variables $y_t = (y_{1t}, \dots, y_{Kt})'$. Based on this and following *Lütkepohl and Krätzig (2004)*, the basic model of order p VAR can be specified as:

$$Y_t = \emptyset + A_1 Y_{t-1} + \dots A_p Y_{t-p} + u_t \quad (5)$$

where Y_t is a (K*1) vector of endogenous variables, $\emptyset$ is a (K*1) vectors of intercepts, A_p are the (K*K) fixed VAR coefficients matrices and u_t = (u_{1t}, …, u_{kt}), is an unobserved error term, with the properties:

E [u_t] = 0 and E [$u_t u_t$] = $\sum_u$(time invariant variance-covariance matrix)

E [$u_t u_s$] = 0, $\forall_t$ ≠ s. It is to be noted that, K is the number of variables.

Given the trending properties of the time series, the study employs the information criteria to select the lag length of the VAR, including a constant and a deterministic trend. The study selects the lag length based on the Akaike Information Criterion (AIC) and Schwartz Bayesian Criterion (SBC).

3. Results

This section presents the results of the study. It begins with the basic statistics, followed by unit root test, the GARCH analysis to determine the volatility of the exchange rate, then the regression results.

3.1 Basic statistics

This section first presents the basic statistics (in levels) of the variables understudy. This was done by inspecting the basic properties of the variables using graphs. Figures A1 to A7 depict the results in relation to the nature of the variables which are found in Appendix. The results indicate that the variables are not stable within the chosen period. Thus, the variables have trends, making their means different from zero and with large variability (standard deviation). However, the variables were differenced lower the conditional variance and the results are indicated by Figures A8 to A14 in Appendix. To be able to clearly examine the basic statistical properties of the variables understudy, the study uses the following: moments, Jarque–Bera test, Ljung–Box test, ARCH-LM test, and ADF test and the results are presented in Table 2.

Table 2

Basic statistics

Test	EXR_VOL	INF	INT	MS	FDI	PD	RMT	Dummy_SB
Mean (p=0)	–0.543	–0.002	0.025	–0.220	–0.059	0.117	0.005	0.048
Std. Dev.	2.590	0.011	0.374	3.396	1.088	0.761	0.246	0.440
Skewness	–0.921	–0.928	0.034	0.749	–1.020	–1.503	–1.375	1.289
Kurtosis	3.540	3.846	3.366	4.646	5.202	5.714	9.227	9.201
Jarque–Bera test (p>0.05)	0.004	0.003	0.500	0.002	0.001	0.001	0.001	0.001
Ljung–Box test (p>0.05)	0.021	0.982	0.279	0	0	0	0	0
ARCH-LM test (p>0.05)	0.163	0.991	0.000	0	0	0	0	0
ADF test (p<0.05)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Source: author's computation.

From Table 2, it can be shown that some of the variables such as interest rate, public debt, remittances as well as the dummy variable have their means close to zero while others have negative values. The standard deviation shows quite small variability of the data. In terms of skewness, the majority of the variables have negative values, indicating there are extreme values to the left of the distribution of the data (the values were decreasing), whereas two have positive values indicating a few to the right of the distribution. Thus, the data is symmetric. In terms of kurtosis, it can be seen that the data-generating process is not normally distributed, so the kurtosis>3, i.e., "leptokurtic", due to the presence of extreme values. With the Jargue–Bera test (normal distribution test), only the interest rate variable (0.500) passed the test with $p > 0.05$, all the rest did not pass the test since the data is not normally distributed. In the case of Ljung–Box test (autocorrelation test), only inflation and interest rate passed the test, the rest did not. Regarding the ARCH-LM test (heteroskedasticity test), only exchange rate and inflation (0.163, 0.991) passed the test, the rest did not. Finally, for ADF test (weak stationarity), all the variables passed the test. This is after the differencing of the variables.

The next section presents the result of the GARCH models and the model selection was based on the AIC as seen in Table 3.

Table 3

Selection of the best model

Model	AIC	(LL)
1. GARCH (1,1)	520.893	–258.446
2. GJR GARCH (1,1,1)	521.138	–257.569
3. GJR GARCH (2,1,2)	494.969	–242.485

Source: author's computation.

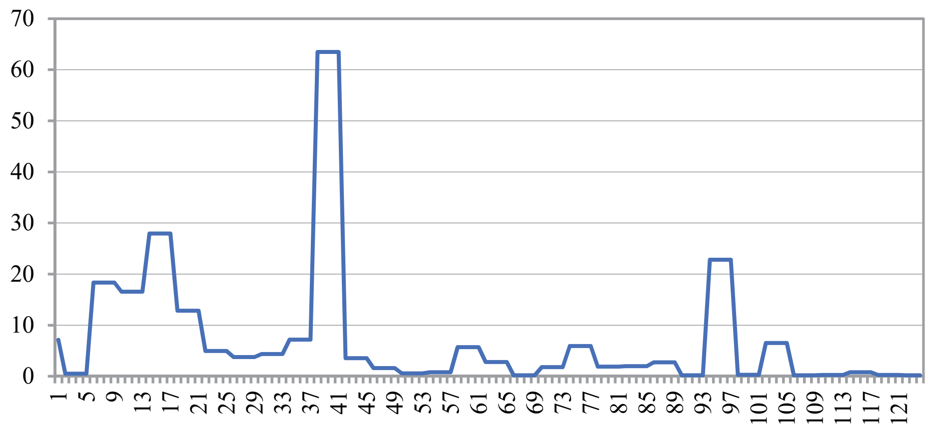
From Table 3, it can be concluded that the best fitting model to the data is model 3, GJR GARCH (2,1,2), since it has the smallest AIC (494.969). This indicates that volatility increases if the exchange rate depreciates in Ghana. The result is consistent with the finding by *Mohammed et al. (2021),* who found the exchange rate to be volatile in the case of Ghana. The parameters under this model are:

$$EXR\_VOL = 0.179369639643158 + 0.999799998139928 - 1.40052630381859e{-}07 + 7.30867113083241e{-}09 + 5.11453143719409 - 0.759667663045595 \quad (6)$$

The conditional variance (ht) associated with the GJR GARCH (2,1,2) model is depicted in Figure 1.

Figure 1

Conditional variance (ht) of the predicted variable



Source: author's computation.

Moreover, Figure 1 indicates that there is an asymmetry in the model. Thus, volatility increases if the exchange rate depreciates in Ghana. The data indicated some sort of extreme values and for that matter, some exogenous shock (Dummy

Variable-Dummy_SB) has been introduced in the model as seen in equation 1, which will help check that. This will feature later in the main analysis of the study.

3.2 Regression results

This section presents the results based on the objective of the study. To be able to apply the VAR model, the stationarity properties of the variables were inspected using the Augmented Dickey-Fuller unit root test and the results are presented in Table 3. From Table 3, it can be shown that the variables were non-stationary in levels except inflation. However, they became stationary after differencing them.

3.3 Unit root test

This section presents the results of the Augmented Dickey-Fuller test (ADF) based on the null hypothesis that the variables have a unit root as against the alternative hypothesis that the variables are stationary. The test was done using only the constant and the results are presented in Table 4.

Table 4

Results of ADF test

Variable	At constant		
	level	1st diff.	conclusion
EXR_VOL	–2.518 (0.114)	–4.132 (0.001)***	I (1)
INF	–3.071 (0.032)**	–	I (0)
INT	–1.571 (0.494)	–7.82609 (0.000)***	I (1)
MS	–2.508 (0.116)	–7.169 (0.000)***	I (1)
FDI	–2.181 (0.214)	–3.27555 (0.018)**	I (1)
PDT	–1.655 (0.452)	–7.116 (0.000)***	I (1)
RMT	–0.438(0.898)	–8.782(0.000)***	I (1)

Note: ** < 0.05; *** < 0.01.
Source: author's computation.

Based on the unit root test, the Vector Autoregressive (VAR) was used to determine the optimal lag length for the Johansen cointegration test, which is based on the AIC, as shown in Table 5. From the results, the optimal lag length based on AIC is 6. Using the selected optimal lag length of 6, the likelihood ratio test, which depends on the maximum eigenvalues of the stochastic matrix of the *Johansen (1991)* procedure for exploring the number of cointegrating was applied.

Table 5

Selection of optimal lag

Lag	LogL	LR	FPE	AIC	SC	HQ
0	–1509.255	NA	479.827	26.039	26.369	26.173
1	–161.717	2487.761	1.10E–07	3.841	5.329	4.445
2	125.423	495.745	1.90E–09	–0.229	2.415*	0.844
3	138.327	20.737	3.60E–09	0.388	4.189	1.931
4	166.956	42.575	5.34E–09	0.736	5.694	2.749
5	313.806	200.822	1.08E–09	–0.937	5.178	1.546
6	465.619	189.441*	2.09e–10*	–2.694*	4.577	0.258*
7	486.364	23.405	4.00E–10	–2.211	6.217	1.210
8	529.300	43.303	5.60E–10	–2.108	7.477	1.784

Note: * is the sign for optimal lag selection.
Source: author's computation.

Thus, with the selected optimal lag of 6, the likelihood ratio test results are presented in Tables 6 and 7. The results show the cointegration test, which helps to deduce whether there are cointegrating relationships among the variables. For instance, from Table 6, on the one hand, the Trace statistics indicate that there are five (5) cointegrating vectors at 5% level of significance. Here, the null hypothesis of zero cointegrating vectors is rejected against the alternative of one cointegrating vector. Therefore, the conclusion is that there are five cointegrating vectors specified in the model.

Table 6

Unrestricted cointegration rank test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace statistic	0.05 critical value	Prob.**
None*	0.594	332.059	159.530	0.000
At most 1*	0.519	223.835	125.615	0.000
At most 2*	0.325	136.116	95.754	0.000
At most 3*	0.278	88.961	69.819	0.000
At most 4*	0.182	49.943	47.856	0.031
At most 5	0.144	25.908	29.797	0.132
At most 6	0.058	7.215	15.495	0.553
At most 7	0.000	0.016	3.841	0.900

* Denotes rejection of the hypothesis at the 0.05 level.
** *MacKinnon et al. (1999)* p-values.
Note: Trace test indicates 5 cointegrating eqn(s) at the 0.05 level.
Source: author's computation.

On the other hand, as seen in Table 7, the Maximum Eigenvalue statistics depicted that there are four (4) cointegrating vectors at 5% level of significance.

The null hypothesis of zero cointegrating vectors is also rejected against the alternative of one cointegrating vector. Therefore, here too, it can be concluded that there are four cointegrating vectors specified in the model.

Table 7

Unrestricted cointegration rank test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen statistic	0.05 critical value	Prob.**
None*	0.594	108.224	52.363	0.000
At most 1*	0.519	87.719	46.231	0.000
At most 2*	0.325	47.154	40.078	0.007
At most 3*	0.278	39.018	33.877	0.011
At most 4*	0.182	24.035	27.584	0.134
At most 5	0.144	18.693	21.132	0.106
At most 6	0.058	7.200	14.265	0.466
At most 7	0.000	0.016	3.841	0.900

* Denotes rejection of the hypothesis at the 0.05 level.
** *MacKinnon et al. (1999)* p-values.
Note: Trace test indicates 5 cointegrating eqn(s) at the 0.05 level.
Source: author's computation.

Regarding the above cointegrating relationships, the equation below (equation 7) shows the results of the coefficient of β matrices in terms of the normalized cointegrating coefficient of the first equation. The results are based on the Trace test. The reason for this is that the Trace test provided the expected results. Moreover, these results indicate the long-run relationship among the variables understudy. From equation 6, it can be said that all the variables examined turned out to be significant and have their expected signs, with the exception of money supply and remittances inflows, which turned out to have different signs. Thus, inflation had a negative influence on the exchange rate and it is significant, indicating that a unit increase in the inflation rate will reduce the exchange rate by 0.4% in the long run, holding all other factors constant.

Interest rate is also significant and had a negative influence on the exchange rate, indicating a unit decrease in local interest rate relative to foreign interest rate will depreciate the exchange rate by 0.5%, holding all other factors constant. Moreover, money supply had a positive and significant influence on the exchange rate in the long-run, showing that a unit increase in money supply will increase the exchange rate (appreciation of the local currency) by 0.7%, holding all other factors constant. Further, foreign direct investment was positive and significant, indicating that a unit increase in FDI inflows in Ghana will increase the exchange rate by 0.3% in the long-run, holding all other factors constant.

$$\begin{aligned} \text{EXR\_VOL} = {} & 0.004^*\text{INF} + 0.005^*\text{INT} - 0.007^*\text{MS} - 0.003^*\text{FDI} + 0.017^*\text{PDT} \\ & (0.001) \quad (0.002) \quad (0.001) \quad (0.003) \quad (0.007) \\ & [4.000] \quad [2.500] \quad [7.000] \quad [1.000] \quad [2.429] \\ & + 0.028^*\text{RMT} \\ & (0.003) \\ & [9.333] \end{aligned} \tag{7}$$

In addition, public debt was also negative and had a significant influence on the exchange rate. This indicates that a unit increase in the country's public debt will reduce the exchange rate by 1.7% in the long-run, holding all other factors constant. Finally, remittances inflows had a negative and significant influence on the exchange rate, indicating that, in the long run, a unit increase in remittances inflows will increase the exchange rate by 2.8%, holding all other factors constant. The results indicate that the variables understudy are significant in determining the volatility of the exchange rate in Ghana.

Furthermore, the short-run dynamics among the variables are explored by using the vector error correction (VECM) and the results are presented in Table 8. The short-run dynamics among the variables are explored by employing the vector error correction model (VECM). Thus, the error correction model allows the introduction of previous disequilibrium as independent variables in the dynamic behaviour of existing variables. In addition, the VECM associates the changes in the exchange rate with the changes in the other lagged variables and the disturbance term of lagged periods. In the first place, they performed some diagnostic or post-estimation tests to validate the results for interpretation. The adjusted R^2 is 66%, indicating that 66% of the variations in the exchange rate were explained by the model and the rest was explained by other factors not included in the model. The coefficient of the speed of adjustment (i.e. ECM (–1)) is negative and significant at 1%. Its estimated coefficient is –0.017 (significant at 1%), indicating that in the absence of changes in the independent variables, deviation of the model from the long-term path is corrected by 2% per quarter. The short-run results further indicate that the first lag of the first difference of LNRGDP exerts a significant and positive effect on the current value exchange rate (appreciation of the local currency).

Table 8

Results of the vector error correction model

Variable	Error correction: D(EXR_VOL)		
	coefficient	standard error	t-statistic
Constant	0.002	–0.001	2.000**
D(EXR_VOL(-1))	0.704	0.169	4.166***
D(INF(-1))	–0.009	–0.0008	–11.250***
D(INT(-4))	–0.004	–0.002	–2.000**
D(MS(-4))	–0.005	–0.002	–2.500***
D(FDI(-2))	0.016	0.005	3.200***
D(PDT(-4))	–0.021	–0.007	–3.000***
D(RMT(-4))	0.005	0.003	1.667**
Dummy_SB	–0.005	–0.002	–2.500***
ECM(-1)	–0.017	–0.004	–4.250***
R-squared	0.787		
Akaike AIC	–6.876		
Adj. R-squared	0.658		
Schwarz SC	–5.819		
F-statistic	6.116***		
Sum sq. resid.	2.039		
Mean dependent	–0.002		
Log likelihood	450.659		
Sum sq. resids.	0.003		
Durbin-Watson stat	2.014		
S.E. equation	0.007		
S.D. dependent	0.011		

Note: *** denote 1% significance level; ** denote 5% significance level.
Source: author's computation.

Additionally, all the variables are significant in their lags. For instance, the past one year of inflation was negative and had a significant influence on the fluctuations of the exchange rate at 1% significance level, indicating that a unit increase in the first lag of inflation will decrease the exchange rate by 0.9%, holding all other factors constant. Also, the past four years' interest rate had a negative and significant influence on the exchange rate at 5% significance level. This suggests that a unit increase in the past four years of interest rate will decrease the exchange rate in Ghana by 0.4%, holding all other factors constant. The past four years of Money supply turned out to have a negative and significant influence on the exchange rate, indicating that a unit increase in the past four years' money supply will decrease the exchange rate by 0.5% in the short run, holding all other factors constant. Interestingly, money supply had a positive influence on the exchange rate in the long run and now turns out to have a negative effect on the exchange rate.

Moreover, the past two years of FDI had a positive and significant influence on the exchange rate, suggesting that a unit increase in the two years of FDI will increase the exchange rate (appreciation of the local currency) by 1.6% in the short run, holding all other things constant. Public debt is also negative and significant in determining exchange rate volatility in Ghana. Thus, a unit increase in the past four years of public debt will decrease the exchange rate by 2.1% in the short run, holding all other factors constant. Further, the past four years of remittances inflows into Ghana had a positive and significant influence on the exchange rate, indicating that a unit increase in the past four years of remittances inflows will increase the exchange rate by 0.5% in the short-run, holding all other factors constant. Finally, the dummy variable representing the shocks to the exchange rate was negative and significant in influencing the fluctuations of the exchange rate at 1% significance level.

The diagnostic tests, such as normality test (Jarque–Bera test), skewness, kurtosis and autocorrelation test in relation to the VAR estimation are reported in Tables 8 and 9 below:

For instance, in Table 9, for the skewness test, the joint p-value (0.000) did satisfy the condition. In the case of kurtosis, the joint p-value was 0.000, which is less than 3. This may be due to some outliers. The normality test (Jarque–Bera test), did not satisfy the condition ($p > 0.05$). Some of the variables had their p-values being greater than 0.05 (3, 4 and 7), others were not. However, for the autocorrelation test in Table 10, some of the variables had their p-values being greater than 0.05 (3, 4 and 7), others were not. This once again may be due to outliers, nevertheless, the dummy variable was included in the model to cater for the outliers.

VAR residual normality tests orthogonalization: Cholesky (Lutkepohl)

Table 9

Diagnostics tests

Component	Skewness	Chi-sq	df	Prob.*
1	1.154	27.322	1	0.000
2	1.216	30.334	1	0.000
3	–0.083	0.143	1	0.706
4	0.038	0.030	1	0.863
5	–0.794	12.927	1	0.000
6	–0.441	3.994	1	0.046
7	–0.030	0.018	1	0.893
Joint		74.767	7	0.000
Component	Kurtosis	Chi–sq	df	Prob.
1	9.129	192.522	1	0.000
2	9.073	189.010	1	0.000
3	5.890	42.790	1	0.000
4	8.278	142.778	1	0.000
5	7.359	97.376	1	0.000
6	7.478	102.762	1	0.000
7	17.940	1143.92	1	0.000
Joint		1911.158	7	0.000
Component	Jarque–Bera		df	Prob.
1	219.844		2	0.000
2	219.344		2	0.000
3	42.933		2	0.000
4	142.808		2	0.000
5	110.303		2	0.000
6	106.756		2	0.000
7	1143.938		2	0.000
Joint	1985.925		14	0.000

Note: * is the significance levels (p-values).
Source: author’s computation.

VAR residual serial correlation LM tests

Table 10

Diagnostics tests

Lag	LRE* stat	df	Prob.	Rao F-stat	df	Prob.
Null hypothesis: No serial correlation at lag h						
1	27.119	49	0.995	0.536	(49, 319.2)	0.995
2	24.010	49	0.999	0.473	(49, 319.2)	0.999
3	46.723	49	0.566	0.952	(49, 319.2)	0.569
4	274.240	49	0.000	7.987	(49, 319.2)	0.000
5	27.988	49	0.993	0.554	(49, 319.2)	0.993
6	14.965	49	1.000	0.291	(49, 319.2)	1.000
7	18.821	49	1.000	0.368	(49, 319.2)	1.000
Null hypothesis: No serial correlation at lags 1 to h						
1	27.119	49	0.995	0.536	(49, 319.2)	0.995
2	68.167	98	0.991	0.668	(98, 356.8)	0.991
3	209.393	147	0.000	1.532	(147, 331.3)	0.000
4	357.612	196	0.000	2.247	(196, 291.2)	0.000
5	395.368	245	0.000	1.940	(245, 246.4)	0.000
6	425.965	294	0.000	1.650	(294, 199.7)	0.000
7	604.761	343	0.000	2.447	(343, 152.1)	0.000

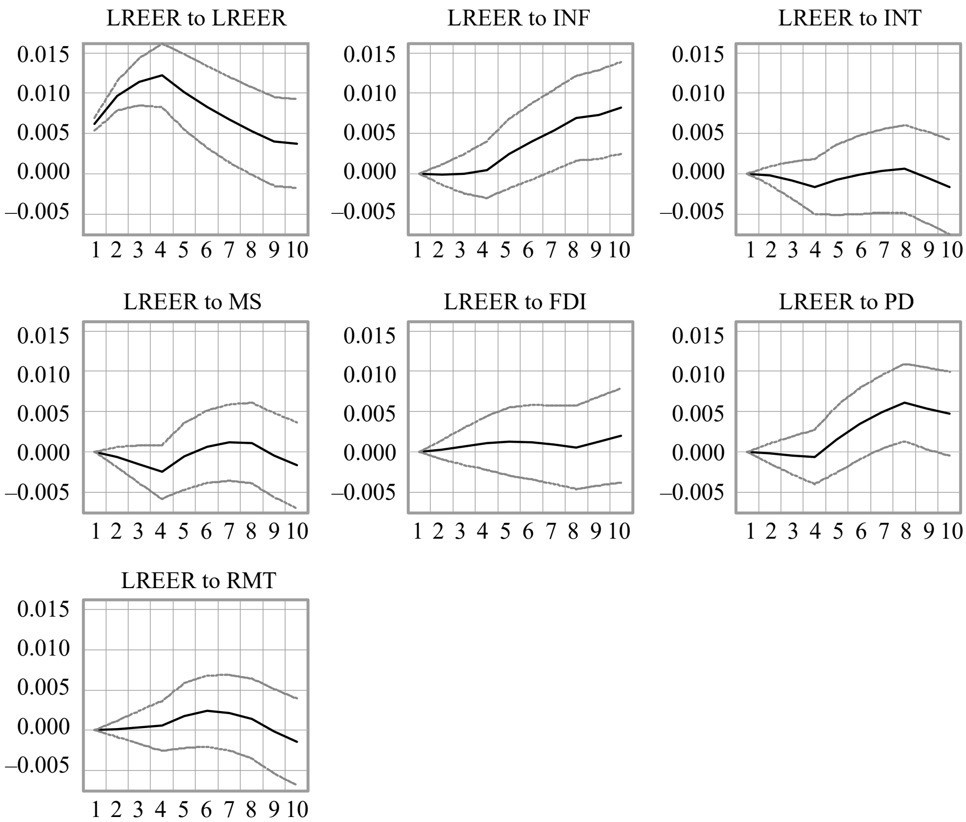
* Edgeworth expansion corrected likelihood ratio statistic.
Source: author's computation.

3.4 Stability tests

This section presents the stability tests to confirm the cointegration analysis as a robustness check, since it merely establishes the existence of long-run relationships among variables but does not fully establish the stability of such relationships, especially in the occurrence of a shock to the system. The study employed the impulse response function and variance decomposition to examine how the exchange rate responds to shocks in the system variables. Here, Figure 2 contains the impulse response functions, while Table 11 presents the Forecast Error Variance Decomposition. From Figure 2, it can be shown that, exchange rate has a positive effect from its own shock from the 1st quarter to the 10th quarter since the mean is within the standard errors' critical bounds. Also, a sudden shock to inflation leads to a sharp increase (positive effect) in exchange rate volatility from the 7th quarter to the 10th quarter. In addition, a sudden shock to public debt leads to an increase (positive effect) in exchange rate volatility from the 7th quarter to the 10th quarter. Further, a sudden shock to the economy of Ghana leads to a decrease (negative effect) in exchange rate volatility from the 1st quarter to the 7th quarter. However, the other variables were not significant.

Figure 2

Response of exchange rate to shocks in its determinants



Source: author's computation.

Further, Table 11 depicts the forecast error variance decomposition. Here, the variance decomposition is done for ten periods. It can be seen that, in the early periods, innovations in the exchange rate are explained accordingly by the preponderance of its own past values (100%) and none by the other variables, but the contribution of the exchange rate to its own decreases with time. As can be seen in Table 11, by period ten, the contribution has dropped from a high of 100% down to around 65.8%. Also, innovations in the exchange rate are explained by the dummy variable for structural break (DUMMY_SB) from the second period, from 1.4% up to 7.4% in the tenth period.

Further, public debt (PD) explained the innovations in the exchange rate from the fourth period, from 1.3% to 9.5% in the tenth period. This is followed by inflation (INF), which explained the innovations in the exchange rate from the sixth period, from 2.1% to11.5% in the tenth period. This is also followed by interest rate (INT), which explained the innovations in the exchange rate from the seventh period, from 1.2% to 1.5% in the tenth period. Moreover, money supply (MS) explained the innovations in the exchange rate from the ninth period, from 1.1% to 1.2% in the tenth period. However, foreign direct investment (FDI) and remittances (RMT) explained infinitesimal innovations in the exchange rate during the periods.

Table 11

Forecast error variance decomposition

Period	S.E.	EXR_ VOL	INF	INT	FDI	MS	PD	RMT	DUMMY _SB
1	0.007	100.000	0.0000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.013	97.889	0.029	0.029	0.016	0.010	0.148	0.037	1.372
3	0.019	95.405	0.015	0.142	0.098	0.044	0.580	0.129	2.672
4	0.024	92.348	0.180	0.344	0.237	0.125	1.300	0.226	3.921
5	0.029	88.564	0.838	0.597	0.409	0.267	2.297	0.284	5.100
6	0.034	84.177	2.142	0.857	0.586	0.465	3.5464	0.280	6.106
7	0.038	79.476	4.038	1.094	0.741	0.692	4.996	0.232	6.846
8	0.042	74.738	6.353	1.292	0.855	0.914	6.557	0.201	7.291
9	0.045	70.156	8.895	1.444	0.918	1.102	8.115	0.279	7.461
10	0.048	65.836	11.496	1.549	0.933	1.238	9.548	0.552	7.413
Cholesky Ordering: EXR_VOL INF INT FDI MS PD RMT DUMMY_SB									

Source: author's computation.

4. Discussion

This section situates the study within the body of literature in order to validate the results obtained. The analysis of the volatility of the exchange rate using the GARCH models proved the persistent existence of volatility in the exchange rate. Thus, the exchange rate in Ghana is volatile within the period under consideration. This situation is supported by the findings of *Mohammed et al. (2021)*. From the results, it can be said that the best fitting model to the data is model 3, GJR

GARCH (2,1,2), since it has the smallest AIC. In relation to both long-run and short-run results, inflation had a negative and significant impact on the exchange rate, indicating that increases in both current and past values of the inflation rate in Ghana lead to fluctuations in the exchange rate.

Thus, the result implied that high inflation rates lead to depreciation of the local currency, thereby making it volatile to the foreign partners' currencies. The results confirm the findings by *Dung and Okereke (2022),* who indicated that high inflation leads to volatility of the exchange rate in Sub-Saharan African countries. In the case of interest rate, the coefficients were negative and significant both in the long run and short-un, showing that volatility of the exchange rate is also determined by high interest rate differential prevailing in the country. That is, the results implied that, if the local interest rate set by the Central bank is lower compared to the foreign interest rate, there will be capital or portfolio outflows, which turn to fluctuate the exchange rate.

Moreover, these results also support the findings by *Dung and Okereke (2022).* However, the results contradict the findings by *Russ (2012),* who found a positive relationship between the variables. Money supply also had a statistically significant impact on the exchange rate, both in the long-run and short-run. However, the money supply was positive in the long-run and negative in the short-run. In terms of the long-run, the result implied that excess in money supply leads to an increase in exchange rate volatility in Ghana and this assertion supports the finding by *Kilicarslan (2018),* who indicated that money supply and exchange rate positively correlate. However, in the short-run, increases in money supply (both its current and previous values) depreciate the local currency.

Furthermore, FDI positively impacted the exchange rate both in the long-run and short-run with both its current and previous values. The results implied that capital or portfolio inflows in Ghana turn to appreciate the local currency, thereby reducing the volatility of the exchange rate. The result confirms the findings by *Kilicarslan (2018),* who studied the relationship between the variables. The study also found that public debt was statistically significant and hurt the exchange rate in both the long-run and short-run. The results implied that excessive borrowing by the government in both domestic and foreign spheres leads to exchange rate volatility. Thus, excessive external borrowing leads to debt servicing, especially if it is in foreign currency turns to depreciate the local currency.

In addition, remittances inflows had a negative influence on the exchange rate in the long-run, indicating that remittances inflows to Ghana rather increase the volatility of the exchange rate. However, in the short-run, remittances inflows had a positive impact on the exchange rate suggesting they reduce exchange rate volatility. The result implied that increases in remittances inflows help to strengthen the local currency, thereby reducing its volatility. The results support the findings by *Ajibola et al. (2017)*. Regarding the dummy variable representing the shocks to the exchange rate, the coefficient was negative and significant, indicating how Ghana's structural reforms and other global economic crises contribute to the volatility of the exchange rate.

Finally, in the case of the stability tests, the impulse response function showed that shocks from the exchange rate itself, inflation and public debt increase (positive effects) the volatility of the exchange rate, while shocks from the dummy variable lead to a negative effect on the exchange rate. In the case of the forecast error variance decomposition, the exchange rate explained its innovations at the initial stage and later dropped. Additionally, innovations in the dummy variable, public debt, inflation, interest rate, money supply, foreign direct investment and remittances in that order also explained the innovations in the exchange rate volatility.

5. Conclusion and policy recommendations

It can be emphasised that one of the crucial factors that determines the competitiveness of a country in international trade is the stability of its exchange rate. Thus, volatility of the exchange rate has negative consequences on the terms of trade and growth of an economy. In recent times, many developing economies have experienced volatility of their exchange rates, which has been attributed to some factors or determinants and Ghana is no exception to this. This study thus examined the determinants of exchange rate volatility in Ghana by employing the GARCH models and the vector autoregression (VAR) model based on a quarterly dataset from 1990Q1–2022Q4.

The study revealed the persistent existence of volatility in the exchange rate in Ghana using the GARCH models. It was also found that the best fitting model to the data is model 3, GJR GARCH (2,1,2), since it has the smallest AIC. In addition, the results of Johansen's cointegration test revealed that there exist long-run and short-run relationships between the exchange rate and its determinants. Specifically, the study revealed that in the long run, money supply and FDI had positive effects on the exchange rate while public debt, inflation, interest rate and remittances had negative effects. In the short-run, the previous value of the exchange rate, two lags of FDI and four lags of remittances inflows had positive effects on the exchange rate, while one lag of inflation, four lags of interest rate, four lags of money supply, four lags of public debt and the dummy variable had negative effects on the exchange rate. Further, the results from the impulse response function revealed that shocks from the exchange rate itself, inflation and public debt had positive effects on the exchange rate, while shocks from the dummy variable led to a negative effect on the exchange rate.

In relation to the forecast error variance decomposition, the exchange rate explained its innovations at the initial stage and later dropped. Also, innovations in the dummy variable, public debt, inflation, interest rate, money supply, foreign direct investment and remittances inflows in that order also explained the innovations in the exchange rate volatility. The results of the study have some policy implications. First, the study has accentuated that both current and previous changes in the variables understudy determine the volatility of the exchange rate in the context of Ghana, thereby informing policymakers and the Government. Second, Bank of Ghana and the Government of Ghana could benefit from the study by frequently stabilising the determinants understudy to avoid their effects on the exchange.

Third, exchange rate volatility has a negative effect on the economic growth of an economy. The study informs policymakers and the central bank to stabilise the exchange rate to avoid its effects. The study recommends that the Government of Ghana, the central bank and policymakers put in place pragmatic measures to stabilise the macroeconomic environment of the country. Especially, policies should be geared towards stabilising the exchange rate, inflation, and interest rate as well as reducing public debt, developing proper channels for remittances inflows, monitoring money supply, attracting FDI and avoiding shocks. The main limitation of the study is in the area of generalisability of the results since it is a country-specific study. Also, the direction of causality of the independent variables on to exchange rate was not considered by the current study. However, these limitations did not affect the quality of the results. Therefore, future studies could consider examining these variables and others using a cross-country approach with different econometrics techniques to study the variables to determine what pertains in other settings.

Appendix

Figure A1

Exchange rate

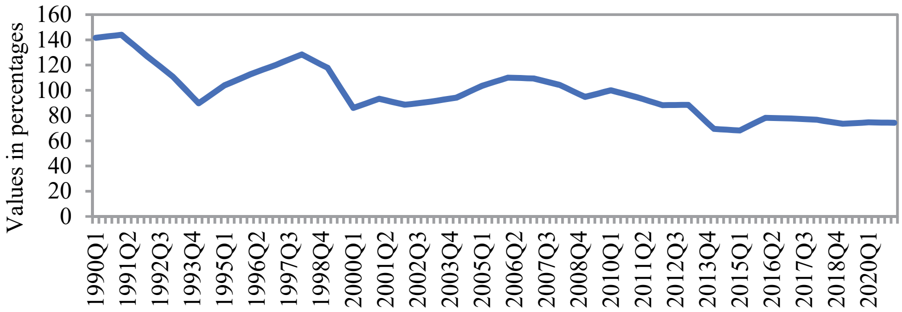


Figure A2

Foreign direct investment

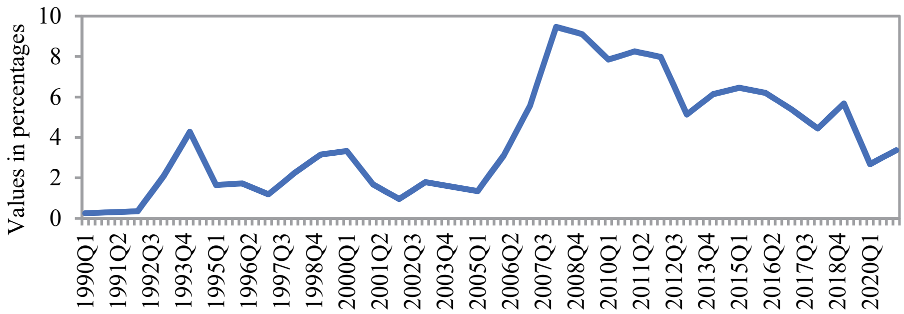


Figure A3

Inflation

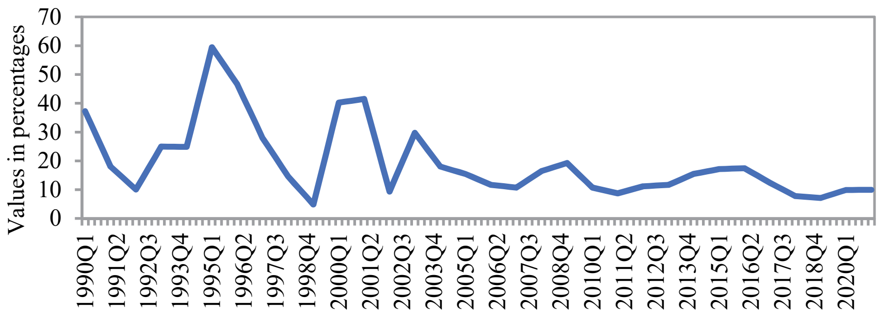


Figure A4

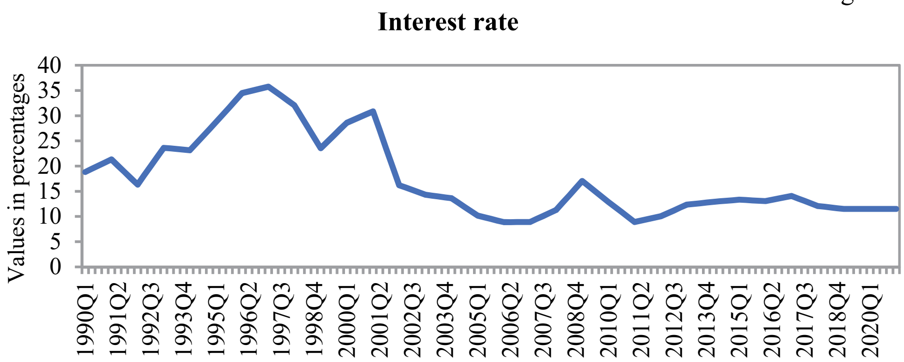


Figure A5

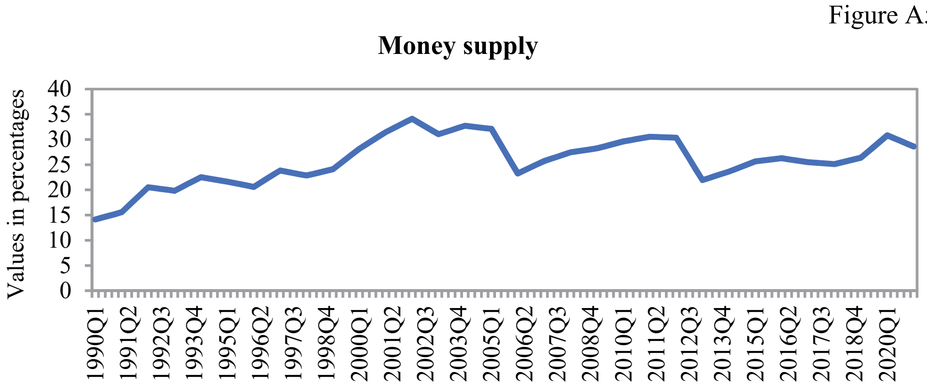


Figure A6

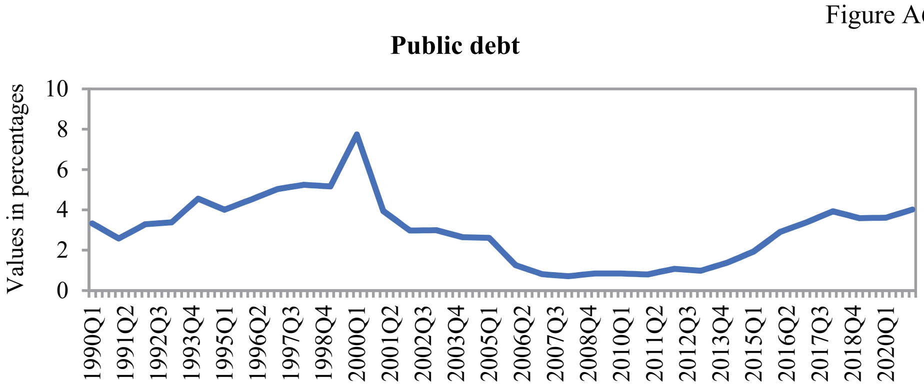


Figure A7

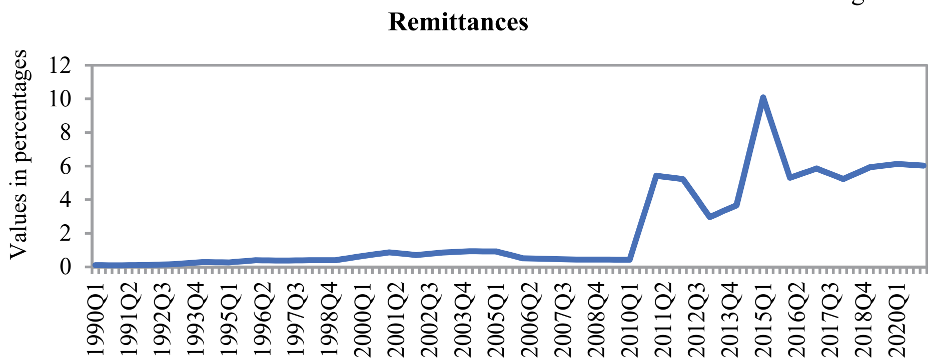


Figure A8

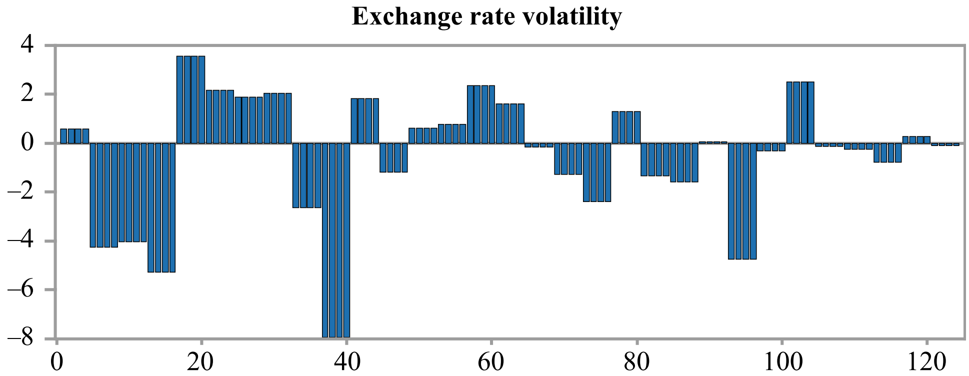


Figure A9

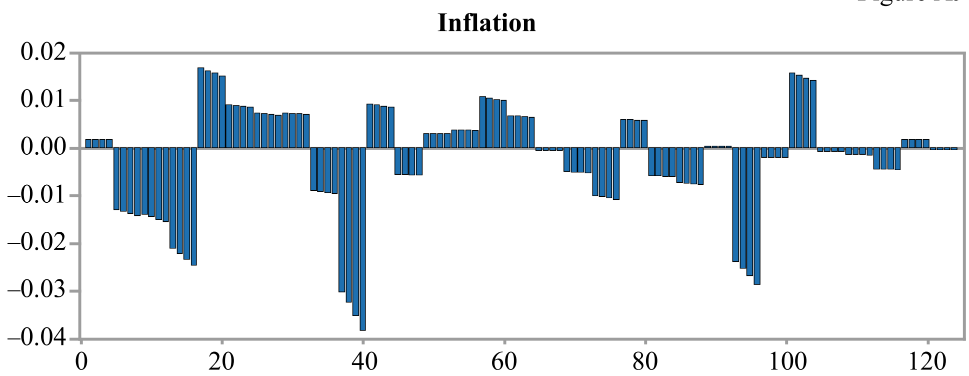


Figure A10

Interest rate

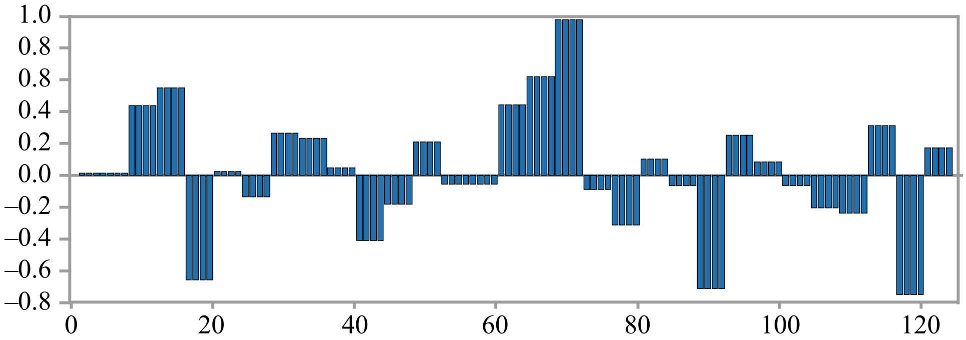


Figure A11

Money supply

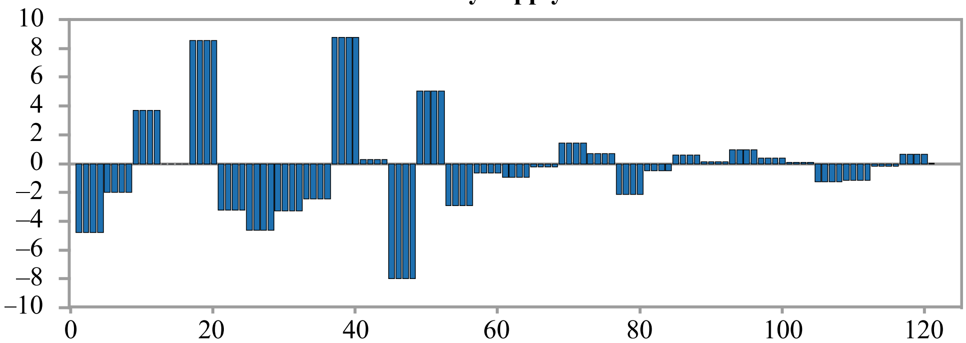


Figure A12

Foreign direct investment

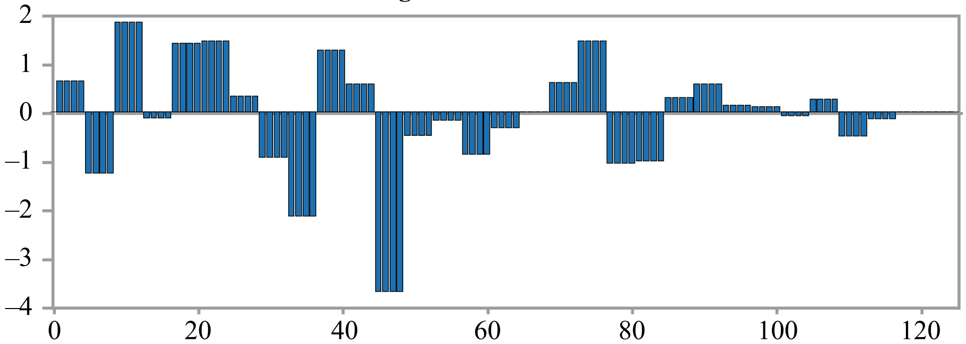


Figure A13

Public debt

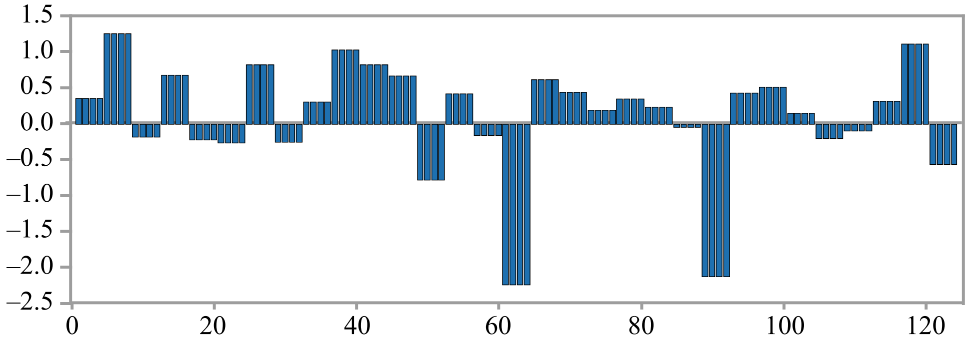
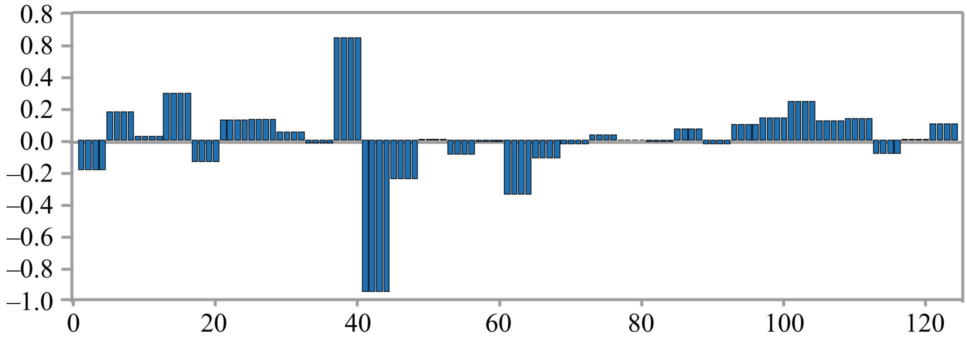


Figure A14

Remittances



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