Patterns and Causal Connections between Changes in Exchange Rates and Interest Rates in Ghana

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Abstract
Trends and causal relationships between Ghana's exchange rate and interest rate are investigated in this paper using Granger causality, cointegration, and error correction models. Monthly data from 2007 to 2020 are employed. The results show that both variables show a strong positive trend. Also, strong causation runs from the exchange rate to the interest rate, but the interest rate only weakly accounts for exchange rate changes. The findings further reveal that the two variables are co-integrated, and thus, using the interest rate lags in describing the exchange rate and vice versa is beneficial. Finally, it is suggested that policymakers closely track the exchange rate-interest rate nexus to craft policies that engender macroeconomic stability in the long run.

Keywords: *Causality, Exchange rate, Cointegration, Interest rate; Ghana*

Introduction

Interest and exchange rates are among the most important macroeconomic indicators (Capasso et al., 2019). In this light, this paper investigates causal relationships between Ghana's exchange rate (*ExR)* and interest rate (*IR)* movements. The two variables share a very complex and dynamic link which varies from economy to economy and even with the level of a country's development (Liu & Lee, 2022; Musa et al., 2021; Ghartey, 2019; Kim & Lim, 2022). Moreover, the interest rate and exchange are crucial monetary policy instruments and targets which are closely monitored by monetary authorities, governments, legislators, investors, global development finance institutions, and the business community (Sen et al., 2020; Capasso et al., 2019; Issahaku et al., 2015; Karamelikli & Karimi, 2022; Sharaf & Shahen, 2023).

After transitioning from a fixed to a floating (managed) exchange rate system in 1983, the Ghana cedi's value fluctuated significantly against the US dollar (Kwakye, 2012). According to Kwakye (2012), the currency, which has undergone numerous changes over the years, has depreciated steadily against other foreign currencies, particularly the US dollar. The

Bank of Ghana conducted a redenomination exercise due to the cedi's continued depreciation, pegging the exchange rate at Gh₵ 0.93 to one US$. Hence, the redenomination exercise in 2007 triggered a sudden and intense drop in *ExR*, as shown in Figure 1. However, the exchange rate depreciated significantly over time after the redenomination, as shown in Figure 2

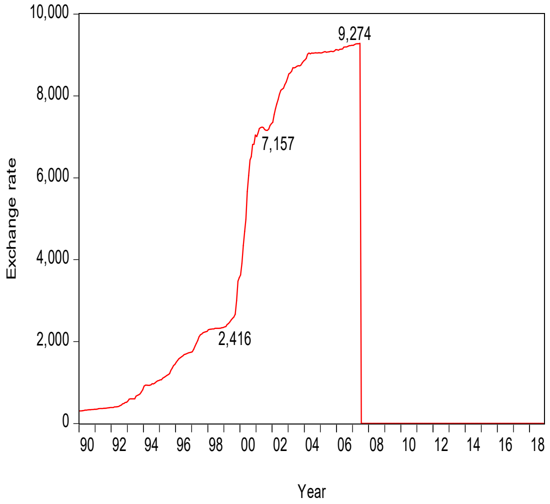


Figure 1: Before the redenomination

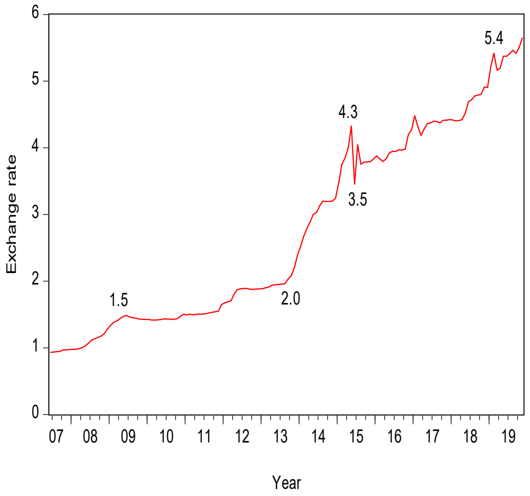
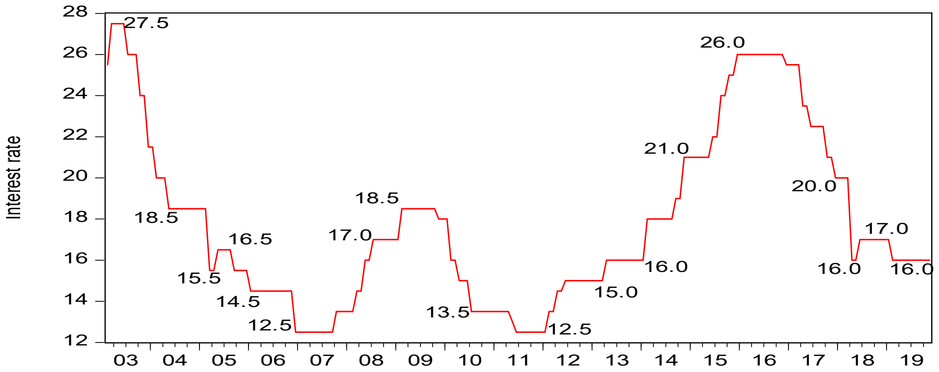


Figure 2: After the redenomination

Source: Authors construction based on data from BoG (2019).

Furthermore, interest rate movement has long concerned the Ghanaian economy. The interest rate has fluctuated throughout history; Figure 3 depicts the shifts in the interest rate from 2003 to 2019. From a high of 27.5 per cent in 2003, interest rates plummeted to 12.5 in 2006, increased to 18.5 per cent in 2009 amid the global economic crises and slumped again to 12.5 per cent in 2012. By 2015, interest rates rose again to 26.0 per cent following a severe energy crisis that reeled the economy and forced policymakers to approach the International Monetary Fund (IMF) for an extended credit facility. The IMF programme saw a downward spiral in the interest reaching 16.0 per cent by 2019. The Coronavirus pandemic in 2020 and, subsequently, the Russian-Ukrain war in 2022, mixed with a huge debt overhung and fiscal indiscipline, have seen interest rates (policy rate) escalate to 29.5 per cent, an all-time high[1].



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[1] See https://www.ceicdata.com/en/indicator/ghana/policy-rate and https://www.bog.gov.gh/monetary-policy/policy-rate-trends/

Figure 3: Interest rate (policy rate) trends in Ghana
Source: Data from BoG, 2019.

In the past, the Bank of Ghana (BoG) has used the interest rate as one of the tools for stabilising the cedi. The BoG adjusts interest rates to try to manage exchange rate depreciation. For example, the BoG's Monetary Policy Committee (MPC) has often hiked the policy rate to raise the cedi's value. This idea is backed by economic theory, as higher domestic interest rates raise the relative returns of domestic securities, attracting foreign investors and resulting in the cedi's appreciation (Mishkin, 2016). Also, the MPC, led by Governor Ernest Addison of the Bank of Ghana, slashed the interest rate by 100 basis points to a 5-year low of 16 per cent on January 28, 2019, and hinted that more interest rate easing could be on the way.

However, it is unclear if this measure resulted in the cedi appreciating since the exchange rate depreciated following the cut in interest rate; in January 2019, the cedi traded at Gh₵ 5.37 to US$ 1.0; on March 15, 2019, the cedi traded at Gh₵ 5.63 to US$1.0; and the cedi continued to depreciate in that year. The potency of the interest rate in anchoring the cedi will depend on the exchange rate's sensitivity to the interest rate. Also, it may well be that the exchange rate is driving interest rate movements (see Armah et al., 2023).

Against this background, this study contributes to knowledge by shedding light on the causal connection between exchange rate and interest rate movements in Ghana. Such knowledge will be a valuable guide for the MPC of Ghana. This study deviates from the extant literature, which has concentrated on the interest rate-inflation link in Ghana (Nkegbe & Abdul Mumin, 2014) and the dynamics of interest rate and exchange rate fluctuations in Ghana (Mohammed et al., 2021) and studies conducted elsewhere in the world which have no policy relevance for the Bank of Ghana (see Capasso et al., 2019; Karamelikli & Karimi, 2022; Liu & Lee, 2022; Musa et al., 2021; Ghartey, 2019; Sen et al., 2020).

We differ from Nkegbe and Abdul Munin (2014) by focusing on *IR* and *ExR* movements rather than on *IR* and inflation. We further deviate from Mohammed et al. (2021), who dwelt on *IR* and *ExR* fluctuations, while our study focuses on the level variables. We clarify the lead-lag association between *IR* and *ExR* in Ghana. Notably, we contribute to knowledge by assessing the relationship between *IR* and *ExR* from a bi-causal perspective. This will help the Bank of Ghana to determine whether the interest rate is a potent instrument for controlling the exchange rate and, on the flip side, whether exchange rate movements drive interest rates in the Ghanaian economy.

Since most foreign transactions between Ghana and its trading partners are conducted in dollars, this paper focuses on the dollar price in terms of the Ghana cedi (Gh₵). Again, because of the lack of high-frequency data on the market *IR* coupled with the policy rate's effect on other interest rates, this paper will concentrate on the policy rate as an approximate measure of the interest rate. The rest of the paper is organised as follows. The literature review comes next in section 2; the research approach follows this in section 3. Results are presented and discussed in section 4, while section 5 concludes and provides implications.

Review of Literature

This section reviews theoretical literature (Interest Parity Condition) and the empirical evidence on the exchange rate-interest rate nexus.

Theoretical Literature

The Interest Parity Condition (IRP) is one of the most reliable theories of global financial integration (Levich, 2013). It is also sometimes called covered interest rate parity (CIRP) or the asset price approach of exchange rate determination. Though IRP theory dates back to David Hume and David Ricardo, Keynes (1923) formalised it. The interest parity condition is closely related to the Uncovered Interest Parity (UIP) and the Purchasing Power Parity (PPP) theories (Güney & Hasanov, 2014). UIP says that the interest differential must exactly equate to the exchange rate depreciation. PPP hypotheses that the exchange rate must equal the inflation differential in that period. The real interest rate parity (RIRP) condition postulates that under conditions of UIP and PPP, the real interest rate must be equal across countries. Thus, the RIRP, like UIP and PPP, assumes zero transaction cost, no taxes and no uncertainty.

If RIRP holds, assets with similar characteristics in terms of maturity, default risk, and exposure to capital controls but denominated in different currencies must yield identical returns. Another implication of RIRP is that a country cannot run an independent monetary policy and thus cannot influence the real sector of the economy. We illustrate the interest parity condition following Levich (2013). Suppose there are two currencies in the world: USD ($) and Ghana cedi (Gh₵). The one period interest rates are denoted by $i(\$,1)$ and $i(Gh¢,1)$, and spot and one-period forward rates expressed as $\$/Gh¢$ are denoted respectively by E_t and $F_{t,1}$. Under the forward contract the buyer is obligated to supply $F_{t,1}$ worth of USD in one period in exchange for Gh₵1. An alternative strategy is to borrow $E_t/(1+i(Gh¢,1))$ now at a cost of $i(\$,1)$, go to the spot market and exchange the USD for Gh₵ and invest it for one period at the rate $i(Gh¢,1)$ to get a return of Gh₵1. Thus, both alternative strategies yield the same returns (Gh₵1) – (1) purchasing Gh₵1 at a cost of $F_{t,1}$ will yield the same cash flows in one period as (2) borrowing USD today at the cost of $i(\$,1)$, exchanging it on the spot for Gh₵, and investing it at the rate $i(Gh¢,1)$. In a world of certainty, zero taxes, and zero transaction cost, the cost or price of the two strategies are equal, giving the following parity relation:

$$F_{t,1} = E_t \frac{1+i(\$,1)}{1+i(Gh¢,1)} \tag{1}$$

From equation (1), in equilibrium, the forward exchange rate is simply equal to the spot rate times the ratio of the yields of the two currencies. We can rearrange equation (1) to get equations (2) and (3) as follows:

$$1 + i(\$,1)F_{t,1} = 1 + i(Gh¢,1)\frac{F_{t,1}}{E_t} \tag{2}$$

$$1 + i(Gh¢,1) = 1 + i(\$,1)F_{t,1}\frac{E_t}{F_{t,1}} \tag{3}$$

Equation (1) demonstrates that investing in USD is tantamount to exchanging USD for Gh₵ today and investing the Gh₵ at the market rate, and then dealing with the currency exposure by selling at the forward rate both the principal and the interest expected. A comparable strategy is equation (3) which reveals that the return on the Gh₵ position is equivalent to a USD position combined with a forward contract to contain currency exposure. The existence of arbitrage aids the equilibrium relationships described in equations (2) and (3). Therefore, the existence of default risk, sovereign risk, capital controls, substantial transaction costs and taxes, which put limits on arbitrage, may cause deviations from parity.

Empirical Review

According to Viktoria, Amartya, and Carlos (2008), the empirical literature on this subject is inconclusive. The *IR*-*ExR* relationship varies by country, with some studies indicating a positive relationship and others indicating a negative one. In Turkey, for example, Taha and Kadir (2016) found no indication that interest rate hikes trigger a depreciation of the exchange rate. In contrast, Furman and Stiglitz (1998) established that interest rate rises weaken the exchange rate. According to Viktoria, Amartya, and Carlos (2008), the relationship between *IR* and *ExR* varies over time, whether short or long. Cho and West (2003) developed and tested a model that allows *IR* shocks to cause *ExR* to appreciate or depreciate. They employed weekly data from Korea, the Philippines, and Thailand.

They revealed that an upsurge in *IR* engineered *ExR* appreciation in Korea and the Philippines and depreciation in Thailand. Selim, Tayfur, and Ahmet (2013) investigated the dynamics of the *IR*-*ExR* link in BRIC-T (Brazil, Russia, India, China, and Turkey). Interest rates affected the exchange rate in China only, and this finding holds in the long term only. Exchange rate shocks, then again, triggered interest rate fluctuations in the short run. In the Mexican case, Capasso et al. (2019) found the impact of the exchange rate on interest rates to be asymmetrical such that positive movements in the exchange rate had lower effects. The effect of interest rate on the exchange rate was found insignificant in the long term. In Turkey, Karamelikli, and Karimi (2022) discovered no short-run relationship but rather an asymmetric impact in the long term, such that positive variations in the interest rate had a stronger impact on the exchange rate than negative variations. Other studies that have examined the *IR*-*ExR* connection include Liu and Lee (2022), who focused on US and China, Musa et al. (2021), who studied the Big 4 in Africa (Algeria, Egypt, Nigeria and South Africa), Ghartey (2019) who focused on selected countries in the Caribbean, and Lim (2022) who examined six emerging countries, and Sen et al. (2020) who looked at fragile emerging countries.

In Ghana, policymakers are looking up to researchers to gain an empirical understanding of the nature of the *IR* and *ExR* connection in the short and long runs. Meanwhile, the literature based on Ghana concentrates on the interest rate and inflation rate connection (Nkegbe & Abdul Mumin, 2014) and the link between interest rate fluctuations and exchange rate fluctuations (Mohammed et al., 2021) using cointegration and error correction-based methods. Nkegbe and Abdul Munin (2014) established a long-ranged association between inflation and interest rate. However, they did not consider the connection between interest and exchange rates. Mohammed et al. (2021) found that the interest rate induces exchange rate instability in the short and long runs. Mohammed et al. (2021) were only interested in assessing a non-bicuasal relationship between *IR* and *ExR* volatility.

While this is crucial, there is also the possibility that excessive exchange rate depreciation also leads to the central bank raising the interest rate – a kind of feedback effect. The question to answer is, is there a one-way or two-way relationship or even no association between *IR* and *ExR* movements in Ghana? The answer to this question has implications for the BoG's use of the policy rate to anchor price stability within the inflation-targeting framework. This paper aims to answer this question to advance the boundaries of the existing literature on the *IR-ExR* nexus.

Methodology

Data

For this analysis, monthly data observations on the variables (exchange rate and interest rate) from 2007 to 2020 were obtained from the Bank of Ghana website. Since the Ghana cedi was re-denominated in 2007, the study period began in 2007. The end date of the data (2020) was chosen because that was the most current data year at the time of conducting this study.

Growth Rates Trends

Approximate values of the growth rates of the variables were calculated using the linear regression method. The logarithms of *ExR* and the *IR* (*ln*) were calculated, and time (*t*) was regressed on them. The econometric models are as follows:

$$InExR = \alpha_0 + \alpha_1 t + \varepsilon_t \tag{4}$$

$$InIR = \beta_0 + \beta_1 t + \mu_t \tag{5}$$

Where *InExR* is the natural logarithm of the exchange rate, *InIR* is the natural logarithm of the interest rate, and ε_t and μ_t are the error terms, respectively. α_1 and β_1 are the approximate time(t) coefficients in (4) and (5), respectively, and α_O and β_0 are the intercepts in (4) and (5), respectively.

Time Series Analysis

Time series is a set of numerical data in which each object corresponds to a specific point in time (Maddala, 1992). Many groups are interested in time series data analysis, including macroeconomists researching national and international economic behaviour, financial economists studying stock markets, and agricultural economists forecasting the supply of and demand for agricultural products (Hill, Griffiths & Lim, 2011). In addition, the concept of a stationarity mechanism has historically been cardinal in time series analysis (Wooldridge, 2009).

The magnitude of the covariance between two time periods only depends on the distance between them, not the period the covariance was calculated. A time series is said to be stationary if its mean and variance remain unchanged over time (Gujarati, 2011). However, time-series research is not limited to just stationary time series. In reality, non-stationary time series make up most of the data we encounter (Maddala, 1992). The main reason for establishing stationary before beginning a regression analysis is that when non-stationary data are employed for regression analysis, there is a danger of getting significant results from unrelated data. Such regressions are regarded as spurious. Since we cannot perfectly predict most economic variables, they are said to exhibit random behaviour. The values of random variables are unknown before they are observed (Hill et al., 2011).

Another important time series concept is the principle of "order of integration." In applied econometric analysis of time series, determining the order of integration has become a standard technique (Sjo, 2008). This is especially important in response to economic theory's suggestion that some series should be integrated, exhibiting a random walk (*Sjo, 2008*). Time series that are integrated of order one is denoted as *I(1)* and can be rendered stationary by taking the first difference. Stationary series are described as zero-order integrated series (0). As a general rule, the order of integration is the least number of times it must be differentiated to become stationary (Hill et al., 2011). Davidson and others criticised this process, claiming that repetitive differentiation yields stationary data at the expense of long-range knowledge, rendering the method ineffective (Nkegbe & Abdul Mumin, 2014). This paper will use the cointegration process to address this flaw, where regressing one non-stationary series on one or more time series does not yield spurious results (Gujarati, 2011). If this occurs, we conclude that the time series under investigation are co-integrated, meaning they have an equilibrium relationship. For non-stationary series, cointegration is a necessary standard for stationarity (Nkegbe & Abdul Mumin, 2014).

The above discussion implies that we must assess the time series properties of *IR* and *ExR* data used in this study so that we do not produce spurious results. Particularly, the variables' stationarity status, the order of integration, and the existence of cointegration must be assessed. We explore this further in the next subsections.

Testing for Stationarity

A time series' stationarity can be examined in three ways: (I) graphical, (II) correlogram, and (III) unit-root analysis (Gujarati, 2011). This study uses unit-root analysis to inspect stationarity since it is more formal than the others. The graphical approach only hints at whether a series is stationary or not; it does not offer strong proof. The correlogram method provides evidence of series stationarity or non-stationarity to some degree, but it is not as robust as unit-root analysis. The unit-root test for our variables is written as:

$$\Delta InX_t = \beta_0 + \beta_1 t + \beta_2 InX_{t-1} + \varepsilon_t \quad (6)$$

Where X_t can represent *IR* and *ExR* depending on the series we are testing at a point in time. $\Delta InX_t = InX_t - InX_{t-1}$, that is, the 1st difference of the log of X_t (either *ExR* or *IR*), *t* is the trend variable; the β's are the estimated coefficients and ε_t is the random error term. The null hypothesis tested is that β_2 is equal to zero ($\beta_2 = 0$). This is called the unit-root hypothesis (Gujarati, 2011). Failure to reject the null hypothesis means that the series is non-stationary. The null hypothesis ($\beta_2 = 0$) appears to be testable using the standard t-statistic, but this is not the case; the t-statistic is only true if the underlying time series is stationary (Gujarati, 2011). As a result, the (tau) statistic developed by statisticians Dickey and Fuller (1979) hence the name Dickey-Fuller test, is the appropriate statistic in this situation (DF test). The error term ε_t is assumed to be uncorrelated in the DF test. If this prediction turns out to be incorrect, the DF test will be invalid. As a result, Dickey and Fuller devised the augmented Dickey-Fuller test, also known as the ADF test (Gujarati, 2011). The lags of the dependent variable ΔInX_t are added to the DF test as follows:

$$\Delta InX_t = \beta_0 + \beta_1 t + \beta_2 InX_{t-1} + \sum_{i=1}^{n} \delta_i \Delta InX_{t-i} + \varepsilon_t \quad (7)$$

where *n* is the lagged dependent variable's maximum duration, β's and δ's are coefficient estimates, and ε_t is the error term. To ensure that ε_t is not autocorrelated or strictly random, the lags of ΔInX_t now 'soak up' any complex structure existing in the dependent variable (Brooks, 2008). The ADF test was used in this paper to help solve the DF test's drawback, which is the possibility of autocorrelation among the residuals, which can produce spurious results (Brooks, 2008; Gujarati, 2011; Hill et al., 2011).

Cointegration

When analysing short-run dynamics, it is common to start by removing trend in the variables, which is typically achieved by differencing. If the series is non-stationary, we differentiate the series to achieve stationarity. We then fit the stationary series with Autoregressive Moving Average (ARMA) models, as indicated by the Box-Jenkins process (Maddala, 1992). However, this approach does not utilise potentially valuable knowledge about long-run relationships, which economic theory has much to say about (Maddala, 1992). The question of whether there is a long-term connection between interest rates and exchange rates is central to the concept of cointegration. Cointegration aims to find the equilibrium or long-term relationship between variables (Nkegbe & Abdul Mumin, 2014).

Testing for Cointegration

The DF and ADF unit root tests on residuals estimated from the cointegration regression, as updated by the Engel-Granger (EG) and Augmented Engel-Granger (AEG) tests (Gujarati, 2011), Non-Linear Autoregressive distributed Lag (NARDL) model, wavelet methodology (see Andrieș et al., 2017) and the Johansen full information maximum likelihood test are some examples of cointegration tests (Johansen & Juselius, 1990). However, the Engel-Granger method has the limitation of not being able to estimate more than one cointegration regression if there are two or more variables. This may lead to multiple co-integrating relationships (Gujarati, 2011). The order in which variables are included in the cointegration regression is another limitation of the EG method. Even if we have three variables, X_t , Y_t, and Z_t , and we find cointegration when we regress Y_t on X_t and Z_t; there is no guarantee that we will find cointegration when we regress X_t on Y_t and Z_t (Gujarati, 2011). Additionally, the EG method requires identifying more than one cointegration relationship and the error correction term for each one when dealing with multiple series.

As a result, the bivariate error correction model will be ineffective, and the vector error correction (VEC) model must be used instead, as per Gujarati (2011). The Johansen method, however, resolves the significant weaknesses of the EG approach. It is necessary to utilise the Johansen and the NARDL methods when analysing the co-integrating relationships of multiple series (time series) as per Gujarati (2011), Arčabić et al. (2021) and Capasso et al. (2019). Also, NARDL is appropriate when asymmetric relationships are involved. Fortunately, in this case, we are only working with linearities between two variables, *ExR* and *IR*, so it is not necessary to delve into the complexities of the Johansen and NARDL techniques; and the EG approach will suffice. The equation for cointegration is as follows:

$$InExR_t = \beta_0 + \beta_1 InIR_t + u_t \tag{8}$$

The series ExR_t and IR_t reflect the exchange rate and interest rate, respectively. Note that, β_0 is the intercept term, β_1 is the co-integrating parameter and u_t is the error term. However, if we rewrite (8) in terms of the error term, we get the following equation:

$$u_t = InExR_t - \beta_0 - \beta_1 InIR_t \tag{9}$$

Assume we perform a unit root analysis on the estimated error term u_t $(= \varepsilon_t)$ and discover that it is stationary, that is, *I (0)*. If the series ExR_t and IR_t are integrated of order one *I (1)*, then the series are co-integrated of order *I* (0, 1). The β_1 in (8) represents the long-run relationship between the series ExR_t and IR_t, with μt representing the deviation from the equilibrium direction.

Granger Causality Test

The Granger causality test determines if one data set can be used to predict another. The test was first proposed by Clive Granger in 1969. Granger found that causality can be determined by measuring the ability to predict the future value of one series using previous values from another series (Granger, 1969). If the forecast of X_{1t} is based on its past values and the past of X_{2t} are stronger than the predictions of X_{2t} based on its own values, we can assume that the series X_{1t}, which evolves over time Granger-causes another series X_{2t}, which also evolves over time. To do so, Engel and Granger (1987) suggested an error correction model to approximate causality in two directions. The following is an example of a model specification for two variables:

$$\Delta X_{1t} = \delta_{1t} + \sum_{i=1}^{k} \alpha_{1i} \Delta X_{1t-i} + \sum_{i=1}^{k} \beta_{1i} \Delta X_{2t-i} + \delta_{1t} z_{t-1} + \varepsilon_{1t} \qquad (10)$$

$$\Delta X_{2t} = \delta_{2t} + \sum_{i=1}^{k} \alpha_{2i} \Delta X_{2t-i} + \sum_{i=1}^{k} \beta_{1i} \Delta X_{1t-i} + \delta_{1t} z_{t-1} + \varepsilon_{2t} \qquad (11)$$

where X_1 represents the logarithm of the exchange rate (lnExR), X_2 represents the logarithm of the interest rate (lnIR), and z represents the cointegration expression which indicates a long-term relationship between *IR* and *ExR*. The calculated coefficients of the lagged interest rate terms in the equation for the exchange rate demonstrate the interaction between *IR* and *ExR*.

Measure of Causality

There are different methods of measuring causality. These include linear Granger causality (also known as Geweke's measure of causality), Kernel generalisation of causality (also known as Kernel Geweke's measure of causality), and transfer entropy. Geweke's test can only be used to assess linear causality and not to measure non-linear causality (Amblard al., 2012). The Kernelized Geweke's measure is used in this discussion because it is a more advanced version of Geweke's measure and focuses on non-linear causality (Zaremba & Aste, 2014).

$$G_{Y\to X} := log \frac{\sigma^2(X_t|X^{t-n})}{\sigma^2(X_t|X^{t-n}, Y^{t-n})} \qquad (12)$$

$$G_{X.Y} := log \frac{\sigma^2(X_t|X^{t-n}, Y^{t-n})}{\sigma^2(X_t|X^{t-n}, Y^{t})} \qquad (13)$$

Where X_t and Y_t are the exchange rate and interest rate, respectively, and X^{t-n} and $Y^{t-n}$are the set of X_t and Y_t past sample signals. As is customary, σ^2 denotes variance, and *log* denotes logarithm. $G_{Y\to X}$, and $G_{X.Y}$ are indexes that calculate or quantify the benefit of using Y_t's history when predicting X_t from its past. The indexes are greater than or equal to zero in theory ($G_{Y\to X}, G_{X.Y} \geq 0$). If including the history of Y_t has no benefit, the value of the indexes will be zero, while if it does, the calculation (the indexes) will be purely positive, in which case Y_t is said to be a prima facie cause of X_t (Amblard et al., 2012).

Error Correction Model (ECM)

When two data sets are co-integrated, it implies that they have a balanced relationship; however, there might be some short-term imbalance. According to the Granger Representation Theorem, if there is cointegration between two variables, Y and X, their relationship can be depicted as an ECM (Gujarati, 2011). The ECM is used to determine the ExR_t and IR_t short-run equilibrium relationship. The following is an example of an ECM specification:

$$\Delta InExR_t = \delta_1 + \delta_2 \Delta InIR_t + \delta_3 u_{t-1} + \varepsilon_t \qquad (14)$$

Where u_{t-1} is the lag values of the error term in equation (9), δ_1 is the intercept, δ_2 is the immediate or short-run effect of $InIR_t$ on $InExR_t$, and ε_t is the white noise error term. Changes in $InExR_t$ are dependent on changes in $InIR_t$ and the lagged equilibrium error term, u_{t-1}, according to the error correction model (ECM). If this error term is zero, there will be no disequilibrium between $InIR_t$ and $InExR_t$, and the long-run relationship will be determined by the cointegration relationship (8). However, the relationship between $InIR_t$ and $InExR_t$is out of equilibrium if the error term is nonzero.

To see how the ECM works, let us suppose $InIR_t$ has not changed ($\Delta InIR_t$ = 0), and let us also assume that u_{t-1} is positive. This implies that $InExR_{t-1}$ would be higher than its equilibrium value. However, we expect δ_3 from (14) to be negative, so the term $\delta_3 u_{t-1}$ from (14) will be negative, and the $\Delta InExR_t$ will be negative in order to restore equilibrium. That is, if the $InExR_t$ is greater than its equilibrium value, it will begin to fall in the following time to correct the equilibrium error; hence, the name ECM (Gujarati, 2011).

Impulse Response Function (IRF)

The impulse response functions (IRF) show the impact of sudden changes on the adjustment process of variables. It illustrates how a shock to one variable affects itself or other variables and vice versa (Nkegbe & Abdul Mumin, 2014). To understand IRF, look at the following univariate sequence (Hill et al., 2011):

$$Y_t = \theta Y_{t-1} + u_t \qquad (15)$$

In cycle one, the exchange rate, Y_t, is subjected to a shock of size (u). Assume an arbitrary time zero starting point for Y_t; Y_0 = 0.

Following the shock, the values of Y_t will be $Y_1 = \theta Y_0 + u_t = u$ at time $t = 1$. Assume that no shocks occur in subsequent time intervals $[u_2 = u_3 = \dots = 0]$, and that at time $t = 2, Y_2 = \theta Y_1 = \theta u$. When $t = 3, Y_3 = \theta Y_2 = \theta(\theta u) = \theta^2 u$, and so on. As a result, the time route of Y_t after the shock is $\{u, \theta u, \theta^2 u \; \dots,\}$. The multipliers are the values of the coefficients $\{1, \theta, \theta^2 \dots\}$ and the impulse response function is the time-path of Y_t considering the shock. A shock to a stable system of equations should eventually decay to zero. Assume that $\theta = 0.9$ and that the shock is unity: $u = 1$=1. Y_t would be {1, 0.9, 0.81 …} eventually reaching zero, according to the report by (Hill et al., 2011). Now following an impulse response function analysis with two series based on a stationary bivariate VAR system:

$$Y_t = \rho_{10} + \rho_{11} Y_{t-1} + \rho_{12} X_{t-1} + u_t^y \qquad (16)$$

$$X_t = \rho_{20} + \rho_{21} X_{t-1} + \rho_{22} Y_{t-1} + u_t^x \qquad (17)$$

Where Y_t and X_t are the exchange rate and interest rate, respectively, u_t^y and u_t^x are the error terms, ρ_{10} and ρ_{20} are the equations' intercepts, and the others are the parameter estimates or coefficients of the lag values of the exchange rate (Y_{t-1}) and interest rate (X_{t-1}).

There are two potential shocks to the system in this situation, one for Y_t and the other for X_t. As a result, we are concerned with four impulse response functions: the impact of a shock to Y_t on the time-paths of Y_t and X_t; the impact of a shock to X_t on the time-paths of X_t and Y_t. Assume there is no issue with identification; to put it another way, Y_t and X_t are dynamically related but not contemporaneously. As shown in equations (16) and (17), respectively, the current value X_t appears in the expression for Y_t and the current Y_t value appears in the equation for X_t. In addition, we must suppose that the errors u_t^y and u_t^x are not related to one another (contemporaneously uncorrelated) and have a natural distribution (Hill et. Al., 2011).

Results and Discussions

Trend and Growth Rate of Variables

The trend regression output is shown in Tables 1 and 2, where *InExR* is the natural log of the exchange rate and *InIR* is the natural log of the interest rate. Time (TIME) is the only independent variable, while *IR* and *ExR* are both outcome variables. The results of regressing *ExR* on time are shown in Table 1, and the results of regressing *IR* on time are shown in Table 2.

Table 1: Linear Regression Results of *InExR on TIME*

Variable	Coefficient	Std. Error	t-Statistic	F-statistic	$\overline{R}^2$
TIME	0.012671	0.000199	63.575***	4041.785***	0.964
C	-0.087509	0.017347	-5.045***	-	

Note: *** shows significance at 1per cent.

In Table 1, the exchange rate exhibits a trend over time at 1 per cent significance level. The coefficient of time is 0.012671. This value is positive, meaning the exchange rate exhibits a positive trend over the period. The positive trend suggests that the exchange rate increases by 0.012671 per cent for each month. This means that from July 2007, when the currency was re-denominated, which resulted in the exchange of Gh¢ 0.92 to US$ 1.0, the lowest exchange rate hitherto, the exchange rate has been depreciating since then.

The results show that the cedi has been depreciating or losing its value against the US dollar. The adjusted $\overline{R}^2$ is 96.4 per cent, which implies that 96.4 per cent of the variations in the exchange rate movements is explained by time. It also suggests that we can predict that the exchange rate will depreciate in the preceding months; all other things equal, as time progresses, the cedi will keep depreciating relative to the US dollar.

Table 2: Linear Regression Results of *InIR on TIME*

Variable	Coefficient	Std. Error	t-Statistic	F-statistic	$\overline{R}^2$
TIME	0.002188	0.000358	6.1056***	37.279***	0.196 ***
C	2.693617	0.031195	86.3483***	-	

Note: *** Shows significance at 1 per cent level.

In Table 2, the interest rate reveals a trend over time at a 1 per cent significance level. The time coefficient is also positive (0.002188), meaning the interest rate exhibits a positive trend over the period. This means that for every month, the *IR* increases by 0.002188 per cent. The adjusted coefficient of determination ($\overline{R}^2$) is 19.6 per cent which means that the portion of the variations in the interest rate that is explained by time is 19.6 per cent.

This means other important factors largely account for the changes in the interest rate. The rising interest rate trends affect financial institutions' profitability and borrowing costs. For financial institutions such as banks, a rising interest rate means a more extensive interest spread and hence higher profitability. But for investors, a rising interest rate means an increased cost of funds and, for that matter, high production costs. This means that the managers of the economy must find that interest rate level or band (optimal rate) which aligns with the interest of financial intermediaries and investors at any point in time.

Kwakye (2010) also recognised the influence of lenders or investors on the interest rate in Ghana. Lenders or investors generally demand a high interest rate if they perceive the risk associated with their lending to be higher. Some risks include expected currency depreciation, inflation, and default. However, these risks must be compensated for, accounting for increasing interest rates in Ghana.

Unit Root Test Results

Table 3 shows the results of a unit root test used to determine the series' stationarity as well as the order of integration, which is a condition for cointegration. The ADF test results are provided for all variables, along with their conclusions. The unit root tests for the variables $InExR_t$ and $InIR_t$ show that at level *I* (0), both variables have a unit root (or are non-stationary).

As a result, we cannot dismiss the null hypothesis of non-stationarity using the ADF test. Nonetheless, after taking the first differential, all non-stationary series become stationary, so we reject the null hypothesis of non-stationarity in the ADF test and conclude that the series are integrated of the order one, that is, *I* (1), at the 1 per cent level of significance, as shown in Table 3. The results that the interest rate and exchange rate series are non-stationary and integrated of order one imply that there is a possibility of a co-integrating and long-run link between the series.

The Akaike Information Criterion (AIC), the Schwarz Information Criterion (SIC), also known as the Bayesian Information Criterion (BIC), and the Hannan-Quinn Criterion (HQC) all choose a maximum lag length of 13, so the lag length of 13 was used in this estimation since it is the maximum lag length.

Table 3: Unit Root Test Results

Variable	ADF	Conclusion
$InExR_t$	-0.793	Non-stationary
$\Delta InExR_t$	-7.511^{***}	*I* (1)
$InIR_t$	-1.341	Non-stationary
$\Delta InIR_t$	-12.001^{***}	*I* (1)

Notes: *** shows statistical significance at 1 per cent. H_0: the series has a unit root (or is non-stationary), the AIC, SIC and HQC are all considered in selecting the maximum lag length.

Causality

As shown in Table 4, the pair-wise Granger causality test reveals a two-way causal relationship between the *ExR* and the *IR* in Ghana. At a 10 per cent significance level, IR only accounts for a relatively small proportion of the fluctuations in *ExR. T*his suggests that fluctuations in *IR* are taken into account in the determination of *ExR* in Ghana.

This result is unsurprising because, although the Central Bank changes the policy rate occasionally to regulate the cedi's depreciation against the US dollar, it is unclear whether this measure is efficient. However, based on the empirical findings in Table 4, it can be inferred that interest rate changes only partially account for exchange rate movements.

The Sticky-price monetary model and the Mundell-Fleming monetary model (which espouse a positive association between the interest rate and the exchange rate) are validated by this analysis, but only at a 10 per cent significance level. The BoG, under the leadership of former governor Dr Henry Kofi Wampah, used higher interest rates to overcome exchange rate crises; this analysis supports this attempt at a 10 per cent significance level. Also, on January 28, 2019, the BoG, led by Dr. Ernest Addison, cut the policy rate by 100 basis points to a five-year low of 16 per cent, among other steps, resulting in a depreciation of the cedi. On the empirical front, the finding of a significant influence of *IR* on *ExR* is confirmed by Cho and West (2003) and Karamelikli and Karimi (2022).

The results in Table 4 also show that at a 1 per cent significance level, the exchange rate influences the interest rate. The policy rate is a benchmark for all other interest rates in Ghana; a rise will increase other interest rates. This will attract foreign investors as the yield on their investments will be greater, leading to an appreciation in the exchange rate. If there is significant instability in the exchange rate, authorities such as the Bank of Ghana might use the policy rate to stabilise it. Hence, at a 1 per cent significance level, interest rate fluctuations follow exchange rate movements in Ghana. Therefore, when the exchange rate is volatile, policymakers will likely adjust the interest rate to stabilise the exchange rate. The results that the exchange rate significantly drives interest rate is consistent with Capasso et al. (2019), who conducted a similar study in Mexico.

Table 4: Granger Causality Test

Null Hypothesis:	F-statistic	P-value
ΔINTERES_R does not Granger Cause ΔEXR	1.51992	0.0975^{*}
ΔEXR does not Granger Cause ΔINTERES_R	2.7830	0.0009^{***}

Note: *** and * indicate 1 per cent and 10 per cent levels of significance, respectively.

Testing for Cointegration

The Engel-Granger tau-statistic (t-statistic) and z-statistic reject the null hypothesis of no cointegration between *ExR* and *IR*, as shown in Table 5. This means that *ExR* and *IR* have an equilibrium relationship; two are co-integrated. Previous studies have found similar cointegration results (see Capasso et al., 2019; Karamelikli & Karimi, 2022; Liu & Lee, 2022; Musa et al., 2021; Ghartey, 2019; Sen et al., 2020)

Table 5: Engel-Granger Cointegration Test Results

Dependent	tau-statistic	Prob.	z-statistic	Prob.
Δ*lnExR*	-7.6363	0.0000	-118.4107	0.0000

$\Delta lnIR$	-12.2092	0.0000	-149.0334	0.0000

Notes: The test statistic is computed using C (intercept). The Schwarz information criterion (SIC) was used as an automatic lag selection criterion with a maximum lag of 13.

The regression results in Table 6 indicate that the interest rate has little effect on the exchange rate. The exchange rate increase resulting from a unit increase in the interest rate is not statistically significant. It suggests that a change in the interest rate does not affect the exchange rate on a unit basis.

Table 6: OLS Regression Results of $\Delta lnExR$ on $\Delta lnIR$

Variable	Coefficients	Standard err	t-statistic	F-statistic	$\overline{R}^2$
$\Delta lnIR$	0.0468	0.0738	0.6334	0.4012	-0.0041
C	0.0121	0.0026	-	4.5988***	-

Notes: $\Delta lnExR$ is the dependent variable, *** shows significance at a 1 per cent level, and C is the intercept.

The estimated residuals (or errors) from the regression shown in Table 6 are tested for unit root using the ADF test, and the output is displayed in Table 7. The test shows that the residual (or error) is stationary, that is, *I* (0). Hence, the residual series is not integrated. For the two series to be co-integrated, the estimated error must be stationary in the order *I* (0). Therefore, this result is consistent with the Engel-Granger cointegration test results, which concluded that *IR* and *ExR* will be co-integrated or be in equilibrium in the long run.

Table 7: Unit Root Test Results for Residuals

Variable	ADF	Conclusion
RESID1	-7.6097***	*I* (0)

Notes: *** shows statistical significance at 1 per cent level. H_0: the series has a unit root (or is non-stationary), the AIC, SIC and HQC are all considered in selecting the maximum lag length, RESID1 represents residuals.

Error Correction Model (ECM)

The coefficient of $\Delta lnIR$, which depicts the long-run relationship between *ExR* and *IR*, is insignificant, as shown in Table 8. It is also worth noting that the coefficient of RESID1 indicates the rate of adjustment to equilibrium; that is, when the relationship between *ExR* and *IR* is out of balance, the coefficient of RESID1 indicates the sum of the discrepancies that will be corrected within a month. The adjustment rate to equilibrium may also indicate how quickly or slowly the variables achieve equilibrium. However, as anticipated, the RESID1 coefficient is negative and significant at the 1 per cent level, implying a short-run disequilibrium between *ExR* and *IR*. Since the rate of adjustment to equilibrium is significant at 1 per cent level, it is expected that the difference will be resolved in the long run to restore equilibrium.

Table 8: Regression Results of ECM

Variable	Coefficient	Std. Error	t-statistic	F- statistic	$\overline{R}^2$
$\Delta lnIR$	0.0695	0.0727	0.9568	4.4497*	0.0448
RESID1	-0.2366	0.0812	-2.9123***		
C	0.0120	0.0026	4.6809***		

Notes: * and *** show statistical significance at 10 per cent and 1 per cent, respectively. Δ*lnExR* is the dependent variable in the regression, RESID1 represents residuals, and C is the intercept.

Impulse Response Function (IRF)

Figure 4 shows the impulse responses of the exchange rate to its own shocks and the response of the exchange rate to a Cholesky one standard deviation shock in the interest rate. Figure 5 depicts the response of *INIR* to its own shocks and the response of interest rate to a Cholesky one standard deviation shock in the exchange rate. The top-left diagram in Figure 4 displays the response of the exchange rate to the previous month's exchange rate. The top-right diagram of Figure 4 illustrates the exchange rate's reaction to interest rate shocks.

When the impulse is the exchange rate, the response can be positive or negative at different periods, as shown in Figure 4. Within the first 20 months, the negative response reaches its highest and then declines to its trough or minimum. The positive response reaches its lowest in the 20th month and then rises to its peak in the next 10 months before becoming stable for the rest of the periods. The data indicates that the exchange rate's response to a one standard deviation change in the previous month's exchange rate is significant and does not level off. This means that shocks in lagged exchange rates are irreversible, causing instability in the Ghanaian economy.

Additionally, the exchange rate's reaction to a one standard deviation change in interest rate shock may be positive and negative, with the positive impact reaching its highest point within the first 20 months. The negative effect begins after the 20th month, continues to the 30th, and stabilises for the remaining periods. Although the exchange rate's reaction to the interest rate is close to zero, it is irreversible, highlighting the system's volatility. This confirms that interest rate contributes to exchange rate volatility, which aligns with Table 4, which shows a mutual relationship between *ExR* and *IR*.

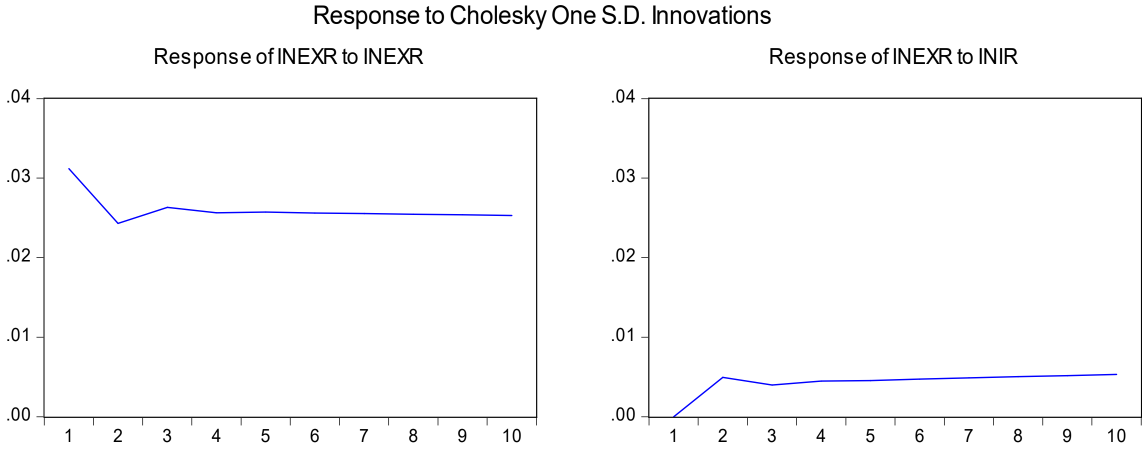

Figure 4: Impulse Response Functions

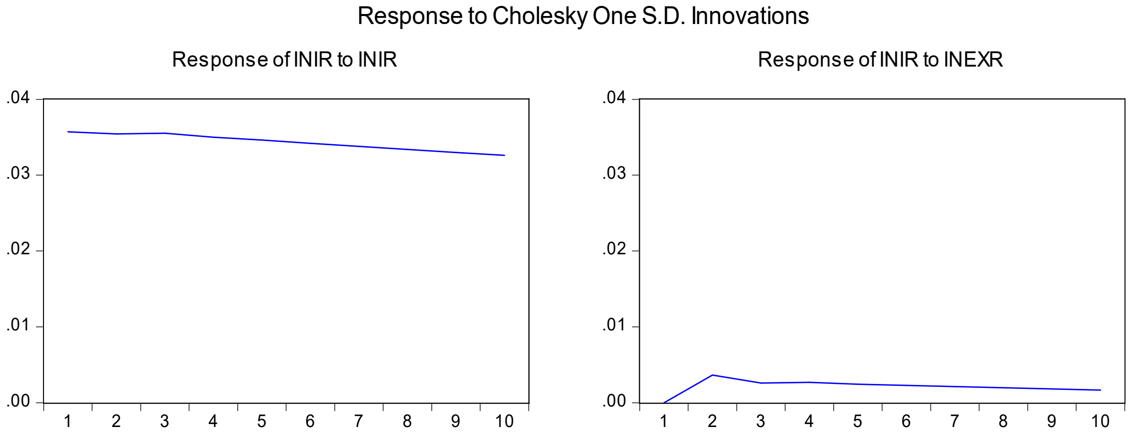

Figure 5: Impulse Response of both Interest Rate and Exchange Rate

Figure 5 shows the effects of Cholesky one standard deviation shock impulse response of the interest rate (INIR) in the error terms u_t^y and u_t^x (in equations 16 and 17) of the *IR* and *ExR* equations. The interest rate reaction to the previous month's interest rate is depicted in the first diagram at the top-left of Figure 5. The top-right diagram in Figure 5 shows the reaction of interest rates to own shocks. The response is consistently negative if the shock originates from the interest rate. But if the shock stems from the exchange rate, the response can be both negative and positive. The positive response starts in the 10th month and increases until it peaks in the 20th month, then declines. After that, the response stays negative for the remaining months.

The Measure of Causality

The indexes ($G_{Y\to X}$ and $G_{X.Y}$) used to measure the degree of causality between *ExR* and *IR* are shown in Table 9. $G_{Y\to X}$ and $G_{X.Y}$ are indexes that calculate the benefit of using $Y_t's$ history while estimating X_t from its past.

The variances of the error terms from autoregressive *ExR* and *IR* forecasts are shown in Table 9 (with one lag period). The indexes should be purely positive if there is a benefit to including the past of Y_t when predicting X_t from its past, but they should be zero if there is no benefit to including the past of Y_t when predicting X_t from its past, $G_{Y\to X}$ is the Granger-type causation. The F-statistic determines how much “Y_t Granger induces X_t.” However, such an estimate could leave the correlation between X_t and Y_t untapped (Dicle & Levendis, 2013). Such estimation does not exploit the contemporaneous or instantaneous feedback between X_t and Y_t; this is the basis for the Geweke measure of linear feedback ($G_{X.Y}$).

The index ($G_{X.Y}$) represents the current relationship between X_t and Y_t, i.e., *IR* and *ExR*. The indexes $G_{Y\to X}$ and $G_{X.Y}$ are both purely positive, indicating that using the history of Y_t in predicting X_t has a benefit. This result is consistent with Table 4, which shows a clear causal link between exchange rate and interest rate at the 1 per cent significance level. These observations also align with the extant literature on *ExR* and *IR* (Karamelikli & Karimi, 2022; Liu & Lee, 2022; Musa et al., 2021; Ghartey, 2019; Sen et al., 2020).

Table 9: Measure of Causality

Measure	Coefficients

$G_{Y\rightarrow X}$	0.9972
$G_{X.Y}$	1.0018
$\sigma^2(X_t\|X^{t-1})$	0.008114
$\sigma^2(X_t\|X^{t-1}, Y^{t-1})$	0.008137
$\sigma^2(X_t\|X^{t-1}, Y^{t})$	0.008123

Conclusion

The Granger causality test was used to uncertain whether there were any causal relations between interest rate and exchange rate. The trend in the exchange rate and interest rate was also assessed. We can infer from the study that both *ExR* and *IR* have a positive trend over time; that there is a two-way causal link between *ExR* and *IR*; that there is a long-run relationship between *ExR* and *IR*; and that there is a benefit to using past interest rate values in explaining exchange rate and vice versa.

Some recommendations are made based on the results of this study. First, stakeholders or investors who invest abroad should consider the relationship between the exchange rate and the interest rate since a change in the domestic interest rate can significantly affect the exchange rate, impacting the cedi value of their investment returns.

Collorary to this, as shown by the impulse response functions in this discourse, an impulse in the exchange rate may have a devastating effect on the domestic interest rate and thus affect foreign investors' returns. Thus, investors must factor into their decision-making matrix that exchange rate shocks can cause interest rate instabilities. Finally, the government and the Bank of Ghana should consider the causal relationships between the interest and exchange rates when making policy decisions.

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Statements and Declarations

Competing Interest: Authors declare that there are no competing interests whatsoever.

Data Availability: The datasets generated during and/or analysed during the current study are available from the corresponding author upon reasonable request.