Gold Prices, Exchange Rates, and Reserves: Econometric Insights into India's Economy

Ashis Kr. Mukherjee[1], Ansh Jethwa[2]

[1]Department of Economics, Nistarini College, Purulia, West Bengal (India)
[2]Student of S.K.B. University, Purulia, West Bengal (India)

Abstract
This study analyses the dynamic interplay between the growth rate of gold prices, rupee-dollar exchange rates, and India's foreign exchange reserves over the period from 1970 to 2018. Applying cointegration and vector error correction models, we will be able to assess long-run and short-run relationships between the variables under investigation. The findings will reveal strong long-run equilibrium relationships and short-run causality among the variables in question and have implications for India's economic scenario. The results will enable policymakers to increase their understanding of these factors and design strategies to stabilize the economy amid global uncertainties.

Introduction:
In India, where gold holds deep cultural significance, it's important to grasp how gold prices relate to currency value and reserves. As an Indian, this relationship is crucial to understanding our economic landscape.
Gold has always been treasured in Indian culture, symbolizing wealth and prosperity. From jewellery worn at weddings to religious artefacts, gold is everywhere. But it's not just about tradition – gold is also important for our economy. It helps protect against rising prices, uncertainty, and changes in currency value.
Currency value, or exchange rates, is another big player. The value of the rupee compared to other currencies, like the dollar, affects how much gold we can buy. When the rupee weakens against the dollar, gold becomes more expensive for us.
Our foreign exchange reserves – the money we keep in other currencies – also matter. India holds a lot of reserves, and part of that is in gold. This gold helps stabilize our economy during uncertain times and gives confidence to investors.
The objective of this article is to delve into the intricate dynamics between gold prices, currency values, and reserves in India. Through analysis of historical trends and data, we strive to gain insight into the enduring correlation between gold prices, exchange rates, and foreign exchange reserves. This knowledge is of great significance to policymakers and individuals with a vested interest in the economic trajectory of India.
As India faces the challenges of a changing world, understanding gold's role can help us make better decisions for our economy. By demystifying this valuable commodity, we can learn lessons that will shape India's economic path forward.

Objective of the study:
The main objectives of this study are:
- To analyse the relationship between the growth rate of gold price, rupee-dollar exchange rate, and foreign exchange reserve.

- To analyse whether the relationships are long-run or short-run phenomena, or both.
- To analyse whether there is any causal relationship between the growth rate of gold price, rupee-dollar exchange rate, and foreign exchange reserve.

Literature review:

Gold, as a vital economic and cultural commodity, has been extensively studied for its relationship with macroeconomic variables like exchange rates and foreign exchange reserves. Existing research highlights its role as a hedge against inflation, a safe-haven asset, and a crucial component in monetary policy.

Shafiee and Topal (2010) used a jump-diffusion model to forecast gold prices over a decade, emphasizing global factors influencing price fluctuations. Other studies, such as Baber et al. (2013) and Sindhu (2013), explored the dynamic interplay of exchange rates, inflation, and international market conditions, consistently finding an inverse relationship between the U.S. dollar and gold prices.

Gangopadhyay et al. (2016) applied vector error correction models to analyze gold prices in India, identifying investment demand and inflation hedging as primary determinants. Similarly, Seshaiah and Tiwari (2017) demonstrated significant relationships between gold prices, crude oil, and macroeconomic indicators using Johansen's cointegration and Granger causality tests.

Recent studies also delve into geopolitical and economic shifts. Arslanalp et al. (2023) observed an increased share of gold in reserves among emerging markets, driven by economic uncertainty and financial sanctions. In contrast, Mahida (2024) found stability in gold's proportion relative to total reserves across major economies, suggesting that reserve management remains unaffected by global volatility.

For the Indian context, Dr. Anu (2022) highlighted the causal impact of exchange rates and foreign exchange reserves on gold prices, using regression models to substantiate a robust positive relationship between these variables. This complements the findings by Jain and Biswal (2019), who emphasized gold's dual role in exchange rate markets and as a hedging instrument.

The broader literature suggests that while gold's price is influenced by external factors like exchange rates and inflation, the dynamics vary across geographical and economic contexts. This study seeks to expand on these findings by analyzing the long-run and short-term relationships among gold prices, exchange rates, and foreign exchange reserves in India, aiming to fill gaps in understanding the interplay of these variables.

Sources of data:

In this study, we use secondary data covering the annual time series of 1970 to 2018 (or 49 observations) in the Indian economy. The data set consists of observations for gold price (Rupees per 10 grams in Mumbai), foreign exchange reserve (₹ crore), and rupee-dollar exchange rates. Maximum data were collected from 'Handbook of statistics on the Indian Economy' (RBI) in the year 2010-11 and 2020-21. Apart from we use the official website of Multi Commodity Exchange Limited (MCX), a leading commodity exchange for metal trade in India.

Methodology: To conduct a comprehensive analysis, we must take into account three crucial variables: the price of gold (gp), the exchange rate between the rupee and the dollar (er), and India's foreign exchange reserves (fer). The time frame under consideration is from 1970 to 2018. Before analyzing the relationship between the price of gold (gp), the rupee-dollar exchange rate (er), and the foreign exchange reserve (fer), the data has been transformed into natural logarithms. In this paper, the relationship between these variables is explained using the following steps:

- In section I**,** we examine the growth rates and trends in gold price, rupee-dollar exchange rates, and foreign exchange reserves. This helps identify patterns and structural changes over time.
- In section II, we test whether the study variables contain unit roots or not. The stationary of each series is tested by using the Augmented Dickey-Fuller method and the Phillips Perron method.

- In section III, we conduct a lag selection method. Using this method, we determine the number of lags appropriate to estimate the model. To estimate the model the number of lagged differences included is determined by LR, FPE, HQIC, SBIC, and AIC methods.
- In section IV, we detect whether there is a long-run relationship exists or not. This is done by using the Johansen test of co-integration.
- In section V, we use the Vector Error Correction Model (VECM) to detect whether as a whole all the lags of the independent variables affect the dependent variable or not.
- In section VI, we explain the stability of the VECM using the method of Eigenvalue. We also explain the impulse response factor and variance decomposition method in this section.
- Finally in section VII, we examine impulse response functions and variance decomposition to understand the dynamic relationships and the contribution of shocks to variable variance.

Model Specification: For the present study, the following model has been used.

gp = f(er,fer)

In log-linear form, the model can be written as ;

$$Loggp = \beta_0 + \beta_1 loger + \beta_2 logfer + €_t$$

Where, Loggp = Logarithmic value of gold price

Loger = Logarithmic value of Exchange rate

Logfer = Logarithmic value of foreign exchange reserve

β_0 = Autonomous part or constant term

β_1 and β_2= Partial slope coefficients

$€_t$ = Random error term

The partial slope coefficient β_1 represents if other things remain constant how one percent changes in rupee-dollar exchange rates affect the percentage change in the gold price on an average, similarly, β_2 represents if other things remain constant how one percent changes in foreign exchange reserves affect the percentage change in the gold price on an average.

Results and discussions:

Section –I

- **Trend and growth rate of gold price and rupee-dollar exchange rates:**

The following figures show the trend and growth rate of gold price, rupee-dollar exchange rate and foreign exchange reserve.

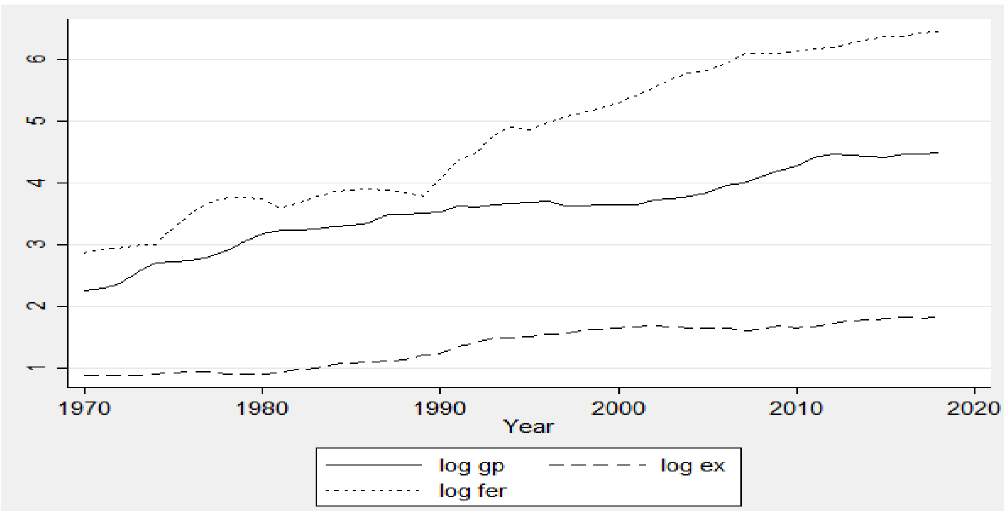


Fig. 1: The trend in the gold price, rupee-dollar exchange rate and foreign exchange reserve.

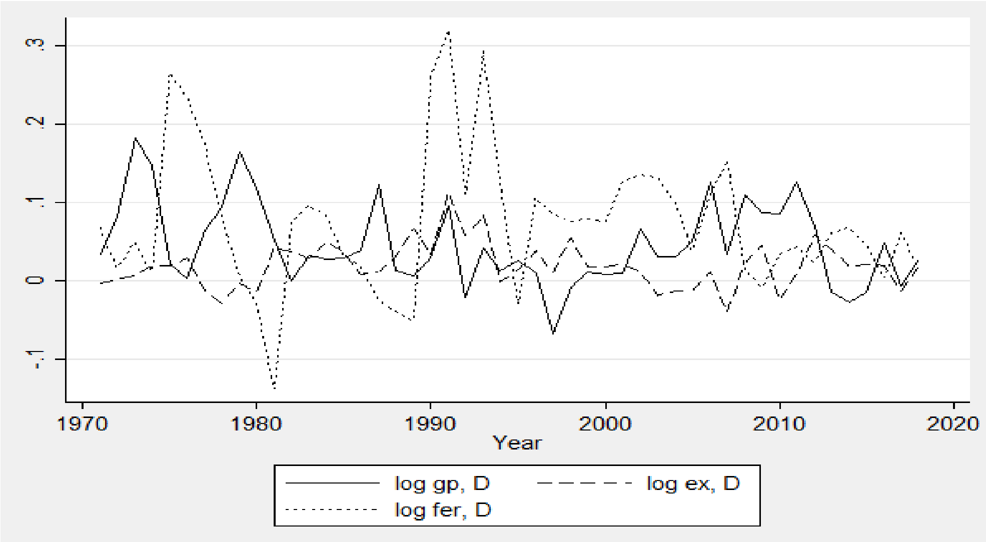


Fig. 2: The trends in Growth in gold price, rupee-dollar exchange rate and foreign exchange reserve.

From the figure 1, it is seen that over the study period, the Y-series gradually goes up i.e. the value of mean and standard deviation of the Y series is not constant over time. So, we suspect that the data is not stationary. The data may be non-stationary in mean or variance or both.

To make the data stationary we consider the first difference of Y-series. The value of the first difference is plotted concerning the year. From the figure 2, we see that there is neither a downward nor an upward trend. In other words, the value of mean and standard deviation may be constant over time and the data converted to a stationary series.

Section –II

Results of Unit Roots Tests:

A random process is said to be stationary if its mean and variance are constant over time and the value of the covariance depends on the lag between two time periods. This type of stationary is also known as a weakly stationary process. There are several ways to test whether a time series data is stationary or not. **Unit root test** is one of the most popular tests to check the stationary of a time series data. Let our model be

$$y_t = \rho y_{t-1} + u_t \quad \dots\dots (i)$$

Where, ρ = Autocorrelation coefficient $(-1 \leq \rho \leq 1)$

U_t = white noise error term satisfies the following assumptions.

i.e. $E(u_t) = 0$, $E(u_t^2) = \sigma^2$, $E(u_t u_s) = 0$ for all $t \neq s$

If ρ=1, then we have

$y_t = y_{t-1} + u_t$

or, $y_t - y_{t-1} = u_t$

or, $\Delta y_t = u_t$

This means that the first difference of the series is stationary.

To check the stationary of a time series data there are several tests. In this paper, we conduct the Augmented Dickey-Fuller test. To ensure accuracy, we also conduct the Phillips-Perron test as a double-check. In both tests, the null hypothesis is

H_0: Presence of unit root or the series is non-stationary.

Against the alternative hypothesis

H_1: Absence of unit root or the series is stationary.
If the value of the test statistic is less than 5% critical value or if the p-value is greater than 5% we accept the null hypothesis that there is a unit root and the series is non-stationary, otherwise the series is stationary. After applying the unit root test the results are as follows:

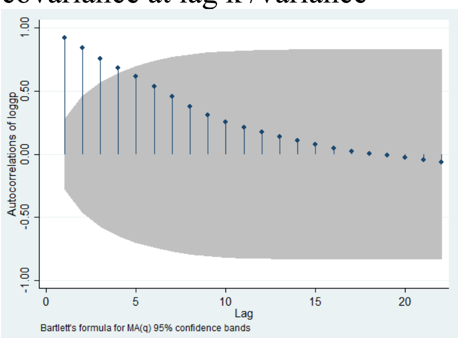
ADF Test				
Variables	Level		First Difference	
	Test statistic	P-value	T-S	p-value
Loggp	-2.376	0.1487	-4.152	0.0008
Logex	-0.421	0.9065	-4.805	0.0001
Logfer	-0.765	0.8290	-4.258	0.0005

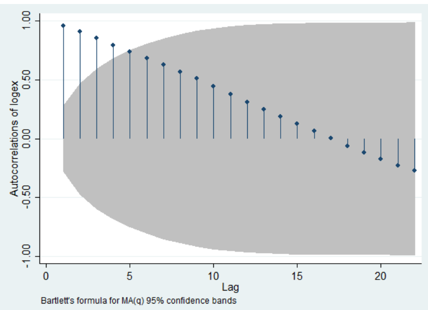
Source: Author's computation using STATA 14 Econometric software.

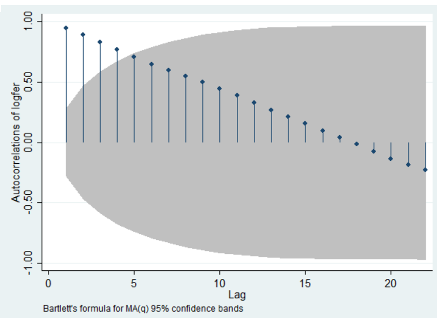
Phillips Perron Test				
Variables	Level		First Difference	
	Test statistic	P-value	Test statistic	p-value
Loggp	Z(rho) = -1.507 z(t) = -2.018	0.2788	Z(rho) = -25.391 z(t) = -4.116	0.0009
Logex	Z(rho) = -0.399 z(t) = -0.493	0.8934	Z(rho) = -33.495 z(t) = -4.882	0.0000
Logfer	Z(rho) = -0.516 z(t) = -0.732	0.8383	Z(rho) = -27.543 z(t) = -4.275	0.0005

Source: Author's computation using STATA 14 Econometric software.

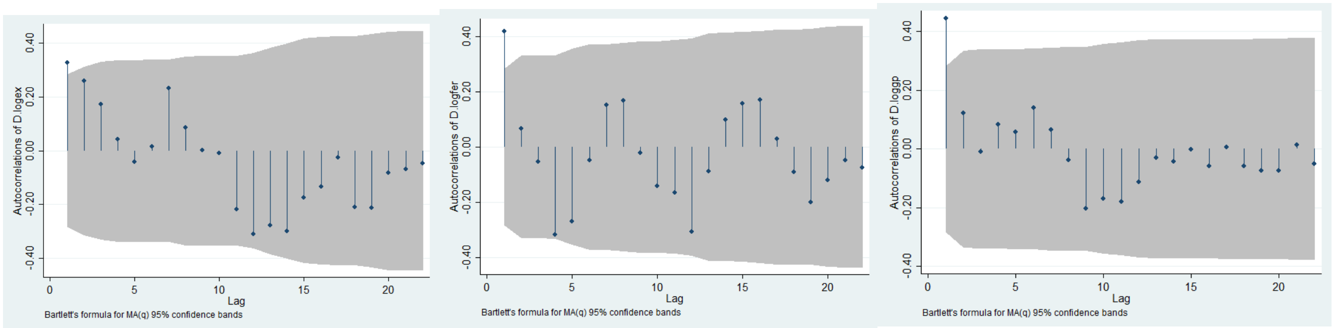
From the table, we see that Loggp, Logex and LER are non-stationary in level. Since the p-value is higher than 5%. This indicates that the statistical significance level is not met and therefore, the null hypothesis cannot be rejected but after taking the first difference they become stationary. Therefore, it may be concluded that all the variables are integrated of order 1. Since the variables are stationary in the first difference, the next step is to judge the long-run association among the variables by conducting a co-integration test. If there is co-integration among the variables we say that the variables have long-run association i.e. there is a long-run relationship between the variables.
Another test for stationary of time series data is the autocorrelation function and use of correlogram. The value of the autocorrelation coefficient of a time series data can be calculated by using the formula, p_k = covariance at lag k /variance







The graphical representation of p_k against different lags is called a Correlogram. The solid vertical straight line represents the zero axis. Observations to the right of the axis are positive and observations to the left of the axis are negative. If the value of p_k at various lag is around zero we can say that the series is stationary, otherwise the series is non-stationary.



The correlograms above show the autocorrelation of the logarithm of Gold price (loggp), an exchange rate (loger) and foreign exchange reserve (logfer) against lag. We can observe a decreasing pattern in Autocorrelation (AC) as the lag increases, AC starts from a high value at lag 1 and then goes down gradually indicative of a potential trend or unit root present in the data. This pattern suggests that nearby observations are correlated, but the correlation diminishes as the time difference between observations increases.

The correlograms above display the autocorrelation of the first difference of the logarithm of gold price (D.loggp), exchange rate (D.logex) and foreign exchange reserve (D.logfer) against lag. Unlike the previous correlogram for logfer, this figure does not exhibit a specific pattern. The absence of a clear autocorrelation pattern suggests that after taking the first difference of the series, the unit root present in the original data has been removed. This indicates that (D.logfer) is stationary, which is a desirable characteristic for further analyses.

Section –III

Results of the Lag-selection Method

Before conducting the co-integration test we have to find out how many lags should be used for estimating the model, lag length determination is an important factor because the larger the lag interval for the variables the more it can reflect the dynamic nature of the model, incorrect lag length can be lead to specification error, incorrect results and cause the problem of autocorrelation.

To choose the appropriate number of lags various information criteria can be used for example Likelihood Ratio (LR), Akaike's Information Criteria (AIC), Schwarz-Bayesain Information Criteria (SBIC) or Hannan-Quinn Information Criteria (HQIC), Final Prediction Error (FPE) all the criteria have a minimum value of lag order one. The result of the lag selection method is shown in the table below;

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-11.3805				0.00038	0.639132	0.684032	0.759576
1	238.806	500.37	9	0	8.40E-09	-10.0803	-9.90067*	-9.59849*
2	247.805	17.998	9	0.035	8.50E-09	-10.0802	-9.76593	-9.23713
3	259.381	23.15*	9	0.006	7.7e-09*	-10.1947*	-9.74569	-8.99025
4	266.175	13.589	9	0.138	8.70E-09	-10.0967	-9.51296	-8.53089

From the table, we see that according to LR, FPE and AIC, the lag should be 3. So, after the comparing Lag Length Criteria, it is found that the optimal lag order for the model is 3.

Section –IV

Cointegration test:- Prof. Clive Granger and Robert Engle offer a solution to the spurious regression problem by introducing the concept of cointegration. It is a technique used to find a possible correlation between the time series process in the long run. There are several types of cointegration tests namely Engle

Granger Cointegration test, Phillips-Ouliaris test and Johanson-Juselius cointegration test. To check the long-run association among the variables we conduct the Johanson-Juselius test of cointegration. The test statistic has two forms.

1. Trace statistic 2. Maximum eigenvalue statistic

From the trace statistic we can evaluate the number of linear combinations (k) in time series data, in this test the null hypothesis is $H_0(k=0)$

Against the alternative hypothesis $H_1(k>0)$

The rejection of the null hypothesis confirms the existence of a cointegration relationship among the variables, on the other hand, the Maximum eigenvalue statistic defines a non-zero vector which, when a linear transformation is applied to it, in this test $H_0(k=0)$

Against the alternative hypothesis $H_1(k=k_0+1)$.

If the null hypothesis is rejected it means that there is only one possible outcome of the variable to produce a stationary process.

The result of the Johanson-Juselius cointegration test is shown in the following table;

maximum rank	parms	LL	Eigenvalue	trace statistic	5% critical value
0	21	239.9445	.	46.4898	29.68
1	26	255.7871	0.49783	14.8045*	15.41
2	29	260.9493	0.20104	4.4801	3.76
3	30	263.1894	0.0928		

At first, we start from rank 0, meaning that no cointegrating relationship among the variables, we see that the value of the trace statistic is greater than the 5% critical value, so we can reject the null hypothesis of no cointegrating relationship among the variables. We move to the next rank in sequence, at rank 1 the value of the test statistic is less than 5% critical value, so we can accept the null hypothesis stating that there is a presence of cointegration in our model at rank 1.

maximum rank	parms	LL	eigenvalue	max statistic	5% critical value
0	21	239.9445	.	31.6852	20.97
1	26	255.7871	0.49783	10.3244	14.07
2	29	260.9493	0.20104	4.4801	3.76
3	30	263.1894	0.0928		

We get the same result from the maximum eigenvalue statistic, in this case, also the value of the test statistic is less than 5% critical value at rank 1. We conclude that there is only 1 cointegrating factor because we cannot reject the null hypothesis for both tests.

Section –V

VECM

Since cointegration has been detected between series, there exists a long-term equilibrium relationship among the variables, the form of VECM is as follows;

$$\partial gp_t = a_0 + \sum_{i=0}^{3} b_i \partial gp_{t-i} + \sum_{i=0}^{3} c_i \partial ex_{t-i} + \sum_{i=0}^{3} d_i \partial fer_{t-i} + \lambda_1 u_{t-1} + u_{1t}$$

$$\partial ex_t = a_1 + \sum_{i=0}^{3} m_i \partial ex_{t-i} + \sum_{i=0}^{3} n_i \partial gp_{t-i} + \sum_{i=0}^{3} o_i \partial fer_{t-i} + \lambda_2 u_{t-1} + u_{2t}$$

$$\partial fer_t = a_2 + \sum_{i=0}^{3} p_i \partial fer_{t-i} + \sum_{i=0}^{3} q_i \partial gp_{t-i} + \sum_{i=0}^{3} r_i \partial ex_{t-i} + \lambda_3 u_{t-1} + u_{3t}$$

The long-run relationship among gold price, exchange rate and foreign exchange rate for one cointegrating vector for India in the period 1970-2020 is displayed below.
When the variables are non-stationary and cointegrated we may use the Vector Error Correction Model (VECM) is also known as restricted VAR, the result of the VECM is shown in the following table,

	Coef.	Std. Err.	z	P>|z|	(95% Conf. Interval)	
D_loggp _cel						
L1.	-0.1112148	0.0508093	-2.19	0.029	-0.2108	-0.1163
loggp						
LD.	0.5094331	0.1494063	3.41	0.001	0.216602	0.802264
L2D.	-0.1778076	0.1336124	-1.33	0.183	-0.43968	0.084068
logex						
LD.	-0.476444	0.3065854	—1.55	0.12	-1.07734	0.124452
L2D.	0.6362994	0.3263812	1.95	0.051	-0.0034	1.275995
logfer						
LD.	0.076717	0.0873974	-0.88	0.38	-0.24801	0.094579
L2D.	-0.026498	0.0801284	-0.33	0.741	-0.18355	0.130551
_cons	0.233216	0.0158615	1.47	0.141	-0.00777	0.05441

The result contains short-run impacts, short-run adjustment coefficient as well as long-run cointegrating relationships among the variables.
All the coefficients are statistically significantly different from 0 since we convert the variables into logarithm and one cointegrating vector is estimated the coefficients can be interpreted as long-run elasticities from the above result we say the appreciation of loggp is related positively with logex and negatively related to logfer. Keeping logfer constant a 1% increase in the exchange rate (ex) will increase in gold price (gp) by 1.0216% on an average, similarly keeping logex constant a 1% increase in the exchange rate (ex) will result in a decrease in gold price (gp) by 0.76268% on an average.
The coefficient -0.1112 is the cointegration term or error correction term implying that if there were any short-term disturbance from the long-run stable relationship such a disturbance could be corrected over time and the long-run relationship would be established. The cointegrating term is also known as the speed of adjustment towards long-run equilibrium, in our analysis the error correction term is negative and also statistically significant so we can say that it is adjusting at the rate of 11.12% towards long-run equilibrium, in other words, there is a long run causality from d(logex) and d(logfer) to d(loggp). All other coefficients except the cointegrating term known as short-run coefficients are statistically insignificant to explain our dependent variable.
The long-run relationship among gold price, exchange rate and foreign exchange rate for one cointegrating vector for India in the period 1970-2018 is displayed below. Regressing loggp on loger and logfer we get the following regression result

Source	SS	df	MS			
Model	15.8165161	2	7.90825804	Number of obs	=	49
Residual	2.05250962	46	.044619774	F(2, 46)	=	177.24
				Prob > F	=	0.0000
				R-squared	=	0.8851
				Adj R-squared	=	0.8801
Total	17.8690257	48	.372271369	Root MSE	=	.21123

loggp	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
logex	-.0318141	.3368588	-0.09	0.925	-.7098757	.6462474
logfer	.496136	.0992298	5.00	0.000	.2963967	.6958752
_cons	1.252317	.1268577	9.87	0.000	.996966	1.507669

On the basis of the above result the estimated regression equation can be written as
Loggp = 1.2523 - 0.3181logex + 0.4961logfer

t-value	(9.87)	(-0.09)	(5.00)
p-value	(0.000)	(0.925)	(0.00)

R^2= 0.8851

All the coefficients except logex is significantly different from 0 since we convert the variables into logarithm and one cointegrating vector is estimated the coefficients can be interpreted as long-run elasticities. The regression analysis reveals that the gold price (loggp) is negatively related to the exchange rate (logex) and positively related to foreign exchange reserves (logfer). Specifically, the estimated equation indicates that a 1% increase in the exchange rate results in a 0.3181% decrease in gold price on an average, while a 1% increase in foreign exchange reserves leads to a 0.4961% increase in the gold price on an average, holding other factors constant.

This negative relationship with the exchange rate suggests that as the local currency depreciates (exchange rate increases), the domestic price of gold, which is priced in USD globally, rises. This higher cost reduces demand, potentially leading to a decline in the market price of gold. On the other hand, the positive relationship with foreign exchange reserves implies that stronger reserves reflect economic stability, supporting gold imports and driving up prices through increased demand.

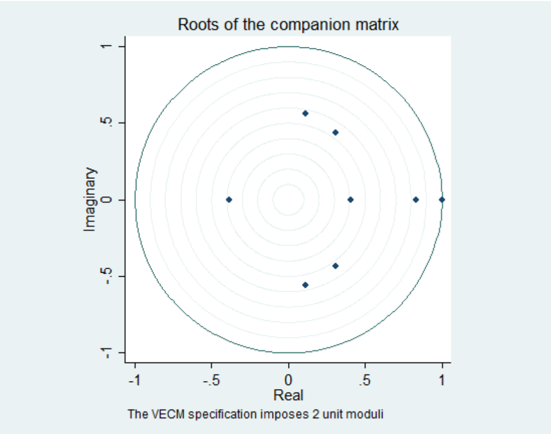
The R^2 value of 0.8851 indicates that approximately 88.51% of the variation in gold prices is explained by the exchange rate and foreign exchange reserves, highlighting the robustness of the model.

Now we want to ensure the VECM is a good fit. The goodness of fit includes the stability test, autocorrelation test and normality of error test.

Section –VI

- ***Test for Stability:***

  In this study, we conduct the test for stability of the estimated VECM. We use the Eigenvalue stability condition. It is seen that the modulus of all roots are less than unity and lies within the unit circle as shown in the following table and figure. All the points lie inside the circle, since there are 3 endogenous variables (k) and one cointegrating equation (x) we have k-x = 3-1 = 2 unit moduli. Which satisfies the stability condition of our model.



Eigenvalue stability condition

Eigenvalue	Modulus
1	1
1	1
.8351997	.8352
.1120226 + .5620455*i*	.5731
.1120226 - .5620455*i*	.5731
.3126392 + .4358891*i*	.536416
.3126392 - .4358891*i*	.536416
.4051139	.405114
-.3850538	.385054

The VECM specification imposes 2 unit moduli.

- ***Test for Autocorrelation:***

To examine the presence of autocorrelation in our model we have to conduct an autocorrelation LM test. The LM statistic follows a chi-square distribution with nine degrees of freedom. We set two hypotheses,
The null hypothesis is H_0: No autocorrelation in the model.
Against the alternative hypothesis H_1: There is a problem of autocorrelation.
The result of the LM test is shown in the following table

Lag	Chi-square	df	p-value
1	7.1128	9	0.62537
2	5.4708	9	0.79149

The above result shows that the value of the computed test statistic (LM Lagrange Multiplier Statistic, follows a Chi-square distribution.) is statistically significant even for (as p-value is greater than .05) even for lag 1 when leads to acceptance of null hypothesis meaning that absence of serial correlation in our model.

- ***Test for Normality of the Residuals:***

To test that the residuals are normally distributed in the VAR model we can use the Jarque - Bera test. The Jarque - Bera statistic follows the chi-square distribution. Here the null hypothesis is
H_0: residuals are normally distributed.
Against the alternative hypothesis
H_1: residuals are not normally distributed.
The result of the Jarque Bera test is shown in the following table

D_loggp	1.171	2	0.55694
D_logex	1.075	2	0.58409
D_logfer	4.911	2	0.08583
ALL	7.157	6	0.30658

From the above result, we say that the residuals are normally distributed. In this case, the p-value is greater than 5%, so there is no reason to reject the null hypothesis and say that the residuals of D_ log GP are normally distributed.

Section –VII

Impulse response function - The impulse response function traces out the response of the dependent variable to shocks in the error term, here responses of different endogenous variables to shocks are shown by the solid line. Analysing these impulse responses we can say that time required by each endogenous

variable to revert back the long-run equilibrium base following shocks. Our target is, if we have a positive shock of one SD to u1 to see the reaction of the variables.
They are useful in understanding the dynamic behaviour of variables in the system, it is an effective tool to predict the affect of shocks and policy analysis.

Conclusion:
In this study, we conducted a comprehensive analysis of the relationship between gold prices, exchange rates, and foreign exchange reserves. Through a series of econometric tests including unit root tests, lag order selection tests, long-run causality tests, cointegration tests and Vector Error Correction Model (VECM) analysis, we aimed to uncover the underlying dynamics among these key economic variables. Notably, we observed a negative correlation between the growth rate of gold price and foreign exchange reserves, coupled with a positive association between the growth rate of gold price and the exchange rate. Employing advanced statistical methods, we established the presence of both short-run impacts and long-run cointegrating relationships among these variables.
These findings hold significant implications for policymakers and stakeholders alike. Understanding these intricate relationships is pivotal for fostering economic stability and bolstering investor confidence within India. By recognizing the nuanced dynamics at play, policymakers can make informed decisions to navigate economic challenges and optimize growth opportunities. Thus, our study contributes valuable insights to the ongoing discourse surrounding India's economic landscape, paving the way for more informed and strategic decision-making.

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