Modeling Indonesian Gold Price Dynamics Using Artificial Intelligence and Vector Error Correction Model (VECM)

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ABSTRACT
This study aims to examine the extent to which key macroeconomic variables namely inflation, the USD exchange rate, and interest rates significantly influence gold prices in Indonesia. By identifying price trends and patterns, the research seeks to determine the most relevant variables for inclusion in subsequent studies focused on forecasting future gold prices for Bullion Business.
The study employs the Vector Error Correction Model (VECM) to analyze long-term relationships, utilizing monthly time-series data from 2013 to 2025. Additionally, it incorporates Artificial Intelligence techniques to enhance predictive analysis. This research also addresses the limited contribution of Indonesian scholars over the past three years, both in Indonesian- and English-language publications, particularly in studies integrating long-term time-series data and advanced analytical methods. The results indicate that all datasets are nonlinear and non-stationary, making the VECM approach unsuitable, despite conducting the Augmented Dickey-Fuller test and applying second-order differencing.

Keyword: Vector Error Correction Model; Gold Price; Artificial Intelligence; Python; Exchange Rate

ABSTRAK
Penelitian ini bertujuan untuk mengkaji sejauh mana variabel-variabel makroekonomi utama, yaitu inflasi, nilai tukar USD, dan suku bunga, secara signifikan memengaruhi harga emas di Indonesia. Dengan mengidentifikasi tren dan pola harga, penelitian ini berupaya menentukan variabel yang paling relevan untuk dimasukkan dalam studi lanjutan yang berfokus pada peramalan harga emas di masa depan untuk Pebisnis Emas Batangan.
Penelitian ini menggunakan metode Vector Error Correction Model (VECM) untuk menganalisis hubungan jangka panjang dengan memanfaatkan data runtun waktu bulanan periode 2013 - 2025. Selain itu, penelitian ini juga mengintegrasikan teknik Artificial Intelligence untuk meningkatkan akurasi analisis prediktif. Penelitian ini turut menjawab keterbatasan kontribusi akademisi Indonesia dalam tiga tahun terakhir, baik dalam publikasi berbahasa Indonesia maupun Inggris, khususnya pada studi yang menggabungkan data runtun waktu jangka panjang dan metode analisis lanjutan. Hasil penelitian menunjukkan bahwa seluruh dataset bersifat nonlinier dan tidak stasioner, sehingga pendekatan VECM tidak sesuai digunakan, meskipun telah dilakukan uji Augmented Dickey-Fuller dan penerapan diferensiasi dua kali.

Kata kunci: Model Koreksi Kesalahan Vektor; Harga Emas; Kecerdasan Buatan; Python, Nilai Tukar

INTRODUCTION

The world already experience gold price fluctuation for centuries but in the modern financial era, significant and continuous price fluctuations began in 1971. Specifically in Indonesia, significant gold price fluctuations became more visible starting in the early 1980s, but major and sustained volatility began around 1997-1998.

The most critical turning point was the Asian Financial Crisis (1997-1998), which severely affected the Indonesian rupiah. During this period, the rupiah depreciated sharply, causing domestic gold prices to surge dramatically even if global gold prices were relatively stable because gold in Indonesia is priced in USD and

converted into rupiah (Hill, 2026).

Between 2000 and 2026, gold prices in Indonesia have shown a strong upward long-term trend with several periods of high volatility, largely influenced by global gold prices and rupiah exchange rate movements. Between 2000 – 2007 is the period of gradual increase as the Indonesian gold prices rose steadily driven by global commodity boom and weakening USD. In this period Rupiah relatively stable compared to the 1998 crisis period.

2008 - 2011 is sharp surge period where there were major spike during and after the global financial crisis. Investors shifted to gold as a safe-haven asset which caused domestic prices increased significantly due to both global price increases and exchange rate effects. Within 2010 to 2015 prices declined after the 2011 global peak but stronger USD pressured global gold prices. Indonesian gold prices automatically adjusted but remained higher than pre-2008 levels.

In the moderate growth period within 2016 – 2019 there was gradual recovery in global gold prices. Unfortunately since Rupiah fluctuated, it contributed to domestic volatility. Due to covid period in 2020 – 2021, gold reached historic highs globally. While within 2022 – 2026, it continued high volatility driven by global inflation, interest rate hikes and geopolitical tensions. While public expected gold price will adjusted properly, prices remain structurally higher compared to early 2000s levels.

In overall conclusion, within 2000 – 2026 it has been long-term upward trend with high sensitivity to USD exchange rate and major volatility during crisis periods 2008 and 2020. The structural price level significantly higher than early 2000s (Kahn et al., 2019).

LITERATURE REVIEW

Empirical research conducted in Indonesia has provided important insights into the determinants of domestic gold prices. A study by (Fadhel Kesarditama et al., 2020), which analyzed data covering the 2014–2019 period, found a positive relationship between the rupiah exchange rate and gold prices in Indonesia. Specifically, the findings indicate that a depreciation of the rupiah against the US dollar leads to an increase in domestic gold prices. This outcome reflects the fundamental pricing mechanism of gold in international markets, where gold is denominated in USD; consequently, when the rupiah weakens, the cost of gold rises in rupiah terms even if global prices remain unchanged.

In contrast, (Dimas Nugroho Dwi Seputro et al., 2024) approached the issue from a different perspective by positioning interest rates as the dependent variable. Using a similar time-series framework covering the 2020–2024 period and applying a multiple linear regression method, their study examined the relationship among inflation, gold prices, and Bank Indonesia's monthly interest rates. The findings demonstrate that both inflation and gold prices significantly influence Bank Indonesia's monthly interest rate, suggesting a dynamic interaction between monetary policy variables and commodity price movements in the Indonesian context.

The majority of the aforementioned studies employed multiple linear regression techniques, which inherently assume a linear relationship between independent and dependent variables. Under this framework, both datasets are treated as linearly related, and no logarithmic transformation or other functional modifications were applied to address potential non-linear characteristics in the data. As a result, the analytical approach may not fully capture complex dynamic interactions or structural adjustments that are often present in macroeconomic and financial time-series data (Ralph B. D'Agostino, 2017).

In a more recent study, (Umi Khozinatul Khoiriyah et al., 2025) examined the 2020–2024 period using a different methodological approach, namely the Error Correction Model (ECM). By incorporating short-run dynamics and long-run equilibrium relationships, the study found that the US dollar exchange rate and inflation exert a statistically significant influence on gold prices in Indonesia, whereas interest rates were found to be insignificant. This methodological shift provides a more comprehensive framework for analyzing cointegrated time-series data compared to standard linear regression models.

Nevertheless, academic contributions published between 2023 and 2025 that directly address gold price modeling in Indonesia remain relatively limited. While some related studies exist, they are often not explicitly focused on domestic gold price determinants. For example, (Rizaldy et al., 2022) concentrated on forecasting future gold prices for trading purposes rather than examining the structural determinants of current gold prices within the Indonesian macroeconomic context. This indicates a continuing research gap in the development of

comprehensive gold price models specifically tailored to Indonesia.

RESEARCH METHOD

Based on the last alinea of the introduction above that within 2000 - 2026 has been long-term upward trend with high sensitivity to USD exchange rate and major volatility during crisis periods 2008 and 2020. The structural price level significantly higher than early 2000s. The vector error correction model (VECM) is used to address particularly the 2000–2026 period because it includes multiple structural shocks and different economic regimes.

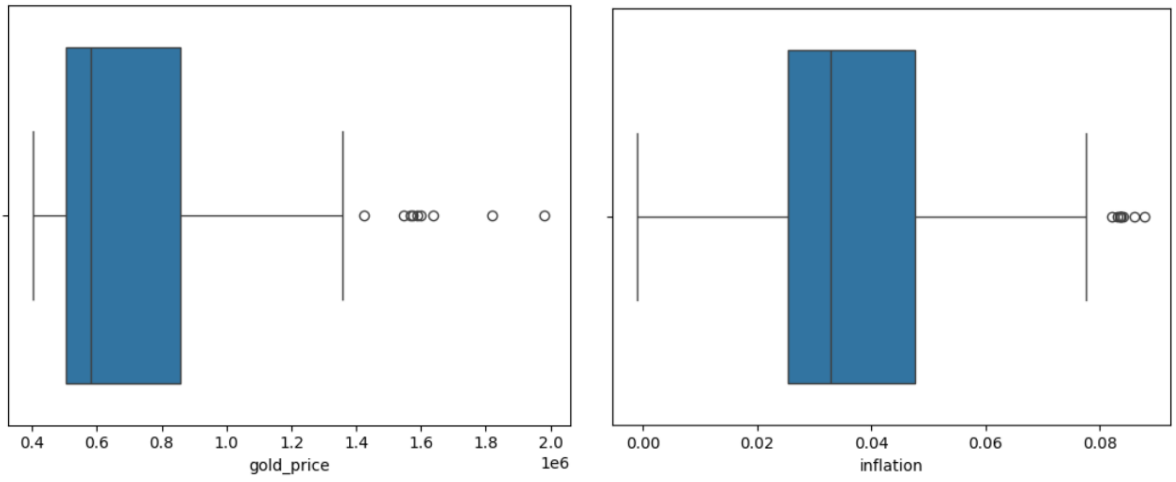
The dataset utilized in this study is a secondary dataset obtained from Statistics Indonesia (BPS /Badan Pusat Statistik) and Bank Indonesia, covering the period from 2013 up to 2025. Gold price as dependent variable is sourced from Indonesian Statistics and are denominated in IDR as a dependent variable (BPS, 2025). Three independent variable i.e. inflation, interest and IDR-USD exchange rate are sourced from the Central Bank of Indonesia (Bank Indonesia - SEKI, 2025)

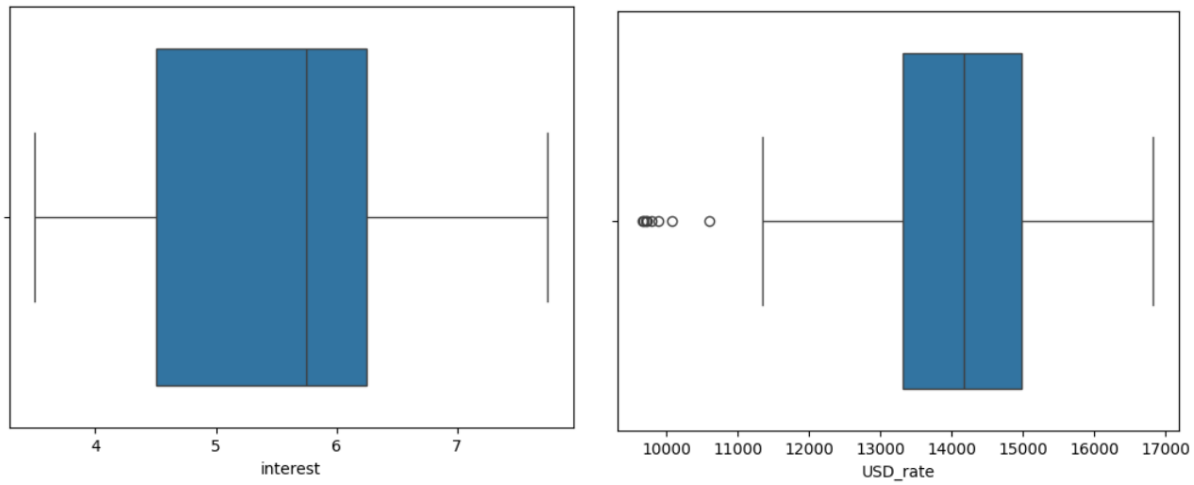
Before commencing the data preprocessing stage, all four datasets were subjected to a comprehensive data cleaning procedure. The missing gold price observations for the year 2021 were completed using data obtained from (Bullion-Rates.com, 2025), as these figures were closely aligned with the corresponding monthly data reported by Indonesian Statistics.

Aside from these supplemented values, the remaining datasets were verified and found to contain no missing entries, duplicate records, or other detectable inconsistencies, indicating that the data were suitable for subsequent analysis.

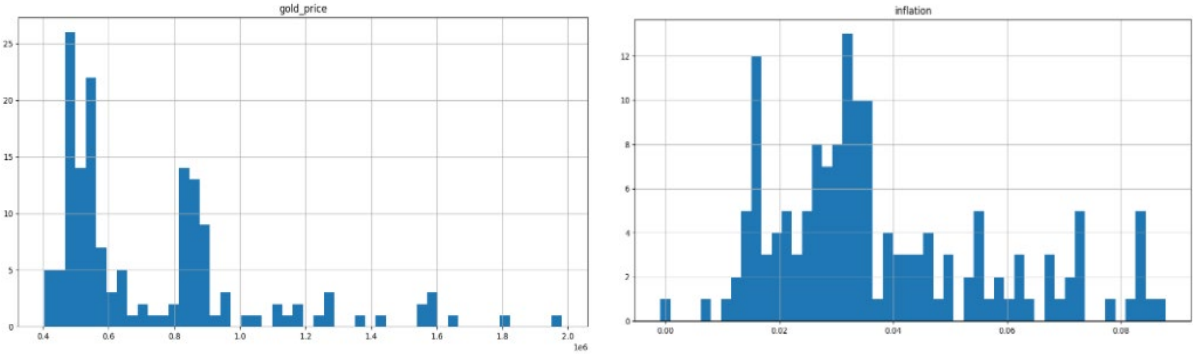
After preprocessing the whole independent and dependent datasets to ensure them normalized and ends up to feature engineering. The last stage is data validation to ensure whether our data is correct, consistent, and suitable for analysis or AI modeling by using Python coding prior training the model with VECM Method. Visual Analysis as exploratory data analysis (EDA) is used to assess whether the data exhibit good data distribution and whether linear or non-linear patterns as depicted in Picture 1, 2 and 3.

The result shows that some data well-distributed and some others not, while one are linear and non-linier for the others. Due to the dataset results as mentioned above, we do differencing which helps in stabilizing variance. The variance stabilization by using differencing is done with Python coding : data_diff = df_numeric.diff().dropna().

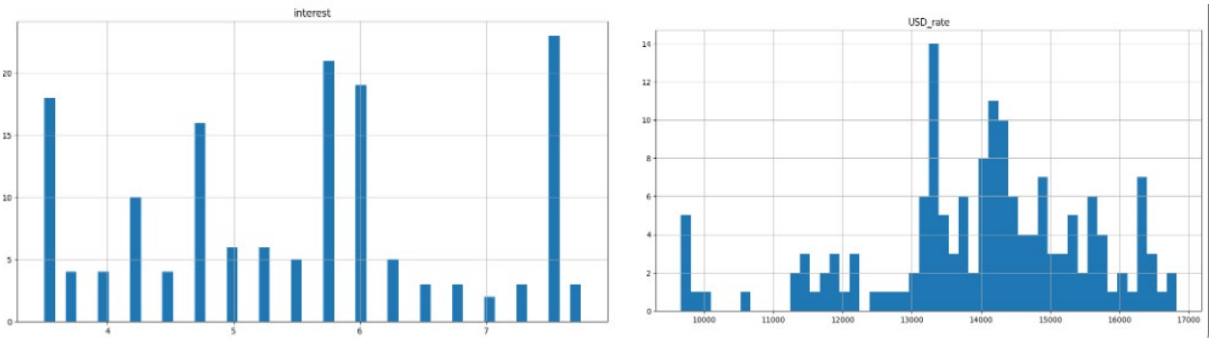




Picture 1. Data Distribution of Gold Price, Inflation, Interest and USD exchange rate within 2013 - 2025



Picture 2. Exploratory Data Analysis (EDA) Histogram Gold Price and Inflation within 2013 – 2025



Picture 3. Exploratory Data Analysis (EDA) Histogram Interest and USD Exchange Rate within 2013 – 2025

RESULT AND DISCUSSION

Prior doing VECM, we must do Augmented Dickey-Fuller test (ADF Test) to check whether the dataset is stationary or non-stationary, followed by Johansen Cointegration Test. ADF Test must be done as VECM requires variables to be I(1).

```
ADF Test for gold_price
ADF Statistic: 5.8178527072365
p-value: 1.0
----------------------------
ADF Test for inflation
ADF Statistic: -1.8365618698579023
p-value: 0.36246668701056495
----------------------------
ADF Test for interest
ADF Statistic: -1.7918337289011252
p-value: 0.38452349143681613
----------------------------
ADF Test for USD_rate
ADF Statistic: -2.3357998838145657
p-value: 0.16068155426571745
----------------------------
```

Picture 4. Result From ADF Test

Unfortunately all variables in dataset show non-stationary based on decision rule that if p-value < 0.05 → Reject H_0 → Stationary, while if p-value > 0.05 → Fail to reject H_0 → Non-stationary as can be seen in Picture 4. After we take first difference of all variables, then re-run ADF test again on the differenced data, they remind non-stationary. The second differencing followed by ADF test also results the same as depicted in Picture 5.

```
ADF Test for gold_price
ADF Statistic: 5.8178527072365
p-value: 1.0
----------------------------
ADF Test for inflation
ADF Statistic: -1.8365618698579023
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p-value: 0.38452349143681613
----------------------------
ADF Test for USD_rate
ADF Statistic: -2.3357998838145657
p-value: 0.16068155426571745
----------------------------
```

Picture 5. Result From ADF Test after 2nd differencing

Based on this test, we cannot force to use VECM. Very importantly in academic perspective we should not manipulate differencing just to make VECM possible, particularly it has been done twice with no significant result. Since the variables remain non-stationary after first differencing, the integration order exceeds I(1), violating the standard assumptions of the VECM framework. Therefore, alternative modeling strategies must be considered.

CONCLUSION AND SUGGESTION

From the above analysis can be concluded that it would be methodologically inappropriate to impose the use of the VECM approach. From an academic standpoint, researchers must avoid manipulating the order of differencing merely to satisfy the technical requirements of a particular econometric model, especially when the differencing procedure has already been applied twice without producing statistically

meaningful outcomes. Given that the variables continue to exhibit non-stationary behavior even after first differencing, their order of integration exceeds I(1), thereby violating the fundamental assumptions underlying the VECM framework.

Consequently, it is necessary to consider alternative modeling strategies that are theoretically sound and empirically consistent with the statistical properties of the data. In the next research we can apply other method which is sutable for the datasets that are non-linier such as Markov-Switching Models, Nonlinear ARDL and Artificial Neural Networks.

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