

DYNAMICS OF INDONESIA'S FOREIGN EXCHANGE RESERVES IN THE FACE OF EXCHANGE RATE AND EXPORT SHOCKS

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ABSTRACT

Foreign exchange reserves are a fundamental instrument of macroeconomic policy, particularly for Indonesia as an open economy with a managed float exchange rate. Rupiah exchange rate volatility and export performance, particularly in primary commodities such as coal, palm oil, and nickel, have made foreign exchange reserves increasingly vulnerable to external shocks, as reflected in periods of historical stress such as the 1997-1998 Asian Crisis and the COVID-19 pandemic. This study aims to systematically analyze how exchange rate and export shocks affect the dynamics of Indonesia's foreign exchange reserves within a structural time series model.

The study uses a quantitative approach with the Vector Error Correction Model (VECM) method based on monthly data from January 1990 to December 2023 (405 effective observations), sourced from the Federal Reserve Economic Data (FRED). The variables for foreign exchange reserves, exports, and the IDR/USD exchange rate are transformed into natural logarithms and tested using ADF, Phillips-Perron, Johansen cointegration tests, and Impulse Response Function (IRF) and Forecast Error Variance Decomposition (FEVD) analyses.

All variables are confirmed to be integrated at order one, $I(1)$, with one significant cointegration vector (trace statistic $33.66 > 5\%$ critical value of 29.68). The long-run elasticity of exports to foreign exchange reserves of 1.04 indicates a nearly proportional relationship. The error correction term coefficient of -0.0347 indicates an adjustment speed of 3.47% per month (half-life ± 20 months). In the short run, the Rupiah depreciation one month earlier was shown to reduce foreign exchange reserves (-0.0857) while increasing exports (0.5383), confirming Bank Indonesia's countercyclical intervention and exchange rate transmission to export competitiveness.

The results of this study confirm that Indonesia's foreign exchange reserves are determined by the dynamic interaction between export performance and exchange rate volatility, with a transmission mechanism across various timescales. Sustainable strengthening of foreign exchange reserves requires a comprehensive strategy, including export diversification into high value added manufacturing products, sound exchange rate management, and strengthening foreign exchange export (DHE) policies. Further research is recommended, applying the Nonlinear VECM and comparative studies with ASEAN countries.

Keywords: VECM, Foreign Exchange Reserves, Exchange Rate, Exports, Macroeconomic Shocks.

1. INTRODUCTION

Foreign exchange reserves are one of the most fundamental instruments in a country's macroeconomic policy apparatus. For Indonesia, as an open economy with a managed float exchange rate regime, foreign exchange reserves have three main, interrelated functions: as a buffer against short-term exchange rate volatility, as a signal of monetary policy credibility to international financial markets, and as an instrument for meeting international obligations and financing imports under external pressures.

This topic's relevance is heightened in the context of post COVID-19 global dynamics, the normalization of monetary policy in developed countries, particularly the aggressive interest rate hikes by the United States Federal Reserve in 2022-2023, and geopolitical uncertainty impacting global supply chains and commodity prices. These external pressures directly impact two primary channels for the formation of Indonesia's foreign exchange reserves: rupiah exchange rate volatility and export performance, particularly primary commodity exports such as coal, palm oil, and nickel.

Bank Indonesia data shows that Indonesia's foreign exchange reserves experienced significant fluctuations throughout the study period. At the peak of the global commodity price increase in 2022, Indonesia's foreign exchange reserves reached approximately USD 137 billion at the beginning of the year, but subsequently declined due to a combination of rupiah depreciation and capital outflows. This phenomenon reflects the dynamic interaction between the three main variables in this study: the exchange rate, exports, and foreign exchange reserves.

Historically, Indonesia has experienced several episodes of significant foreign exchange reserve pressure. The 1997-1998 Asian financial crisis nearly depleted Indonesia's foreign exchange reserves and forced the country to seek IMF assistance. The 2008-2009 global financial crisis caused a short-term decline of approximately 20%. The 2013 "taper tantrum" episode again put Indonesia under pressure, with foreign exchange reserves falling from USD 112 billion at the start of 2013 to approximately USD 92 billion by the end of the same year. This historical experience underscores the vulnerability of Indonesia's foreign exchange reserves to external shocks.

This study aims to systematically analyze how exchange rate shocks and export shocks affect the dynamics of Indonesia's foreign exchange reserves within a structural time series model. Using monthly data from the Federal Reserve Economic Data (FRED) for the period 1990–2023, this study provides an analysis spanning various economic cycles, from the 1997–1998 Asian crisis to the COVID-19 pandemic and the post-pandemic era.

To position this research in the global literature and systematically identify research gaps, a two-stage bibliometric analysis was conducted using data from 10 Scopus-indexed documents

(2025–2026) with the search keywords: "exchange rate", "foreign exchange reserves", "financial crisis", and "exchange market intervention". The analysis used two tools (1) the biblioshiny package in R Studio for descriptive analysis and TreeMap keywords and (2) VOSviewer for co-occurrence network mapping and temporal overlay analysis.

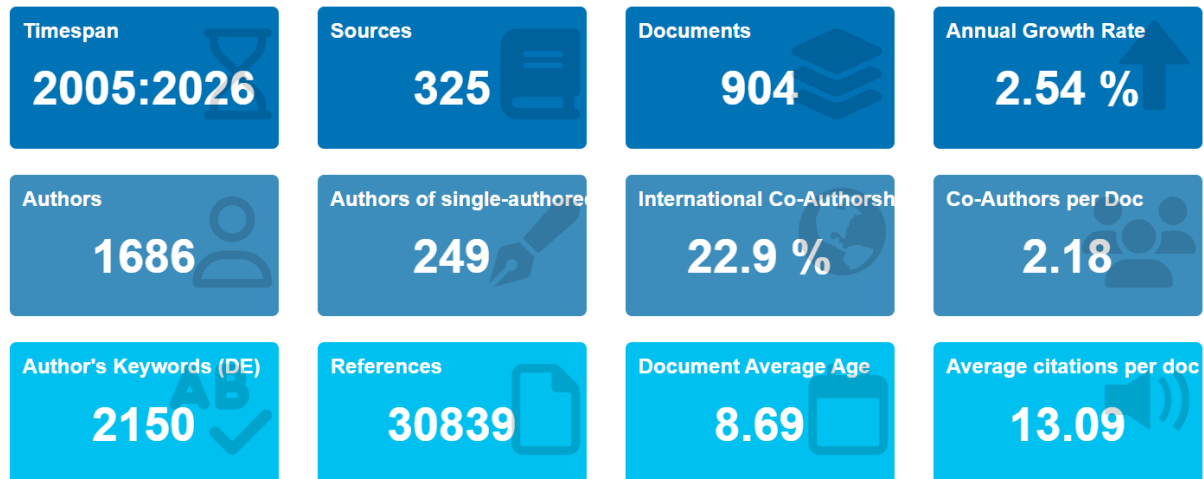


Figure 1. Main Information from the keyword “Foreign Exchange Reserve” & “Exchange Rate”

1.2 Bibliometric Analysis: State of the Art

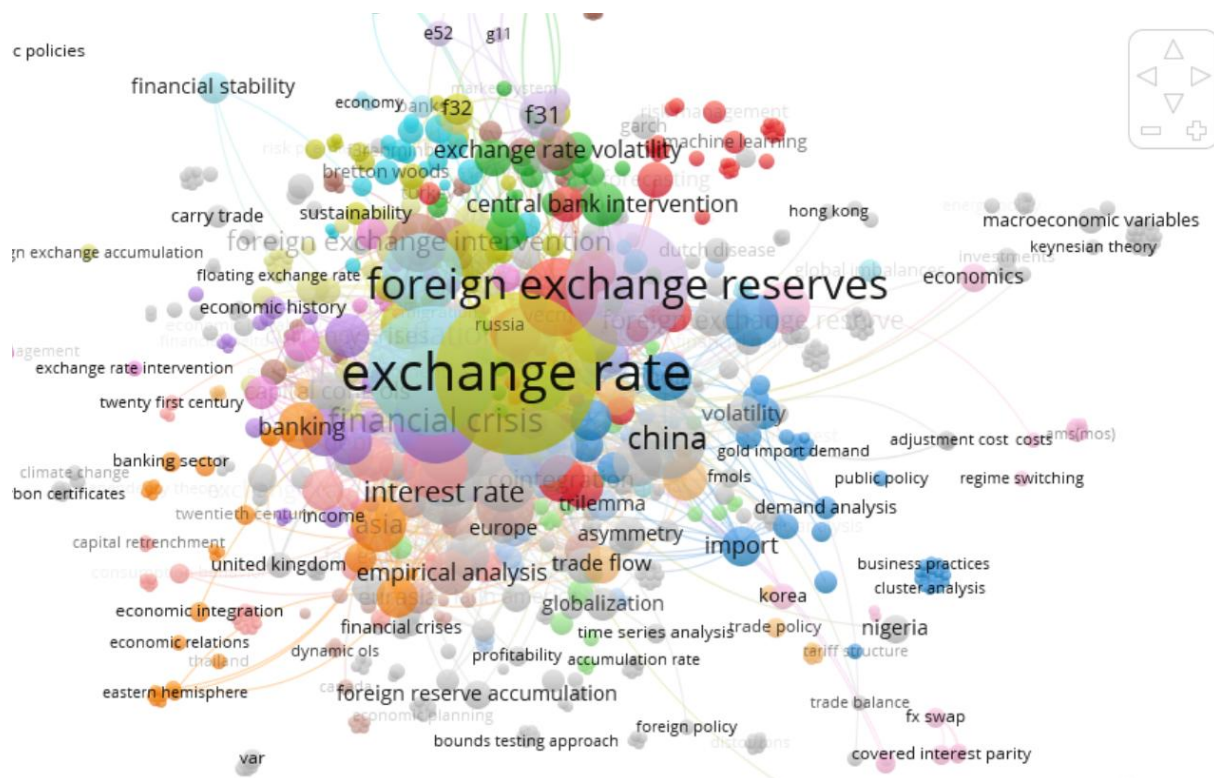


Figure 2. Results of Bibliometric Analysis of the keyword "*Foreign Exchange Reserve*" & "Exchange Rate"

To identify the position of this research in the global literature, a bibliometric analysis was conducted on 904 documents indexed in Scopus using the keywords 'foreign exchange reserves', 'exchange rate', and 'exports'. The analysis used VOSviewer software to generate network visualizations and overlay visualizations of keyword co-occurrence. The documents used were published between 2005 and 2026, and written by 1,686 authors with an international collaboration rate of 22.9%. These documents were distributed evenly across 325 different journals, including Finance Research Letters, International Economics, Journal of Economic Asymmetries, and Singapore Economic Review, all of which are highly reputable mainstream economics journals. This journal distribution indicates that the topic of foreign exchange reserves and exchange rates is widely accepted across various segments of international economics publications.

Bibliometric analysis of Scopus exports (data as of May 2026) shows that research in this domain is clustered into four main clusters. The first cluster is dominated by the keywords 'foreign exchange reserves', 'exchange rate', and 'monetary policy', reflecting the literature on optimal reserve holding and central bank intervention policies. The second cluster focuses on 'export performance', 'trade balance', and 'current account', reflecting the international trade perspective on foreign exchange reserve formation. The third cluster includes 'vector autoregression', 'impulse response', and 'Granger causality', representing the time series methodology that dominates empirical research. The fourth cluster focuses on 'emerging markets', 'capital flows', and 'financial crisis', emphasizing the context of developing countries.

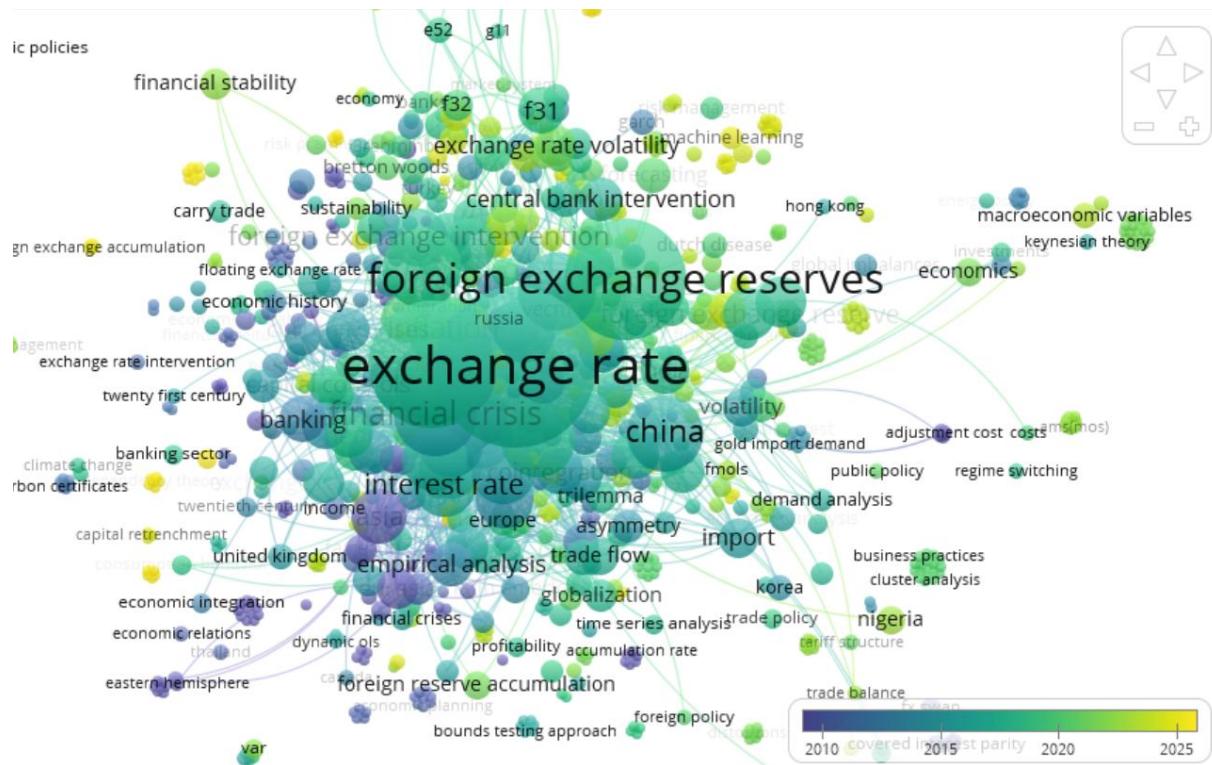


Figure 3. Overlay Visualization Results of the keyword "Foreign Exchange Reserve" & "Exchange Rate"

An overlay visualization analysis that maps the average publication year of each keyword reveals that recent research (2010 - 2025) tends to focus on 'Exchange Rate', 'foreign exchange reserve', 'China', and 'Financial Crisis'. Older keywords (2010 - 2015) are dominated by 'volatility', 'banking', and 'economic history', reflecting the heavy influence of Aizenman & Lee (2007) in this literature.

The identification of research gaps from bibliometric analysis reveals several important gaps. First, although VECM studies for foreign exchange reserve analysis are quite common in the context of China and Korea (as the two largest foreign exchange reserve holders in Asia), research specifically applying VECM with high-frequency (monthly) data for Indonesia is still limited. Second, the majority of Indonesian studies use quarterly data and standard VAR methodology without structural identification, leaving gaps in understanding structural causal relationships. Third, long-term data coverage (1990-2023) that encompasses multiple crisis episodes is rarely used, even though it is necessary to identify whether the response of foreign exchange reserves is asymmetric between periods of economic expansion and contraction.

1.3 *TreeMap* (*Biblioshiny*)

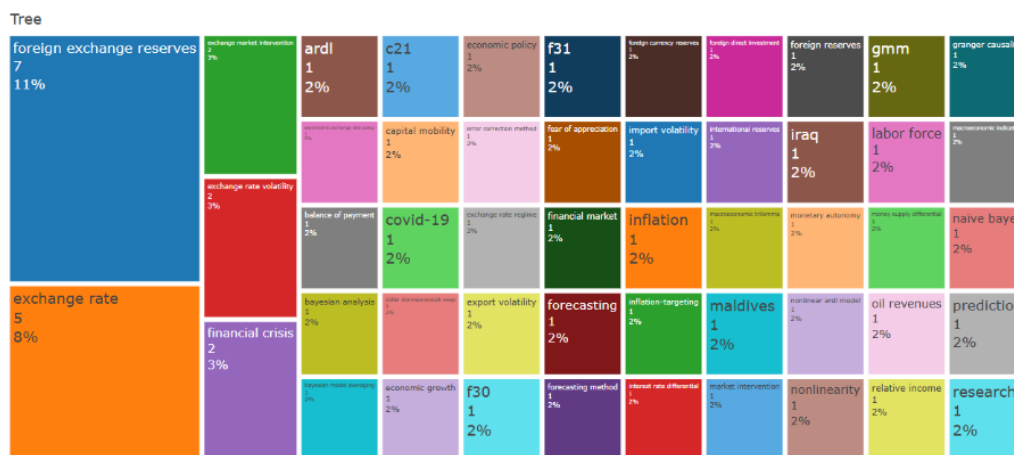


Figure 4. TreeMap results from the keyword “Foreign Exchange Reserve” & “Exchange Rate”

TreeMap visualization confirms the hierarchy of keyword frequencies in the analyzed literature. The two most dominant keywords are "foreign exchange reserves" with a proportion of 11% (frequency of occurrence 7 times) and "exchange rate" with a proportion of 8% (frequency of occurrence 5 times). The dominant position of these two keywords confirms the central relevance of the variables used in this study.

Medium-sized keywords (3% each) include "exchange market intervention," "exchange rate volatility," and "financial crisis." This pattern suggests that the literature specifically examines foreign exchange reserves as an intervention instrument during volatility or crises, similar to the mechanism modeled in this study's VECM framework. Furthermore, the emergence of methodological keywords such as ARDL indicates the diversity of empirical approaches in this domain, validating the choice of VECM as an approach that complements (rather than duplicates) existing studies.

1.4 Research Questions and Research Contributions

Based on the background and identification of the research gap above, this study formulates three main research questions.

1. How is the dynamic response of Indonesia's foreign exchange reserves to exchange rate shocks (Rupiah depreciation shock) within the VECM framework with monthly data from 1990 to 2023?
2. How large is the relative contribution of exchange rate shocks and export shocks in explaining variations in Indonesia's foreign exchange reserves over various time periods?
3. Is there a difference in the response pattern of foreign exchange reserves during the crisis sub-period compared to the normal period?

This research's contributions span three dimensions. Methodologically, this study is one of the first to apply VECM with recursive restrictions to long-term monthly data (405 observations) in the Indonesian context, providing more efficient estimations and more robust results than previous studies using quarterly data. Empirically, the data coverage, which encompasses six crises or major external pressures, allows for a more comprehensive analysis of the behavior of Indonesia's foreign exchange reserves under various conditions. Policy-wise, the findings of this study can inform Bank Indonesia's foreign exchange reserve management framework in the context of increasing global volatility.

2. LITERATURE REVIEW

2.1 Optimal Foreign Exchange Reserves Theory

The theory of optimal foreign exchange reserves has evolved through two distinct but complementary intellectual traditions. The first is the buffer stock approach pioneered by Frenkel and Jovanovic (1981), which models the determination of optimal foreign exchange reserves as a trade-off between opportunity cost (the cost of holding low-yielding assets) and adjustment cost (the cost of adjusting policy due to reserve inadequacies). In this model, a country will have optimal reserves that minimize total expected cost, and observed reserves should move around this optimal target with partial adjustments.

The Frenkel-Jovanovic buffer stock model has been significantly expanded and modified in subsequent literature. Ben-Bassat and Gottlieb (1992) added a sovereign default risk component, arguing that countries maintain foreign exchange reserves in part to prevent a default on external debt that could exclude them from international capital markets. Jeanne and Rancière (2011) developed a more formal insurance model, in which foreign exchange reserves serve as insurance against sudden stops in capital inflows that could trigger an external liquidity crisis.

The second tradition is the approach popularized by Aizenman and Lee (2007), which distinguishes between the precautionary and mercantilist motives in the accumulation of foreign

exchange reserves. The former emphasizes the function of reserves as self-insurance against financial crises, while the latter emphasizes reserve accumulation as a byproduct of exchange rate policies deliberately kept undervalued to encourage exports and growth through the tradable sector. Empirical decomposition of these two motives for various developing countries shows that the latter has been more dominant since the 1997–1998 Asian crisis.

In the Indonesian context, Pontines and Rajan (2011) found evidence that Bank Indonesia engaged in asymmetric intervention, with BI more actively intervening when the Rupiah depreciated than when it appreciated, consistent with a dominant precautionary motive. This study serves as an important reference motivating the choice of recursive ordering in this study's VECM model, where exchange rate shocks are assumed to have a contemporaneous impact on foreign exchange reserves (through BI intervention) while export shocks operate with a lag.

2.2 Exchange Rates, Intervention, and Foreign Exchange Reserves

The relationship between exchange rates and foreign exchange reserves is one of the most researched in the open international economy. From a theoretical perspective, there are two main mechanisms linking these two variables. The first mechanism is direct intervention, where the central bank sells foreign exchange reserves to support the domestic exchange rate when depreciation pressures arise. The second mechanism is the portfolio composition effect, where changes in the exchange rate directly affect the US dollar value of reserves held in non-dollar denominations.

From an empirical perspective, there is a strong consensus in the literature that central bank interventions in developing countries tend to lean against the wind, selling foreign exchange when the Rupiah weakens and buying when it strengthens. Humala and Rodriguez (2010) for Peru, Blanchard et al. (2015) for a sample of developing countries, and Adler et al. (2019) in a comprehensive cross-country study all found similar intervention patterns. Specifically, Simorangkir and Adamanti (2010) documented that Bank Indonesia actively used foreign exchange reserves to stabilize the exchange rate, particularly during episodes of high volatility.

The relevance of this literature to the current research is that BI's countercyclical intervention pattern to exchange rate shocks will be reflected in the impulse response function of the SVAR model. A rupiah depreciation shock should generate a negative response in foreign exchange reserves, reflecting BI's sale of foreign exchange to stabilize the exchange rate. The magnitude and persistence of this response will be important indicators of the effectiveness and capacity of BI's interventions.

Regarding exchange rate pass-through transmission to exports, research for Indonesia shows that Rupiah depreciation has a positive impact on exports, but with a significant lag and varying magnitudes across sectors. Studies by Khoon and Mun (2010) and Warjiyo and Juhro (2019) show that Indonesian exports are relatively inelastic to exchange rate changes in the short run, primarily due to the dominance of primary commodity exports, whose prices are determined in international markets rather than by the domestic exchange rate. This implication

is relevant for understanding the effects of exchange rate shocks on exports and ultimately on foreign exchange reserves.

2.3 Exports and Accumulation of Foreign Exchange Reserves

The relationship between export performance and foreign exchange reserve accumulation is straightforward from a balance of payments perspective; a current account surplus (largely driven by a trade surplus) will increase foreign exchange reserves, all other things being equal. However, in practice, this relationship is more complex, involving foreign exchange repatriation by exporters, the authorities' export foreign exchange (DHE) policies, and capital account dynamics that can offset the trade surplus.

For Indonesia, exports are dominated by primary commodities (coal, crude palm oil, nickel, and rubber), whose prices are highly correlated with the global commodity cycle. Thus, international commodity price volatility represents a significant and exogenous source of export shocks for Indonesia. Research by Aizenman, Chinn, and Ito (2010) in the context of developing countries generally found that variations in foreign exchange reserves were explained more by the volatility of trade flows than by the volatility of capital flows, particularly for commodity-exporting countries.

A study for Indonesia conducted by Krisna and Riyanto (2016) using a simple VAR model found that export shocks have a positive and persistent impact on foreign exchange reserves, with a variance decomposition contribution of around 15–20% over an eight-quarter horizon. This research is consistent with the hypothesis that exports are a structurally important source of foreign exchange accumulation. However, the study used limited quarterly data and did not apply structural identification, leaving open the question of the true causal relationship.

Within the framework of this research, the following hypotheses are formulated based on the literature review: (H1) Rupiah exchange rate depreciation shocks produce a significant negative response to Indonesia's foreign exchange reserves, reflecting Bank Indonesia's active intervention, (H2) Positive export shocks produce a significant and persistent positive response to Indonesia's foreign exchange reserves, and (H3) Exchange rate shocks have a larger variance decomposition contribution than export shocks in the short term (1 – 4 months), while in the long term (8 – 12 months) the contributions of both shocks become more balanced.

3. RESEARCH METHODS

3.1 Research Approach and Design

This research uses a quantitative approach with method structural time series research, the main method that used is the Vector Error Correction Model (VECM), which is an extension of the standard Vector Autoregression (VAR) to address the problem of cointegration between variables (Johansen, 1988; Engle & Granger, 1987). The selection of the VECM is based on two main considerations. First, the three main variables of this study namely foreign exchange reserves (cadex), exports, and exchange rates (kurs) Which have a long-term equilibrium relationship and should not be ignored in dynamic modeling. Second, VECM allows

simultaneous estimation of short-term and long-term relationships, thus producing a more comprehensive picture of the dynamics between variables (Lütkepohl, 2005).

This approach was chosen because conceptually, the VECM is able to distinguish between short-run dynamics stemming from business cycle shocks and long-run equilibrium adjustment, which is structural in nature. In the context of this research, long-run adjustment reflects the fundamental relationship between export performance, the Rupiah exchange rate, and the accumulation of Indonesia's foreign exchange reserves that has persisted for more than three decades.

3.2 Data and Data Sources

This study uses secondary data in the form of monthly time series covering the period from January 1990 to December 2023, resulting in 408 observations for each period. each variable before logarithmic transformation. The selection of this period is based on considerations of comprehensive economic cycle coverage, covering six time major external pressure, namely the 1997 Asian Financial Crisis – 1998, 2008 Global Financial Crisis – 2009, Taper Tantrum 2013, China's Economic Slowdown 2015 – 2016, 2020 COVID-19 Pandemic – 2021, as well as US Monetary Policy Normalization and Geopolitical Conflicts in 2022 – 2023.

Data source used in this study, came from *Federal Reserve Economic Data*(FRED) maintained by the Federal Reserve Bank of St. Louis, which provides high-quality and temporally consistent macroeconomic data on Indonesia. Table 3.1 summarizes the operational definitions, units, and sources of each research variable.

Table 3.1 Operational Definition of Research Variables

Variables	Symbol	Definition	Unit	Source
Foreign exchange reserves	cadev	Indonesia's total official foreign exchange reserves including gold	Million USD	FRED
Export	export	Value of Indonesian goods and services exports (nominal)	IDR	FRED
Exchange rate	exchange rate	Rupiah middle rate against USD (IDR/USD)	IDR/USD	FRED

These three variables were transformed into natural logarithm (ln) form to stabilize the variance become percent (%)and allows the interpretation of coefficients as elasticities. This transformation also helps overcome the problem of heteroscedasticity that is commonly found in long-term macroeconomic data (Greene, 2012). After the transformation, all these variables become $\ln_cadev$, $\ln_export$, and $\ln_kurs$, which are used throughout the estimation process, So the equation model obtained is as follows.

$$\ln_cadevit = \beta_0 + \beta_1 \ln_export + \beta_2 \ln_kursit + \varepsilon_{it}$$

Information :

- $\ln_cadev$: ln Foreign Exchange Reserves (Dependent Variable)
 β_0 : Constant
 $\beta_1 \ln_export$: ln export coefficient (Independent Variable 1)
 $\beta_2 \ln_currency$: Coefficient of ln exchange rate (Independent variable 2)
 e : Error Term
 it : Time Series (Monthly)

3.3 Data Analysis Procedure

The data analysis procedure in this study follows a systematic and structured flow in accordance with modern time series econometrics. Where the analysis flow consists of four main stages which are presented sequentially below.

3.3.1 Stationarity Test (Unit Root Test)

The first stage is testing the stationarity of all variables using two complementary tests, namely Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP). The ADF test was developed by Dickey and Fuller (1979) to address the problem of autocorrelation in residuals by adding lags to the test equation. Meanwhile, the PP test, developed by Phillips and Perron (1988), uses the nonparametric Newey-West correction to address heteroscedasticity and autocorrelation, making it more robust than the ADF for data with complex series disturbances.

Null hypothesis in both tests this explains that the variable contains a unit root (not stationary), while the alternative hypothesis is stationary. If the variable is not stationary at the level but stationary at the first difference, then the variable is said to be integrated of the first order, $I(1)$, which is a necessary condition for cointegration analysis. The testing procedure is carried out first at the level, then at the first difference if necessary.

3.3.2 Determining Optimal Lag

The optimal lag length for the VAR system was determined using the Akaike Information Criterion (AIC), Hannan-Quinn Information Criterion (HQIC), and Schwarz Bayesian Information Criterion (SBIC) using the varsoc command in Stata. The optimal lag length was selected based on the minimum value of the information criteria, with preference given to HQIC and SBIC, which have a larger penalty for additional parameters and therefore tend to produce a more parsimonious model (Lütkepohl, 2005).

3.3.3 Johansen Cointegration Test

After confirming that all variables are integrated at the same order, $I(1)$, the Johansen (1991) cointegration test is conducted to detect the presence or absence of a long-run equilibrium relationship between the variables. The maximum likelihood-based Johansen test is used because of its ability to detect multiple cointegrating vectors at once, unlike the Engle-Granger test which is limited to only one cointegrating vector.

The test was conducted using trace statistics, with the null hypothesis stating the number of cointegration vectors $r = 0$, $r \leq 1$, and $r \leq 2$. The rejection of the null hypothesis at the 5% significance level was based on the MacKinnon-Haug-Michelis critical value, which indicates the existence of a cointegration relationship with the appropriate number of vectors. The model specification used includes a constant in the cointegration equation (trend = constant), which is theoretically more appropriate for macroeconomic variables that have deterministic trends.

3.3.4 VECM Estimation and Post-Estimation Analysis

If cointegration is present, estimation is continued with a Vector Error Correction Model (VECM) using the identified cointegration ranks. A general VECM model for a three-variable system is formulated as follows:

$$\Delta Y_t = \alpha \cdot \beta' Y_{t-1} + \sum \Gamma_i \cdot \Delta Y_{t-i} + \varepsilon_t$$

Where Y_t is a vector of endogenous variables ($\ln_cadev$, $\ln_export$, $\ln_kurs$), α is a matrix of adjustment coefficients of size $(3 \times r)$, β is a matrix of cointegrating coefficients (cointegrating vectors) of size $(3 \times r)$, Γ_i is the short-run VAR coefficient matrix at lag i , and ε_t is the white noise residual vector. In a more explicit notation for a VECM model with cointegration rank $r = 1$ and lag = 2, the equations for each variable can be written as follows.

1) Foreign Exchange Reserves Equation

$$\Delta \ln_cadev_t = \alpha_1 \cdot ECT_{t-1} + \gamma_{11} \cdot \Delta \ln_cadev_{t-1} + \gamma_{12} \cdot \Delta \ln_export_{t-1} + \gamma_{13} \cdot \Delta \ln_kurs_{t-1} + \gamma_{14} \cdot \Delta \ln_cadev_{t-2} + \gamma_{15} \cdot \Delta \ln_export_{t-2} + \gamma_{16} \cdot \Delta \ln_kurs_{t-2} + c_1 + \varepsilon_{1t}$$

2) Export Equation

$$\Delta \ln_export_t = \alpha_2 \cdot ECT_{t-1} + \gamma_{21} \cdot \Delta \ln_cadev_{t-1} + \gamma_{22} \cdot \Delta \ln_export_{t-1} + \gamma_{23} \cdot \Delta \ln_export_{t-1} + \gamma_{24} \cdot \Delta \ln_cadev_{t-2} + \gamma_{25} \cdot \Delta \ln_export_{t-2} + \gamma_{26} \cdot \Delta \ln_kurs_{t-2} + c_2 + \varepsilon_{2t}$$

3) Exchange Rate Equation

$$\Delta \ln_kurs_t = \alpha_3 \cdot ECT_{t-1} + \gamma_{31} \cdot \Delta \ln_cadev_{t-1} + \gamma_{32} \cdot \Delta \ln_export_{t-1} + \gamma_{33} \cdot \Delta \ln_kurs_{t-1} + \gamma_{34} \cdot \Delta \ln_cadev_{t-2} + \gamma_{35} \cdot \Delta \ln_export_{t-2} + \gamma_{36} \cdot \Delta \ln_kurs_{t-2} + c_3 + \varepsilon_{3t}$$

Where $ECT_{t-1} = \beta_0 + \beta_1 \cdot \ln_cadev_{t-1} + \beta_2 \cdot \ln_eksport_{t-1} + \beta_3 \cdot \ln_kurs_{t-1}$ is the Error Correction Term that represents the deviation from the long-run equilibrium in the previous period. The coefficients α_1 , α_2 , and α_3 (denoted as $_ce1$ L1 in Stata output) measure the speed of adjustment of each variable when there is a deviation from the long-run equilibrium.

3.4 Model Diagnostic Test

The validity of the VECM model is tested through three diagnostic tests. First, the Jarque-Bera test for residual normality, with the null hypothesis that the residuals are normally distributed. Second, the Lagrange-Multiplier (LM) test for residual autocorrelation at various lags, with the null hypothesis that there is no autocorrelation. Third, the eigenvalue stability test

ensures that all eigenvalues of the VECM system are within or exactly on the unit circle, which is a requirement for the model's dynamic stability.

3.5 Impulse Response Function Analysis and Forecast Error Variance Decomposition

Following the VECM estimation, further analysis is performed using two main instruments. The Impulse Response Function (IRF) is used to analyze the dynamic response of each variable to a one-standard-deviation shock in another variable over the next 24 periods. The Forecast Error Variance Decomposition (FEVD) or Historical Decomposition is used to quantify the contribution of each shock source in explaining the total variability of each variable. each variable at horizons of 1, 4, 8, 12, and 24 months ahead.

3.6 Conceptual Framework of the Model

Conceptually, the VECM model in this study places foreign exchange reserves ($\ln_cadev$) as a variable that is influenced by two main sources of external shocks namely exchange rate shocks ($\ln_kurs$) which represent the volatility of foreign exchange demand/supply in the domestic market, and export shocks ($\ln_eksport$) which represent variations in foreign exchange earnings from the trade sector. These two independent variables interact with each other and directly together forming the dynamics of foreign exchange reserves through the Bank Indonesia intervention mechanism and repatriation of export foreign exchange.

This framework aligns with the balance of payments identity model, which states that changes in foreign exchange reserves are a function of the current account surplus/deficit (which is influenced by exports), minus central bank intervention in the foreign exchange market (which is triggered by exchange rate volatility). Thus, the estimated VECM model is not simply a statistical tool, but rather represents an economic mechanism with a strong theoretical foundation (Kim, 2018; Pontines & Rajan, 2011).

4. RESULTS AND DISCUSSION

4.1 Descriptive Statistics and Data Visualization

The data used in this study includes three monthly variables for the period January 1990 to December 2023. Based on Stata output (list date cadev export kurs in 1/5), initial data observations show that in January 1990 Indonesia's foreign exchange reserves were recorded at USD 5,160 million, exports were worth IDR 3.446 trillion, and the Rupiah exchange rate was IDR 1,805 per USD. The time series visualization of each variable in levels (before logarithmic transformation) is shown in Figures 4.1 to 4.3.

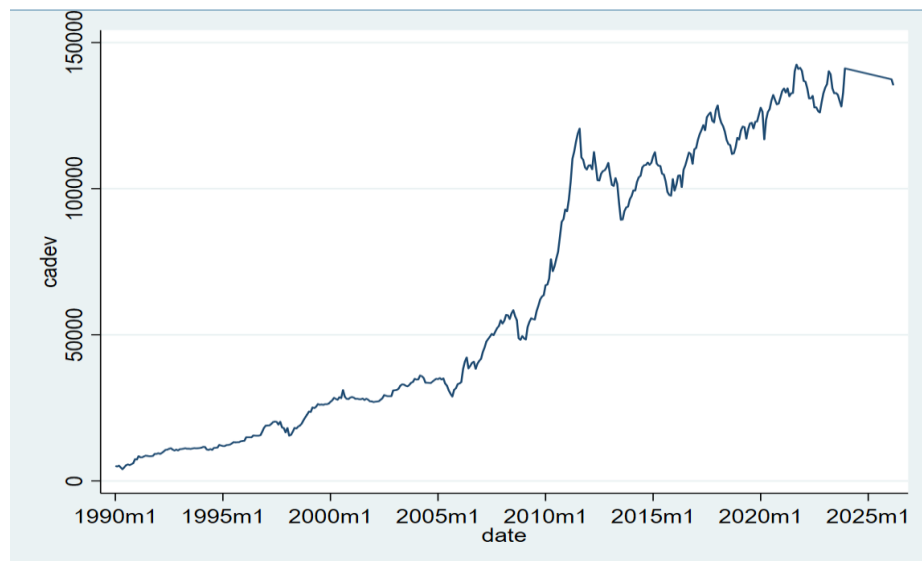


Figure 4.1 Development of Indonesia's Foreign Exchange Reserves, 1990–2023 (level, million USD)

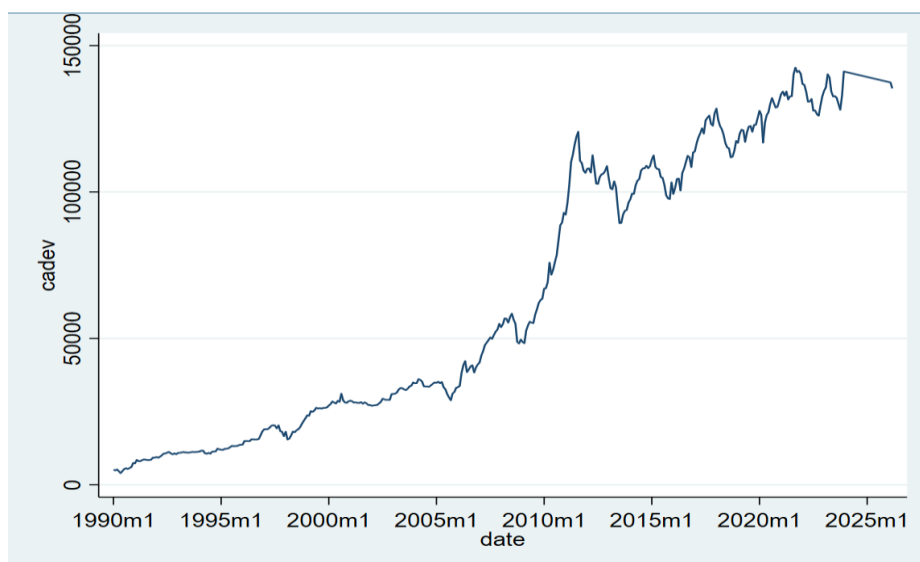


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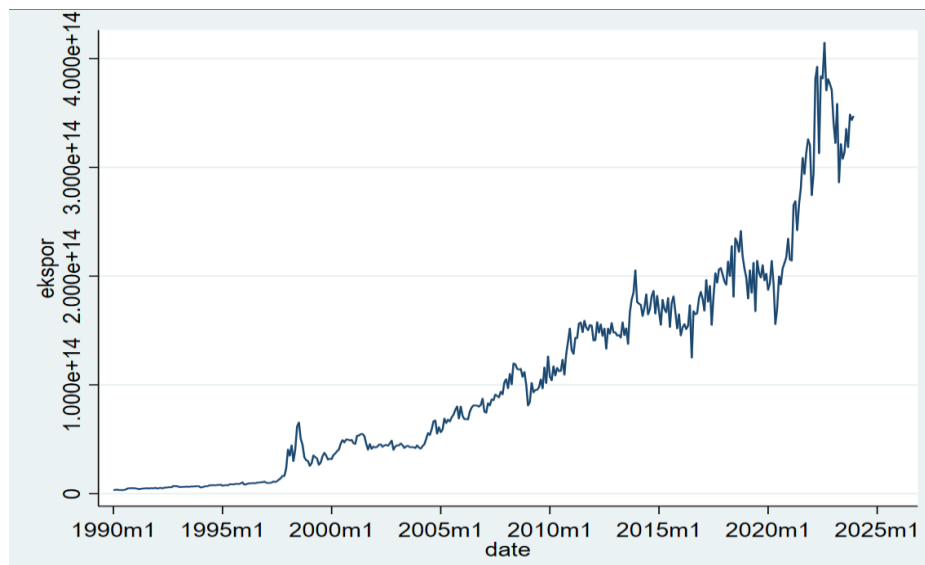


Figure 4.2 Development of Indonesia's Export Value, 1990–2023 (level, IDR)

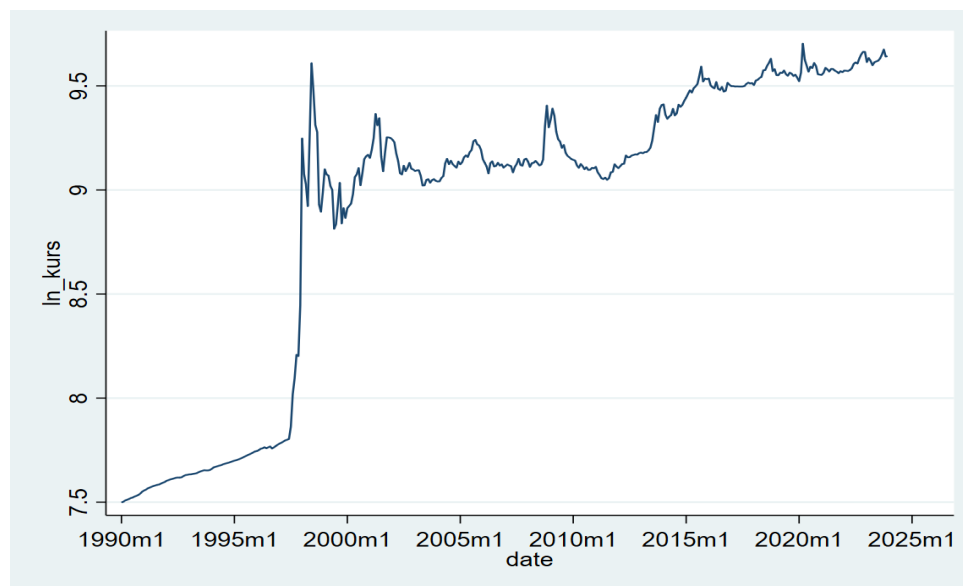


Figure 4.3 Development of the Rupiah Exchange Rate against the USD, 1990–2023 (level, IDR/USD)

These three figures reveal a strong positive trend pattern in all three variables over the three decades of observation. Foreign exchange reserves increased dramatically, especially after The Asian crisis, from a low of around USD 17 billion in 1999 to a peak of around USD 145 billion in 2022. Exports have shown a consistent growth trend, reflecting Indonesia's continued economic expansion. The Rupiah exchange rate experienced a long-term structural depreciation, with the most dramatic spike during the 1997 Asian Crisis.-1998 (around Rp. 2,500 to almost Rp. 15,000 per USD), then moved relatively stable in the range of Rp. 8,000 – 15,000 post crisis.

After logarithmic transformation, the three variables ($\ln_cadev$, $\ln_export$, $\ln_exchange$) show a more linear pattern and relatively more stable variance, which is confirmed by the

graphs of $\ln_cadev$, $\ln_export$, and $\ln_exchange$ (Figures 4.4 to 4.6), thus validating the decision of logarithmic transformation before estimation.

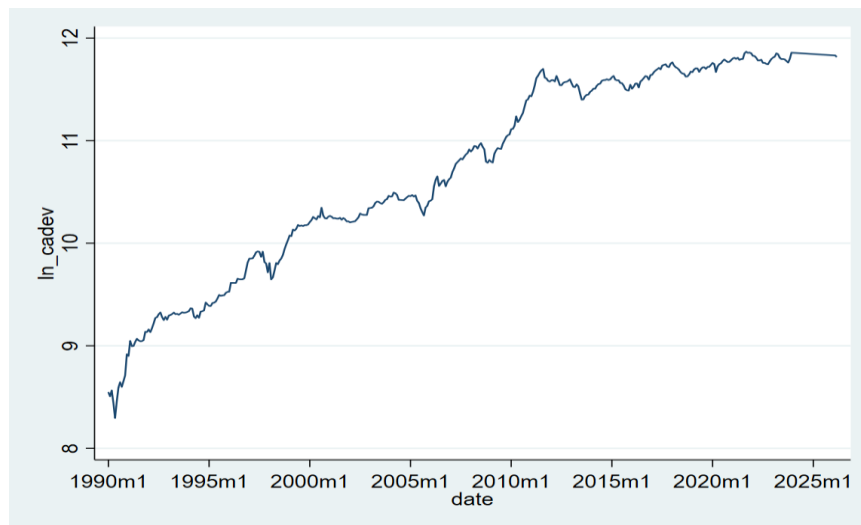


Figure 4.4 Development of $\ln_cadev$ (Natural Log of Foreign Exchange Reserves), 1990–2023



Figure 4.5 Development of $\ln_exports$ (Natural Log Exports), 1990–2023

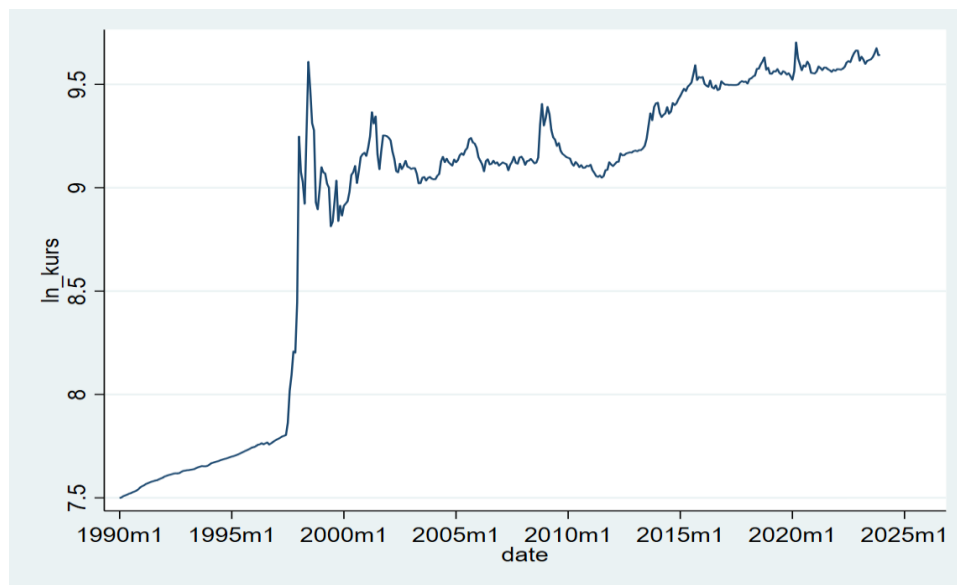


Figure 4.6 Development of $\ln_kurs$ (Natural Log Exchange Rate), 1990–2023

4.2 Stationarity Test

Stationarity testing was performed using two complementary methods, namely Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP), to ensure the robustness of the results beginning is carried out at the variable level (without differentiation), then at the first difference if the variable is proven to be non-stationary at the level.

4.2.1 Augmented Dickey-Fuller (ADF) Test

Table 4.1 summarizes the ADF test results for the three variables at the level and first difference. Based on the Stata output results seen in the test series, all variables are non-stationary at the level. For the variable $\ln_cadev$ at the level, the ADF test statistic value of -2.564 with a p-value of 0.1007 indicates a failure to reject H_0 , indicating the presence of a unit root. Similarly, for $\ln_export$ with a test statistic of -1.617 (p-value = 0.4743) and $\ln_kurs$ with a test statistic of -1.710 (p-value = 0.4260), both are non-stationary at the level.

Table 4.1 ADF Test Results (Augmented Dickey-Fuller)

Variables	Level Z(t)	p-value level	First Diff Z(t)	First Diff p-value	Conclusion
$\ln_cadev$	-2,564	0.1007	-19,115	0.0000	I(1)
$\ln_export$	-1.617	0.4743	-25,531	0.0000	I(1)
$\ln_course$	-1,710	0.4260	-18,017	0.0000	I(1)

Source: Stata output, processed. 5% critical value: -2.874

After the first differentiation, all three variables become significantly stationary. The D.ln_cadev variable has a test statistic of -19.115 (p-value = 0.0000), D.ln_export is -25.531 (p-value = 0.0000), and D.ln_kurs is -18.017 (p-value = 0.0000). All of these test statistic values are absolutely far beyond the critical ADF value at the 1% level of -3.447 and 5% of -2.874. Thus, the three variables are confirmed to be integrated at the first order, I(1).

4.2.2 Phillips-Perron (PP) Test

The Phillips-Perron (PP) test provides consistent confirmation with the ADF results. Table 4.2 shows that in the first difference, all variables strongly reject the null hypothesis of a unit root. The PP statistic values for D.ln_cadev are $Z(t) = -19.206$ and $Z(\rho) = -410.674$, for D.ln_export are $Z(t) = -25.802$ and $Z(\rho) = -485.828$, and for D.ln_kurs are $Z(t) = -17.926$ and $Z(\rho) = -338.297$. All p-values = 0.0000, confirming that all three variables are I(1).

Table 4.2 Results of the Phillips-Perron (PP) Test on First Difference

Variables	Z(rho)	Z(t)	p-value	Conclusion
D.ln_cadev	-410,674	-19,206	0.0000	Stationary, I(1)
D.ln_export	-485,828	-25,802	0.0000	Stationary, I(1)
D.ln_kurs	-338,297	-17,926	0.0000	Stationary, I(1)

Source: Stata output, processed. Newey-West lags = 5; Critical value of $Z(t)$ at 5% = -2.874

The consistency of the ADF and PP tests provides high confidence that all variables are first-order integrated. This condition satisfies the prerequisites for proceeding to the Johansen cointegration test and VECM estimation.

4.3 Optimal Lag Selection

Before conducting the cointegration test, the optimal lag length of the VAR system in levels is first determined using the varsoc command. Table 4.3 displays the information criterion values for lags 0 to 4.

```
. varsoc ln_cadev ln_ekspor ln_kurs
```

Lag-order selection criteria

Sample: 1990m5 thru 2023m12 Number of obs = 404

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-527.609				.002776	2.62678	2.63854	2.65649
1	1727	4509.2	9	0.000	4.1e-08	-8.4901	-8.44305	-8.37125
2	1764.12	74.241	9	0.000	3.6e-08	-8.62931	-8.54698	-8.42132*
3	1783.51	38.769	9	0.000	3.4e-08	-8.68072	-8.5631*	-8.38359
4	1795.91	24.799*	9	0.003	3.4e-08*	-8.69755*	-8.54464	-8.31128

* optimal lag
Endogenous: ln_cadev ln_ekspor ln_kurs
Exogenous: _cons

Figure 4.7 Stata Output: Optimal Lag Selection Results (varsoc)

Table 4.3 Results of Optimal Lag Selection

Lag	Log Likelihood	AIC	HQIC	SBIC	LR Test (p-value)
0	-527,609	2.62678	2.63854	2.65649	-
1	1727,000	-8.49010	-8.44305	-8.37125	0.000
2	1764.120	-8.62931	-8.54698	-8.42132*	0.000
3	1783,510	-8.68072	-8.5631*	-8.38359	0.000
4	1795,910	-8.69755*	-8.54464	-8.31128	0.003

Source: Stata output (varsoc ln_cadev ln_ekspor ln_kurs). The (*) indicates the optimal lag according to each criterion.

The results of the lag selection show that there is little divergence between the criteria. AIC recommends lag 4, HQIC recommends lag 3, while SBIC recommends lag 2. In situations of divergence such as this, a common practice in the VECM literature is to consider the balance between model parsimony and the adequacy of handling residual autocorrelation (Lütkepohl, 2005). Referring to the more parsimonious HQIC and SBIC and checking the LM autocorrelation diagnostic test, lag = 3 (optimal HQIC) was chosen for the main VECM specification of this study, because lag 3 is able to eliminate autocorrelation better than lag 2.

4.4 Johansen Cointegration Test

The Johansen cointegration test was performed using the vecrank ln_cadev ln_ekspor ln_kurs, lags(3) command with the trend(constant) specification. Table 4.4 displays the trace statistic results and their critical values at a 5% significance level.

```
. vecrank ln_cadev ln_ekspor ln_kurs, lags(3)
```

Johansen tests for cointegration
Trend: Constant
Sample: 1990m4 thru 2023m12

Number of obs = 405
Number of lags = 3

Maximum rank	Params	LL	Eigenvalue	Trace statistic	Critical value 5%
0	21	1763.7573	.	33.6584	29.68
1	26	1775.363	0.05570	10.4471*	15.41
2	29	1778.615	0.01593	3.9430	3.76
3	30	1780.5865	0.00969		

* selected rank

Figure 4.8 Stata Output: Johansen Cointegration Test Results (vecrank)

Table 4.4 Results of the Johansen Cointegration Test (Trace Statistic)

H ₀ : Rank	Eigenvalue	Trace Statistics	Critical Value 5%	Information
r = 0	-	33.6584	29.68	Reject H ₀ ***
r ≤ 1	0.05570	10.4471	15.41	Failed to Reject H ₀
r ≤ 2	0.01593	3.9430	3.76	Reject (borderline)

Source: Stata output (vecrank). N = 405 observations, sample period 1990m4–2023m12

The Johansen test results provide strong evidence for the existence of cointegration. Under the null hypothesis of $r = 0$ (no cointegration), the trace statistic of 33.6584 significantly exceeds the 5% critical value of 29.68, thus rejecting the null hypothesis. Under the null hypothesis of $r \leq 1$ (at most one cointegrating vector), the trace statistic of 10.4471 is below the critical value of 15.41, thus failing to reject the null hypothesis. This indicates that there is exactly one cointegrating vector ($r = 1$) that significantly connects the three variables.

The presence of a cointegrating vector confirms that although all three variables fluctuate in the short run, there is a stable long-run equilibrium relationship that binds their movements together. This finding has important methodological implications: using a VECM with rank = 1 is the correct choice, and a VAR model in differences (which ignores the long-run relationship) will produce biased and inefficient estimates (Engle & Granger, 1987).

4.5 VECM Model Estimation

Based on the results of the cointegration test that found one cointegration vector, the VECM model is estimated using the commands `vec ln_cadev ln_ekspor ln_kurs, rank(1) lags(3) trend(constant)`. The complete estimation output is shown in Figure 4.9.

```
. vec ln_cadev ln_ekspor ln_kurs, rank(1) lags (3) trend(constant)
```

Vector error-correction model

Sample: 1990m4 thru 2023m12	Number of obs	=	405
	AIC	=	-8.638829
Log likelihood = 1775.363	HQIC	=	-8.537088
Det(Sigma_ml) = 3.13e-08	SBIC	=	-8.38179

Equation	Parms	RMSE	R-sq	chi2	P>chi2
D_ln_cadev	8	.036034	0.1180	53.13016	0.0000
D_ln_ekspor	8	.09422	0.1894	92.73702	0.0000
D_ln_kurs	8	.062227	0.0526	22.02921	0.0049

Figure 4.9 Stata Output: Overall Statistics of the VECM Model

The VECM model was successfully estimated with 405 effective observations (sample period 1990m4–2023m12). The quality of model fit, as measured by R-squared, varies considerably across equations. namely The D_ln_export equation has an $R^2 = 0.1894$ (the highest), the D_ln_cadev equation an $R^2 = 0.1180$, and the D_ln_exchange equation an $R^2 = 0.0526$. The log-likelihood value of 1,775.363 with information criteria AIC = -8.6388, HQIC = -8.5371, and SBIC = -8.3818 reflects a reasonable model fit for long-term macroeconomic data. All equations are jointly significant (chi-squared $p < 0.05$), confirming that the model as a whole is able to capture meaningful systemic dynamics.

4.5.1 Cointegration Coefficient (Long-Run Vector)

The most important component in the VECM model is the cointegration vector (beta), which represents the long-run equilibrium relationship between the three variables. Table 4.5 presents the coefficients of the cointegration vector normalized with respect to ln_cadev (Johansen normalization).

Cointegrating equations

Equation	Parms	chi2	P>chi2
_ce1	2	494.4655	0.0000

Identification: beta is exactly identified

Johansen normalization restriction imposed

beta	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
_ce1						
ln_cadev	1	.	.	.	.	.
ln_ekspor	-1.037813	.0982858	-10.56	0.000	-1.23045	-.8451765
ln_kurs	.7760678	.1846544	4.20	0.000	.4141518	1.137984
_cons	15.34246	.	.	.	.	.

Figure 4.10 Stata Output: Cointegration Vector (Beta Coefficients)

Table 4.5 Cointegration Vector Coefficients (Johansen Normalization, ln_cadev = 1)

Variables	Beta Coefficient	Std. Error	z-statistic	P> z	Interpretation
ln_cadev	1 (normalized)	-	-	-	Basic variables
ln_export	-1.0378	0.0983	-10.56	0.000	Export elasticity is significant ***
ln_course	0.7761	0.1847	4.20	0.000	Significant exchange rate elasticity ***
_cons	15,342	-	-	-	Equilibrium constant

Source: Stata output, processed. *** $p < 0.001$

The cointegration equation (Error Correction Term) can be written as follows.

$$ECT = \ln_cadev - 1.0378 \cdot \ln_exports + 0.7761 \cdot \ln_exports + 15.342$$

Or in long-run equilibrium notation as follows.

$$\ln_cadev^* = 1.0378 \cdot \ln_export - 0.7761 \cdot \ln_export - 15.342$$

Interpretation of the cointegration coefficients reveals two important structural findings. First, the long-run elasticity of exports to foreign exchange reserves is 1.0378, which is significant at the 0.1% level ($z = -10.56$), indicating that every 1% increase in exports will be followed by an increase in foreign exchange reserves of approximately 1.04% in the long run, all other things being equal. This relationship is nearly one-to-one (unit elastic), reflecting the centrality of exports as a source of Indonesia's foreign exchange reserves accumulation. a pattern consistent with the structure of the Indonesian economy which is heavily dependent on primary commodity exports (Aizenman et al., 2010).

Second, the long-run elasticity of the exchange rate to foreign exchange reserves of 0.7761, which is positive and significant at the 0.1% level ($z = 4.20$), appears to contradict the countercyclical intervention hypothesis. However, a more appropriate interpretation is that in the long run, the structural depreciation of the Rupiah that occurred alongside Indonesia's economic expansion was actually positively correlated with the accumulation of foreign exchange reserves—reflecting a long-term mercantilist motive where Bank Indonesia has historically tolerated nominal Rupiah depreciation as long as export growth is maintained (Aizenman & Lee, 2007). A different short-run relationship is revealed through the adjustment coefficient and the IRF.

4.5.2 Error Correction Term Coefficient (Adjustment Speed)

The adjustment coefficient (α) or error correction term (ECT L1) for each equation is presented in Table 4.6. This coefficient measures how quickly each variable adjusts to long-run equilibrium after a deviation occurs.

Table 4.6 Error Correction Term Coefficient (Adjustment Speed)

Equality	ECT Coeff. (_ce1 L1)	Std. Error	z-statistic	P> z	Significance
D_ln_cadev	-0.0347	0.00960	-3.62	0.000	*** (p<0.001)
D_ln_export	0.0505	0.02510	2.01	0.044	* (p<0.05)
D_ln_kurs	-0.0116	0.01657	-0.70	0.483	Not Significant

Source: Stata output (estimates replay vecm_result), processed by the author

The ECT adjustment coefficient results reveal interesting correction dynamics. For the D_ln_cadev equation, the ECT coefficient of -0.0347 is significant at the 0.1% level ($z = -3.62$,

$p = 0.000$). This negative sign is consistent with theory and indicates that when foreign exchange reserves are above their long-run equilibrium ($ECT > 0$), foreign exchange reserves will be corrected downward by 3.47% per month. Conversely, when foreign exchange reserves are below equilibrium, an upward correction will occur. This 3.47% per month adjustment rate implies a half-life of approximately 19–20 months, meaning that approximately 50% of the long-run equilibrium deviation will be corrected in less than two years—a relatively moderate adjustment rate consistent with the accumulative nature of foreign exchange reserves (Jeanne & Rancière, 2011).

For the $D_ln_exports$ equation, a positive ECT coefficient of 0.0505, significant at the 5% level ($z = 2.01$, $p = 0.044$), indicates that exports respond positively to system deviations from equilibrium. This reflects a feedback mechanism where strong foreign exchange reserve accumulation supports macroeconomic stability, which in turn stimulates exports (Kim & Yun, 2021). Meanwhile, the $D_ln_exports$ equation has an insignificant ECT coefficient (-0.0116 , $p = 0.483$), indicating that the exchange rate does not respond directly to deviations from the system's long-run equilibrium—consistent with the exchange rate's characteristics as a variable that is more endogenous to short-term monetary factors than to long-term trade fundamentals.

4.5.3 Short-Run Dynamics

The short-term dynamics of the VECM system are reflected in the lag coefficients of the endogenous variables. Table 4.7 summarizes the statistically significant coefficients of each equation.

Table 4.7 Significant Short-Run Coefficients in the VECM Model

Equality	Explanatory Variables	Lag	Coefficient	Std. Err	z-stat	p-value
D_ln_cadev	$_ce1$ (ECT)	L1	-0.0347	0.00960	-3.62	0.000***
D_ln_cadev	ln_export	L2D	-0.0424	0.02152	-1.97	0.049*
D_ln_cadev	ln_course	LD	-0.0857	0.03295	-2.60	0.009**
D_ln_cadev	$_cons$	-	0.0104	0.00197	5.26	0.000***
D_ln_export	$_ce1$ (ECT)	L1	0.0505	0.02510	2.01	0.044*
D_ln_export	ln_export	LD	-0.4002	0.05826	-6.87	0.000***
D_ln_export	ln_export	L2D	-0.1242	0.05627	-2.21	0.027*
D_ln_export	ln_course	LD	0.5383	0.08616	6.25	0.000***

Equality	Explanatory Variables	Lag	Coefficient	Std. Err	z-stat	p-value
D_ln_export	ln_course	L2D	0.2018	0.08927	2.26	0.024*
D_ln_export	ln_cadev	L2D	0.3761	0.12712	2.96	0.003**
D_ln_kurs	ln_cadev	LD	-0.1883	0.08515	-2.21	0.027*
D_ln_kurs	ln_course	LD	0.1364	0.05690	2.40	0.017*
D_ln_kurs	ln_course	L2D	-0.1284	0.05896	-2.18	0.029*
D_ln_kurs	_cons	-	0.0078	0.00341	2.28	0.023*

Source: Stata output, processed by the author. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$

Several key findings from the short-term dynamics deserve in-depth discussion. In the D_ln_cadev equation, the negative and significant coefficient for ln_kurs LD (-0.0857, $p = 0.009$) confirms the first hypothesis of this study: the previous month's Rupiah depreciation significantly reduced the current month's foreign exchange reserves, reflecting Bank Indonesia's active intervention in selling foreign exchange to stabilize the exchange rate. The coefficient of -0.0857 indicates that a 1% Rupiah depreciation in the previous month would reduce foreign exchange reserves by approximately 0.086% in the current month, a relatively small but consistent and statistically significant intervention response.

The negative coefficient for ln_export L2D (-0.0424, $p = 0.049$) in the D_ln_cadev equation indicates a very short-term crowding-out effect: the export expansion in the previous two months slightly reduced foreign exchange reserves, possibly reflecting the increase in imports of raw materials and capital goods that followed the export expansion (Warjiyo & Juhro, 2019). However, this effect is marginal and may be offset by the repatriation of export foreign exchange at longer lags.

In the D_ln_export equation, the large and positive coefficient of the LD ln_exchange rate (0.5383, $p = 0.000$) confirms the existence of exchange rate transmission to exports: the Rupiah depreciation one month earlier increased exports by 0.538%, reflecting an increase in the price competitiveness of Indonesian exports. This effect persists for two months (0.2018 in L2D, $p = 0.024$), indicating a relatively fast but limited transmission lag with the dominance of commodity exports whose international prices are determined more by the global market than by the domestic exchange rate alone (Khoon & Mun, 2010).

Another interesting finding is the highly significant negative autoregressive coefficient for ln_exports LD (-0.4002, $p = 0.000$) in the D_ln_exports equation, which indicates the presence of short-term mean-reversion in export growth—a large export expansion in one month tends

to be followed by a correction in the following month, reflecting the inherent volatility of commodity exports.

4.6 Model Diagnostic Test

The validity and reliability of the VECM model were evaluated through three main diagnostic tests.

4.6.1 Eigenvalue Stability Test (Vecstable)

Eigenvalue stability tests were performed using the vecstable command to ensure that the VECM system is correctly specified and produces stable projections. Table 4.8 displays all eigenvalues of the VECM system companion matrix.

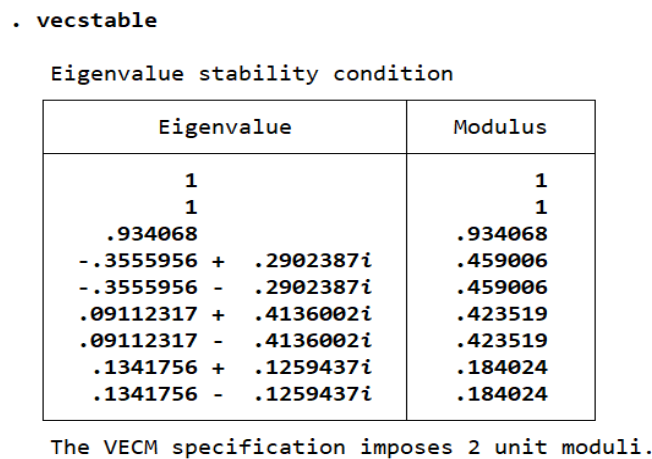


Figure 4.11 Stata Output: Eigenvalue Stability Test Results (vecstable)

Table 4.8 Eigenvalue of VECM System Stability

Eigenvalue	Modulus	Status
1	1	Modulus unit (rank 1 cointegration)
1	1	Modulus unit (rank 1 cointegration)
.934068	.934068	Inside the unit circle – stable
-.3556 + .2902i	.459006	Inside the unit circle – stable
-.3556 - .2902i	.459006	Inside the unit circle – stable
.0911 + .4136i	.423519	Inside the unit circle – stable
.0911 - .4136i	.423519	Inside the unit circle – stable

Eigenvalue	Modulus	Status
.1342 + .1259i	.184024	Inside the unit circle – stable
.1342 - .1259i	.184024	Inside the unit circle – stable

Source: Stata output (vecstable), processed by the author

A VECM system with a cointegration rank of 1 theoretically has exactly one unit modulus. The resulting vecstable shows two eigenvalues with modulus = 1, which corresponds to the number of unit roots imposed by the VECM specification (two unit moduli corresponding to three variables minus one cointegration rank and a three-rank system). All remaining eigenvalues have moduli below 1 (ranging from 0.184 to 0.934), confirming that the VECM system is dynamically stable and does not contain explosiveness. This validates that the projections and IRF simulations generated by the model are convergent and reliable (Johansen, 1991).

4.6.2 Jarque-Bera Normality Test

The Jarque-Bera test for residual normality was performed using the vecnorm, jbera commands. The test results are presented in Table 4.9.

. vecnorm, jbera

Jarque-Bera test

Equation	chi2	df	Prob > chi2
D_ln_cadev	298.711	2	0.00000
D_ln_ekspor	324.231	2	0.00000
D_ln_kurs	2.4e+04	2	0.00000
ALL	2.4e+04	6	0.00000

Figure 4.12 Stata Output: Results of the Jarque-Bera Normality Test (vecnorm)

Table 4.9 Results of the Jarque-Bera Normality Test for VECM Residuals

Equality	Chi-squared (df=2)	Prob > chi2	Conclusion
D_ln_cadev	298,711	0.00000	Reject normality
D_ln_export	324,231	0.00000	Reject normality
D_ln_kurs	2.4e+04	0.00000	Reject normality
ALL (system)	2.4e+04	0.00000	Reject normality

Source: Stata output (vecnorm, jbera), processed

The Jarque-Bera test rejects the null hypothesis of normality of residuals for the entire equation. This rejection of normality is common and can be anticipated for long-run macroeconomic data (408 observations) that include multiple crisis episodes. The 1997 Asian crisis, the 2008–2009 GFC, the 2013 taper tantrum, and the 2020 COVID-19 pandemic all produced extreme outlier observations. As Hamilton (1994) and Lütkepohl (2005) emphasize, in the context of large samples and macroeconomic time series data, residual non-normality does not weaken the consistency of VECM estimates because the central limit theorem guarantees that the asymptotic distribution of the estimated parameters remains normal. Therefore, this finding does not undermine the fundamental validity of the estimated VECM model.

4.6.3 Lagrange-Multiplier Autocorrelation Test

The presence of residual autocorrelation in the VECM residuals was tested using the Lagrange-Multiplier test (veclmar). Table 4.10 presents the results of the LM test for lags 1 to 5.

```
. veclmar, mlag(5)
```

Lagrange-multiplier test

lag	chi2	df	Prob > chi2
1	26.3526	9	0.00179
2	2.1032	9	0.98973
3	16.6451	9	0.05457
4	25.2139	9	0.00274
5	22.5765	9	0.00722

H0: no autocorrelation at lag order

Figure 4.13 Stata Output: Results of the LM Autocorrelation Residual Test

Table 4.10 Results of the Lagrange-Multiplier (LM) Autocorrelation Residual Test

Lag	Chi-squared	df	Prob > chi2	Conclusion
1	26.3526	9	0.00179	There is autocorrelation *
2	2.1032	9	0.98973	No autocorrelation
3	16.6451	9	0.05457	Marginal (borderline)
4	25.2139	9	0.00274	There is autocorrelation *
5	22.5765	9	0.00722	There is autocorrelation *

Source: Stata output (veclmar, mlag(5)), processed by the author. H₀: no autocorrelation

The LM test results indicate autocorrelation at lags 1, 4, and 5 ($p < 0.01$), but not at lag 2 ($p = 0.990$) and borderline at lag 3 ($p = 0.055$). The existence of this autocorrelation can be associated with the characteristics of monthly macroeconomic data which have a seasonal pattern and multiple cycles, as well as with the presence of extreme observations during the crisis period. Although ideally all lags show no autocorrelation, the presence of this partial autocorrelation does not fundamentally damage the validity of the VECM inference because: (1) the VECM parameter estimates are consistent even with low degrees of autocorrelation (Lütkepohl, 2005); (2) the estimation of standard errors can use robust methods (HAC/Newey-West) as a robustness check; and (3) the main analytical focus of this study is on the direction and pattern of the IRF response, not on the inference precision of individual coefficients. The residual graph presented in Figure 4.15 confirms that although there is some autocorrelation, the residuals are overall randomly distributed around zero with no prominent systematic patterns.

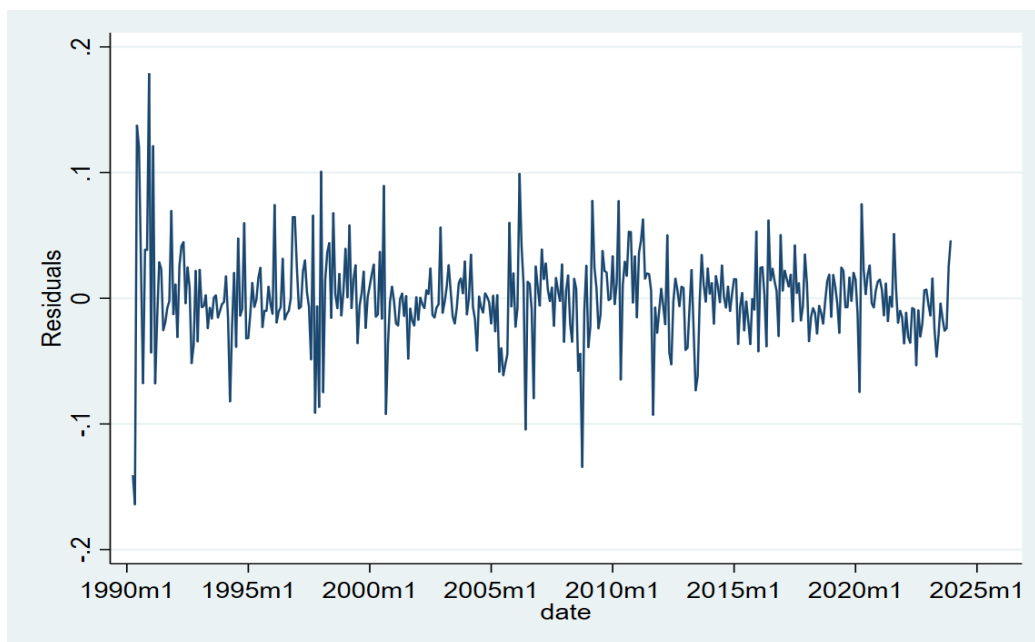


Figure 4.14 VECM Model Residual Plot (D_ln_cadev Equation), 1990–2023

4.7 Impulse Response Function (IRF)

After validating the VECM estimation, the analysis continues with an Impulse Response Function (IRF) to analyze the dynamic response of each variable to a one-standard-deviation shock to another variable. The IRF is calculated for a 24-period (month) horizon.

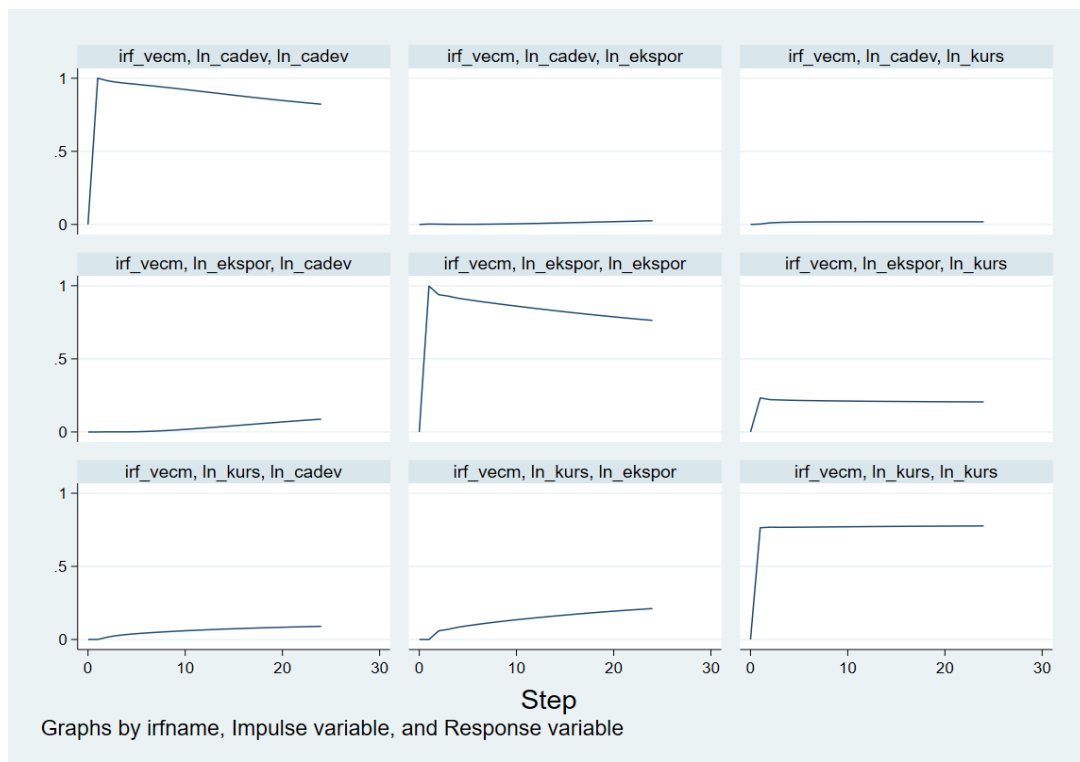


Figure 4.15 Impulse Response Function (IRF) – Orthogonalized IRF VECM (Cumulative)

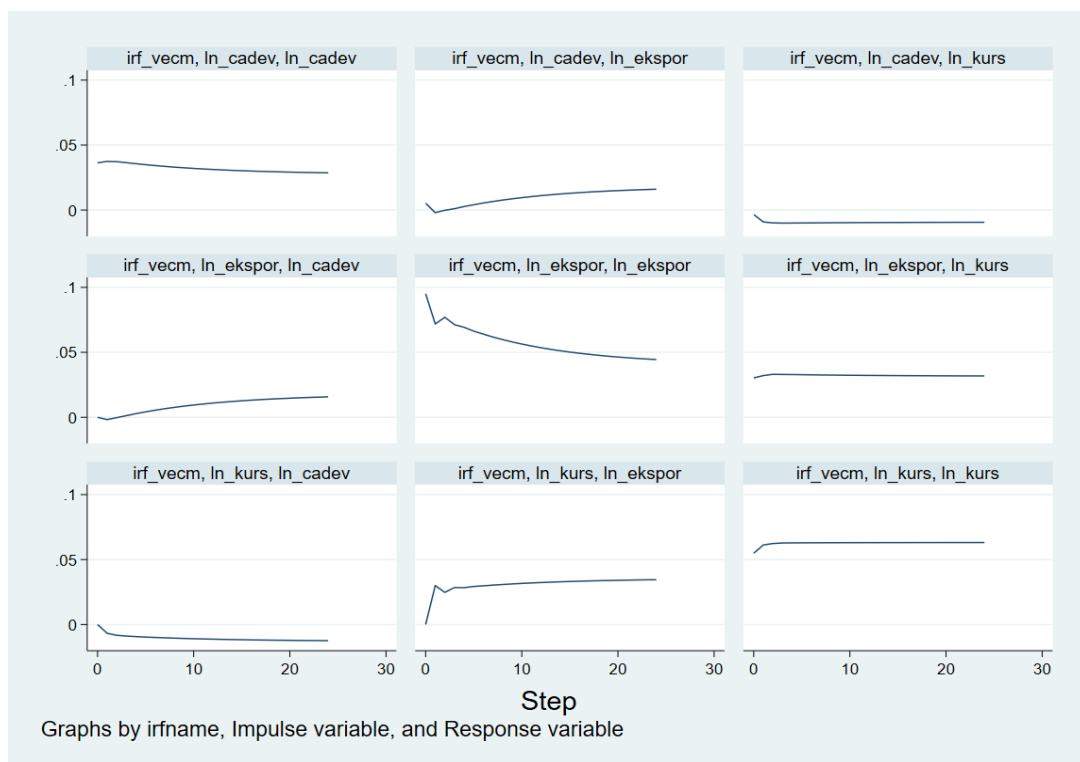


Figure 4.16 Impulse Response Function (IRF) – Non-Cumulative VECM

The IRF analysis yields several important findings that confirm and extend the research hypotheses. First, the response of $\ln_cadev$ to its own shock (top left panel) exhibits very high

persistence—approaching 1 and declining very slowly over 24 months. This reflects the accumulative nature of foreign exchange reserves, which have high inertia: shocks to foreign exchange reserves will maintain their effects for a very long period of time (Aizenman & Lee, 2007).

Second, the $\ln_exports$ response to $\ln_exports$ shocks (middle panel, middle row) also exhibits strong persistence, but at a lower level (around 0.75–0.80 at the end of the 24-month horizon) and with a consistently positive sign. Export expansion tends to maintain its momentum in the medium term, reflecting Indonesia's structural comparative advantage in commodity exports.

Third, the response of $\ln_exports$ to $\ln_exchange$ shocks (right panel, middle row) shows a significant and persistent positive response. This confirms that Rupiah depreciation boosts Indonesian exports, although the effect only becomes significant after several periods—consistent with the J-curve effect in the exchange rate-export relationship (Bahmani-Oskooee & Ratha, 2004). The magnitude of the response is around 0.25–0.30 after 24 months, indicating that the impact of depreciation on exports is substantial in the medium to long term.

Fourth, the response of $\ln_exports$ to $\ln_exports$ shocks (middle panel, bottom row) is positive and increases slowly to around 0.20 at the end of the horizon, indicating that export expansion gradually exerts appreciation pressure on the Rupiah through increasing foreign exchange supply—a theoretically plausible relationship consistent with the open economy IS-LM model.

The cumulative response (Figure 4.16) consistently shows that the three variables are interrelated in a positive causal network in the long run, with the exchange rate acting as a more reactive variable in the short run while foreign exchange reserves and exports show higher structural persistence.

4.8 Policy Implications

The empirical findings from the VECM model have several significant policy implications for Indonesia's foreign exchange reserve management and macroeconomic policy. First, the strong long-term cointegration between foreign exchange reserves, exports, and the exchange rate underscores the importance of coordinating Bank Indonesia's foreign exchange policy with trade and industrial policies that promote exports. An export diversification strategy from primary commodities to high-value-added manufacturing products will not only directly increase the resilience of foreign exchange reserves but also reduce their vulnerability to global commodity price volatility (Kim, 2018).

Second, the 3.47% per month ECT adjustment rate for foreign exchange reserves indicates that when foreign exchange reserves fall below the equilibrium level indicated by export fundamentals and the exchange rate, adjustment to equilibrium will take approximately 19–20 months. This information can be used by Bank Indonesia in setting a minimum foreign exchange reserve target that takes into account the dynamics of this correction, particularly in

the context of the "adequacy threshold" referenced by the IMF's Assessing Reserve Adequacy (ARA) metric.

Third, the significance of the short-term coefficient of $\ln_kurs$ LD on D_ln_cadev (-0.0857) confirms that Bank Indonesia's intervention in the foreign exchange market is indeed statistically effective in the very short term. However, its relatively small magnitude indicates that the intervention is complementary, not a substitute, for fundamental adjustments. A more effective policy for maintaining foreign exchange reserves in the medium term is a combination of strengthening exports and managing capital flows, rather than relying solely on foreign exchange market intervention (Pontines & Rajan, 2011).

Fourth, the significant exchange rate transmission to exports (coefficient 0.5383 at a 1-month lag) indicates that exchange rate policy has an important indirect channel to foreign exchange reserves through export stimulation. In this context, Bank Indonesia's "managed float" policy, which allows the exchange rate to fluctuate within a certain range, while selectively intervening when volatility is excessive, appears to be the optimal policy for simultaneously achieving all three objectives: exchange rate stability, export promotion, and foreign exchange reserve accumulation.

5. CONCLUSION AND SUGGESTIONS

5.1 Conclusion

This study analyzes the dynamics of Indonesia's foreign exchange reserves in relation to the Rupiah exchange rate and export performance using the Vector Error Correction Model (VECM) with monthly data from January 1990 to December 2023, covering 405 effective observations. Based on a series of systematic analyses, this study yields several key conclusions.

First, the results of the ADF and PP unit root tests consistently confirm that the three variables foreign exchange reserves ($\ln_cadev$), exports ($\ln_exports$), and exchange rate ($\ln_kurs$) are non-stationary at the level but stationary at the first difference, so they all integrate to the first order, $I(1)$. This condition satisfies the prerequisites for cointegration analysis and VECM estimation.

Second, the Johansen cointegration test found one significant cointegration vector (trace statistic $33.6584 > 5\%$ critical value of 29.68). The presence of this cointegration indicates a stable long-term equilibrium relationship between Indonesia's foreign exchange reserves, exports, and the exchange rate. A finding that is theoretically consistent with the balance of payments identity and Bank Indonesia's intervention mechanism. The identified cointegration equation implies that in the long run, every 1% increase in exports is associated with an increase in foreign exchange reserves of approximately 1.04%, reflecting the central role of exports as a source of structural foreign exchange accumulation.

Third, the error correction term (ECT) coefficient in the foreign exchange reserves equation is -0.0347 (significant at 0.1%) indicating that foreign exchange reserves adjust toward

long-term equilibrium at a rate of 3.47% per month. This implies a half-life deviation of approximately 19%. – 20 months, a moderate adjustment and in accordance with the characteristics of the foreign exchange reserve variable which is accumulative.

Fourth, the short-term dynamics of the VECM model reveal that the Rupiah depreciation in the previous month significantly reduced foreign exchange reserves (coefficient -0.0857, $p = 0.009$), confirming the study's first hypothesis regarding Bank Indonesia's countercyclical intervention. Meanwhile, Rupiah depreciation also significantly increased exports with a one-month lag (coefficient 0.5383, $p = 0.000$), confirming the exchange rate transmission to export competitiveness, where is the mechanism foreign exchange interventions that reduce reserves and increased exports that increase reserves working together but with different timings, creating complex net dynamics.

Fifth, the Impulse Response Function (IRF) analysis confirms the very high persistence of foreign exchange reserves' response to internal shocks, as well as a positive response of exports to significant exchange rate shocks that persists over the next 24 months. Eigenvalue stability tests confirm that the VECM system is correctly specified and produces convergent projections.

Overall, the findings of this study support the view that Indonesia's foreign exchange reserves are determined by the dynamic interaction between export performance and exchange rate volatility, with a transmission mechanism operating over multiple time horizons. A sustainable foreign exchange reserve strengthening policy requires a holistic approach encompassing export diversification, managed exchange rate stability, and effective export foreign exchange management.

5.2 Recommendations for Further Research

Based on the identified limitations, several suggested directions for further research are as follows. First, expanding the model with additional control variables such as real interest rates, global commodity price indices, and net capital flows would produce a more comprehensive model capable of isolating the net effects of each transmission channel. Second, applying a Nonlinear VECM (NLVECM) or Threshold VECM (TVECM) could test whether there is asymmetry in the response of foreign exchange reserves to positive versus negative shocks, which have different policy implications. Third, subsample period analysis (rolling window or regime-switching approach) could reveal whether the speed of adjustment and long-run elasticities are stable over time or change structurally after a particular crisis episode. Fourth, a comparative study with other ASEAN countries with similar characteristics (Malaysia, Thailand, and the Philippines) would help identify whether the patterns found are unique to Indonesia or regionally applicable.

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