Vector Error Correction Model (VECM) Modeling in Indonesian Economic Growth Analysis (2014 - 2023) using Artificial Intelligence (AI) Based Statistical Analysis Tools

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Abstract – Vector Error Correction Model (VECM) is a time series modeling method that is often referred to as a form of restricted VAR. It is useful in understanding the interrelationship between variables where all variables are treated as endogenous variables. This study focuses on the analysis of Indonesia's economic growth using four variables, namely: GDP, Trade Openness, Exchange Rate, and the amount of money in circulation (M2) during the period 2014 - 2023. The analysis was carried out using the AI-based STATA application which was carried out in stages starting from the stationary test, determining the optimal lag, stability, cointegration, VECM and finally the Impulse Response Function (IRF). The results of the analysis carried out using the Johansen Cointegration Test for the four variables have a long-term equilibrium stability relationship (cointegration) with each other. The model formed is VECM (1). From the structural analysis of the IRF, it can be seen that all response movement variables are approaching the equilibrium point (convergence) or returning to their previous equilibrium.

Keywords – VECM, GDP, Trade Openness, Excange Rate, M2.

Introduction

Economic growth is a reflection of a country's economic development. The increase in wealth and the increase in goods and services are caused by the process in the economy due to economic growth. The production of increasing goods is proportional to economic growth. Thus, the level of community welfare increases. Economic growth is the expansion of economic activities that occur periodically which results in an expansion of real national income (Erlando et al., 2020). According to (Aminullah, 2024), the growth of a country's potential GDP or output and the annual calculation of GDP development indicators. The amount and quantity of a country's Gross Domestic Product can be used to measure economic growth (GDP) (Resosudarmo & Abdurohman, 2018). According to (Kurniawan & Managi, 2018), Total income and total expenditure on goods and services during a certain period of time are known as gross domestic product (GDP). GDP at constant prices is used as the value of gross domestic product to calculate economic growth.

Annual GDP growth at constant prices is economic growth. According to (Resosudarmo & Abdurohman, 2018) Exports and imports have a major impact on economic growth. Export expansion causes uncertainty in the financial market because it increases a country's ability to receive foreign currency, which in turn drives faster economic growth (Rahman et al., 2022). A trade balance deficit will occur if import growth exceeds export growth, which will have an impact on slowing domestic economic activity (Romadona et al., 2021). The slowdown in domestic economic performance has led to a decrease in entrepreneurs' interest in investment (Susanti et al., 2023). Indonesia is a country that implemented an open economic system in 1969. Starting from that year, the economy in Indonesia has continued to increase from year to year. The high number of demand and supply from the community requires the country to carry out

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export and import activities. These activities are closely related to the movement of fluctuations in the rupiah exchange rate against foreign currencies. The stability of a country's economy can be seen from the stability of the rupiah exchange rate against foreign currencies (Susanti et al., 2023). If economic growth is stable, it can be concluded that a country is experiencing good economic conditions (Huang & Chang, 2014).

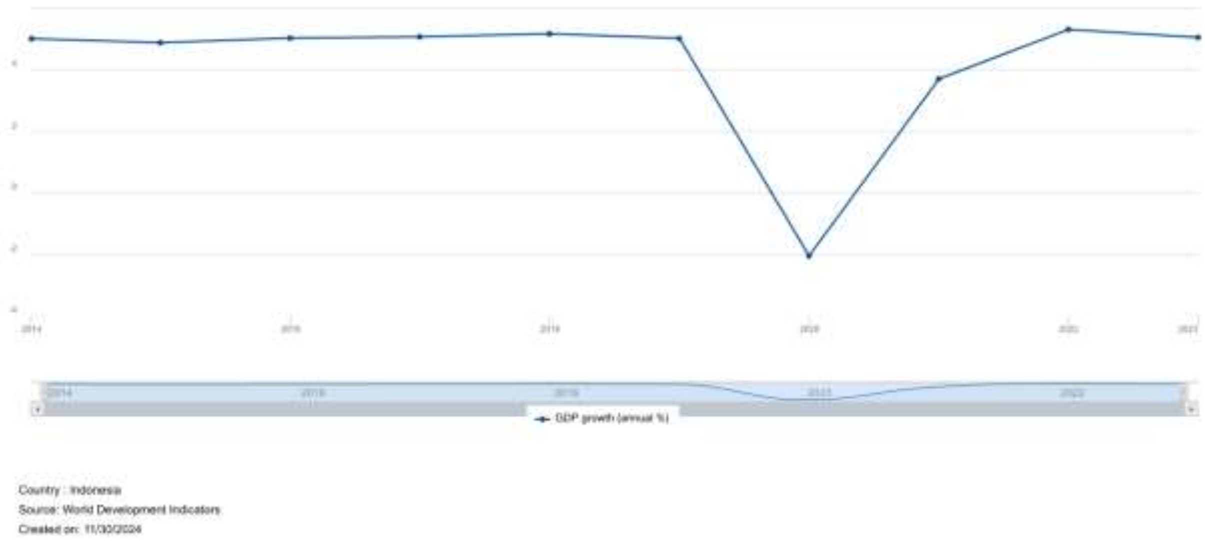

Figure 1. Indonesia Growth GDP 2014-2023 (2024b).

Source: World Development Indicators (2024).

Indonesia's economy in Q3-2024 was able to grow by 4.95% (yoy), 1.5% (qtq), or 5.03% (ctc) amidst still high uncertainty and various global challenges that still loom, such as geoeconomic fragmentation, geopolitical tensions, to the projection of a global economy growing 3.2% in 2024 and 2025, which is still below the historical average. The economic growth rate in Q3-2024 was supported by low and controlled inflation in the target range of 2.5% ±1%, namely 1.71% in October 2024 with a controlled debt ratio of 39.4% in June 2024. Indonesia's economic performance also remained solid, even better than other developed or developing countries, such as Singapore (4.1%), Saudi Arabia (2.8%), and Mexico (1.5%). All components of expenditure also experienced positive growth. Household Consumption grew by 4.91% and became the highest source of growth of 2.55% driven by an increase in the hotel and restaurant sector. Meanwhile, PMTB grew by 5.15%, driven by government and private investment, especially in infrastructure development (2024a) (2024b).

The crucial issue in analyzing economic growth is the use of time series data, data often shows non-stationary conditions. In 1981, Granger created the concept of cointegration. Cointegration is a combination of linear relationships of non-stationary variables, but stationary at the same differentiation (Emirmahmutoglu et al., 2021). Variables that are cointegrated with each other mean that they have a long-run equilibrium relationship. However, in a short-run equilibrium relationship, it is possible that these variables do not have equilibrium. This requires adjustment. The model that includes adjustments to correct short-term imbalances towards long-term equilibrium is called the Error Correction Mechanism (ECM). In 1990, Johansen and Juselius developed the concept of VECM (Vector Error Correction Model). Thus, VECM is used to model cointegrated and non-stationary time series data (Elias et al., 2023).

Literature Review

Recent studies on the Vector Error Correction Model (VECM) demonstrate that cointegration-based approaches like VECM are effective in explaining both short- and long-run dynamics of economic growth in developing countries. Erlando, Riyanto, and Masakazu (2020) find that financial inclusion is linked to growth in eastern Indonesia, highlighting the importance of domestic structural variables. Emirmahmutoglu et al. (2021) reveal a regime-dependent causal relationship between energy use and GDP in OECD nations, confirming that VECM can capture differing structural effects. Elias, Dachito, and

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Abdulbari (2023) show that currency devaluation affects Ethiopia's main exports using VECM and the Johansen test, a result relevant to the exchange-rate variable in this study. Hafner and Herwartz (2023) introduce correlation impulse response functions to assess shock transmission across variables, complementing conventional IRF analysis. Hauzenberger, Pfarrhofer, and Rossini (2025) develop a time-varying parameter VECM (TVP-VECM) for electricity prices, underscoring the need for model flexibility under high volatility.

In the Indonesian context, Sadik et al. (2024) examines technological innovation and GDP growth with an ARDL-ECM and long-run projections, underscoring the significance of M2 and trade openness variables. Susanti, Putra, and Bahtiar (2023) describe banking performance before and during COVID-19 and its impact on credit distribution and GDP, providing empirical support for including monetary indicators. Rahman et al, (2022) show that the corruption index influences Indonesia's rubber exports, confirming the relevance of institutional quality in trade-based growth models. These findings reinforce the justification for selecting GDP, trade openness, exchange rate, and M2 as key variables in the present study.

Method

A. Vector Autoregression (VAR)

The Vector Autoregression (VAR) model is one of the multivariate time series analysis models. In VAR, all variables are considered symmetrical (each variable influences changes between variables directly or indirectly). According to Sims (1986), in VAR analysis, there are usually no exogenous (independent/free) variables (Hauzenberger et al., 2025). Given the general VAR model:

$$Xt = A0 + A1Xt{-}1 + \cdots + ApXt{-}p + \varepsilon t$$

B. Stationarity

The testing steps are as follows:

1. Hypothesis:

H0: $\delta = 0$ (there are unit roots/non-stationary data)

H1: $\delta < 0$ (no unit roots/stationary data)

2. Test Statistics used:

$$\tau = \frac{\delta}{\mathrm{se}(\delta)}$$

Test criteria: reject H_0 if $\tau > \tau$ Mackinnon or by comparing the p-value of the calculation results is smaller than the desired degree of confidence, if the data is not yet stationary then differentiation is carried out.

C. Determining Optimum Lag

One method for determining the length of the lag is to look at the smallest AIC (Akaike Information Criteria):

$$AIC = \ln(\frac{RSS}{n}) + \frac{2k}{n}$$

D. Stability

A VAR system is said to be stable if all roots lie within the unit circle, meaning if the absolute value of the unit root is less than one. A stable VAR model is shown if $det\ (Ik - \boldsymbol{A}1z - \cdots - \boldsymbol{A}pzp) \neq 0\ untuk\ |z| \leq 1$ (Rahman et al., 2025).

E. Cointegration

Cointegrated means that there is a long-term relationship between the time series data (Rahman et al., 2025). Testing for cointegration is done using the Johansen test (Khurshid, 2023).

1. Hypothesis

H_0: There is no cointegration equation

H_1: There is a cointegration equation

2. Test Statistics

Maximum eigenvalue test statistics:

$$LR_{max}(r|r+1) = -T\log(1-\lambda_{r+1}) = LR_{tr}(r|k) - LR_{tr}(r+1|k)$$

Where $LR_{tr}(r|k)$ is the trace value:

$$LR_{tr}(r|k) = -T\sum_{i=r+1}^{k}\log(1-\lambda_i),\ \text{for } r = 0, 1, \ldots, k-1$$

3. Test criteria

Reject H_0 if the trace test statistic and or maximum eigenvalue is greater than the critical value at when α= 5%, or the p value is smaller than the significant value α= 5%.

F. Vector Error Correction Model (VECM)

If a VAR model time series data is proven to have a cointegration relationship, then VECM can be used to determine the short-term behavior of a variable in relation to its long-term value (Koondhar et al., 2021). The general form of the VECM model is as follows:

$$\Delta X_t = A_0 + A_1\Delta X_{t-1} + \cdots + A_{p-1}\Delta X_{t-p+1} + \lambda ECT_{t-1} + \varepsilon_t$$

ECT_{t-1} is the error correction term in the previous period:

$$ECT_{t-1} = x_{1t} - a_0 - \beta_1 x_{2t} - \cdots - \beta_n x_{nt}$$

This ECT value is called a disequilibrium error. From equation ΔX_t, it can be explained if there are k-variables:

$$\begin{bmatrix}\Delta x_{1t}\\ \Delta x_{2t}\\ \vdots\\ \Delta x_{kt}\end{bmatrix} = \begin{bmatrix}a_{10}\\ a_{20}\\ \vdots\\ a_{k0}\end{bmatrix} + \sum_{i=1}^{p-1}\begin{bmatrix}a_{11,i} & a_{12,i} & \cdots & a_{1k,i}\\ a_{21,i} & a_{22,i} & \cdots & a_{2k,i}\\ \vdots & \vdots & \cdots & \vdots\\ a_{k1,i} & a_{k2,i} & \cdots & a_{kk,i}\end{bmatrix}\begin{bmatrix}\Delta x_{1t-i}\\ \Delta x_{2t-i}\\ \vdots\\ \Delta x_{kt-i}\end{bmatrix} + \begin{bmatrix}\lambda_1\\ \lambda_2\\ \vdots\\ \lambda_k\end{bmatrix}[ECT_{t-1}] + \begin{bmatrix}e_{1t}\\ e_{2t}\\ \vdots\\ e_{kt}\end{bmatrix}$$

G. Impulse Response Function (IRF)

IRF shows the response of each dependent variable over time to shocks from the variable itself and other dependenous variables. The horizontal axis is the time in the period of days after the shock occurs, while the vertical source is the standard deviation value that measures how much response is given by a variable if there is a shock to another variable (Hafner & Herwartz, 2023).

Results and Discussion

A. Stationarity

In summary, the results of the stationarity test for each variable using the ADF test:

Table 1. Uji Kestasioneran Menggunakan Uji ADF

Variabel	Nilai $\boldsymbol{\tau}$	Nilai $\boldsymbol{\tau}$ Mackinnon	Probabilitas
GDP	12.13215	2.786567	0.0002
TO	8.043175	2.685564	0.0000
Kurs	7.607864	2.797221	0.0000
M2	5.691458	2.798607	0.0021

Source: Processed Secondary Data

It can be seen that all variables are stationary, all variables have met the stationarity requirements of the ADF test.

B. Determining Optimum Lag

Determine the optimal lag length by looking at the AIC (Akaike Information Criteria) value:

Table 2. Uji Panjang Lag Optimal

Model *VAR* (p = lag)	AIC
VAR (0)	38.23889
VAR (1)	37.66499
VAR (2)	37.53713 *
VAR (3)	37.73187
VAR (4)	38.16476
VAR (5)	38.24656
VAR (6)	37.68335
VAR (7)	37.71487

Source: Processed Secondary Data

From the table, it can be seen that the results of the lag length test with AIC provisions show that the optimal lag length is 1 with an AIC value of 37.53713.

C. Stability

There are 4 variables used in this study and the optimal lag size that has been obtained is, so that the Roots of Characteristic Polynomial on the graph are 2.

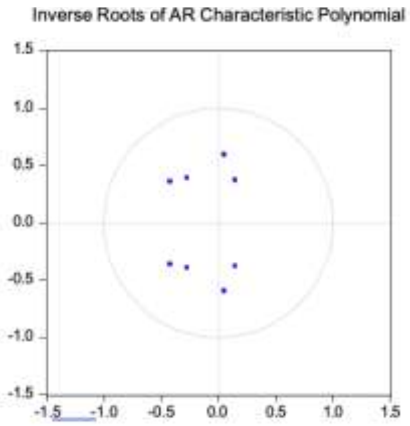

Figure 2. Roots of Characteristic Polynomial

Source: Processed Secondary Data

Table 3. Roots of Characteristic Polynomial

No.	Root (x, y)	Absolute Unit Root
1.	-0.029280, - 0.573366i	0.574113
2.	-0.029280, + 0.573366i	0.574113
3.	-0.401712, - 0.400534i	0.567275
4.	-0.401712, + 0.400534i	0.567275
5.	0.084256, - 0.435314i	0.443393
6.	0.084256, + 0.435314i	0.443393
7.	-0.180664, - 0.254323i	0.311961
8.	-0.180664, + 0.254323i	0.311961

Source: Processed Secondary Data

From the results of the graphs and tables, it can be seen that the model formed is in a stable condition, because all the inverse root points of all variables are within the unit circle and show that all absolute values of the unit roots are less than one (Rahman et al., 2024).

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D. Cointegration Test

Table 4. Johansen Cointegration Test Result (trace statistics)

H0	λ	trace statistic	5% Critical Value	Probabilitas
r = 0*	0.653400	239.6270	47.85613	0.0001
r ≤ 1*	0.569692	153.8007	29.79707	0.0001
r ≤ 2*	0.479039	85.49700	15.49471	0.0000
r ≤ 3*	0.331981	32.67851	3.841466	0.0000

Source: Processed Secondary Data

Table 5. Johansen Cointegration Test Result (maximum eigenvalue)

H0	λ	Maximum-eigen statistic	5% Critical Value	Probabilitas
r = 0*	0.653400	85.82637	27.58434	0.0000
r ≤ 1*	0.569692	68.30367	21.13162	0.0000
r ≤ 2*	0.479039	52.81849	14.26460	0.0000
r ≤ 3*	0.331981	32.67851	3.841466	0.0000

Source: Processed Secondary Data

From the test results above, it is clear that there is cointegration that is suspected to exist in the model. In other words, the four variables have a long-term equilibrium stability relationship (cointegration) with each other.

E. VECM (Vector Error Correction Model)

Table 6. Estimation VECM Result

Variabel Eksogen		Variabel Dependen			
		D(GDP)	D(TO)	D(Kurs)	D(M2)
ECT1	Koef	-2.114732	-0.801044	-666.5386	106363.0
	SD	(0.19289)	(1.30483)	(655.950)	(77471.1)
	T stat	[-10.9635]	[-0.61391]	[-1.01614]	[1.37294]
	Prob	0.0000	0.5412	0.3129	0.1740
ECT2	Koef	-0.049707	-0.650716	304.8999	12221.19
	SD	(0.02109)	(0.14267)	(71.7223)	(8470.78)
	T stat	[-2.35685]	[-4.56095]	[4.25111]	[1.44275]
	Prob	0.0211	0.0000	0.0001	0.1534
ECT3	Koef	4.58E-05	0.001503	-0.675989	33.72205
	SD	(4.9E-05)	(0.00033)	(0.16558)	(19.5555)
	T stat	[0.94067]	[4.56376]	[-4.08263]	[1.72443]
	Prob	0.3500	0.0000	0.0001	0.0889
D(GDP(-1))	Koef	0.320872	0.271405	257.0292	-77592.26
	SD	(0.10755)	(0.72755)	(365.745)	(43196.4)
	T stat	[2.98345]	[0.37304]	[0.70275]	[-1.79627]
	Prob	0.0039	0.7102	0.4844	0.0766
D(TO(-1))	Koef	0.026570	0.155867	-97.68696	-7881.469
	SD	(0.01926)	(0.13030)	(65.5040)	(7736.36)
	T stat	[1.37937]	[1.19620]	[-1.49131]	[-1.01876]
	Prob	0.1720	0.2355	0.1402	0.3117
D(KURS(-1))	Koef	2.53E-06	-0.000833	-0.215372	25.92230
	SD	(3.5E-05)	(0.00024)	(0.12052)	(14.2346)
	T stat	[0.07131]	[-3.47341]	[-1.78696]	[1.82108]
	Prob	0.9433	0.0009	0.0781	0.0727

D(M2(-1))	Koef	1.29E-07	6.23E-07	0.000633	0.320572
	SD	(2.6E-07)	(1.8E-06)	(0.00088)	(0.10400)
	T stat	[0.49793]	[0.35551]	[0.71941]	[3.08247]
	Prob	0.6200	0.7232	0.4742	0.0029
C	Koef	0.000379	-0.007701	-4.075340	-7.942892
	SD	(0.01160)	(0.07848)	(39.4528)	(4659.58)
	T stat	[0.03264]	[-0.09813]	[-0.10330]	[-0.00170]
	Prob	0.9741	0.9221	0.9180	0.9986
R-squared		0.825889	0.268865	0.450327	0.752006
Adj. R-squared		0.809194	0.198757	0.397618	0.728226

Source: Processed Secondary Data

The dependent variable D(GDP) has 3 exogenous variables that significantly influence it, namely ECT1, ECT2, and D(GDP (-1)). So, it can be said that there is a short-term relationship balance between D(GDP) and ECT1, ECT2, and D(GDP(-1)). From the significance of ECT1 and ECT2, it shows that the response given by the GDP variable to the imbalance has an effect on the creation of long-term balance. The adjusted R squared value obtained is 0.8092. This means that the lag and exogenous variables selected in this equation can explain the D(GDP) variable by 80.92%. From the adjusted R squared value, the D(GDP) equation model is considered quite good.

The dependent variable D(TO) has 3 variables that significantly influence it, namely ECT2, ECT3, and D(KURS (-1)). So, it can be said that there is a short-term relationship balance between D(TO) and ECT2, ECT3, and D(KURS (-1)). From the significance of ECT2 and ECT3, it shows that the response given by the Net Expor (TO) variable to the imbalance has an effect on the creation of long-term equilibrium. The adjusted R squared value obtained is 0.1988. This value is relatively small, meaning that most of the variables that affect D (TO) are outside the model.

The dependent variable D (KURS) has 2 exogenous variables that significantly influence it, namely ECT2, ECT3. So, it can be said that there is a balance in the short-term relationship between D (KURS) and ECT2 and ECT3. From the significance of ECT2 and ECT3, it shows that the response given by the KURS variable to the imbalance has an effect on the creation of long-term equilibrium. The adjusted R squared value obtained is 0.3976. This value is relatively small, meaning that most of the variables that affect D (KURS) are outside the model.

Dependent variable D (M2) There is only 1 variable that significantly influences it, namely D (M2 (-1)). So, it can be said that there is a balance in the short-term relationship between D (M2) and D (M2 (-1)). The adjusted R squared value obtained is 0.7282. This means that the lag and independent variables selected in this equation can explain the variable D(M2) by 72.82%. From the adjusted R squared value, the D(M2) equation model is considered quite good.

F. Impulse Response Function (IRF)

IRF provides the best picture of how a variable will respond in the future if there is a shock to another variable. Here are the results of the IRF analysis:

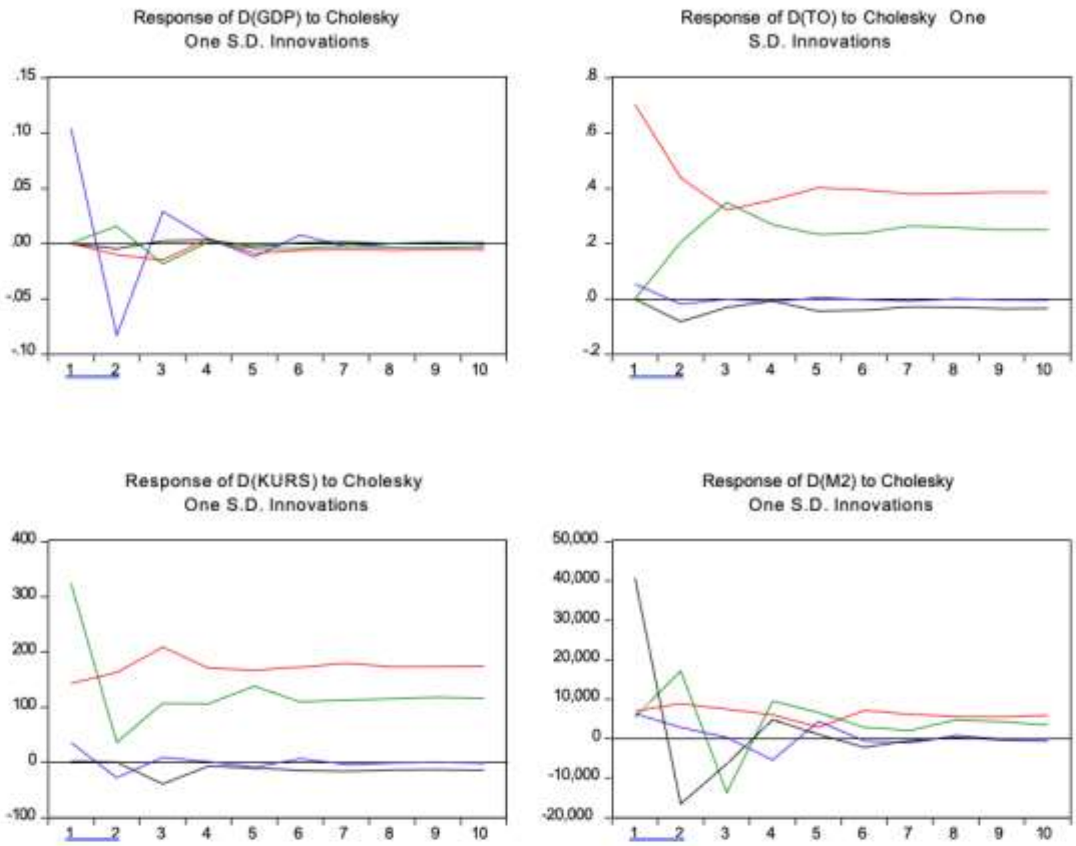

Figure 2. IRF Analysis Result

Source: Processed Secondary Data

In GDP, the variable that gives a stable response in the long term is the M2 variable. While the GDP variable itself, Trade Openness (TO), and Exchange Rate give a stable response in the short term. The impact of the endogenous GDP variable that responds negatively comes from the Trade Openness (TO) and Exchange Rate variables.

In the Trade Openness (TO) variable, the variables that give a stable response in the long term are GDP and M2. While the Trade Openness (TO) variable itself, and the Exchange Rate give a stable response in the short term. The variables that give a negative response impact are GDP and M2. While the Trade Openness (TO) variable itself and the Exchange Rate give a positive response.

In the Exchange Rate variable, the variables that give a stable response in the long term are GDP and Trade Openness (TO). For the M2 variable, it gives a negative response impact on the Exchange Rate. While the Trade Openness (TO) and Exchange Rate variables themselves give a positive response to the endogenous Exchange Rate variable. For the M2 variable, all variables give a stable response in the short term. The variables that show a positive response impact are Trade Openness (TO) and Exchange Rate.

Conclusion

Based on the results and discussion of the modeling process that has been carried out, several conclusions can be drawn, including: (1) First difference stationary data. In the cointegration analysis of GDP, Trade Openness (TO), Exchange Rate, and M2 variables, the results show a long-term relationship balance between the variables. (2) Based on the model specifications, the VECM (1) model is obtained as the selected model. In the short term, the Open Economy Degree variable is significantly influenced by the variables ect1, ect2, and DPT with an adjusted R squared value of 80.92%. The Trade Openness (TO) variable is significantly influenced by ect2, ect3, and Exchange Rate with an adjusted R squared value of 19.88%. The Exchange Rate variable is significantly influenced by ec2, ect3 with an adjusted R squared value of 39.76%. The money supply variable (M2) is significantly influenced by M2 itself with an adjusted R squared value of 72.82%. (3) From VECM (1), the results of the structural analysis of the Impluse Response Function (IRF) graph show that the impact of the response received by the endogenous variables as a whole over 10 years is convergence (its movement is getting closer to the equilibrium point).

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