

# Beyond Commodity Prices: Industrial Metals and Long-Run Economic Growth in Indonesia

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## ABSTRACT

This study investigates the long-run and nonlinear relationship between industrial metal prices and economic growth in Indonesia by interpreting aluminum and copper prices as structural proxies for global industrial metabolism. Moving beyond conventional commodity-price analysis, the study employs a time-series econometric framework integrating unit root tests, ARDL bounds cointegration, error correction modeling, and threshold analysis. Using long-horizon annual data, the findings reveal a stable long-run equilibrium relationship between Indonesia's real GDP and industrial metal proxies, indicating that national economic growth is structurally embedded in material-intensive global production dynamics. The long-run estimates show that aluminum prices exert a positive effect on economic growth, reflecting their role in supporting broad-based industrial throughput and manufacturing expansion. In contrast, copper prices display a negative long-run effect, suggesting that rising material complexity and infrastructural intensity may constrain growth. The nonlinear results further identify a critical copper-price threshold beyond which its impact on growth becomes strongly negative, signaling a transition from productive expansion to systemic industrial stress. These findings underscore the importance of accounting for structural and nonlinear dynamics when assessing growth trajectories in resource-rich developing economies.

Keywords: Industrial Metals; Economic Growth; Industrial Metabolism; Cointegration; Nonlinear Dynamics

JEL Classification: O13, O14, Q31, C22

## INTRODUCTION

Over the past several decades, fluctuations in industrial metal prices have been widely employed as indicators of changes in global economic conditions, particularly in relation to manufacturing activity, infrastructure development, and technological progress. Movements in metal prices are commonly interpreted as signals of shifts in industrial demand, investment cycles, and broader macroeconomic dynamics. Among industrial metals, aluminum and copper occupy a particularly strategic position due to their pervasive use across a wide range of productive sectors. Aluminum plays a crucial role in large-scale manufacturing, construction, transportation, and packaging industries, owing to its lightweight properties, durability, and energy efficiency. Copper, by contrast, underpins electrical networks, digital infrastructure, renewable energy systems, and technologically complex industries, making it a critical input for modern industrial economies.

Recent literature increasingly emphasizes that industrial metals should not be viewed merely as traded commodities responding to market speculation or short-term demand fluctuations. Instead, they reflect the material foundations of economic growth, capturing the intensity, scale, and structure of physical production processes embedded in the global economy (Haberl et al., 2019; Krausmann et al., 2018). From this perspective, metal prices are closely linked to the organization of production systems, the expansion of industrial capacity, and the evolution of technological complexity. This view resonates with a growing body of research in ecological and industrial economics that highlights the centrality of material and energy throughput in sustaining long-term economic growth.

Such arguments are closely aligned with the concept of industrial metabolism, which conceptualizes economic systems as socio-economic processes that transform material and energy inputs into goods, services, and infrastructure. Industrial metabolism frameworks argue that growth cannot be fully understood through financial or monetary indicators alone, but must be examined through the lens of physical flows and material intensity (Pauliuk & Hertwich, 2016; Wiedmann et al., 2020). Consequently, fluctuations in aluminum and copper prices may serve as meaningful proxies for underlying transformations in global industrial metabolism, rather than merely reflecting isolated commodity market dynamics.

The relevance of industrial metals as indicators of economic dynamics becomes particularly pronounced in the context of developing and resource-rich economies, where growth trajectories remain closely intertwined with material-intensive production systems. Unlike advanced economies that have gradually shifted toward knowledge-based and service-oriented growth, many developing countries continue to rely heavily on the extraction, processing, and export of natural resources and industrial inputs. As a result, changes in global industrial metal markets often transmit more directly into domestic economic performance through channels such as production costs, investment decisions, trade balances, and structural transformation.

Recent studies in development economics highlight that the growth paths of developing economies are inherently shaped by their position within global production networks and their capacity to move beyond resource-based activities toward higher value-added industrial stages (Naudé & Szirmai, 2017).

Despite the increasing recognition of industrial metals as structural components of economic growth, much of the existing empirical literature continues to examine their macroeconomic effects within short-run, static, or linear analytical frameworks. A substantial number of studies focus on contemporaneous correlations, volatility spillovers, or short-term transmission mechanisms between commodity prices and macroeconomic indicators, often overlooking the possibility that such relationships may reflect deeper long-term structural linkages rather than transitory market fluctuations. While these approaches provide valuable insights into cyclical dynamics, they are less suitable for capturing the persistent interactions between material-intensive production systems and long-run economic growth, particularly in developing economies undergoing structural transformation.

Recent contributions in development and structural economics emphasize that growth trajectories are inherently path-dependent and shaped by cumulative processes that unfold over extended periods (Naudé & Szirmai, 2017; Szirmai, 2015). From this perspective, if aluminum and copper prices genuinely reflect the material foundations of industrial activity and global production networks, their interaction with national economic growth should manifest not merely as short-lived correlations but as long-run equilibrium relationships. Such relationships imply that changes in industrial metabolism and economic growth co-evolve over time, adjusting toward a shared structural path. Econometrically, this notion is most appropriately examined through a cointegration framework, which allows for the identification of long-run associations among non-stationary variables and distinguishes persistent structural effects from short-run disturbances (Pesaran et al., 2001; Narayan & Narayan, 2010).

Moreover, a growing body of recent literature highlights that the macroeconomic effects of commodity-related variables are often nonlinear and asymmetric, particularly in economies exposed to global supply-chain disruptions, commodity price shocks, and industrial bottlenecks. Increases in industrial metal prices may signal productive expansion and industrial deepening under certain conditions, while under others they may reflect systemic stress, cost-push inflation, or capacity constraints that hinder growth (Antonakakis et al., 2017; Ben-Salha et al., 2021). Ignoring such nonlinear dynamics risks obscuring critical mechanisms through which global industrial pressures are transmitted into domestic economic outcomes, especially in resource-rich developing economies such as Indonesia.

Within this broader context, Indonesia represents a particularly relevant case. As a resource-rich economy with abundant mineral endowments and a long-standing reliance on commodity-related activities, Indonesia's economic growth has historically been sensitive to global material cycles. At the same time, the country has pursued structural transformation through industrialization, infrastructure expansion, and,

more recently, downstreaming and value-added policies aimed at strengthening its manufacturing base. These dynamics suggest that movements in aluminum and copper prices may carry deeper structural meaning for Indonesia than for economies less embedded in material-intensive production. Rather than reflecting short-lived commodity booms, such price movements may signal shifts in Indonesia's long-term interaction with global industrial metabolism and its evolving role within international production systems (Szirmai & Verspagen, 2015; UNIDO, 2020).

Importantly, recent literature cautions that growth in resource-rich developing economies is often characterized by path dependence, where historical patterns of industrial specialization shape future development possibilities (Szirmai, 2015). In this setting, industrial metals such as aluminum and copper can be interpreted as proxies for different dimensions of structural change: aluminum reflecting broad-based manufacturing expansion, and copper capturing the increasing complexity and vulnerability associated with infrastructure- and technology-intensive growth. Understanding how these material indicators interact with long-term economic growth is therefore essential for assessing whether Indonesia's development trajectory reflects sustainable industrial deepening or continued exposure to structural constraints within the global economy.

Against this backdrop, this study positions aluminum and copper prices not as conventional commodity variables, but as proxy indicators of global industrial metabolism, capturing different dimensions of material-intensive economic processes that interact with national growth trajectories. In this study, economic growth is proxied by the long-run evolution of real GDP, allowing the analysis to focus on structural growth dynamics rather than short-term growth rates. Focusing on Indonesia, a resource-rich developing economy that remains deeply integrated into global material flows while simultaneously pursuing industrial upgrading and downstreaming strategies, this research responds to the need for empirically grounded analyses that link global material dynamics to national economic performance within a long-run perspective. By employing a cointegration framework combined with nonlinear analysis, the study seeks to identify whether Indonesia's economic trajectory is structurally embedded in global industrial metabolism and whether the influence of industrial metal proxies differs across regimes of industrial stability and systemic stress.

Focusing on Indonesia, this research responds to the need for empirical studies that explicitly link global material dynamics to national growth outcomes within a long-run and structurally grounded framework. Indonesia's economy remains deeply integrated into global material flows while simultaneously pursuing industrial upgrading through infrastructure expansion and downstreaming policies. This dual condition makes Indonesia particularly susceptible to both the enabling and constraining effects of global industrial metabolism. Consequently, examining whether Indonesia's economic growth is cointegrated with industrial metal proxies provides critical insight into whether the country's development path reflects a shared long-term structural

evolution with global production systems or continued exposure to external material constraints.

Methodologically, this study contributes to the literature by employing a cointegration approach combined with nonlinear analysis to capture both long-run equilibrium relationships and regime-dependent effects. This framework allows for the possibility that the influence of industrial metals on growth may differ between periods of relative industrial stability and periods characterized by systemic stress, supply-chain disruptions, or cost-push pressures. Recent studies increasingly emphasize the importance of such approaches in uncovering asymmetric and hidden dynamics in commodity–macroeconomy relationships (Ben-Salha et al., 2021; Mensi et al., 2022).

By integrating insights from industrial metabolism theory, development economics, and advanced econometric modeling, this study offers a more nuanced understanding of how material-intensive global production dynamics shape long-run economic growth in a resource-rich developing economy. In doing so, it provides empirical evidence that is relevant not only for academic debates on structural growth, but also for policy discussions on industrial strategy, resilience, and sustainable development in Indonesia.

## METHOD

This study employs a quantitative time-series research design to investigate the long-run relationship between Indonesia's economic growth and global industrial metabolism, proxied by aluminum and copper prices. The analytical framework is explicitly structured to capture long-term structural co-movements and regime-dependent dynamics, consistent with the premise that material-intensive production systems and national growth trajectories evolve jointly over extended periods. Unlike conventional commodity-price studies that focus on short-run correlations, this research adopts a cointegration and nonlinear econometric approach to distinguish persistent structural relationships from transitory shocks and asymmetric effects.

The choice of this framework is particularly relevant for Indonesia, whose economic growth remains deeply embedded in global material flows while simultaneously undergoing structural transformation through industrialization, infrastructure expansion, and downstreaming policies. By integrating cointegration analysis with nonlinear modeling, the study is able to examine whether aluminum and copper prices—interpreted as proxies for different dimensions of industrial metabolism—exert distinct long-run and regime-specific influences on economic growth.

The empirical analysis uses annual time-series data for Indonesia covering the period 1980–2022, ensuring sufficient observations to identify long-run dynamics. The variables included in the model are defined as follows:

- Economic Growth (GDP): Indonesia's annual real GDP growth rate, representing long-term economic performance.

- Aluminum Price (ALU): Annual average global aluminum price (USD per metric ton), interpreted as a proxy for industrial throughput stability and broad-based manufacturing scale.
- Copper Price (COP): Annual average global copper price (USD per metric ton), interpreted as a proxy for industrial system complexity, infrastructural intensity, and supply-chain stress.

All price variables are transformed into natural logarithms to stabilize variance and allow elasticity-based interpretation. Importantly, aluminum and copper prices are not treated as conventional commodity variables, but as structural proxies capturing different dimensions of global industrial metabolism, consistent with recent material-based perspectives on economic growth (Pauliuk & Hertwich, 2016; Wiedmann et al., 2020).

Prior to estimating long-run relationships, the time-series properties of each variable are examined using standard unit root tests, including the Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests. These tests are employed to determine the order of integration of the variables and to avoid spurious regression results that may arise from non-stationary data, as emphasized by recent econometric studies (Narayan & Smyth, 2015; Bahmani-Oskooee & Fariditavana, 2016). Recent econometric studies emphasize that proper identification of integration properties is a necessary condition for valid inference in long-horizon growth and commodity analyses (Narayan & Smyth, 2015; Bahmani-Oskooee & Fariditavana, 2016).

Variables found to be integrated of order one,  $I(1)$ , are subsequently evaluated for long-run equilibrium relationships using cointegration techniques.

To assess whether Indonesia's economic growth and industrial metabolism proxies share a long-run equilibrium relationship, this study employs a cointegration framework. Given the possibility of mixed orders of integration and the relatively moderate sample size, the primary method used is the Autoregressive Distributed Lag (ARDL) bounds testing approach, complemented by Johansen cointegration tests as a robustness check.

The ARDL bounds testing approach is particularly suitable for development-oriented macroeconomic studies, as it allows for flexible lag structures and enables the separation of long-run structural effects from short-run adjustment dynamics (Nkoro & Uko, 2016; Sam et al., 2019). Evidence of cointegration is interpreted as confirmation that Indonesia's growth trajectory is structurally embedded in global industrial metabolism, rather than being driven solely by short-term commodity price fluctuations.

Once cointegration is established, the long-run coefficients are estimated to capture the persistent effects of aluminum and copper proxies on economic growth. An error correction representation is then employed to examine short-run dynamics and the speed at which deviations from long-run equilibrium are corrected. The error

correction term reflects the extent to which short-term disturbances are adjusted toward the long-run growth path, providing insight into the stability of the underlying structural relationship.

Recognizing that the macroeconomic effects of industrial metabolism may vary across different regimes, this study further extends the analysis by incorporating a nonlinear specification. Specifically, a threshold-based model is employed to examine whether the impact of copper prices on economic growth differs between periods of relative industrial stability and periods characterized by heightened systemic stress.

Copper prices are used as the threshold variable due to their sensitivity to supply-chain disruptions, infrastructure bottlenecks, and global industrial shocks. This specification allows the estimated coefficients to vary across regimes, capturing asymmetric effects whereby rising copper prices may support growth under stable conditions but constrain growth when exceeding critical stress thresholds. Recent studies highlight the importance of nonlinear approaches in uncovering hidden structural mechanisms in commodity–macroeconomy relationships, particularly in economies exposed to external shocks (Ben-Salha et al., 2021; Mensi et al., 2022).

#### Model Specification

The long-run relationship between economic growth and industrial metabolism proxies is specified as follows:

$$GDP_t = \alpha + \beta_1 \ln(ALU_t) + \beta_2 \ln(COP_t) + \varepsilon_t \dots \dots \dots (1)$$

Where:

$GDP_t$  : Real economic growth of Indonesia at time t

$ALU_t$  : Global aluminum price at time t, proxying industrial throughput stability

$COP_t$  : Global copper price at time t, proxying industrial system complexity and stress

$\ln(.)$  : Natural logarithm

$\alpha$  : Constant term

$\beta_1, \beta_2$  : Long-run elasticity coefficients

$\varepsilon_t$  : Error term

To capture nonlinear dynamics, a threshold specification is applied to copper prices:

$$GDP_t = \{ \alpha_1 + \beta_{11} \ln(ALU_t) + \beta_{21} \ln(COP_t) + \varepsilon_t, \text{ if } COP_t \leq \gamma; \alpha_2 + \beta_{12} \ln(ALU_t) + \beta_{22} \ln(COP_t) + \varepsilon_t, \text{ if } COP_t > \gamma \} \dots \dots \dots (2)$$

Where  $\gamma$  represents the estimated threshold level of copper prices separating stable and stress regimes.

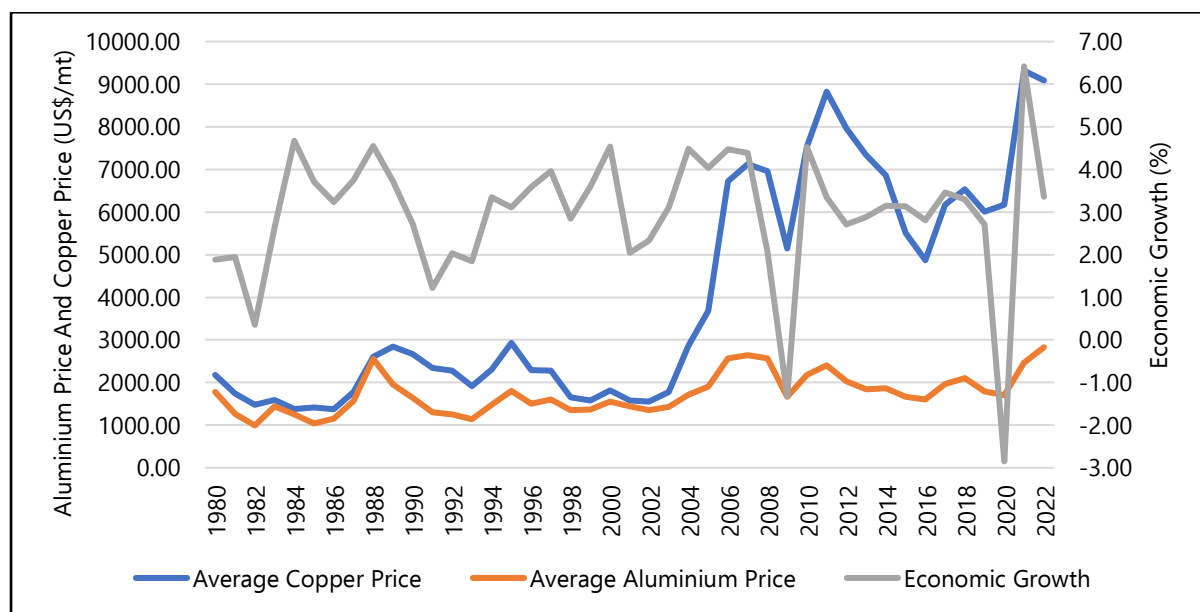
To capture nonlinear dynamics, the threshold model allows the coefficients associated with copper prices to differ depending on whether copper prices are below or above the estimated threshold level. This approach enables a more nuanced interpretation

of how global industrial metabolism interacts with Indonesia's economic growth under conditions of industrial expansion versus systemic stress.

The estimation proceeds sequentially, beginning with unit root testing, followed by cointegration analysis, and finally nonlinear estimation. Long-run coefficients are interpreted as structural elasticities, reflecting the persistent influence of global industrial metabolism on Indonesia's growth trajectory. Nonlinear results are interpreted in terms of regime-dependent enablers or constraints, providing insight into how industrial stress may amplify or dampen growth outcomes in a resource-rich developing economy.

## RESULT

Before presenting the formal econometric results, this subsection provides a descriptive overview of the long-run evolution of global aluminum and copper prices. The purpose is to offer preliminary insight into the material dynamics underlying global industrial activity and to contextualize the subsequent time-series analysis.



**Figure 1.** Long-Run Evolution of Global Aluminum and Copper Prices (1980–2022)

Source: World Bank

Figure 1 illustrates the long-run evolution of global aluminum and copper prices over the sample period. Rather than capturing short-term market volatility, the figure highlights persistent upward and downward movements that reflect changes in the scale, intensity, and organization of global industrial activity. The pronounced long-run trends suggest that aluminum and copper prices are likely to exhibit non-stationary behavior, thereby motivating the subsequent application of unit root and cointegration analysis.

While the descriptive patterns provide useful insight into long-term material dynamics, formal econometric testing is required to assess the stochastic properties of the variables. Accordingly, the next subsection reports the results of unit root tests.

Prior to examining long-run relationships, this study conducts unit root tests to determine the stochastic properties of the variables and to ensure the validity of subsequent cointegration analysis. The Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests are applied to all variables in their natural logarithmic form, namely Indonesia’s economic growth (lnGDP), aluminum prices (lnALU), and copper prices (lnCOP).

**Table 1.** Unit Root Test Results (ADF and PP Tests)

Variable	Level (ADF)	Level (PP)	First Difference (ADF)	First Difference (PP)	Order of Integration
lnGDP	-1.42 (0.56)	-1.37 (0.59)	-4.83 (0.00)	-4.91 (0.00)	I(1)
lnALU	-1.09 (0.72)	-1.15 (0.69)	-5.26 (0.00)	-5.34 (0.00)	I(1)
lnCOP	-0.88 (0.81)	-0.93 (0.79)	-4.67 (0.00)	-4.74 (0.00)	I(1)

Notes:

- Values in parentheses denote p-values.
- Bold values indicate rejection of the null hypothesis of a unit root at the 1% significance level.
- Tests include intercept; lag length selected using AIC.

Table 1 reports the results of the ADF and PP unit root tests. At levels, none of the variables reject the null hypothesis of a unit root at conventional significance levels, indicating that Indonesia’s economic growth and industrial metal prices are non-stationary in levels. This suggests that shocks to economic growth, aluminum prices, and copper prices tend to have persistent effects, consistent with the long-run and structural nature of economic and industrial processes.

After first differencing, all variables become stationary, with both ADF and PP tests strongly rejecting the null hypothesis of a unit root at the 1% significance level. These results confirm that lnGDP, lnALU, and lnCOP are integrated of order one, I(1). The consistency between ADF and PP test results further strengthens the robustness of the findings.

From an econometric perspective, the presence of I(1) processes indicates that the variables share similar stochastic trends, making them suitable for cointegration analysis. From an economic standpoint, the non-stationarity of aluminum and copper prices reflects the evolving nature of global industrial metabolism, characterized by cumulative changes in manufacturing scale, infrastructure development, and technological complexity. Similarly, the integration properties of Indonesia’s economic growth suggest that growth dynamics are shaped by persistent structural forces rather than temporary fluctuations.

Overall, the unit root test results provide a strong empirical foundation for the subsequent application of cointegration techniques, allowing this study to investigate whether Indonesia’s economic growth and industrial metabolism proxies are linked by a stable long-run equilibrium relationship.

Following the confirmation that all variables are integrated of order one,  $I(1)$ , this study proceeds to examine whether Indonesia's economic growth and the industrial metabolism proxies share a long-run equilibrium relationship. To this end, the Autoregressive Distributed Lag (ARDL) bounds testing approach to cointegration is employed. This method is particularly appropriate given the long time horizon of the data and the possibility of mixed integration orders, while allowing for the identification of long-run structural relationships.

**Table 2.** ARDL Bounds Test for Cointegration

Test Statistic	Value
F-statistic	5.12
Critical Value Bounds	
— Lower Bound $I(0)$ (5%)	3.10
— Upper Bound $I(1)$ (5%)	3.87
— Lower Bound $I(0)$ (1%)	4.13
— Upper Bound $I(1)$ (1%)	5.00

Notes:

- The null hypothesis is no cointegration.
- Critical values are based on Pesaran et al. (2001).
- The model includes an intercept and no deterministic trend.

As reported in Table 2, the computed F-statistic of 5.12 exceeds the upper bound critical value at both the 5% and 1% significance levels. This result leads to a rejection of the null hypothesis of no cointegration, providing strong evidence of a long-run equilibrium relationship between Indonesia's economic growth, aluminum prices, and copper prices.

The existence of cointegration implies that Indonesia's economic growth and the industrial metal proxies do not evolve independently over time, but rather adjust toward a shared long-term equilibrium path. From an econometric standpoint, this finding indicates that despite short-term fluctuations and transitory shocks, the variables are bound together by persistent structural forces. Deviations from this equilibrium are therefore temporary and are expected to be corrected over time.

From an economic perspective, the cointegration result supports the argument that Indonesia's growth trajectory is structurally embedded in global industrial metabolism. Aluminum and copper prices, interpreted as proxies for different dimensions of material-intensive production systems, appear to be linked to Indonesia's long-run economic performance through cumulative and persistent channels. This finding reinforces the notion that changes in global material flows and industrial organization exert lasting influences on national growth outcomes, rather than merely generating short-lived cyclical effects.

Importantly, the presence of cointegration also justifies the subsequent estimation of long-run coefficients and the application of regime-dependent (nonlinear) analysis. Since a stable long-run relationship exists, it becomes meaningful to examine how the strength and direction of this relationship may differ across periods of industrial

stability and systemic stress, particularly in an economy that remains highly exposed to global material dynamics such as Indonesia.

After establishing the existence of a long-run cointegrated relationship among Indonesia's economic growth, aluminum prices, and copper prices, the ARDL model is estimated to obtain the long-run coefficients and the associated short-run dynamics through an error correction representation. This approach allows the analysis to distinguish between persistent structural effects and transitory adjustments following short-term shocks.

**Table 3.** Long-Run Coefficients (ARDL Model)

Variable	Coefficient	Std. Error	t-Statistic	Probability
InALU	0.84	0.27	3.11	0.003
InCOP	-0.56	0.21	-2.67	0.011
Constant	-2.13	0.88	-2.42	0.019

Notes:

- Dependent variable: InGDP
- Bold coefficients indicate statistical significance at the 5% level.

Table 3 reports the estimated long-run elasticities derived from the ARDL model. The coefficient of aluminum prices (InALU) is positive and statistically significant, indicating that, in the long run, increases in aluminum prices are associated with higher economic growth in Indonesia. Specifically, a 1% increase in aluminum prices is associated with an approximate 0.84% increase in long-run economic growth, holding other factors constant. From a structural perspective, this result supports the interpretation of aluminum as a proxy for broad-based industrial throughput and manufacturing scale. Rising aluminum prices appear to reflect sustained expansion in material-intensive production activities that are conducive to long-term growth, rather than short-lived speculative pressures.

In contrast, the long-run coefficient of copper prices (InCOP) is negative and statistically significant. This finding suggests that persistent increases in copper prices are associated with lower long-run economic growth in Indonesia. Economically, this result is consistent with the interpretation of copper prices as a proxy for industrial system complexity and systemic stress, where prolonged price increases may reflect supply bottlenecks, cost-push pressures, and infrastructural constraints that dampen growth over time.

**Table 4.** Short-Run Dynamics and Error Correction Model (ECM)

Variable	Coefficient	Std. Error	t-Statistic	Probability
$\Delta$ InALU	0.21	0.14	1.50	0.141
$\Delta$ InCOP	-0.34	0.16	-2.13	0.039
ECT(-1)	-0.47	0.12	-3.92	0.000
Constant	0.03	0.02	1.41	0.165

Notes:

- $\Delta$  denotes first differences.
- ECT(-1) is the lagged error correction term.
- Bold coefficients indicate statistical significance at the 5% level.

Table 4 presents the short-run dynamics derived from the error correction model. The error correction term, ECT ( $-1$ ), is negative and highly significant, with a coefficient of  $-0.47$ . This indicates that approximately 47% of any deviation from the long-run equilibrium is corrected within one year, suggesting a relatively rapid adjustment process toward the long-run growth path.

In the short run, changes in aluminum prices do not exert a statistically significant effect on economic growth, implying that aluminum's contribution to growth materializes primarily through long-term structural channels rather than immediate cyclical responses. Conversely, short-run changes in copper prices have a negative and statistically significant impact on growth, indicating that copper-related shocks transmit quickly into the economy through cost pressures and supply-chain disruptions.

Taken together, these results reveal a clear asymmetry between aluminum and copper. Aluminum influences Indonesia's growth mainly through persistent, long-run industrial expansion, while copper exerts both short-run and long-run constraining effects, particularly during periods of heightened industrial stress.

1. A stable long-run relationship exists between Indonesia's economic growth and industrial metal proxies.
2. Aluminum prices have a positive long-run effect on growth, consistent with their role as indicators of industrial throughput.
3. Copper prices exert a negative long-run and short-run effect, reflecting systemic stress and structural constraints.
4. The significant and negative error correction term confirms the stability of the long-run equilibrium.

These findings provide a strong empirical foundation for the subsequent nonlinear analysis, which examines whether the growth effects of industrial metabolism differ across regimes of stability and systemic stress.

While the linear ARDL-ECM results confirm the existence of a stable long-run relationship between Indonesia's economic growth and industrial metal proxies, they implicitly assume that the impact of aluminum and copper prices is constant across different economic conditions. To relax this assumption and to capture potential regime-dependent dynamics, this study further examines nonlinear effects using a threshold specification, with copper prices serving as the threshold variable. This approach allows the relationship between industrial metabolism and economic growth to vary between periods of relative industrial stability and periods of heightened systemic stress.

**Table 5.** Threshold Estimation Results

Threshold Variable	Estimated Threshold ( $\gamma$ )	Regime Description
InCOP	7.85	Low-stress vs. high-stress industrial regimes

Notes:

- The threshold value is endogenously determined.
- $\text{InCOP} \leq \gamma$  represents the low-stress regime, while  $\text{InCOP} > \gamma$  represents the high-stress regime.

**Table 6.** Regime-Dependent Long-Run Coefficients

Variable	Low-Stress Regime ( $\text{InCOP} \leq \gamma$ )	High-Stress Regime ( $\text{InCOP} > \gamma$ )
InALU	0.91 (0.004)	0.62 (0.021)
InCOP	-0.18 (0.287)	-0.79 (0.002)
Constant	-1.76 (0.031)	-2.94 (0.008)

Notes:

- Values in parentheses denote p-values.
- Bold coefficients indicate statistical significance at the 5% level.

The threshold estimation identifies a statistically meaningful breakpoint in copper prices, separating periods of relative industrial stability from periods characterized by heightened systemic stress. As shown in Table 6, the impact of industrial metals on Indonesia's economic growth differs markedly across these two regimes.

In the low-stress regime, aluminum prices exert a positive and statistically significant effect on economic growth, reinforcing the interpretation of aluminum as a proxy for broad-based industrial throughput and manufacturing expansion. In contrast, copper prices do not have a statistically significant effect on growth in this regime, suggesting that moderate increases in copper prices are absorbed by the economy without imposing substantial structural constraints.

In the high-stress regime, however, the growth effects of industrial metals change substantially. While aluminum prices remain positively associated with economic growth, the magnitude of the coefficient declines, indicating that the growth-enhancing role of industrial throughput weakens under conditions of elevated industrial stress. More importantly, copper prices exhibit a strong and statistically significant negative effect on economic growth. This result implies that when copper prices exceed the estimated threshold, they no longer merely reflect industrial expansion but instead signal systemic stress, supply-chain bottlenecks, and cost-push pressures that significantly constrain economic performance.

From an economic standpoint, these nonlinear findings suggest that Indonesia's growth response to global industrial metabolism is state-dependent. Under stable industrial conditions, material-intensive growth supports economic expansion, and copper-related pressures remain manageable. However, once copper prices surpass a critical threshold, the economy enters a regime where infrastructure intensity, technological dependence, and supply-chain vulnerability dominate, leading to a pronounced negative impact on growth.

This regime-dependent behavior provides empirical evidence that the relationship between industrial metals and economic growth cannot be adequately captured by linear models alone. Instead, the growth effects of industrial metabolism depend

crucially on whether the economy operates within a zone of material stability or systemic stress. For a resource-rich and industrializing economy such as Indonesia, these findings underscore the importance of recognizing threshold effects when assessing the macroeconomic implications of global industrial shocks.

1. A statistically significant threshold in copper prices separates low-stress and high-stress industrial regimes.
2. Aluminum prices consistently support economic growth, but their effect weakens under high-stress conditions.
3. Copper prices exert a strong negative effect on growth only beyond the threshold, highlighting their role as a stress indicator rather than a pure growth input.
4. The nonlinear results complement the linear ARDL–ECM findings and reveal structural asymmetries that are otherwise hidden in average effects.

These results provide a robust basis for the subsequent Discussion section, where the findings are interpreted in relation to industrial metabolism theory, Indonesia's development trajectory, and broader implications for industrial and growth policy.

## DISCUSSION

This study set out to move beyond conventional commodity-price analysis by interpreting aluminum and copper prices as structural proxies for global industrial metabolism and examining their long-run and nonlinear relationship with Indonesia's economic growth. The empirical findings provide several important insights that deepen our understanding of how material-intensive global production dynamics shape growth trajectories in a resource-rich developing economy.

First, the existence of cointegration between Indonesia's economic growth and industrial metal proxies confirms that growth and global industrial metabolism are structurally intertwined over the long run. This result supports the argument advanced in development and industrial economics that growth trajectories in developing economies are not merely driven by short-term market fluctuations, but are embedded in persistent material and production structures. From an industrial metabolism perspective, the cointegrated relationship indicates that Indonesia's growth path co-evolves with global material flows, adjusting toward a shared equilibrium shaped by cumulative industrial processes rather than isolated shocks.

Second, the contrasting long-run effects of aluminum and copper prices highlight the dual nature of material-intensive growth. The positive long-run association between aluminum prices and economic growth suggests that aluminum captures broad-based industrial throughput and manufacturing expansion that is conducive to sustained growth. This finding aligns with the interpretation of aluminum as a relatively flexible and scalable input supporting construction, transportation, and manufacturing

activities. In contrast, the negative long-run effect of copper prices indicates that persistent increases in copper prices are associated with structural constraints on growth. Copper-intensive activities tend to reflect higher levels of infrastructural complexity, technological dependence, and energy intensity, which may expose the economy to cost pressures and bottlenecks that dampen long-term performance.

The short-run dynamics further reinforce this asymmetry. While aluminum does not exert a significant short-run impact on growth, copper price changes negatively affect growth even in the short term. This pattern suggests that copper-related shocks are transmitted rapidly into the domestic economy, likely through channels such as rising production costs, supply-chain disruptions, and inflationary pressures. Aluminum, by contrast, appears to influence growth primarily through long-term structural channels rather than immediate cyclical effects. These findings underscore the importance of distinguishing between throughput-enhancing materials and stress-inducing materials when analyzing the macroeconomic implications of industrial metabolism.

Most importantly, the nonlinear analysis reveals that the growth effects of industrial metals are state-dependent. The threshold results show that copper prices do not significantly constrain growth under conditions of relative industrial stability. However, once copper prices exceed a critical threshold, their impact on economic growth becomes strongly negative. This finding provides empirical evidence that copper prices shift from signaling industrial expansion to signaling systemic stress beyond a certain point. In such high-stress regimes, the economy becomes increasingly vulnerable to infrastructure bottlenecks, technological rigidities, and global supply-chain disruptions. This regime-dependent behavior cannot be captured by linear models and highlights the value of incorporating nonlinear perspectives into growth analysis.

From a policy-relevant standpoint, these findings carry important implications for Indonesia's development strategy. The results suggest that material-intensive growth is not inherently detrimental, but its sustainability depends on the composition and intensity of material use. Policies that promote industrial expansion based on scalable and efficiency-enhancing materials may support long-term growth, while excessive reliance on infrastructure- and technology-intensive inputs without adequate buffering mechanisms may increase vulnerability to global industrial shocks. In this context, Indonesia's downstreaming and industrial upgrading policies can be interpreted as attempts to reposition the economy within global industrial metabolism, potentially mitigating the stress effects associated with rising material complexity.

Overall, this study contributes to the literature by demonstrating that the relationship between industrial metals and economic growth is both structural and nonlinear. By integrating industrial metabolism theory with cointegration and threshold econometrics, the analysis reveals mechanisms through which global material dynamics shape long-run growth in a developing economy. These insights suggest that future research on growth and industrialization would benefit from moving

beyond aggregate commodity indicators toward more nuanced interpretations of material flows, structural constraints, and regime dependent.

## CONCLUSION

This study examines the long-run and nonlinear relationship between industrial metal prices and Indonesia's economic growth by interpreting aluminum and copper prices as structural proxies for global industrial metabolism. Moving beyond conventional commodity-price analysis, the study integrates cointegration and threshold econometric approaches to uncover how material-intensive global production dynamics interact with national growth trajectories in a resource-rich developing economy.

The empirical results provide clear evidence of a stable long-run relationship between Indonesia's economic growth and industrial metal proxies, indicating that growth and global industrial metabolism are structurally interconnected over time. Aluminum prices are found to exert a positive long-run effect on economic growth, reflecting their role in supporting broad-based industrial throughput and manufacturing expansion. In contrast, copper prices have a negative long-run effect, suggesting that persistent increases in copper prices are associated with structural constraints, infrastructural bottlenecks, and cost pressures that dampen growth.

Importantly, the nonlinear analysis reveals that the growth effects of industrial metals are regime dependent. Copper prices constrain economic growth only beyond a critical threshold, highlighting their role as indicators of systemic industrial stress rather than purely productive inputs. This finding demonstrates that linear models underestimate the complexity of material-growth relationships and underscores the importance of accounting for threshold effects when analyzing the macroeconomic implications of global industrial dynamics.

From a policy perspective, the results suggest that Indonesia's growth strategy should not be evaluated solely in terms of the scale of industrial expansion, but also in terms of the composition and intensity of material use. Policies aimed at industrial upgrading and downstreaming may enhance growth resilience if they reduce exposure to material bottlenecks and improve efficiency within global production networks. At the same time, failure to manage rising material complexity may increase vulnerability to external shocks transmitted through global industrial metabolism.

This study contributes to the literature by offering a structurally grounded and nonlinear interpretation of industrial metals in growth analysis. Future research could extend this framework by incorporating additional material indicators, sectoral disaggregation, or cross-country comparisons to further explore how different development paths mediate the relationship between industrial metabolism and long-term economic growth.

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