

# Quantile-on-Quantile Connectedness of Commodity Prices and Economic Growth: Evidence From Advanced and Emerging Economics

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## ABSTRACT

This study investigates the non-linear and time-varying connectedness between global commodity prices and economic growth in the United States, the EU27, China, and India from January 1990 to June 2025. Employing the quantile-on-quantile connectedness (QQ) approach, the analysis assesses spillover effects across various quantiles. The results indicate that, since the onset of the COVID-19 pandemic in 2020, industrial production and precious metal prices have exhibited inverse movements in the United States and India. In contrast, in China, increases in precious metal prices are generally associated with higher industrial production, while the EU27 demonstrates a negative relationship. A persistent positive correlation exists between energy prices and industrial production across all economies. Following 2020, food prices and industrial production have moved in parallel, influenced by factors such as pandemic-induced supply chain disruptions and shocks in food commodity and fertilizer prices resulting from Russia's invasion of Ukraine.

*Keywords: Economic Growth, Commodity Prices, Quantile-on-Quantile Connectedness*

## Emtia Fiyatları ve Ekonomik Büyüme Arasındaki Kantil-Kantil Bağlantısı: Gelişmiş ve Gelişmekte Olan Ekonomilerden Kanıtlar

### ÖZET

Bu çalışma, Ocak 1990 ile Haziran 2025 tarihleri arasında Amerika Birleşik Devletleri, AB27, Çin ve Hindistan'da küresel emtia fiyatları ile ekonomik büyüme arasındaki doğrusal olmayan ve zamana bağlı bağlantıyı araştırmaktadır. Çalışmada kantil-kantil bağlantı (QQ) yaklaşımını kullanarak, çeşitli kantiller arasında yayılma etkileri değerlendirilmektedir. Elde edilen sonuçlar, COVID-19 pandemisinin başlangıcından bu yana, ABD ve Hindistan'da sanayi üretimi ve değerli metal fiyatlarının ters yönde hareket ettiğini göstermektedir. Buna karşılık, Çin'de değerli metal fiyatlarındaki artışlar genellikle daha yüksek sanayi üretimiyle ilişkilendirilirken, AB27'de negatif bir ilişki gözlemlenmektedir. Tüm ekonomilerde enerji fiyatları ve sanayi üretimi arasında sürekli pozitif bir korelasyon mevcuttur. 2020'den sonra, gıda fiyatları ve endüstriyel üretim,

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pandemi kaynaklı tedarik zinciri aksamaları ve Rusya'nın Ukrayna'yı işgalinden kaynaklanan gıda emtia ve gübre fiyatlarındaki şoklar gibi faktörlerden etkilenerek paralel hareket etmiştir.

*Anahtar Kelimeler: Ekonomik Büyüme, Emtia Fiyatları, Kantil-Kantil Bağlantılık*

## 1. INTRODUCTION

Commodity prices serve as important forward-looking indicators of economic growth (Stock and Watson, 2003). The evolution of financial markets, particularly the financialization of commodities (Basak and Pavlova, 2016), has further increased their relevance as indicators of economic activity (Balcilar and Bekun, 2020; Gokmenoglu et al., 2021; Li, 2023). The capital-intensive nature of commodity production results in inelastic short-run supply functions, as significant time is required to develop capital (Kydland and Prescott, 1982). As a result, short-run supply, including inventories, is often considered fixed. Changes in production by a global representative firm typically lead to corresponding fluctuations in commodity prices. The slow adjustment of supply to changing demand can align commodity price cycles with global economic activity cycles, resulting in common cycles (Herrera and Rangaraju, 2020; Duarte et al., 2021). Rising commodity prices can reduce households' discretionary incomes, as higher production costs and international commodity prices lead to increased retail prices. This reduction in available funds for consumption and saving may decrease overall consumption and potentially slow economic growth (Edelstein and Kilian, 2009). Conversely, declining commodity prices generally lower production costs, making retail prices more competitive and encouraging increased household consumption. This change can support long-term GDP growth by improving consumption patterns. Overall, fluctuations in commodity prices influence economic growth by either accelerating or decelerating it, depending on supply conditions, and also impact household welfare (Enilov, 2024).

In recent years, fluctuations in commodity prices have created economic uncertainty, negatively affecting supply and demand and thus restricting economic growth. The impact of commodity prices on income operates through both cost and income channels (Ferraro and Peretto, 2018). Commodity prices determine not only the value of the commodities themselves but also their demand within the agricultural and manufacturing sectors. According to the net benefit approach proposed by Deaton (1989), the effects of commodity price changes on income depend on whether a country is a net exporter or net importer of a given commodity. Typically, rising commodity prices benefit net exporters while imposing losses on net importers. Conversely, declining commodity prices tend to reverse these effects (Asif et al., 2020). Wachtmeister et al. (2018) emphasize that natural resources, which comprise the most heavily traded commodities globally, are crucial for the economic growth of many countries. Certain commodities, such as oil, display greater price volatility than others, including gold and copper (Marwanti and Robiyanto, 2021). This price volatility contributes to uncertainty that can hinder the economic progress of

nations heavily dependent on commodities. In export-driven, resource-rich economies, rising commodity prices typically increase income and foster economic development. In contrast, economies reliant on importing these resources may experience reduced demand, lower production, and overall economic contraction during price surges. Conversely, declining commodity prices can stimulate economic growth (Van Eyden et al., 2019; Akinsola and Odhiambo, 2020).

Global economic uncertainty has recently increased due to geopolitical tensions, health crises, and tariffs. Understanding the impact of commodity price movements on economic growth is therefore essential for policymakers, as it facilitates the forecasting of policy outcomes. The US-China trade war has raised concerns regarding a potential global economic slowdown (Boer and Rieth, 2024; Yoganandham, 2025). Inconsistent statements from the Trump administration regarding tariffs have contributed to market volatility, resulting in selling pressures within the commodity sector. Concerns about a potential intensification of the trade war have underscored the risks of a deeper economic downturn. The unpredictability of U.S. policies and ongoing geopolitical risks has led to significant increases in the prices of energy, raw agricultural products, and precious metals (Rifa'i, 2026). As the commodity market is a key indicator of economic growth, these price fluctuations have heightened concerns about a potential slowdown in global economic activity.

This paper investigates the non-linear, asymmetric, and time-varying connectedness between commodity markets and economic growth in the United States, the European Union, China, and India. Employing the quantile-on-quantile connectedness (QQ) approach, it analyzes spillovers across various quantiles. The study provides insights into the dynamics of global commodity prices and economic growth in these countries from January 1990 to June 2025. Specifically, the following research questions are addressed:

\* Does extreme value dependence exist between commodity prices and output growth?

\* How does the relationship between commodity prices and economic growth vary across these nations?

This study aims to contribute to the existing literature in several ways. Globalization has resulted in a substantial increase in countries' reliance on commodities, with over half of nations worldwide classified as commodity-dependent since 2019. Approximately ten percent of developed countries are commodity-dependent, compared to two-thirds of emerging economies (UNCTAD, 2025). As a result, emerging economies are more susceptible to fluctuations in commodity prices. Most academic research on commodity-driven growth has focused on developed economies, particularly the United States (Alexeev and Chin, 2021; Gao et al., 2022), leading to a significant gap in understanding the influence of commodity prices on economic growth in developing economies (Duarte et al., 2021). To address this gap, the present study examines the relationship between commodity markets and economic growth in both developed and emerging countries that are major commodity exporters and importers. Secondly, numerous studies investigate the

impact of oil prices on economic growth (Wang and Liao, 2022). However, it is essential to acknowledge that commodity-dependent economies often rely on a diverse range of commodities, encompassing both fuel and non-fuel resources. The existing literature provides limited analysis of non-fuel commodities, resulting in a gap regarding whether the prices of these goods can forecast economic growth. To address these research deficiencies, this study analyzes the extent to which commodity prices serve as predictors of economic growth, evaluates the sensitivity of different countries to specific commodity groups, and examines how a nation's stage of development may influence its reliance on commodity prices for growth. Thirdly, this study utilizes a broad data period, spanning from January 1990 to June 2025, which encompasses significant economic, political, and geopolitical events. These events include the 2008 Global Financial Crisis, the 2009-2010 European debt crisis, the COVID-19 pandemic, the Russia-Ukraine conflict, the Federal Reserve's rate increases, the China-US trade war, and the imposition of tariffs by the United States. The estimation period begins in 1990, a time characterized by a substantial increase in global trade and financial openness, commonly referred to as Globalization. This comprehensive timeframe enables a long-term perspective on how major external shocks impact the relationship between commodity prices and economic growth. By incorporating these crisis episodes, the study provides policy-relevant insights into the interactions between commodity price movements and concerns about global economic growth. Fourthly, to comprehensively capture interconnected effects across various quantiles, this study employs the quantile-on-quantile connectedness methods developed by Gabauer and Stenfors (2024). This methodology offers a robust framework for analyzing connectedness across quantiles, illustrating how uncertainty and energy price dynamics evolve under both normal and extreme economic conditions. The approach accounts for the non-linear and state-dependent relationships between commodity markets and economic growth. This methodological sophistication enables the identification of specific periods when commodity price fluctuations have a significant impact on economic growth, thereby enhancing our understanding of the transmission mechanisms linking developed and emerging economies to global commodity markets. Finally, the study calculates total connectedness indices, both direct and indirect, to examine how economic growth influences commodity prices and how fluctuations in commodity prices, in turn, impact economic growth. This bidirectional approach highlights the frequently overlooked feedback relationship between these variables.

The paper is organized as follows: Section 2 outlines the theoretical framework and empirical methodology, Section 3 presents the new data, Section 4 details the applied methodology, Section 5 discusses the empirical results and their implications, and Section 6 concludes with key findings and policy recommendations.

## **2. LITERATURE**

A significant topic in contemporary economic literature is the impact of commodity prices on economic growth. These prices affect not only the production of commodities but also the production and consumption of related goods and services. The relationship between commodity prices and economic growth is widely discussed, with research outcomes differing according to commodity type and the specific country or region examined. Four primary transmission channels—Dutch disease, price volatility, rentier-state, and the crowding-out effect—are identified in the literature as mechanisms explaining the negative effects of commodity markets on economic growth. The Dutch disease channel posits that large-scale natural resource exports generate substantial foreign currency inflows, causing local currency appreciation. This appreciation reduces the competitiveness of the manufacturing sector, reallocates capital and labor toward resource and service sectors, and undermines sustainable economic growth (Corden, 1984). The price volatility channel suggests that fluctuations in commodity prices lead to revenue instability. A sharp decline in prices can trigger economic shocks for countries dependent on these exports. Ross (2003) observes that commodity prices are more volatile than those of manufactured goods. Such revenue fluctuations can induce exchange rate volatility, which subsequently deters foreign investment and impedes economic growth (Gylfason, 2006; Budina et al., 2007). The rentier-state channel highlights the role of institutional quality in the resource curse debate. Robust institutions are essential for economic development, as empirical studies demonstrate that institutional quality significantly shapes the relationship between natural resource wealth and economic growth (Moshiri and Hayati, 2017; Abdulahi et al., 2019). Finally, the crowding-out effect describes how reliance on natural resources can erode social, human, physical, and real capital, all of which are vital for economic growth, thereby hindering development (Gylfason, 2006).

Existing literature has extensively analyzed the impact of energy commodities, particularly oil and natural gas, on economic growth (Adedoyin et al., 2020; Alexeev and Chin, 2021; Gao et al., 2022), while often neglecting other commodities as potential leading indicators. Ge and Tang (2020) reported that commodity prices significantly predict economic growth in about half of the G20 countries. Harvey et al. (2017) demonstrated that commodity price movements exert asymmetric effects on GDP growth. Duarte et al. (2021) established a positive association between commodity price growth rates and global economic activity. Álvarez et al. (2021) found that higher metal prices reduced poverty in Chile, while Guan et al. (2021) observed that volatility in oil and gold prices negatively affected long-term growth in top-producing countries. Krasnovskiy et al. (2022) reported that volatility in agricultural raw material prices impedes economic growth in developed importing nations. Li (2023) identified positive correlations between various commodity price volatilities and China's economic growth. Teye-Gaga et al. (2023) found that although increasing raw material prices contribute to income growth, high volatility in these prices has detrimental effects. Furthermore, Şen et al. (2024) noted that energy and fertilizer prices have a negative impact on economic growth across all income levels, whereas food and metal prices generally have a positive effect.

The debate regarding the long-term effects of commodity prices is complicated by methodological challenges, as many empirical studies fail to account for the potential nonlinear impacts of commodity price shocks. Most research employs cointegration methods such as Vector Autoregression (VAR), Error Correction Models (ECM), and Autoregressive Distributed Lag (ARDL) models within a linear framework, which may not accurately capture complex relationships. Consequently, the nonlinear effects of commodity price shocks remain underexplored, with only a limited number of studies addressing this issue (Bildirici and Gokmenoglu, 2020; Tahar et al., 2021). For example, Bildirici and Sonustun (2018) investigated the impact of gold and oil prices on oil-exporting economies, highlighting the importance of price volatility. Bildirici and Gokmenoglu (2020) evaluated the metal curse hypothesis among leading precious metal exporters, revealing significant relationships between various metals and economic growth, with impacts differing by metal type and economic context. Tahar et al. (2021) examined the asymmetric effects of commodity prices on output per capita in commodity-dependent countries, utilizing panel nonlinear ARDL models to demonstrate that positive price changes have greater long-term effects, while negative shocks produce immediate impacts. Enilov (2024) investigated the predictive power of commodity prices for economic growth using a time-varying mixed-frequency vector autoregressive model, finding that economic dependence on commodities has increased substantially since the onset of financialization, particularly in developing countries. Mehta et al. (2022) employed quantile regression analysis to examine the impact of aluminum price fluctuations on India's manufacturing sector during the COVID-19 pandemic, concluding that rising prices have a positive effect on manufacturing output. Additionally, Liu and Serletis (2022) studied the volatility dynamics of commodity prices in relation to output growth in G7 and EM7 economies, identifying varying levels of dependence. Zou and Hu (2025) examined the relationship between Chinese macroeconomic uncertainty and commodity market volatility, showing that macroeconomic conditions have a significant influence on commodity prices used in manufacturing.

This study contributes to the literature by examining the nonlinear, asymmetric, and time-varying connectedness between global commodity prices—including beverages, fertilizers, metals and minerals, food, precious metals, and energy—and the economic growth of both developed and emerging countries. While previous research has primarily focused on low-income countries reliant on a narrow range of commodities, as well as on commodity-importing countries and the U.S. economy, the present analysis distinguishes itself by considering both developed and emerging markets. In particular, it focuses on the U.S., the European Union, China, and India, which act as both commodity importers and exporters. The study examines the non-linear dynamics underlying the relationship between economic growth and commodity prices, particularly during periods of significant stress, such as the COVID-19 pandemic, the Russia-Ukraine conflict, the Israel-Iran conflict, the imposition of tariffs by the Trump administration, the U.S.-China trade wars, and interest rate hikes by the Federal Reserve. Traditional linear models often fail to capture these complex relationships, particularly under extreme conditions.

**Table 1.** Literature on the commodity price-economic growth relationship

Author(s)	Commodity Focus	Country Group(s)	Methodology	Key Findings
Harvey et al. (2017)	Aggregated commodity index	Developed: US; Exporter: Chile	Stationary Vector Autoregression (VAR)	Asymmetric effects: Declines help importers, harm exporters.
Bildirici and Sonustun (2018)	Oil and Gold	Oil-exporting countries	Nonlinear Time Series Models	Volatility significantly affects macroeconomic stability.
Ge and Tang (2020)	Broad commodities	G20 (EU, Saudi Arabia, others)	Mixed-Frequency Vector Autoregression (VAR)	Predictive power of commodity returns in ~50% of countries.
Adedoyin et al. (2020)	Oil	General	Time Series Econometric Analysis	Oil plays a key role in macroeconomic performance.
Bildirici and Gokmenoglu(2020)	Precious Metals	Metal-exporting countries	Nonlinear Panel Analysis	Impact varies by metal and macroeconomic context.
Duarte et al.(2021)	Oil	Global (macro-financial)	Derived-Demand VAR Model	Positive link between oil price growth and economic activity.
Álvarez et al.(2021)	Metal-Mining Prices	Chile (Developing)	Microdata Analysis (Household-level Panel Data)	Rising prices reduce poverty and increase employment.
Guan et al. (2021)	Oil and Gold	Top Producers	Panel Autoregressive Distributed Lag (Panel ARDL)	Volatility negatively affects long-term growth.
Tahar et al.(2021)	General commodity prices	Commodity-dependent countries	Panel Nonlinear ARDL Model	Positive price shocks have stronger long-run impact.
Enilov (2024)	Commodities (general)	Developed and Developing Countries	Time-Varying Mixed-Frequency VAR	Post-2008, developing countries became more commodity-dependent.
Alexeev and Chin (2021)	Oil	General	Cross-Country Econometric Survey	Oil remains central in growth-energy discussions.
Gao et al.(2022)	Oil	General	Econometric Time-Series Models	Oil volatility significantly affects growth.
Krasnovskiy et al. (2022)	Agricultural Raw Materials	Developed (importers)	Generalized Autoregressive Conditional Heteroskedasticity (GARCH)	Volatility reduces economic growth in developed importers.
Liu and Serletis (2022)	Commodities (varied)	G7 vs EM7	Volatility Modeling (Stochastic Volatility, VAR)	Growth dependence varies across G7 and EM7 countries.
Mehta et al. (2022)	Aluminum	India (Emerging Market)	Quantile Regression Analysis	Higher aluminum prices raised manufacturing output.
Teye-Gaga et al. (2023)	Raw Materials	Developed countries	Two-Stage Least Squares (2SLS)	Prices increase GDP; volatility has negative impact.
Li (2023)	Agriculture, Coal, Oil, Metals, Livestock	China (Emerging)	Error Correction Model (ECM)	Positive relationship between commodity prices and growth.

<b>Şen et al. (2024)</b>	Global: Beverages, Energy, Fertilizers, etc.	High, Upper- Middle, Lower- Middle	Cross-Sectional Panel Regression	Mixed effects: Energy ↓ GDP; Food & Metals ↑ GDP; income-specific patterns.
<b>Zou and Hu (2025)</b>	Industrial Inputs (Commodities)	China	Interaction Models with Macroeconomic Uncertainty	Uncertainty influences commodity-linked growth.

## 2.1. Research Gap

Most research on commodity-driven growth has focused on developed economies, particularly the United States (Alexeev and Chin, 2021; Gao et al., 2022), creating a gap in understanding the impact of commodity prices on economic growth in developing economies (Duarte et al., 2021). This study aims to address this gap by examining the relationship between commodity markets and economic growth in both developed and emerging countries that are significant commodity exporters and importers.

While many studies investigate oil prices' effects on economic growth (Wang and Liao, 2022), it is important to note that commodity-dependent economies rely on a variety of commodities, including both fuel and non-fuel resources. Limited analysis of non-fuel commodities raises questions about their potential to predict economic growth. Thus, this study assesses how commodity prices can serve as predictors of growth, evaluates country sensitivity to different commodity groups, and explores how a nation's development stage influences its reliance on commodity prices.

This analysis provides a long-term perspective on how external shocks affect the relationship between commodity prices and economic growth. By incorporating crisis episodes, the research offers insights into the interaction between commodity price movements and global economic growth concerns. Additionally, employing quantile-on-quantile connectedness methods by Gabauer and Stenfors (2024), the study analyzes the non-linear relationships between commodity markets and economic growth across different economic conditions. Finally, the study computes total connectedness indices to explore the feedback relationship between economic growth and commodity prices, highlighting their interdependent dynamics.

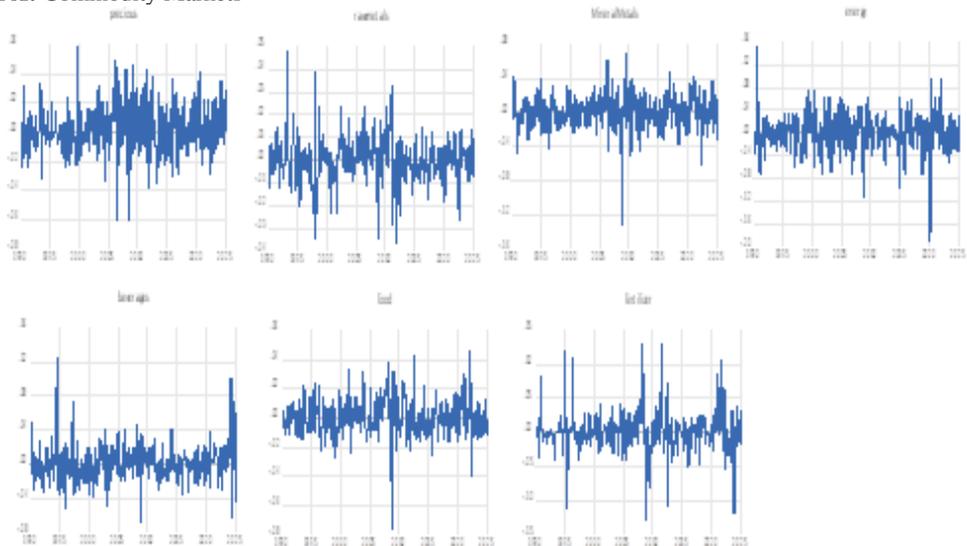
## 3. DATA

This study offers a comprehensive analysis of the asymmetric relationship between commodity prices and economic growth in the United States, the European Union, China, and India. Collectively, these economies represent over 67% of global economic output. As major participants in both commodity import and export markets, they are significantly affected by fluctuations in commodity prices, particularly those associated with the implementation of tariffs during the Trump administration. The analysis utilizes monthly data spanning from January 1990 to June 2025.

This study adopts the methodologies established by Fernández et al. (2020) and Liu and Serletis (2022) to construct a global real commodity price index. Consistent with Fernández et al. (2020), the index encompasses a broad range of commodities, focusing on monthly prices from seven primary categories: food, beverages, agricultural raw materials, metals and minerals, fertilizers, energy, and precious metals. The monthly price data, reported in current U.S. dollars, is obtained from the World Bank’s Commodity Price database (Pink Sheet). According to the Pink Sheet, these prices reflect comprehensive information from all 40 commodities listed in the World Bank's database. The total industrial production index is used as a proxy for real output in both developed and developing countries, with output data primarily sourced from the OECD database. The growth rate of commodity prices is calculated by the difference in the logarithm of the global real commodity price index, expressed as  $\Delta \ln P_t = \ln P_t - \ln P_{(t-1)}$ . In parallel, we determine output growth by utilizing the difference in the logarithm of the industrial production index, represented as  $\Delta \ln Y_t = \ln Y_t - \ln Y_{(t-1)}$ . Figure 1 illustrates the growth rates of the commodity prices and industrial production indices since 1990. Additionally, Table 2 presents comprehensive descriptive statistics for the variables.

**Figure 1** The Graphs of Commodity Markets and Industrial Production Indices

**Panel A:** Commodity Markets



**Panel B:** Industrial Production Indices

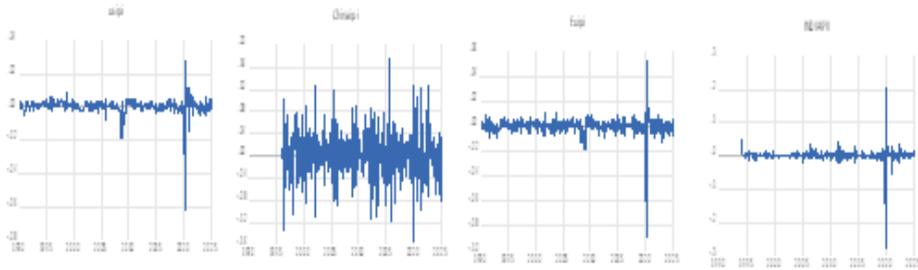


Table 2 indicates that precious metals yield the highest average return among commodity markets, whereas the China Industrial Production Index (IPI) records the highest mean. Both commodity markets and industrial production indices demonstrate a wide range, reflecting substantial differences between minimum and maximum values. The energy market exhibits the greatest risk, as measured by standard deviation. Returns for mineral and metal, energy, and food commodity markets, along with all industrial production indices except those in China, display negative skewness. This left-skewed distribution suggests the presence of extreme events. The kurtosis of returns exceeds the threshold value of 3 for all banks, and the Jarque-Bera statistics surpass the critical value of 5.99 associated with a normal distribution. Therefore, the return series are not normally distributed and are characterized as leptokurtic.

**Table 2: Descriptive Statistics**

	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	JB
<b>Commodity Markets</b>								
PRECIOUS	0.002109	-0.000029	0.058071	-0.061004	0.016033	0.077643	3.952326	16.53***
RAWMETALS	0.000345	0.000559	0.047880	-0.036671	0.009964	0.094134	6.017359	162.23***
MINERALMETALS	0.000966	0.001507	0.068819	-0.132225	0.020738	-0.786053	7.615772	422.04***
ENERGY	0.001120	0.003064	0.151047	-0.191680	0.034823	-0.543338	6.165663	198.84***
BEVERAGES	0.001622	0.001003	0.124631	-0.069142	0.020716	0.978500	8.058053	522.09***
FOOD	0.000639	-0.000780	0.046494	-0.076425	0.012651	-0.231392	6.554759	228.10***
FERTILIZER	0.001535	0.001009	0.130897	-0.127276	0.027437	0.325492	9.684882	800.73***
<b>Industrial Production Indices</b>								
USIPI	0.000430	0.000561	0.027696	-0.061690	0.004836	-5.886588	82.679270	95689.06***
CHINA IPI	0.001849	0.001175	0.175248	-0.155641	0.044517	0.018736	4.402259	29.02***
EUIPI	0.000388	0.000563	0.053035	-0.088087	0.007907	-3.615513	57.129520	43988.82***
INDIA IPI	0.001770	0.001958	0.205046	-0.277503	0.021679	-3.885948	102.433100	146723.20***

Note: \*\*\* indicates significance level at 1%. JB: Jarque-Bera

## 4. METHODOLOGY

The Quantile-on-Quantile (QQ) connectedness method is utilized to analyze the dynamics of both direct and inverse spillovers between commodity prices and economic growth. Introduced by Gabauer and Stenfors (2024), this approach significantly advances the earlier quantile connectedness framework developed by Chatziantoniou et al. (2021). The method examines the relationships among various quantiles ( $\tau_1, \tau_2, \dots, \tau_K$ ) of two key financial indicators: commodity prices and economic growth. Specifically, it assesses how changes in a particular quantile ( $\tau_1$ ) of commodity prices influence the corresponding quantile ( $\tau_2$ ) of economic growth. This technique, grounded in the QQ regression method proposed by Sim and Zhou (2015), extends its application to dynamic connectedness as described by Diebold and Yilmaz (2012). This analysis seeks to provide a comprehensive understanding of the relationship between commodity prices and economic performance across different quantiles, offering valuable insights for policymakers and researchers.

Unlike traditional methods that focus on specific quantiles (for example,  $\tau_1 = 0.05, \tau_2 = 0.05$ ), the proposed approach robustly captures spillover effects across a broader range of quantiles (for example,  $\tau_1 = 0.05, \tau_2 = 0.95$ ). This methodological advancement challenges the conventional assumption of positive correlation in time series, facilitating a comprehensive analysis of interconnectedness, even when time series exhibit divergent quantile behaviors. The method effectively identifies the dynamics of spillover effects across quantiles, highlighting the importance of both the magnitude and direction of correlations. The QQ connectedness method demonstrates a higher degree of inversely related Total Connectedness Index (TCI) compared to traditional quantile connectedness techniques (Gabauer and Stenfors 2024). To investigate the Quantile-on-Quantile transmission mechanism between commodity prices and economic growth, this study extends the quantile connectedness framework introduced by Chatziantoniou et al. (2021). This extension is designed to capture variations in interdependencies across quantiles, allowing for a more accurate assessment of quantile-dependent interdependencies.

We will enable an accurate assessment of interdependencies that fluctuate across quantiles. We utilize a QVAR(p) model to facilitate the precise estimation of dependencies across multiple quantiles:

$$X_t = \mu(\tau) + \sum_{j=1}^p B_j(\tau)x_{t-j} + u_t(\tau) \tag{1}$$

The vectors  $x_t$  and  $x_{t-j}$  are  $K \times 1$  dimensional endogenous variable vectors. The vector  $\tau$  represents quantiles that fall within the interval  $[0, 1]$ , and  $p$  indicates the lag length of the QVAR. The term  $\mu(\tau)$  defines the  $K \times 1$  dimensional conditional mean vector, while  $B_j(\tau)$  stands for the  $K \times K$  – dimensional coefficient matrix associated with the QVAR. Furthermore,  $u_t(\tau)$  denotes a  $K \times 1$  dimensional error vector, which is linked to a  $K \times K$  dimensional variance-covariance matrix,  $H(\tau)$ . In order to effectively compute the generalized forecast error variance decomposition (GFEVD) introduced by Koop et al. (1996), the QVAR undergoes a transformation into a Quantile Vector Moving Average

(QVMA) as mandated by the Wold representation theorem.  $x_t = \mu(\tau) + \sum_{j=1}^p B_j(\tau)x_{t-j} + u_t(\tau) = \mu(\tau) + \sum_{i=0}^{\infty} A_i(\tau)u_{t-i}(\tau)$ .

The F-step ahead GFEVD shows the effect of a shock in series  $j$  on series  $i$ :

$$\phi_{i \leftarrow j, t}^g = \frac{\sum_{f=0}^{F-1} (e_i' A_f(\tau) H(\tau) e_j)^2}{H_{ii}(\tau) \sum_{f=0}^{F-1} (e_i' A_f(\tau) H(\tau) A_f(\tau)' e_i)} \quad gSOT_{i \leftarrow j, t}(F) = \frac{\phi_{i \leftarrow j, t}^g(F)}{\sum_{j=1}^k \phi_{i \leftarrow j, t}^g(F)} \quad (2)$$

Where  $e_i$  represents a  $K \times 1$  – dimensional zero vector, with a unit in the  $i$ th position. Given that the row sum of  $\phi_{i \leftarrow j, t}^{gen}$  does not equal one, Diebold and Yilmaz (2012) proposed a critical normalization step: dividing  $\phi_{i \leftarrow j, t}^g(H)$  by its row sum. This adjustment results in the scaled generalized forecast error variance decomposition (GFEVD), labeled as  $gSOT_{i \leftarrow j, t}(F)$ . This normalization is not merely a technical requirement; it enhances clarity by ensuring that the row sums equal one, allowing for a straightforward interpretation of the individual contributions of various variables to the forecast error variance. Thus, it effectively transforms complex data into actionable insights.

The scaled GFEVD is fundamental to the connectedness approach and is essential for calculating total directional connectedness, both TO and FROM others. The “TO” clearly shows the influence that series  $i$  has on all other series, whereas the “FROM” demonstrates the impact that all series have on series  $i$ . These connectedness measures can be calculated as follows:

$$S_{i \rightarrow \blacksquare, \tau}^{gen, to} = \sum_{k=1, i \neq j}^K gSOT_{k \leftarrow i, \tau} \quad (3)$$

$$S_{i \leftarrow \blacksquare, \tau}^{gen, from} = \sum_{k=1, i \neq j}^K gSOT_{i \leftarrow k, \tau} \quad (4)$$

The difference between the TO and FROM leads to the NET total directional connectedness of series  $i$ ,

$$S_{i, \tau}^{gen, net} = S_{i \rightarrow \blacksquare, \tau}^{gen, to} - S_{i \leftarrow \blacksquare, \tau}^{gen, from} \quad (5)$$

If  $S_{i, \tau}^{gen, net} > 0$  ( $S_{i, \tau}^{gen, net} < 0$ ), series  $i$  impresses all other series more (less) than being impressed by them, which states that it is a net transmitter (receiver) of shocks.

The adjusted TCI of Chatziantoniou et al. (2021) is calculated as follows

$$TCI_{\tau}(F) = \frac{K}{K-1} \sum_{k=1}^K S_{k \leftarrow \blacksquare, \tau}^{gen, from} \equiv \frac{K}{K-1} \sum_{k=1}^K S_{k \rightarrow \blacksquare, \tau}^{gen, to} \quad (6)$$

This index ranges  $[0, 1]$  and measures the degree of network interconnectedness. Therefore, the higher TCI indicates the increasing market risk.

## 5. EMPIRICAL RESULTS

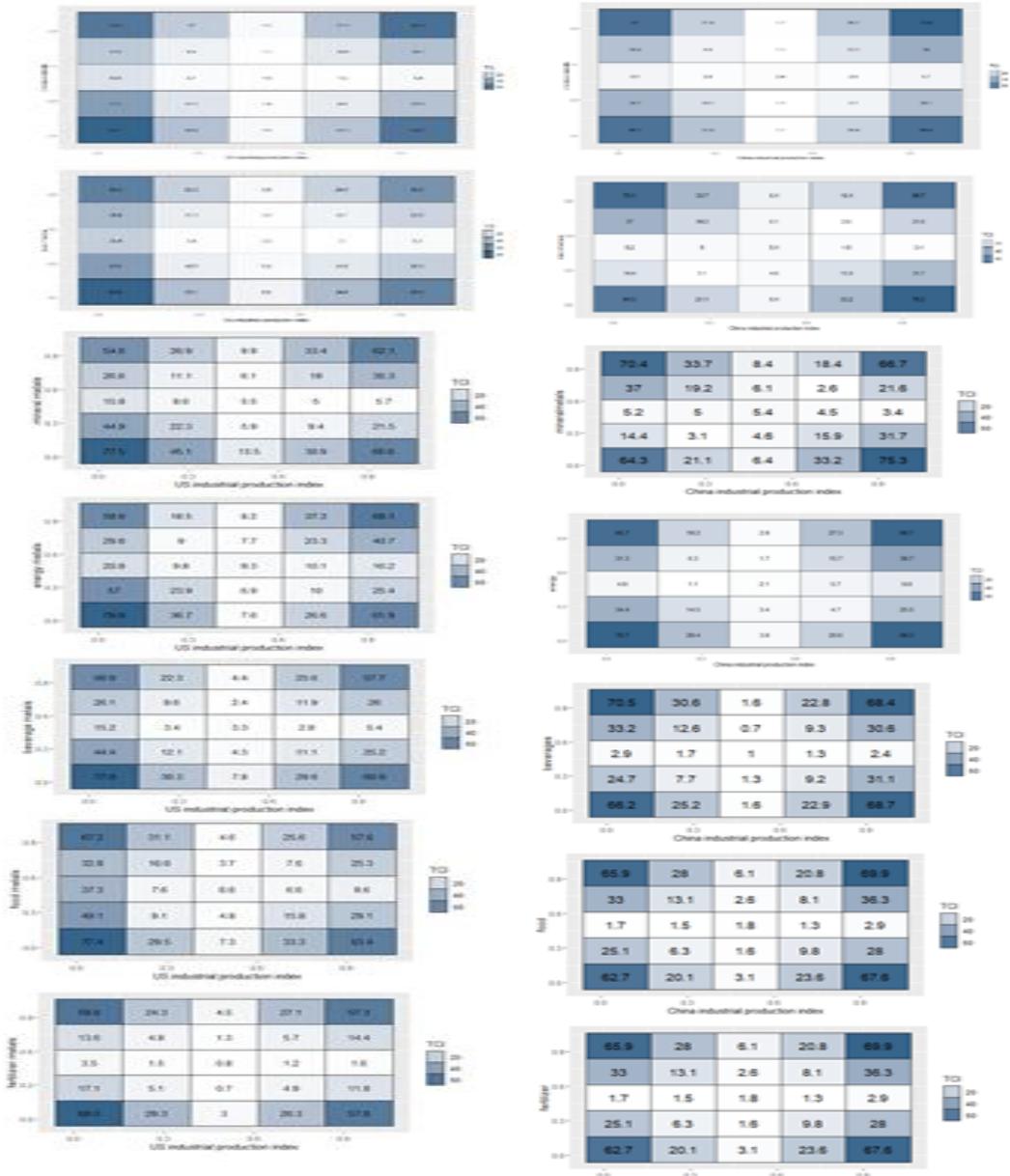
The QQ approach is applied to investigate the nonlinear, asymmetric, and time-varying connectedness between commodity prices and economic growth. Bivariate QVAR models are estimated using a rolling window of 100 months with a 20-step ahead forecast horizon. The lag length is set to 1 based on the Akaike Information Criterion (AIC). To ensure robustness, models are also estimated using alternative window sizes of 60 and 150 months.

Figure 2 presents the averaged dynamic quantile-on-quantile total connectedness indices for each pair across five quantiles, ranging from 0.05 to 0.95, with intervals of 0.225 between consecutive quantiles. Darker shades of blue indicate a higher degree of interconnectedness, while lighter blue hues transitioning to white signify a weaker level of connectedness. In the US, the strongest averaged Total Connectedness Index (TCI) is 81.8%, observed between the 5% quantile ( $\tau_1 = 0.05$ ) of raw metals and the 5% quantile ( $\tau_2 = 0.05$ ) of the US Industrial Production Index (IPI). For the EU27 and India, the highest averaged total connectedness is 80.6% and 72.4%, respectively, achieved for the ENERGY-IPI pair at matching quantiles ( $\tau_1 = 0.05$ ,  $\tau_2 = 0.05$ ). These results indicate that TCIs reach their largest values at this same extreme quantile. For China, the peak average TCI of 75.3% occurs between the 5% quantile ( $\tau_1 = 0.05$ ) of mineral metals and the 95% quantile ( $\tau_2 = 0.95$ ) of the Chinese IPI. These findings are significant, as existing studies utilizing the quantile connectedness approach typically focus on directly related quantiles (Chatziantoniou et al., 2021) and may have overlooked this effect.

**Figure 2** Quantile Total Connectedness Indices

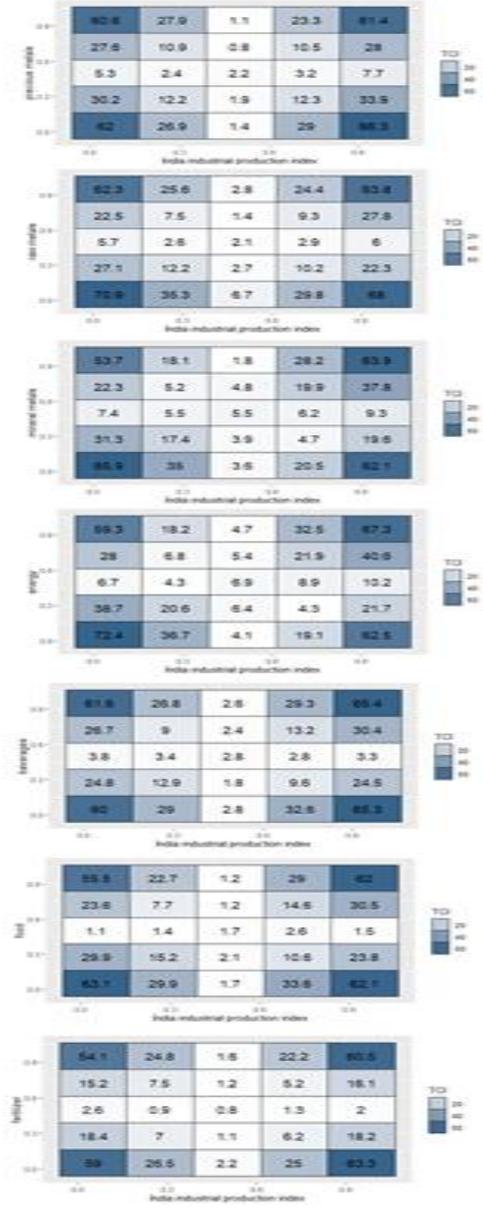
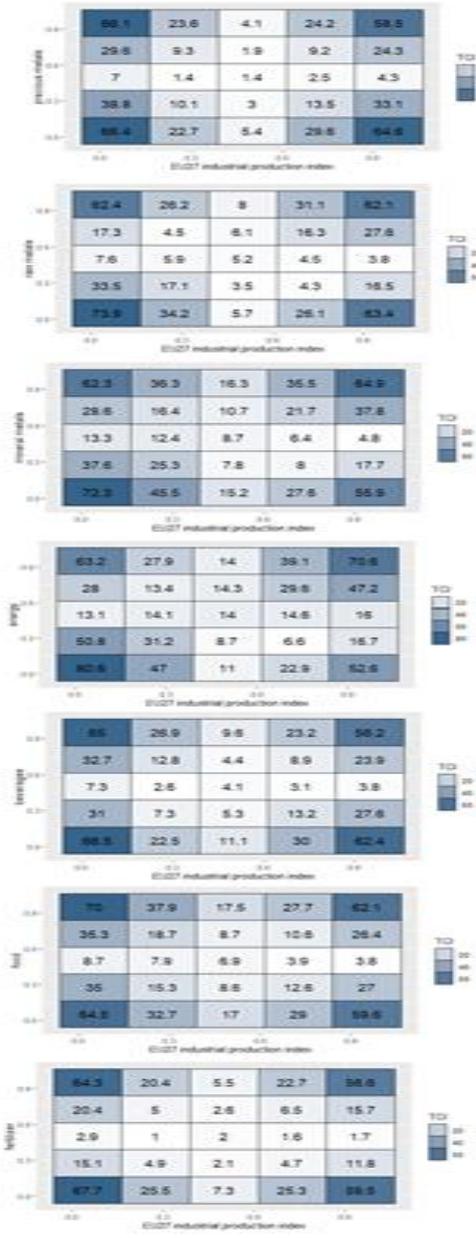
a. US IPI and Commodity Prices

b. China IPI and Commodity Prices



c. EU27 IPI and Commodity Prices

d. India IPI and Commodity Prices



To illustrate the counter-directional and parallel shifts in connectedness between pairs over time, the total connectedness indices (TCIs)—both direct and inverse—along with their differences ( $\Delta$ TCI) are presented in Figure 3. When the inverse TCI exceeds the direct TCI, this indicates a significant negative correlation between the series. For the precious metal-USIPI pair,  $\Delta$ TCI remains negative until the onset of the COVID-19 pandemic in 2020, reflecting a consistent trend. After this period,  $\Delta$ TCI primarily fluctuates above zero, indicating opposing movements between USIPI and precious metals. Gold, silver, and platinum are recognized as safe-haven assets, providing protection against adverse economic conditions, particularly during periods of asset price volatility. During the COVID-19 pandemic, silver and platinum demonstrated safe-haven properties, whereas gold and palladium did not (Khaskheli et al., 2022). This shift coincided with the implementation of fiscal and monetary stimulus packages by the US government on March 17, 2020 (Akhtaruzzaman et al., 2021). The pandemic impacted commodity markets, leading to increased prices. Although silver prices experienced a significant decline in mid-March, they rebounded due to improved industrial growth and increased investment demand (Hasan et al., 2021). In contrast to gold, silver and platinum have substantial industrial applications, making platinum particularly attractive to investors seeking stability. The production of gold and copper has been found to have a negative impact on economic growth in the United States, a leading producer of precious metals. Thus, an abundance of these metals correlates with a decline in US economic growth (Bildirici and Gokmenoglu, 2019). Throughout the sample period, a positive correlation is observed between precious metals and China's industrial production index (IPI), as  $\Delta$ TCI consistently remains below zero. This suggests that increases in precious metal prices are associated with rising industrial production in China, highlighting the interconnection between these variables. Since 1949, China has developed a comprehensive precious metals industry encompassing geological prospecting, mining, mineral processing, smelting, and the processing of platinum-group metals, silver, and gold. The industry also emphasizes the recycling of secondary resources and integrates research, design, production, education, and investment. In the twenty-first century, rapid growth in this sector has enhanced its overall capacity and strength. Consequently, China has become a leading producer of gold and silver and a significant consumer market for precious metals globally (Jialin and Kuangdi, 2023). The analysis reveals a distinct negative correlation between precious metals and EU27 industrial production, as  $\Delta$ TCI remains positive throughout the sample period, indicating a persistent inverse relationship between the two. This relationship can be attributed to various economic, financial, and industrial factors. Precious metals, particularly silver and platinum, are essential industrial inputs in sectors such as electronics, automotive, and green technologies. Increases in the prices of these metals raise production costs for EU manufacturers, reduce profit margins, and ultimately lead to lower output. The relationship between precious metals and industrial production in India underwent significant changes during the COVID-19 pandemic in 2020. Before the pandemic, precious metals and industrial production markets moved in tandem.

However, following the onset of COVID-19, a negative correlation emerged, as evidenced by  $\Delta TCI$  consistently remaining above zero.

Between 2014 and 2020, the relationship between the USIPI and agricultural raw metals exhibited a distinct pattern. During this period, the change in the  $\Delta TCI$  consistently showed positive values, indicating that the movements of these two variables were often opposing; when one increased, the other tended to decrease. Beginning in 2020, this dynamic shifted, as the  $\Delta TCI$  began to display negative values, suggesting that the two variables started to move in tandem and experienced simultaneous fluctuations. This shift may reflect broader economic trends or changes in market conditions that warrant further investigation. Analysis reveals a significant negative correlation between agricultural raw metals and industrial production in China throughout the entire sample period. This finding suggests that as the production of agricultural raw materials increases, industrial production tends to decrease, indicating a potential inverse relationship between these sectors. Additionally, the  $\Delta TCI$  consistently remains above zero during this period, reflecting a persistent level of optimism in trade conditions despite sectoral fluctuations. In contrast, the relationship between agricultural raw materials and the EU27 industrial production index is notably positive, indicating that increases in agricultural raw material production are associated with rising industrial output within the EU27. This correlation is significant, as the  $\Delta TCI$  consistently reflects positive values, suggesting a stable and beneficial interaction between these sectors. This relationship may be attributed to the essential role of agricultural raw materials in various industrial processes, which can drive growth and productivity in the broader economy. A noteworthy trend is also observed in the relationship between agricultural raw materials and industrial production in India. Until 2010, a negative correlation existed, indicating that fluctuations in agricultural raw materials had an adverse effect on industrial output. However, from 2010 onward, a positive correlation emerged, supported by the  $\Delta TCI$ , which remained below zero during the earlier period, underscoring the strength of the initial inverse relationship. The subsequent years reflect a more interconnected relationship between agriculture and industry, highlighting a significant transformation in India's economic landscape. Agricultural raw materials, including timber, cotton, natural rubber, and tobacco, are essential for industries such as textiles, housing, and transportation. Increases in the prices of these raw materials can benefit producers and exporters by enhancing profitability and competitiveness. However, such price fluctuations may also increase costs for consumers and importers, creating economic challenges. This situation underscores the disparities that can exist between countries and their respective markets (Şen et al., 2024).

There is a significant adverse correlation between metals and minerals prices and industrial production in China throughout the entire sample period. In contrast, a positive relationship exists between these prices and industrial production in the United States, the EU27, and India, as  $\Delta TCI$  consistently remains below zero. The price of metals and minerals is crucial to the global economy. These materials are essential for a wide range of industries, including construction, manufacturing, and technology, and have substantial

implications for the economies of both producing and consuming countries. Increases in metals and minerals prices benefit net producer and exporter countries, which possess abundant natural resources and supply these commodities to the international market. As prices rise, these countries generate higher export revenues, leading to increased income, improved economic growth, and greater investment in infrastructure and social services. Conversely, net consumer and importer countries, which rely on importing these materials for their industries, face economic challenges when prices rise. Higher costs for metals and minerals increase production costs for manufacturers, which may be passed on to consumers as higher prices for goods and services. This dynamic can result in reduced profit margins for businesses, slower economic growth, and potential declines in overall consumer spending (Rossen, 2015; Şen et al., 2024). The dynamics of metal and mineral prices have a significant impact on both producing and consuming countries, influencing economic stability, growth prospects, and industrial competitiveness worldwide. China is the world's largest consumer of industrial metals (Khadan et al., 2025). Consequently, rising prices of metals and minerals create cost pressures that slow production. India, recognized as one of the fastest-growing economies and emerging markets globally, benefits significantly from the aluminium industry, which contributes to the country's economic development. Recent research indicates that aluminium prices have a statistically significant positive impact on the Indian manufacturing sector (Mehta et al., 2022).

Throughout the sample period, a consistent positive correlation was identified between energy prices and industrial production in the United States, China, the European Union (EU27), and India. This finding indicates that increases in energy prices are generally associated with higher levels of industrial production in these economies. As a result,  $\Delta TCI$  has remained persistently below zero, reflecting ongoing difficulties for industrial sectors in managing costs amid volatile energy prices. This relationship highlights the significant impact of energy costs on industrial production and overall economic performance in these countries. Energy sources such as coal, crude oil, and natural gas are essential inputs in the production of a broad array of goods and services. Non-renewable energy continues to account for a significant share of total energy supply. Consequently, rising energy prices lead to increased costs at all stages of economic production. Although such price increases may benefit net exporters and some importing nations, they typically present challenges for net importers and consumer-oriented countries. Shahbaz et al. (2019) demonstrated that oil prices contribute to long-term economic growth in the United States, as capital is a critical element of the production function and has a positive influence on economic expansion.

Historically, beverage markets and industrial production in the United States and China have moved in tandem. Since 2018, however, a negative correlation has emerged, as evidenced by  $\Delta TCI$  consistently remaining above zero. This change is likely attributable to policy shifts following the 2018 US-China trade war. For the beverage market and EU27 industrial production index (IPI) pair, opposing trends between beverage prices and industrial production were observed in all periods except 2012-2014 and 2022. In India,

industrial production was closely tied to beverage prices until 2020, after which the relationship reversed.

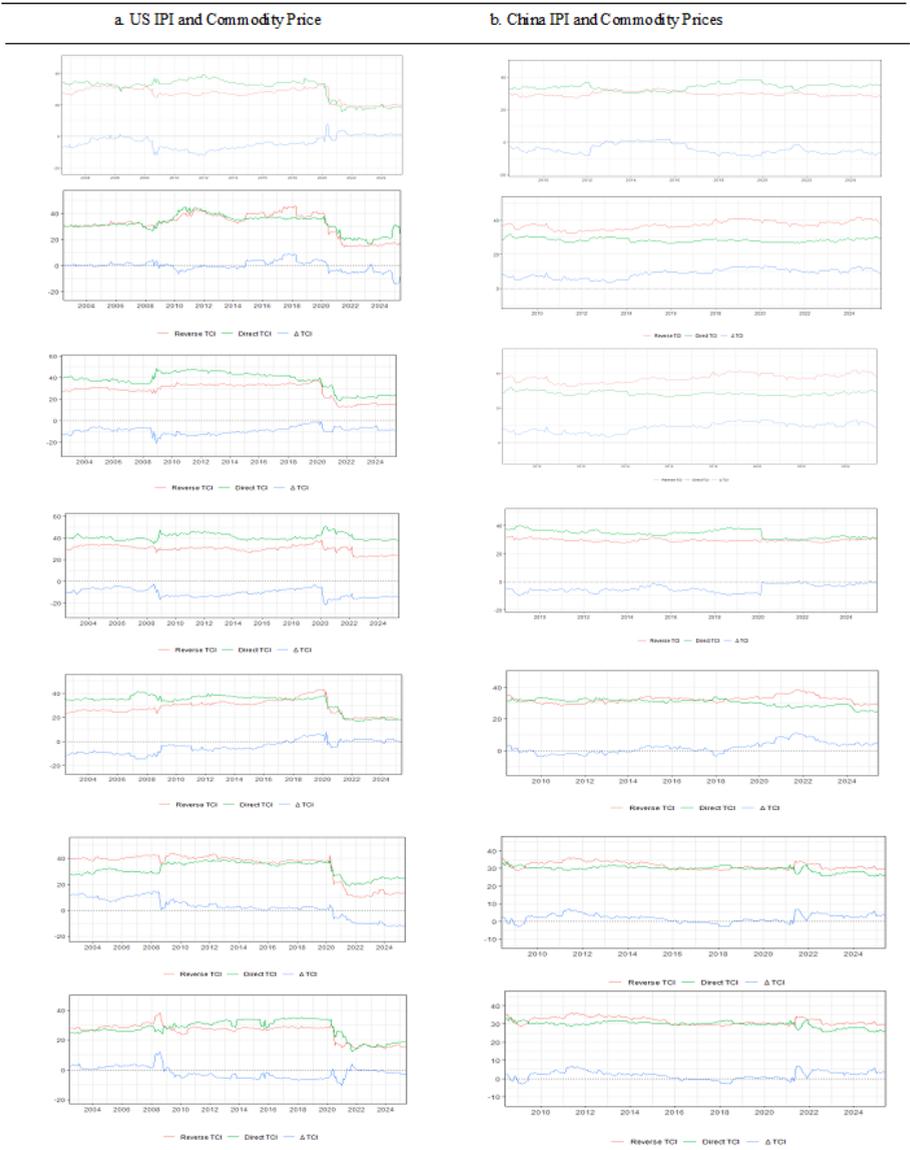
The analysis revealed a negative correlation between food prices and industrial production in the United States, the EU-27, and India up to 2020. During this period, changes in  $\Delta TCI$  predominantly exhibited positive values. After 2020, a significant shift occurred, with  $\Delta TCI$  primarily fluctuating below zero, indicating increased comovement between food prices and industrial production in these regions. This evolution highlights the complex and dynamic nature of the economic landscape. Beginning in mid-2021, food prices rose at the fastest rate in decades. This increase was driven by multiple factors, including supply chain disruptions and labor shortages related to the pandemic, higher transportation costs and wages, shocks in food commodity and fertilizer prices resulting from Russia's invasion of Ukraine, and potentially increased demand due to recent monetary and fiscal stimulus measures (Adjemian et al., 2024).

Fertilizer is a fundamental input in agriculture, significantly contributing to the enhancement of crop yields. It serves as a crucial input in agriculture, enhancing overall agricultural productivity. By supplying essential nutrients to the soil, fertilizers enable more efficient and healthy crop growth, resulting in increased yields and improved food security. Fertilizer costs account for approximately 15–20% of total agricultural production expenses, underscoring the importance of effective cost management to ensure sustainable farming practices and economic viability. Understanding the dynamics of fertilizer prices and their impact on agricultural budgets is therefore crucial for optimizing productivity and maintaining profitability in the agricultural sector (Headey and Fan, 2008; Şen et al., 2024). For the fertilizer-USIPI pair, changes in  $\Delta TCI$  were positive until 2018, indicating an inverse relationship between the two variables. After 2018,  $\Delta TCI$  mainly fluctuated below zero, indicating that fertilizer prices and industrial production moved in tandem throughout the remainder of the sample period. For the fertilizer-China IPI pair,  $\Delta TCI$  consistently remained above zero, indicating a negative relationship between fertilizer prices and industrial production in China. In the fertilizer-EU27 IPI pair, opposing movements between fertilizer prices and industrial production were observed during significant periods from 2004 to 2008 and from 2020 to the end of the sample period, as evidenced by positive  $\Delta TCI$  values. Similarly, fertilizer prices had a negative impact on industrial production in India between 2012 and 2020.

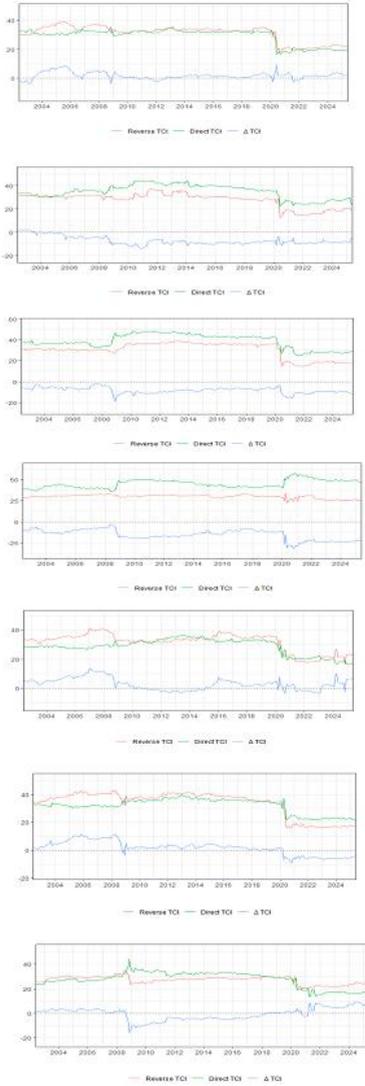
Next, we analyze the net directional connectedness across quantiles. Figure 4 illustrates the net directional spillovers of commodity prices and industrial production for the United States, China, the EU 27, and India. The figure employs a three-color gradient: blue represents higher (positive) values, white signifies moderate values (around zero), and red indicates the lowest (negative) values. The positive values within the quantiles suggest that commodity prices act as net transmitters, while the negative values indicate that the industrial production indices serve as net transmitters.

Panel A of Figure 4 demonstrates that the number of quantiles where mineral, metals, and energy markets are net transmitters to the US industrial production index is consistently higher than those that serve as net receivers. Panel B shows that the raw metals and mineral metals markets are the primary source of information transmission to industrial production in China across all quantiles. The net directional spillovers among beverage, food, and fertilizer markets, as well as industrial production, reveal significant variations, especially when the values of these commodity markets are situated at upper quantiles. According to Panel C, the net directional spillovers among commodity markets and industrial production in the EU-27 indicate that, except for the fertilizer market, commodity markets are substantial net transmitters to industrial production. The impact of the fertilizer market on industrial production is notable at various quantiles, escalating when the fertilizer market reaches its lowest extreme quantile ( $\tau_1=0.05$  while EU27IPI values are situated  $\tau_2=0.05$ ). Considering Panel D, the food market serves as the most significant transmitter to the industrial production in India, particularly concentrated at the quantile ( $\tau_1=0.05$ ,  $\tau_2=0.725$ ). In contrast, the influence of the energy market on the industrial production index is not pronounced.

Figure 3 Direct and Reverse Total Connectedness Indices



c. EU27 IPI and Commodity Price



d. India IPI and Commodity Prices

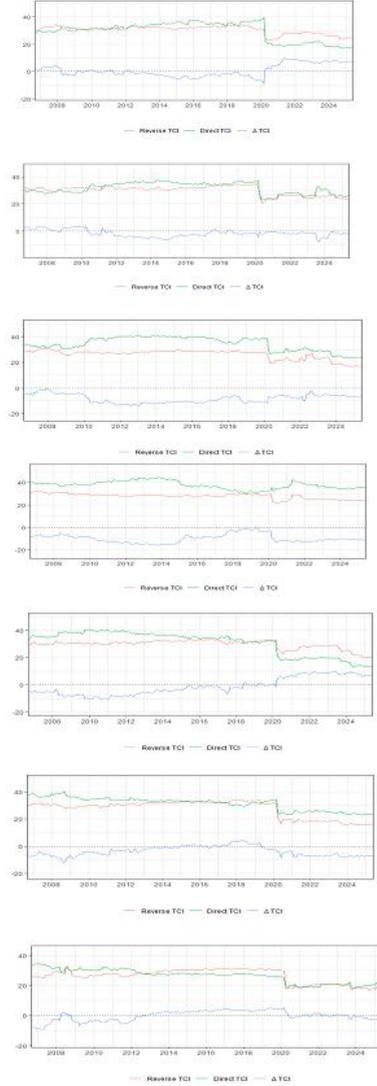
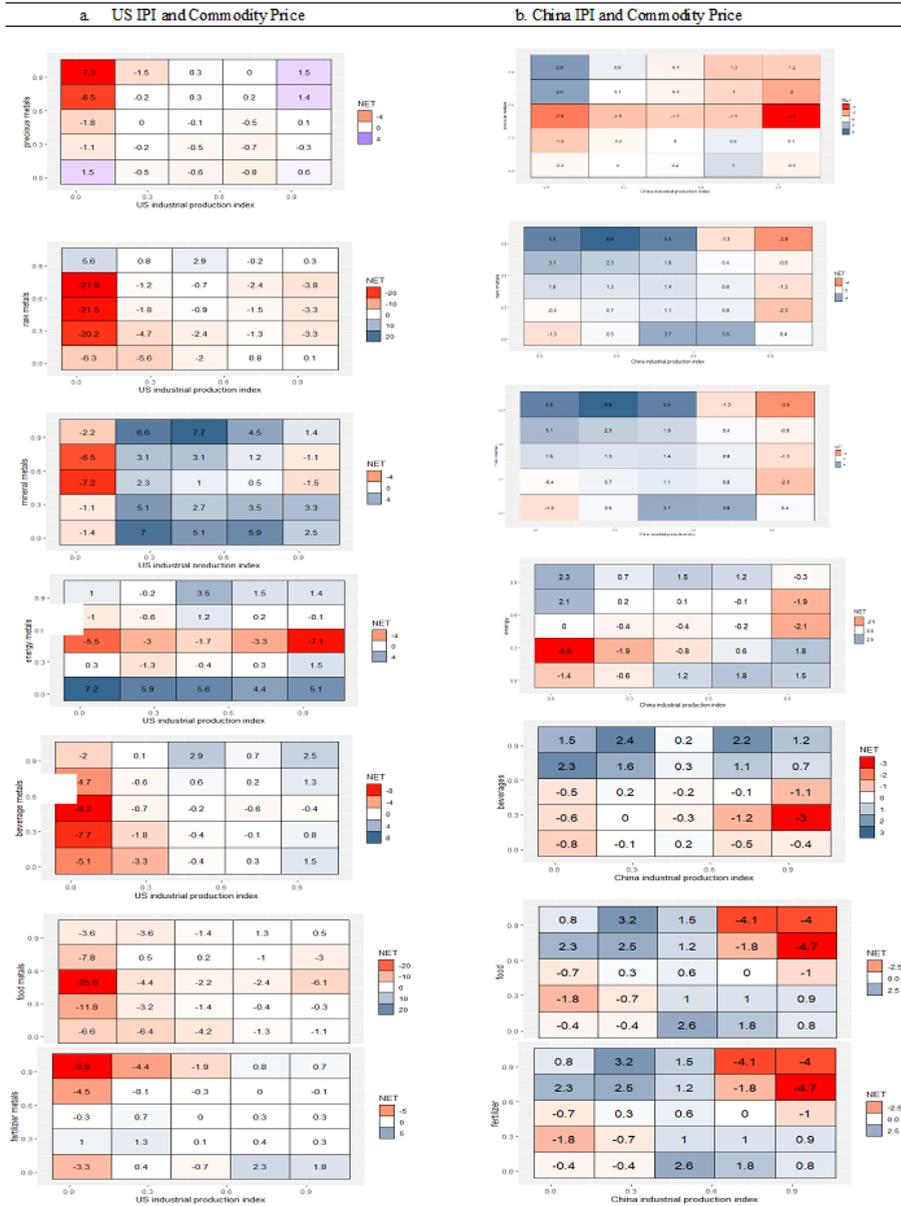
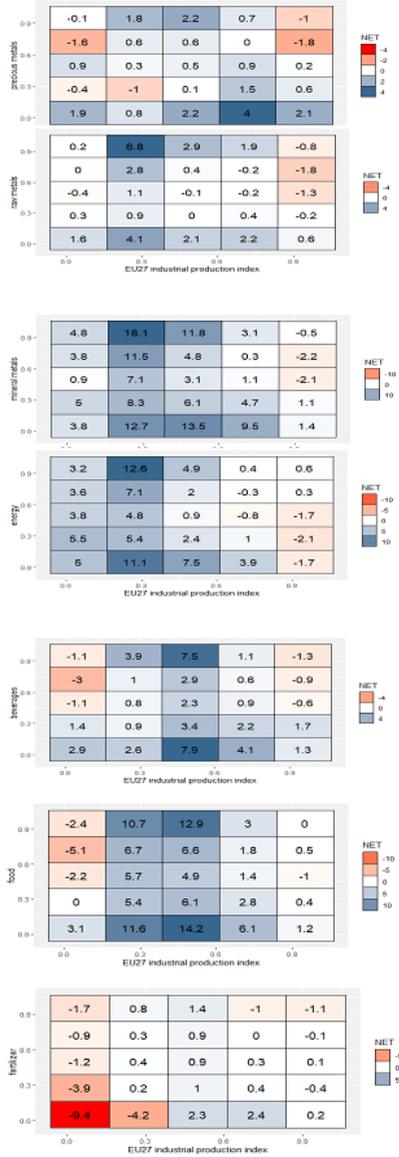


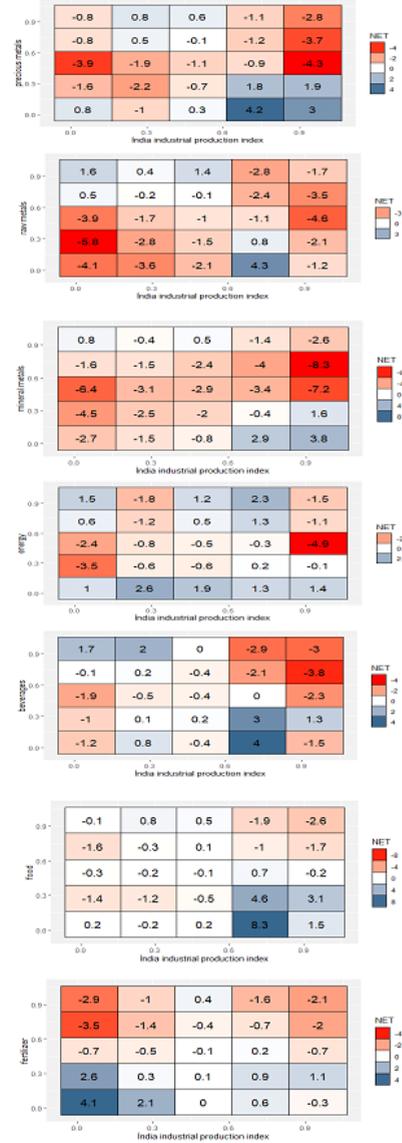
Figure 4 Net Quantile Connectedness



c. EU27 IPI and Commodity Price



d. India IPI and Commodity Price



## 6. CONCLUSION

In recent years, global commodity prices have experienced significant and unpredictable fluctuations, in contrast to the relative stability of previous decades. These shifts have substantial implications for the macroeconomic stability of countries worldwide. Although existing research has primarily examined the effects of commodity price changes on the economic growth of low-income countries, particularly those dependent on a limited range of exports, a significant gap remains in understanding the impact of these price changes on countries across different income levels. Additionally, the literature lacks a comprehensive analysis of how price fluctuations in various commodity groups influence the income levels of a wide range of countries. To address these gaps, the present study investigates the relationship between changes in commodity prices and industrial production across countries classified by income group. The analysis focuses on seven commodity groups: beverages, energy resources, fertilizers, food products, precious metals, agricultural raw materials, and metals and minerals. This study aims to provide insights into the effects of commodity price fluctuations on industrial production in major economies, including the United States, China, the European Union (EU27), and India, thereby contributing to a more nuanced understanding of the global economic landscape.

The study's findings indicate that, following the COVID-19 pandemic, adverse movements occurred between the U.S. industrial production index and the prices of precious metals. During this period, silver and platinum functioned as safe havens, in contrast to gold and palladium. This shift was influenced by the U.S. government's fiscal and monetary stimulus implemented on March 17, 2020. Both silver and platinum possess strong industrial applications, which make them attractive to investors seeking stability. Conversely, gold and copper production can have a negative impact on U.S. economic growth, suggesting that an oversupply of these metals may lead to weaker economic performance. In China, a positive correlation exists between precious metals and industrial production, reflecting the country's role as a major producer and consumer of these resources. In the EU27, however, rising prices for metals such as silver and platinum tend to increase production costs for manufacturers. The relationship between precious metals and industrial production in India also experienced significant changes during the pandemic. The analysis reveals a negative impact of agricultural raw material prices on industrial production in China, whereas the effects in the EU27, the United States, and India are positive. The influence of agricultural raw material prices on industrial production varies considerably across regions. In China, increasing prices of agricultural raw materials negatively affect industrial production, whereas in the EU27, the United States, and India, the effect is positive. These results suggest that, for all country groups except China, the benefits derived from higher prices of metals and minerals outweigh the associated losses. Furthermore, the study reveals a negative correlation between energy prices and industrial production across all examined countries. This observation is consistent with the findings of Shahbaz et al. (2019), which suggest that higher oil prices can contribute to economic growth in the United States, given the significance of oil in the production function. The

relationship between beverage markets and industrial production in the United States and China has shifted due to policy changes following the 2018 US-China trade war. The study also identifies a negative correlation between food prices and industrial production in the United States, the EU27, and India. Since mid-2021, food prices have increased rapidly due to supply chain disruptions, labor shortages resulting from the pandemic, higher transportation costs, and fluctuations in food and fertilizer prices associated with Russia's invasion of Ukraine. Increased demand driven by recent monetary and fiscal stimulus measures may have further contributed to this trend. The analysis demonstrates that fertilizer prices and industrial production in the United States have moved in tandem since the 2018 China-US trade war. In contrast, a negative relationship is observed between fertilizer prices and industrial production in China, the EU27, and India.

The study finds that minerals, metals, and energy markets act as net transmitters to the U.S. Industrial Production Index across a greater number of quantiles than they do as net receivers. In China, raw metals and mineral markets primarily transmit information to industrial production. Net spillovers among beverage, food, and fertilizer markets display significant variation, especially at higher quantiles. Within the EU27, all commodity markets, except for fertilizer, are substantial net contributors to industrial production. In India, the food market emerges as the most significant transmitter, whereas the energy market exerts minimal influence on the Industrial Production Index.

The findings indicate significant implications for countries affected by fluctuations in commodity prices. In the current interconnected and globalized economy, all nations, regardless of income level, encounter challenges arising from volatile commodity prices. This situation highlights the pressing need for international policies that promote cooperation and solidarity among countries, as national policies alone are insufficient to address the complexities of the global market. The analysis demonstrates that rising prices of key commodities, including energy, fertilizers, and agricultural raw materials, negatively affect the income levels of nearly all country groups. This trend highlights the need for collaborative international efforts, as no single country can effectively address these challenges on its own. Furthermore, policies aimed at preventing, mitigating, and compensating for the adverse effects of commodity price fluctuations must be implemented in a manner that is both coordinated and integrated across sectors and nations. Such integration enables countries to better prepare for and respond to the economic consequences of commodity price movements, thereby promoting a more stable and equitable global economy.

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### **Yazarların Makaleye Katkı Oranları**

Makalenin tamamı makale yazarı tarafından kaleme alınmıştır.

### **Çıkar Beyanı**

Yazarın herhangi bir kişi ya da kuruluş ile çıkar çatışması yoktur.

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