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Research article

Greening commodity markets: How the inflation reduction act reshapes interdependencies across energy, metals, and agriculture

Nader Naifar*

Department of Finance, Imam Mohammad Ibn Saud Islamic University (IMSIU), Riyadh, 11432, Saudi Arabia

* **Correspondence:** Email: naneifar@imamu.edu.sa.

Abstract: This study investigated how the Inflation Reduction Act (IRA), a landmark U.S. policy promoting clean energy and decarbonization, has restructured commodity market interdependencies across agriculture, industrial metals, and traditional energy sectors. Using a time-varying parameter vector autoregression (TVP-VAR)-based decomposed and partial connectedness framework, the analysis distinguishes between internal (within-group) and external (between-group) spillovers, as well as inclusive and exclusive transmission channels across commodity groups. The findings demonstrate a shift toward sector-driven dynamics: industrial metals exhibit strengthened internal cohesion, while cross-sector spillovers significantly weaken. Copper emerges as the dominant net transmitter before and after the IRA, reinforcing its critical role in electrification and clean energy infrastructure. In contrast, crude oil and natural gas remain persistent net receivers, indicating the diminishing systemic influence of fossil fuels. The total connectedness index also declines post-IRA, indicating lower overall market contagion. These results emphasize that the IRA has accelerated a structural realignment in commodity markets, positioning industrial metals at the core of the energy transition. As renewable energy adoption advances, strategic investment and risk management strategies must increasingly account for the rising centrality of critical minerals and the fading dominance of traditional energy commodities.

Keywords: inflation reduction act; green policy shocks; commodity markets; renewable energy; partial connectedness

JEL Codes: C32, G15, Q02, Q42, Q48

1. Introduction

The IRA, signed into law on August 16, 2022, represents the most significant climate legislation in U.S. history, with $370 billion allocated for clean energy investments (Barbanell, 2022). It aims to promote clean energy adoption, enhance carbon management, encourage electrification, curb methane emissions, strengthen domestic supply chains, and address environmental justice concerns (Bistline et al., 2023a). The act includes provisions for consumer rebates on electric vehicles (EVs), tax credits for energy storage, and incentives for low-carbon technologies (Shan and Kittner, 2024). While these measures are expected to reduce greenhouse gas emissions, their effectiveness will depend on industry adoption and regulatory actions (Jordan et al., 2023). Moreover, the IRA's emphasis on domestic content requirements for EVs and clean energy components is expected to shift global trade flows and commodity markets, particularly affecting North American supply chains (Cheng and Fan, 2024).

While existing studies have examined the IRA's impact on clean energy development, trade patterns, fiscal policy, and environmental sustainability (Mirza et al., 2023; Li et al., 2024; Jiang et al., 2024), there is limited research on its effect on commodity market interdependencies. The IRA's incentives for renewable energy infrastructure, EV adoption, and biofuels are expected to reshape demand for critical raw materials, affecting price spillovers and risk transmission across commodity groups (Cheng et al., 2023; Li et al., 2024). Specifically, increased demand for metals in clean energy technologies, such as copper, nickel, and aluminum, could strengthen their role in market connectedness. At the same time, the declining reliance on fossil fuels could weaken the systemic influence of crude oil and natural gas (Li et al., 2024).

Importantly, the commodity-market changes examined in this study should not be interpreted as originating solely with the IRA. The U.S. energy system had already been undergoing a longer-term transition before 2022, driven by rapid growth in wind and, especially, solar generation, declining coal dependence, falling battery and renewable technology costs, and the expanding electric-vehicle market. In this sense, the IRA is best viewed not as the starting point of the clean-energy transition but as a large policy accelerator that likely reinforced and reorganized pre-existing market trends. This distinction is important for empirical interpretation: our analysis does not claim that the IRA created these structural forces ex nihilo but rather examines whether the policy coincided with a measurable reconfiguration in cross-commodity connectedness, above and beyond the broader transition already underway.

Existing studies have examined the IRA's implications for clean energy development, trade restructuring, fiscal policy, and sustainability (e.g., Cheng et al., 2023; Li et al., 2024; Jiang et al., 2024), yet they provide limited evidence on whether the IRA coincided with a structural reshaping of connectedness across commodity groups central to the energy transition. In particular, prior research has not examined whether linkages among agricultural biofuel feedstocks, industrial metals, and traditional energy commodities became more internally cohesive, less externally synchronized, or otherwise reconfigured in the post-IRA environment. Addressing this gap is important because changes in connectedness affect systemic risk transmission, diversification opportunities, and the strategic positioning of transition-related commodities. At the same time, any interpretation of post-2022 agricultural commodity dynamics must be situated within broader pre-existing and overlapping forces, including the sharp COVID-19 disruption to fuel and ethanol demand in 2020–2021 and the subsequent expansion of electric vehicle adoption, both of which affected the strategic role of corn in energy-linked commodity markets.

To analyze these changing interdependencies, this study employs spot price data from S&P Goldman Sachs Commodity Index (S&P GSCI) sub-indices, covering January 2017 to December 2024. Using time-varying parameter vector autoregression (TVP-VAR) models, we quantify temporal, directional, and intensity-based changes in market connectedness before and after the IRA's enactment. While the IRA was signed into law on August 16, 2022, many of its major tax-credit and clean-energy incentive provisions became economically operative beginning in 2023. Accordingly, the post-IRA period in this study should be interpreted primarily as a transition from enactment to implementation, with 2023–2024 capturing the clearest window of active policy transmission within our sample. Thus, our empirical design does not assume that the law's effects materialized immediately upon passage in August 2022 but rather examines whether connectedness patterns shifted around the enactment date and became more visible during the subsequent implementation phase. This study addresses two key questions: First, how did commodity market connectedness evolve around the enactment and early implementation of the IRA across biofuel-linked agricultural commodities, industrial metals, and traditional energy markets? Second, do these changes suggest a structural reconfiguration in commodity market linkages consistent with clean energy transition priorities?

This study contributes to the literature on commodity market dynamics and energy policy in several ways. First, to our knowledge, it is among the first to examine how the post-IRA policy environment coincided with changes in the dynamic interactions among agricultural commodities, industrial metals, and traditional energy markets. Second, it integrates partial and decomposed measures of connectedness to provide a more refined view of interdependencies before and after the IRA. Third, by jointly examining biofuel feedstocks, industrial metals, and fossil fuels, it offers a cross-sectoral perspective on how a major climate-policy package may have accelerated an ongoing transition away from traditional energy dependence and toward clean energy–related commodity linkages.

The remainder of the paper is structured as follows: Section 2 provides the theoretical background and reviews the relevant literature. Section 3 describes the data and outlines the research methodology. Section 4 presents empirical results and discusses their implications. Section 5 conducts robustness checks to validate the findings. Finally, Section 6 concludes the study with key takeaways and policy recommendations.

2. Theoretical background and literature review

The IRA introduced a mix of incentives, standards, and investments with far-reaching effects on commodity markets. To structure the theoretical basis for this study, we distinguish three primary transmission channels: (1) policy mechanisms that directly shift incentives and capital flows; (2) the structural reshaping of commodity demand through the clean energy transition; and (3) financialization-driven contagion effects across asset classes, which amplify systemic risk. These channels are not invoked in a purely general sense; rather, they provide a framework for interpreting the empirical patterns examined in this paper, including changes in internal versus external connectedness, the rising systemic role of industrial metals, and the evolving positions of agricultural and fossil fuel commodities in the post-IRA period.

2.1. Policy transmission mechanisms

Major government interventions alter incentives, expectations, and economic capital flows. The IRA's climate-related incentives span the entire energy value chain, from raw material producers to end-use consumers, setting "considerable new forces in motion" (Bistline et al., 2023b). Generous subsidies and regulatory preferences for clean energy and electric vehicles raise expected returns in green sectors while reducing the attractiveness of fossil-fuel industries. These policy shocks change relative prices (via taxes, credits, or standards), prompting firms and investors to reallocate resources, thereby reshaping production, consumption, and investment patterns. As investors accelerate funding toward renewable energy, critical minerals, and carbon-saving technologies, corresponding divestment from carbon-intensive assets leads to repricing and volatility across financial markets [Network for Greening the Financial System (NGFS), 2024].

Policy transmission mechanisms, therefore, suggest that significant public incentives, such as tax credits and manufacturing subsidies, shift market expectations, modify profit outlooks, and drive structural changes in both financial and commodity markets (Bloom, 2009; Pastor and Veronesi, 2012). These shifts transform commodity demand and pricing dynamics even before full policy implementation. However, recent analyses stress the limits of single-policy interventions. Jordan et al. (2023) emphasized that while the IRA marks a significant milestone, it alone may not be sufficient to achieve net-zero emission targets, underscoring the need for complementary regulatory mechanisms, technology mandates, and carbon pricing to transmit policy objectives into market behaviors fully. Similarly, Gillingham and Stock (2018) stressed that efficient emission reduction strategies ideally involve market-based instruments like carbon taxes. However, political realities often favor technology deployment incentives, as embodied by the IRA.

2.2. Clean energy transition

The clean-energy transition predates the IRA by many years. Prior to 2022, the United States had already experienced sustained growth in renewable electricity, especially wind and solar, alongside a longer-run decline in coal's role in power generation. Similarly, electric-vehicle adoption and falling battery costs were already reshaping expectations for future demand for copper, nickel, aluminum, and other transition-related materials. Against this backdrop, the IRA should be interpreted as a powerful reinforcing policy shock that accelerated existing structural trends rather than initiating them from scratch.

The IRA catalyzes the clean energy transition, and theory predicts that decarbonization will reconfigure commodity demand across sectors. As economies transition to low-carbon technologies, reliance on fossil fuels is gradually replaced by an increased reliance on industrial metals and minerals required for clean energy infrastructure. Renewable energy systems and electrification are far more material-intensive than the incumbent fossil-based system. For example, electric vehicles, solar panels, wind turbines, and battery storage require significant inputs of metals like copper, lithium, nickel, cobalt, and rare earth elements. The International Monetary Fund analysis projects that in a global net-zero emissions scenario, metal prices could reach unprecedented highs, and the total value of metal production from 2021 to 2040 would rise more than fourfold, rivaling the total value of crude oil production over that period (Boer et al., 2021). This stark projection indicates how a successful energy transition elevates the strategic importance of metals while potentially diminishing the role of hydrocarbons. On the other side of the ledger, demand for fossil fuels is expected to diminish in a decarbonizing world. Climate-driven scenarios by the International Energy Agency illustrate this shift: between 2020 and 2050, global demand for coal falls by around 90%, oil by 75%, and natural gas by 55% in the net-zero pathway [International Energy Agency (IEA), 2021].

Policies like the IRA reinforce these trends by directly boosting clean energy adoption (thus reducing future fossil fuel needs) and indirectly signaling a long-term commitment to phasing out high-carbon energy. The resulting structural change is a rebalancing of commodity markets: “green” commodities (renewable energy inputs and critical minerals) face upward demand pressure, whereas “brown” commodities (fossil fuels) face a managed decline. However, the transition introduces new vulnerabilities. Baker and Coleman (2024) highlighted that this increasing reliance on critical minerals creates new fragilities in global supply chains, making mineral markets highly sensitive to geopolitical tensions and trade fragmentation. Similarly, Alvarez (2023) discussed how intensified geoeconomic fragmentation can heighten volatility in mineral markets essential for clean energy technologies.

This alters long-run price levels and the interdependence between commodity classes. For instance, a surge in metals demand can increase mining activity and prices, affecting energy usage (mining is energy-intensive) and influencing agricultural production through the cost of inputs like fuel and fertilizers. Likewise, reduced dependence on oil may lower certain energy costs for industry and transport, with knock-on effects for the cost structure of agriculture and mining. Thus, the clean energy transition paradigm implies a rewiring of commodity linkages, as substituting fuel with metals creates new couplings (e.g., energy-metal links) even as traditional oil–gas–coal complementarities wane. Moreover, energy system dynamics evolve alongside these structural changes. Bichler et al. (2022) noted that the rising share of intermittent renewable sources such as solar and wind introduces additional variability into energy markets, fundamentally transforming market design and price dynamics. Du and Xu (2024) further showed that spillovers between clean and traditional energy markets are increasingly time-varying and sensitive to external shocks like economic policy uncertainty and geopolitical risk. This adds another layer of complexity to the energy transition’s impact on commodity market structures. Importantly, the clean energy transition does not imply that all transition-related metals will play identical systemic roles. Metals with broad and immediate input relevance across electrification technologies, such as copper, may emerge as more central shock transmitters, whereas metals subject to greater supply-chain concentration, geopolitical exposure, or market-specific volatility, such as nickel, may become more vulnerable to external disturbances despite strong long-run demand prospects.

2.3. Commodity financialization and systemic risk

Beyond fundamental demand shifts, commodity markets have become increasingly interconnected through financial channels. Since the early 2000s, commodities have emerged as an investable asset class, and speculative capital flows have tightened correlations across sectors. Tang and Xiong (2012) showed that non-energy commodities, such as food and metals, became more correlated with oil prices, especially for those included in major indices, reflecting the broader financialization trend. This growing integration means that shocks in one commodity, whether triggered by demand shifts, geopolitical events, or policy interventions, can quickly propagate across markets via cross-asset portfolios. Adams and Glück (2015) emphasized that financialization has transformed commodities from diversification tools into contagion channels, amplifying systemic risks during market turbulence.

Significant policies like the IRA can reverberate through these financialized networks: traders anticipating a boost in metals and a decline in fossil fuels may realign their portfolios accordingly, heightening co-movements between markets. Broader macroeconomic shifts, such as inflation spikes or interest rate adjustments induced by green investments, can also collectively influence commodity prices. He et al. (2023) demonstrated that commodities' systemic risk contributions change dynamically with market conditions, particularly during crises and booms, indicating the time-varying nature of commodity interdependence. These dynamics frame how the IRA may have reshaped commodity market connectedness. At the same time, financialization does not necessarily imply a uniform increase in cross-market connectedness. When policy shifts induce sector-specific repricing and portfolio reallocation toward particular transition-related commodities, broader commodity systems may become more segmented, with stronger within-group co-movements but weaker spillovers across unrelated sectors. In this sense, a decline in external connectedness can also be consistent with a more specialized and policy-differentiated market structure.

Moreover, any broad repricing across commodities, spurred by IRA-induced shifts, could propagate through financial indices or changes in investor risk appetite. Recent evidence from Caporale et al. (2023) and Naifar (2025) highlighted how major international policy events, such as COP26, significantly alter the connectedness between fossil and renewable energy markets, reinforcing the expectation that the IRA would similarly reshape commodity interdependencies.

These three channels generate a set of more precise empirical expectations. First, policy transmission mechanisms imply that the IRA may trigger sector-specific reallocation of expectations, capital, and demand, thereby altering commodity connectedness even before full implementation. Second, the clean energy transition channel suggests stronger internal cohesion among industrial metals, especially around broadly used electrification inputs such as copper, alongside a weakening systemic role for fossil-fuel commodities. Third, the financialization channel implies that connectedness may become more differentiated rather than uniformly stronger, with policy-induced repricing potentially increasing within-group spillovers while reducing external spillovers across less related commodity sectors.

3. Data and research methodology

3.1. Data

This study investigates the interdependence among three critical commodities: agricultural commodities, industrial metals, and traditional energy commodities, given their strategic importance in the renewable energy transition and decarbonization efforts. Agricultural commodities such as corn, soybeans, and sugar are essential biofuel feedstocks, directly linking food markets to renewable energy policies, incentivizing ethanol and biodiesel production. Industrial metals, including copper, nickel, and aluminum, are indispensable for clean energy technologies, playing fundamental roles in producing solar panels, wind turbines, electric vehicles, and modernized power grids. While still central to global energy markets, traditional energy commodities such as crude oil and natural gas are facing a gradual shift as economies prioritize carbon neutrality and diversify their energy sources.

The empirical analysis is based on daily log returns of the S&P GSCI sub-indices for these commodities, covering the period from January 3, 2017, to December 26, 2024. This timeframe was chosen to capture commodity market dynamics before and after the enactment of the Inflation

Reduction Act (IRA), which was signed in August 2022, while also allowing an observation of its initial implementation phase during 2023–2024. Because many major IRA tax incentives became effective beginning in January 2023, the empirical comparison should be interpreted as contrasting a pre-IRA period with an enactment/early-implementation period rather than assuming immediate full implementation upon the law's passage. The S&P GSCI indices were selected for several reasons. First, they offer broad and consistent market coverage, representing production-weighted global benchmarks across commodity sectors. Second, they provide highly liquid and investable proxies for commodity performance, minimizing concerns about illiquidity, thin trading, or data anomalies that can affect less standardized datasets. Third, their construction methodology ensures comparability across time and sectors, critical for modeling dynamic spillovers and volatility transmissions in a unified framework.

Recent empirical studies have also adopted S&P GSCI sub-indices to investigate commodity market dynamics (e.g., Parnes and Parnes, 2025; Jirou et al., 2025; Cui and Maghyereh, 2025; Alomari et al., 2024, among others). Daily frequency allows for a detailed analysis of short-term and medium-term volatility spillovers, which is particularly important in capturing dynamic policy effects and rapidly changing market interdependencies. Given the time-varying nature of spillovers expected during major policy transitions, this high-frequency dataset is well-suited for the TVP-VAR connectedness methodology employed in the study. Because the IRA occurred within a broader energy-transition environment that predates 2022, the before-and-after comparison should be interpreted as evidence of post-IRA reconfiguration rather than as proof that all observed structural changes were uniquely caused by the Act alone. Table 1 presents the descriptive statistics.

Table 1. Descriptive statistics.

	Corn	Soybean	Sugar	Copper	Nickel	Aluminum	Crude oil	Natural gas
Mean	0.012	0.00011	−0.003	0.024	0.022	0.021	0.014	−0.00011
Variance	2.128	1.495	2.79	1.608	5.605	1.795	9.809	12.243
Skewness	−0.155***	−0.141***	−0.00024	−0.207***	4.386***	0.049	−3.197***	−0.228***
Ex.Kurtosis	2.804***	2.748***	0.654***	2.003***	98.331***	2.369***	72.671***	2.428***
JB	666.325***	638.577***	35.848***	350.014***	815816.556***	470.434***	445489.824***	510.931***
ERS	−10.265	−5.191	−7.212	−3.879	−6.422	−19.777	−11.337	−12.371
Q(20)	23.746***	19.466**	11.621	11.954	47.740***	15.959*	78.891***	22.582***
Q2(20)	593.694***	272.945***	66.835***	79.481***	36.089***	421.179***	461.575***	367.419***

Note: JB represents the Jarque–Bera test for normality. ERS refers to the Elliott–Rothenberg–Stock unit root test, where more negative values suggest stronger stationarity. Q(20) denotes the Ljung–Box test for autocorrelation up to 20 lags, while $Q^2(20)$ applies the Ljung–Box test to squared returns, assessing volatility clustering over the same lags. Significance levels are indicated by ***, **, and * at 1%, 5%, and 10%, respectively.

Table 1 indicates notable differences in return characteristics across commodities. Nickel and crude oil exhibit extreme kurtosis and skewness, signaling heavy-tailed distributions prone to significant price shocks. Natural gas and crude oil are the most volatile, with the highest return variances. While most commodities show mild negative skewness, crude oil has a strong left tail, and nickel is notably right-skewed. The Jarque-Bera test confirms non-normality across all series, indicating the need for non-Gaussian modeling. The Ljung-Box $Q^2(20)$ test also reveals strong volatility clustering, indicating that past market fluctuations influence future volatility. Finally, the ERS unit root test confirms stationarity, making the data suitable for econometric analysis.

3.2. Research methodology

This study adopts the decomposed connectedness methodology developed by Gabauer and Gupta (2018) to analyze the dynamic interdependencies among commodities. This approach extends the traditional TVP-VAR connectedness framework by distinguishing between internal connectedness (within-group interactions) and external connectedness (between-group interactions). Unlike the models based on rolling-window VAR estimation, such as Diebold and Yılmaz (2012), the Gabauer and Gupta (2018) methodology does not require an arbitrary window size selection, thus avoiding potential biases due to data loss and smoothing. A key innovation of the decomposed connectedness approach lies in its ability to quantify the intensity of intragroup and intergroup spillovers separately, offering richer insights into structural changes within and across commodity classes. This feature is particularly valuable when assessing policy-driven structural shifts, such as those induced by the IRA. Therefore, the Gabauer and Gupta (2018) framework is especially suited for capturing the dynamic and heterogeneous spillover expected in the current energy transition and commodity financialization context. The net and total connectedness measures are calculated as follows:

$$NET_{II,mt}^{int}(H) = TO_{II,mt}^{int}(H) - FROM_{II,mt}^{int}(H) \tag{1}$$

$$TCI_{II,t}^{int}(H) = l_I^{-1} \sum_{m=1}^{l_I} TO_{II,mt}^{int}(H) = l_I^{-1} \sum_{m=1}^{l_I} FROM_{II,mt}^{int}(H) \tag{2}$$

$$NET_{It}^{ext}(H) = TO_{It}^{ext}(H) - FROM_{It}^{ext}(H) \tag{3}$$

$$TCI_I^{ext}(H) = K^{-1} \sum_{I=1}^{K} TO_{It}^{ext}(H) = K^{-1} \sum_{I=1}^{K} FROM_{It}^{ext}(H) \tag{4}$$

where t represents the year, H denotes the forecast horizon, and m corresponds to the m^{th} series within the group I . The variable k represents the total number of series in the group I, and l_I denotes the total number of groups. $TO_{II,mt}^{int}(H), FROM_{II,mt}^{int}(H), TO_{It}^{ext}(H)\ FROM_{It}^{ext}(H)$ correspond to the total directional connectedness within the group and to and from external groups. $NET_{II,mt}^{int}(H), NET_{It}^{ext}(H)$ capture the internal connectedness within the group I and the net external connectedness between the group I and other groups. $TCI_{II,t}^{int}(H)$ measures total internal connectedness within group I, and $TCI_I^{ext}(H)$ reflects total external connectedness.

The decomposed connectedness measures distinguish between internal spillovers within a commodity group and external spillovers between different groups. Equations (1) and (2) define internal connectedness. Specifically, $NET_{II,mt}^{int}(H)$ in equation (1) captures the net directional connectedness of the series m to I, calculated as the difference between shocks transmitted to other series in the same group (TO) and shocks received from them (FROM). A positive net value indicates that a series is a net transmitter of shocks within its group, while a negative value suggests it is a net receiver. $TCI_{II,t}^{int}(H)$ in equation (2) measures the total internal connectedness for the group I, averaged across all series. It reflects the overall degree of interdependence within the group over the forecast horizon H.

Equations (3) and (4) focus on external connectedness. $NET_{It}^{ext}(H)$ in equation (3) measures the net external directional connectedness of the group I, for all other groups. A positive value implies that the group I is a net transmitter of volatility toward external groups, whereas a negative value implies that it is predominantly a receiver of external shocks. $TCI_{I}^{ext}(H)$ in equation (4) captures the total external connectedness between groups I and the rest of the system, averaged across groups.

To further refine the analysis of commodity market interdependencies, we complement the decomposed connectedness framework with the partial connectedness approach proposed by Chatziantoniou et al. (2023). Although decomposed connectedness separates internal and external linkages across predefined groups, partial connectedness further isolates the specific dynamics of interest, excluding irrelevant interactions that could distort empirical findings. In this framework, inclusive connectedness captures all interactions involving a targeted set of variables (e.g., clean energy–related commodities). In contrast, exclusive connectedness removes spillovers that do not involve the target group, allowing a sharper focus on the underlying structural relationships. This methodological refinement is advantageous when the goal is to disentangle the direct effects of major policy changes, such as the IRA, on renewable energy-related commodities, minimizing noise from other sectors. Moreover, it enhances interpretability in large interconnected systems where traditional total connectedness measures might obscure specific transmission pathways. The net and total connectedness measures are calculated as follows:

$$NET_{it}^{inc}(H) = \sum_{j=1,i\neq j}^{K} \tilde{\omega}_{jit}^{inc}(H) - \sum_{j=1,i\neq j}^{K} \tilde{\omega}_{ijt}^{inc}(H) \quad (5)$$

$$TCI_{t}^{inc} = k^{-1} \sum_{i=1}^{k} \sum_{j=1,i\neq j}^{K} \tilde{\omega}_{jit}^{inc}(H) \quad (6)$$

$$NET_{it}^{exc}(H) = \sum_{j=1,i\neq j}^{K} \tilde{\omega}_{jit}^{exc}(H) - \sum_{j=1,i\neq j}^{K} \tilde{\omega}_{ijt}^{exc}(H) \quad (7)$$

$$TCI_{t}^{exc} = k^{-1} \sum_{i=1}^{k} \sum_{j=1,i\neq j}^{K} \tilde{\omega}_{jit}^{exc}(H) \quad (8)$$

Equations (5) and (6) define inclusive connectedness. $NET_{it}^{inc}(H)$ in equation (5) measures the net directional spillovers for the series i across all other series, accounting for the full system of interactions. It is calculated as the difference between the shocks transmitted by the series i and the shocks received by it. A positive value indicates that the series i is a net transmitter in the full system, while a negative value indicates that it is a net receiver. TCI_{t}^{inc} in equation (6) measures the total inclusive connectedness of the system at time t, averaging the spillovers among all series when considering the full set of interactions.

In contrast, equations (7) and (8) introduce exclusive connectedness. $NET_{it}^{exc}(H)$ in equation (7) measures the net directional spillovers for series i, after removing the influence of a selected subset of series (for example, excluding clean energy commodities when analyzing fossil fuel dynamics). This isolation provides a clearer view of direct transmission effects. TCI_t^{exc} in equation (8) measures the total exclusive connectedness, averaging spillovers across series while excluding interactions with the omitted group. $\widetilde{\omega}_{jit}^{inc}(H)$ and $\widetilde{\omega}_{jit}^{exc}(H)$ denote the pairwise connectedness measures under inclusive and exclusive settings, respectively. In practice, inclusive connectedness captures the global interconnectedness, including all variables, reflecting broader market dynamics. In contrast, exclusive connectedness focuses on specific channels by excluding unwanted influences, allowing for a more precise attribution of spillovers. This distinction is particularly valuable when analyzing how targeted policies like the IRA reshape commodity linkages by affecting only a subset of commodities.

It is important to clarify that the connectedness framework employed in this study is designed to identify time-varying interdependencies, spillover patterns, and structural reconfigurations in commodity markets, rather than to establish causal effects in a strict econometric sense. Although the pre- and post-IRA comparison provides useful evidence on how market connectedness changed around the enactment and early implementation of the policy, the TVP-VAR framework does not control for all potential confounding factors or isolate the IRA from other concurrent macroeconomic, geopolitical, and post-pandemic influences. Accordingly, the empirical results should be interpreted as documenting associations and structural shifts consistent with the post-IRA environment, rather than as definitive proof that the IRA alone caused the observed changes in commodity connectedness.

4. Empirical results

This section goes beyond documenting changes in connectedness measures by interpreting the economic mechanisms underlying the results and relating them to the broader literature on commodity spillovers, energy transition dynamics, and policy-driven market reallocation. In particular, the discussion focuses on whether the post-IRA environment is associated with greater sectoral specialization, stronger internal cohesion among transition-related commodities, and a weakening of traditional cross-sector contagion.

4.1. Average connectedness

For interpretive clarity, the post-IRA estimates should be viewed as reflecting the law's enactment and early implementation phase, with the most economically meaningful implementation window concentrated in 2023–2024 rather than immediately after August 2022. The following results are interpreted as evidence of changing connectedness around the enactment and early implementation of the IRA, rather than as causal estimates that fully isolate the policy from all other contemporaneous shocks. Table 2 captures the dynamic interdependence among commodities before and after the IRA.

Table 2. Average connectedness before and after the IRA.

	Agriculture commodities			Industrial metals			Energy		
	Corn	Soybean	Sugar	Copper	Nickel	Aluminum	Oil	Gas	FROM
Corn	64.31(68.29)	26.08(22.19)	3.27 (2.10)	1.38 (1.71)	0.95 (0.61)	0.98 (1.00)	2.21 (3.11)	0.82 (0.98)	35.69 (31.71)
Soybean	25.61(19.63)	63.26(62.64)	3.79 (2.61)	2.42 (4.32)	1.47 (2.66)	1.00 (2.19)	1.81 (5.30)	0.63 (0.67)	36.74 (37.36)
Sugar	4.05 (2.55)	4.65 (3.60)	79.77(81.90)	2.55 (3.24)	1.61 (1.50)	1.91 (2.56)	4.81 (3.97)	0.67 (0.68)	20.23 (18.10)
Copper	1.24 (1.41)	2.48 (4.37)	2.00 (2.52)	60.57(53.92)	15.78 (9.15)	12.79(21.10)	4.33 (6.85)	0.81 (0.68)	39.43 (46.08)
Nickel	0.98 (0.69)	1.54 (3.30)	1.30 (1.38)	16.61(11.78)	66.90(71.08)	9.04 (8.87)	2.73 (2.41)	0.90 (0.49)	33.10 (28.92)
Aluminum	0.97 (0.91)	1.12 (2.40)	1.66 (1.95)	14.43(22.91)	10.09 (7.56)	68.65(58.22)	2.17 (4.97)	0.91 (1.08)	31.35 (41.78)
Oil	2.49 (2.87)	2.16 (6.01)	4.59 (3.77)	5.67 (8.31)	3.29 (2.10)	2.73 (5.34)	77.94(70.18)	1.13 (1.41)	22.06 (29.82)
Gas	1.13 (1.46)	0.97 (0.97)	0.77 (1.40)	0.97 (0.66)	1.24 (0.40)	1.03 (1.22)	1.57 (2.03)	92.31(91.86)	7.69 (8.14)
TO	36.47 (29.51)	38.99 (42.85)	17.38 (15.72)	44.04 (52.93)	34.42 (23.99)	29.47 (42.28)	19.64 (28.63)	5.88 (5.99)	226.29(241.91)
NET	0.78 (−2.20)	2.26 (5.49)	−2.86 (−2.38)	4.62 (6.85)	1.32 (−4.93)	−1.88 (0.50)	−2.42 (−1.18)	−1.81 (−2.15)	32.33/28.29(34.56/30.24)

Note: The post-Inflation Reduction Act is noted in parentheses (after August 16, 2022).

Table 2 presents the dynamic interdependence among key commodity markets before and after the IRA's enactment, indicating significant shifts in connectedness patterns. Overall, the Total Connectedness Index (TCI) declined from 34.56 before the IRA to 30.24 after its enactment, suggesting a weakening of cross-commodity spillovers. This moderation likely reflects the IRA's targeted clean energy incentives, which accelerated sector-specific developments, particularly in renewable energy infrastructure and decarbonization technologies, thereby reducing the synchronization of commodity price movements across broad sectors.

Several notable commodity-specific dynamics emerge. Corn, previously a modest net transmitter of shocks (+0.78), shifted to a net receiver (−2.20) in the post-IRA period. While this transition is consistent with the IRA's support for electrification and the longer-run weakening of ethanol-linked demand growth, it should not be attributed to the IRA alone. Corn and ethanol markets were already heavily affected by the COVID-19 shock in 2020–2021, when the collapse in mobility and gasoline consumption sharply reduced ethanol demand. As these markets recovered in 2022–2023, the rapid expansion of electric vehicle adoption was also beginning to reshape expectations for future transport-fuel demand. Accordingly, the weakening of corn's systemic influence is better interpreted as the outcome of overlapping forces, pandemic disruption, post-pandemic recovery, expanding electrification, and IRA-related policy acceleration, rather than as a standalone effect of the IRA.

Copper, by contrast, solidified its dominance as a systemic transmitter. Already the leading transmitter pre-IRA (+4.62), copper's influence increased further post-IRA (+6.85). This outcome aligns closely with copper's indispensable role in electrification and renewable energy infrastructure, including EVs, solar panels, and grid expansion, sectors receiving strong support under IRA provisions. The rising systemic importance of copper underscores its centrality to the clean energy transition. Soybeans also emerged as a stronger transmitter, increasing net connectedness from +2.26 to +5.49. This result likely reflects the IRA's agricultural sustainability incentives and the continued relevance of soy-based biodiesel in renewable fuel strategies, reinforcing the intersection between agricultural commodities and clean energy initiatives. Aluminum's transition from a net receiver (−1.88) to a modest net transmitter (+0.50) similarly mirrors its growing demand for lightweight vehicles, renewable energy systems, and grid modernization—all explicitly supported under the IRA.

Additional insights from Table 2 further substantiate the structural realignment of commodity markets. Sugar became more isolated post-IRA, with its internal connectedness (self-dependence) rising, indicating that it became less influenced by broader commodity market dynamics. This isolation is logical, as significant clean energy incentives directly impact sugar less than other agricultural commodities. Traditional fossil fuels, namely oil and gas, maintained high internal connectedness but exhibited declining outbound spillovers, suggesting their systemic influence over other markets weakened in the post-IRA environment. This shift is consistent with the IRA's emphasis on decarbonization and energy diversification, gradually eroding the central role of fossil fuels in driving broader commodity market behavior.

These results point to a mechanism of sectoral reallocation rather than uniform market-wide intensification. The post-IRA environment appears to have increased the strategic centrality of commodities directly tied to electrification and renewable infrastructure, while reducing the systemic importance of commodities whose role is more closely linked to conventional fuel systems. This interpretation is broadly consistent with studies showing that commodity connectedness is highly sensitive to major structural and geopolitical shocks (Umar et al., 2021; Jiang and Chen, 2024), but our findings extend that literature by showing that climate policy–related transition dynamics may be associated not only with changing volatility levels but also with a reorganization of the architecture of inter-commodity spillovers. In particular, the stronger role of copper and the weaker role of fossil fuels suggest a transition from broad energy-led contagion toward more differentiated and technology-specific transmission channels.

4.2. Internal and external connectedness

Table 3 presents the internal connectedness within each commodity group (net agriculture, net industrial, and net energy) and the external spillovers outside their group (net external).

Table 3 indicates a structural shift toward stronger within-group dynamics and reduced cross-sector contagion, consistent with the IRA's focus on sector-specific development in clean energy and sustainable agriculture. Among agricultural commodities, corn transitioned from a weak net transmitter of shocks (+0.30) to a net receiver (−2.12) following the IRA. This shift reflects the decreasing strategic role of corn as the U.S. pivots away from ethanol-based transportation fuels toward electrification, weakening corn's systemic influence even within the agricultural sector. In contrast, soybean strengthened its role as a key internal transmitter, with its net influence rising from +1.33 to +3.56. This is economically intuitive given soybeans' growing importance in biodiesel production and sustainable agriculture programs incentivized under the IRA, positioning soybeans as a central node within agricultural commodity linkages.

Table 3. Partial connectedness before and after the IRA.

	Agriculture commodities			Industrial metals			Energy		
	Corn	Soybean	Sugar	Copper	Nickel	Aluminum	Oil	Gas	FROM
Net agriculture	0.30 (−2.12)	1.33 (3.56)	−1.64 (−1.44)						
Net industrial				2.48 (4.44)	0.21 (−3.94)	−2.69 (−0.50)			
Net energy							0.44 (0.61)	−0.44 (−0.61)	
Net external	0.47 (−0.07)	0.93 (1.94)	−1.22 (−0.95)	2.14 (2.42)	1.11 (−0.99)	0.81 (1.00)	−2.86 (−1.80)	−1.37 (−1.54)	11.06/9.68(14.94/13.07)

Note: The post-Inflation Reduction Act is noted in parentheses (after August 16, 2022). Net agriculture, net industrial, and net energy refer to internal connectedness within each commodity group. Net external measures the external spillovers each commodity receives from outside its own group.

Within industrial metals, copper continued to consolidate its internal dominance, with its net transmitter role increasing markedly from +2.48 to +4.44. Copper's systemic rise is consistent with its indispensable role in electrification infrastructure, ranging from electric vehicles to solar panels, areas strongly supported by IRA investments. Conversely, nickel shifted from a marginal transmitter (+0.21) to a notable receiver (−3.94), suggesting that despite its importance for battery technologies, nickel markets are increasingly subject to external shocks, likely due to supply chain vulnerabilities and geopolitical risks. Aluminum improved its external connectedness position, reducing its external dependence from −2.69 to −0.50. This shift indicates aluminum's growing resilience and strategic integration within clean technology value chains, such as lightweight transportation and renewable energy installations, sectors bolstered by IRA policies.

In the energy sector, oil and natural gas remained net receivers before and after the IRA. Notably, natural gas exhibited slightly increased vulnerability, with its net external connectedness declining from −0.44 to −0.61. This trend reflects the broader policy-driven transition away from fossil fuels, which has weakened their systemic influence even within energy markets.

An important systemic observation is the overall decline in external spillovers, with net external connectedness falling from 14.94 to 13.07. This suggests a progressive segmentation of commodity markets into more autonomous groups, driven by differentiated policy incentives. The IRA's targeted measures, supporting clean energy supply chains, sustainable farming, and domestic manufacturing, appear to have reduced the traditional interconnectedness that historically linked agricultural, metal, and energy commodities.

Figure 1 provides a time-varying perspective on total, internal, and external connectedness, complementing the average values reported in Table 3.

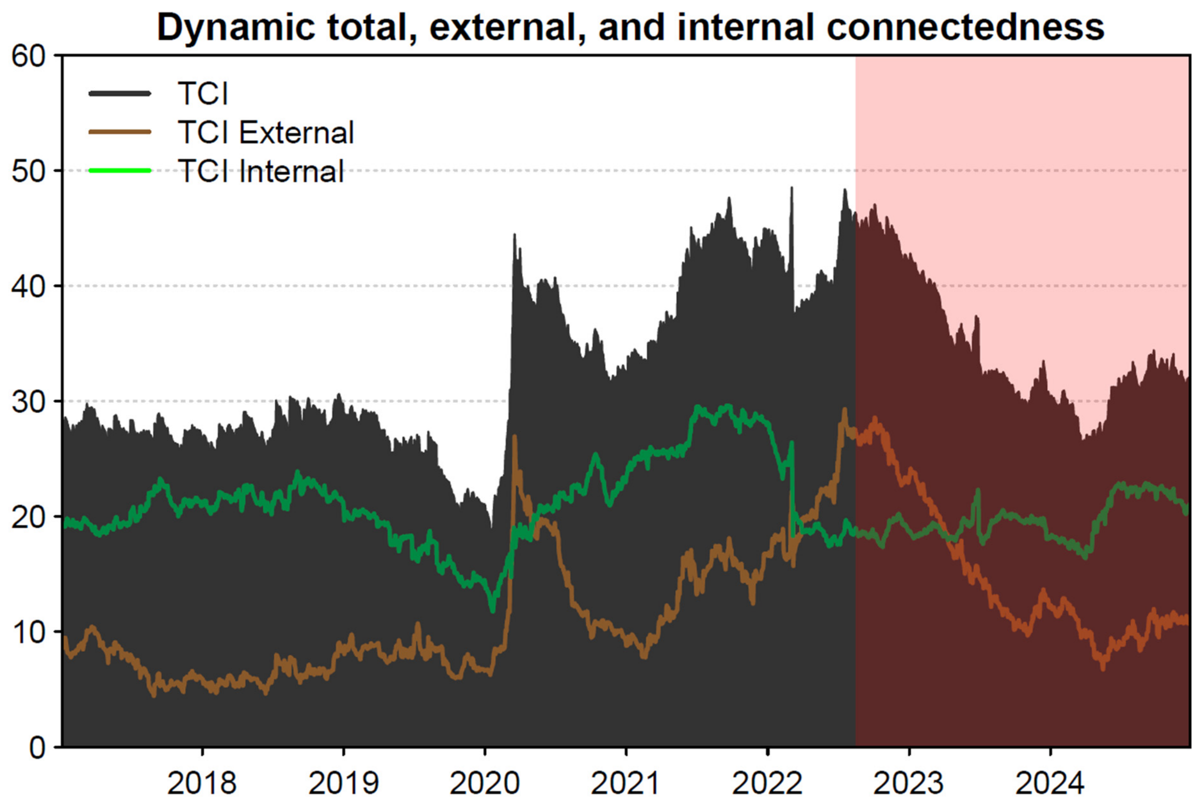

Figure 1. Dynamic total, external, and internal connectedness. Note: The red-shaded area represents the post-IRA enactment period, beginning in August 2022; the main implementation phase of many IRA tax incentives starts in January 2023.

Before the IRA enactment in mid-2022 (unshaded area), the TCI fluctuated around 30%, reflecting moderate systemic integration across commodity markets. Significant spikes are observed around 2020, corresponding to the onset of the COVID-19 pandemic, when sharp uncertainty and synchronized global shocks temporarily intensified volatility spillovers among commodities. For agricultural commodities, this episode also coincided with a severe pandemic-related disruption to fuel demand and ethanol markets, which is particularly relevant for corn given its close biofuel linkages. This confirms the commodity system's sensitivity to broad macroeconomic and geopolitical events.

Internal connectedness (depicted by the green line) exhibited a gradual upward trend before and after the IRA. This pattern suggests strengthening within-group linkages among commodities, particularly within industrial metals, agricultural feedstocks, and energy groups. The increase in internal cohesion is economically consistent with a broader transition toward sector-specific developments, such as clean energy infrastructure and sustainable agriculture, where commodities become more interconnected within their technological ecosystems.

In contrast, external connectedness (brown line) shows a sharp and sustained decline following the implementation of the IRA. This decline reflects a weakening of cross-sector spillovers, indicating that commodities in different groups (e.g., energy versus agriculture) have become more decoupled. The divergence between rising internal connectedness and falling external connectedness during the post-IRA period (red-shaded area) highlights a structural segmentation of commodity markets, where sector-specific fundamentals, driven by policy incentives, play a more significant role in price dynamics than broad, system-wide factors.

The gradual decline in overall TCI post-IRA further suggests that clean energy policies and targeted industrial support have mitigated broad cross-commodity contagion, reducing systemic risk across markets. As renewable energy deployment, electrification, and sustainable farming incentives accelerate, commodities essential to these sectors, such as copper, aluminum, and soybeans, become more internally connected but less reliant on traditional fossil fuel–related dynamics. This evolving structure reflects a realignment of market interdependencies, consistent with a policy-driven shift toward low-carbon economic activities.

Figure 2 provides a dynamic perspective on the total connectedness within each commodity group, reinforcing the conclusions from Table 3 regarding internal stability shifts post-IRA.

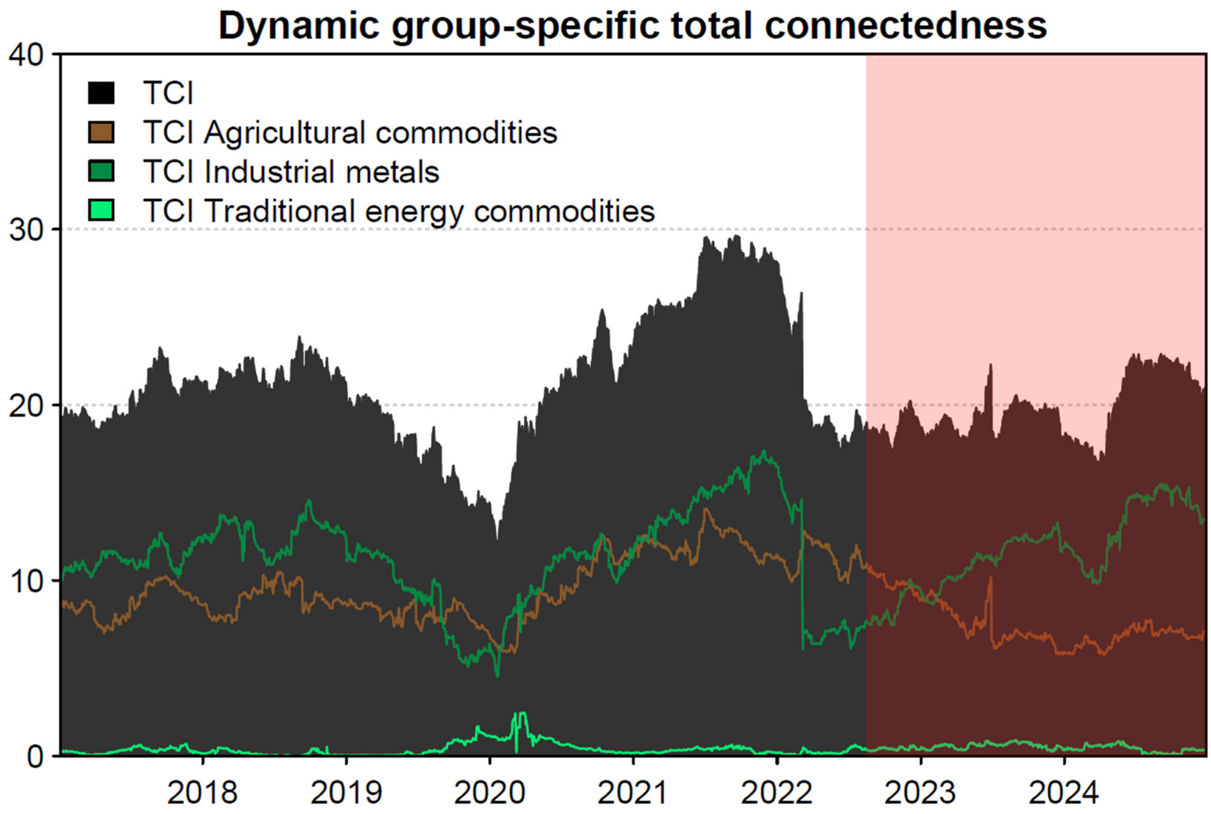

Figure 2. Dynamic group-specific total connectedness. Note: The red-shaded area represents the post-IRA enactment period, beginning in August 2022; the main implementation phase of many IRA tax incentives starts in January 2023.

Figure 2 clearly illustrates a structural divergence in market behavior following the IRA implementation in mid-2022. The most striking trend is the substantial and sustained increase in the internal connectedness of industrial metals (green line) during the post-IRA period. This pattern confirms that industrial metals have become more internally cohesive, reflecting the sector's growing systemic role in the clean energy transition. As renewable infrastructure, electric vehicles, and energy storage demand expand, sectors heavily incentivized by the IRA, metals such as copper, nickel, and aluminum are drawn into tighter production and price linkages. This trend is consistent with the earlier finding that copper's internal dominance has intensified post-IRA, as indicated in Table 3.

In contrast, agricultural commodities (brown line) display a relatively stable internal connectedness post-IRA, with only a slight downward adjustment. This suggests that while individual commodities within the group experienced redistribution of influence, such as corn's reduced systemic role and soybeans' strengthening position, the group retained its internal stability. Rather than weakening the agricultural sector's internal dynamics, the IRA appears to have subtly shifted the composition of influence within the group, likely reflecting a reorientation toward biofuel-linked crops and sustainable farming practices.

Meanwhile, traditional energy commodities (light green line) consistently exhibit the weakest internal connectedness throughout the sample period, with no substantial recovery post-IRA. The persistently low connectivity among oil and gas markets indicates a fragmentation within the traditional energy sector. This fragmentation is aligned with declining investment prospects, regulatory pressures, and policy-driven divestments to accelerate the transition toward low-carbon energy systems. Furthermore, as indicated by Table 3, oil and gas commodities remained net receivers of shocks, highlighting their diminishing systemic influence even within their group.

From a mechanism perspective, the divergence between rising internal and declining external connectedness suggests that the commodity system became more segmented and policy-differentiated in the post-IRA period. Rather than generating a uniform increase in spillovers across all sectors, the transition appears to have concentrated transmission within commodity groups linked by similar demand fundamentals and technological use cases. This interpretation complements prior evidence highlighting that spillovers between energy, metals, and agricultural markets are time-varying and shock-dependent (Gao and Liu, 2024; Jiang and Chen, 2024), while adding the new insight that a major climate-policy regime may coincide with stronger within-group cohesion and weaker between-group contagion.

4.3. Inclusive and exclusive connectedness

Table 4 illustrates the differences between net-inclusive and net-exclusive connectedness among commodities, providing deeper insights into how market interactions have evolved before and after the IRA. Net-inclusive measures reflect a commodity's spillovers within the broader system, while net-exclusive measures isolate interactions within specific commodity groups, excluding external influences.

Table 4. Inclusive and exclusive connectedness before and after the IRA.

	Agriculture commodities			Industrial metals			Energy		
	Corn	Soybean	Sugar	Copper	Nickel	Aluminum	Oil	Gas	FROM
Net-inclusive	0.78 (−2.19)	2.26 (5.50)	−2.86 (−2.39)	0.63 (0.97)	0.21 (−0.60)	0.14 (0.48)	−0.41 (−0.26)	−0.75 (−1.50)	16.87/14.76 (17.54/15.34)
Net-exclusive	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	3.99 (5.89)	1.11 (−4.33)	−2.02 (0.01)	−2.01 (−0.92)	−1.06 (−0.65)	15.46/13.53 (17.04/14.91)

Note: The post-Inflation Reduction Act is noted in parentheses (after August 16, 2022). Net-inclusive represents the total net spillovers a commodity receives from all other commodities in the system, capturing overall interconnectedness. Net-exclusive isolates connectedness within a specific subset of commodities, excluding influences from other groups.

In the agricultural sector, corn transitioned from a weak net transmitter (+0.78) to a net receiver (−2.19) under the inclusive measure, indicating a significant decline in its influence over broader commodity markets. This finding is consistent with the IRA's policy focus on electrification, which indirectly diminishes corn's strategic role linked to ethanol-based biofuels. Soybean, in contrast, strengthened its net inclusive connectedness, rising from +2.26 to +5.50, reinforcing the growing importance of soybean-linked biodiesel production under clean energy and sustainable agriculture initiatives. Sugar remained a strong net receiver before and after the IRA, suggesting that its marginal role persists within both agricultural and broader commodity systems.

In the industrial metals sector, copper's net inclusive connectedness remained relatively stable, moving slightly from +0.63 to +0.97, suggesting a consistent overall influence across the system. However, copper's significant rise in net-exclusive connectedness is a striking development, from 0.00 to +3.99, post-IRA. This shift indicates that copper's systemic role has become increasingly concentrated within the industrial metals group rather than exerting broad market-wide influence, aligning with its critical function in electrification technologies, where demand is highly sector-specific. Nickel, meanwhile, shifted from a weak net transmitter (+0.21) to a net receiver (−0.60 inclusive, −4.33 exclusive). The sharp deterioration in nickel's net-exclusive position suggests growing vulnerability to internal group pressures, likely due to supply chain instabilities and geopolitical uncertainties impacting battery metal markets. Aluminum also experienced a notable shift: its net-exclusive connectedness moved from −2.02 to a near-neutral 0.01, reflecting an improvement in internal sectoral integration and reduced dependence on external commodity movements.

For the energy sector, crude oil and natural gas remained consistent net receivers, with gas becoming even more dependent on external shocks post-IRA (worsening from −0.75 to −1.50 inclusive). This persistent negative positioning underscores the structural weakening of traditional fossil fuels within commodity network dynamics, as the global energy transition intensifies. Across the broader system, the slight decline in FROM values (16.87 to 14.76 inclusive; 15.46 to 13.53 exclusive) suggests a general weakening of market-wide interdependencies post-IRA. This trend aligns with previous findings showing that policy-driven sectoral specialization reduces commodities' systemic exposure to unrelated market shocks, especially favoring clean energy technologies.

Figure 3 provides a time-varying view of total, inclusive, and exclusive connectedness among commodities before and after the IRA, further enriching the interpretation of structural shifts captured in Tables 3 and 4.

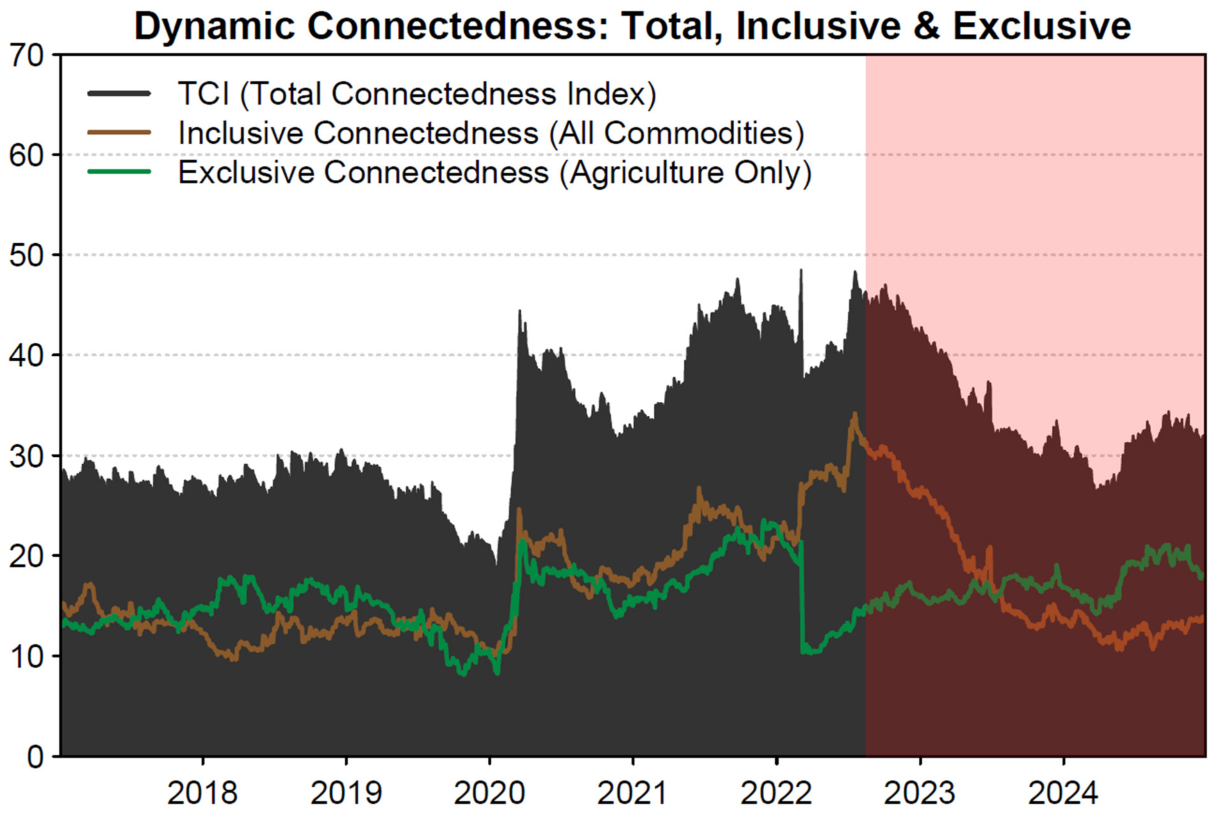

Figure 3. Total, inclusive, and exclusive connectedness. Note: The red-shaded area represents the post-IRA enactment period, beginning in August 2022; the main implementation phase of many IRA tax incentives starts in January 2023.

The TCI (black area) exhibits significant fluctuations over time, with pronounced spikes corresponding to major global shocks, particularly during the COVID-19 pandemic of 2020. These spikes reflect heightened uncertainty and generalized volatility spillovers across commodity markets during systemic crises. Following the enactment of the IRA in mid-2022 (red-shaded area), a notable downward trend emerges in the TCI, indicating a sustained weakening of broad market spillovers. This decline is consistent with the hypothesis that the IRA catalyzed a structural decoupling of commodity markets by incentivizing targeted clean energy sectors and reducing cross-sector dependencies.

Inclusive connectedness (brown line), which measures the overall net spillovers each commodity receives from all others, reflects this pattern. Inclusive connectedness surged during global turmoil but declined sharply post-IRA, reflecting a fragmentation of the broader commodity network. This trend reinforces findings from Table 4, where commodities such as corn and nickel displayed reduced system-wide influence after the policy shift, becoming more sectorally contained or isolated. In contrast, exclusive connectedness (green line), which isolates internal interactions within a specific group (here, agricultural commodities), remained relatively stable but exhibited a moderate upward trend post-IRA. This suggests that while cross-sector contagion weakened, within-group relationships strengthened. Commodities tied to the same technological ecosystems or policy incentives, such as biofuel-linked crops, have become more tightly integrated internally, even as their influence across unrelated sectors diminished. Figure 3 confirms that the IRA has contributed to restructuring commodity market dynamics. Cross-sector spillovers have weakened, while internal sectoral cohesion has strengthened. This realignment reflects a broader shift toward a more segmented, policy-driven commodity market architecture, where clean energy priorities and sector-specific developments shape interdependencies more decisively than generalized global macroeconomic factors.

The inclusive-exclusive decomposition also reveals that transition-related commodities do not respond uniformly to the low-carbon shift. Copper's stronger exclusive role suggests that it functions as a core internal transmitter within the industrial metals cluster, consistent with its broad use across grids, electric vehicles, and renewable infrastructure. By contrast, nickel's weaker position indicates that strategic importance in the transition does not automatically translate into systemic leadership, particularly when a commodity is more exposed to supply-chain concentration, geopolitical uncertainty, or market-specific volatility. This heterogeneous result adds nuance to the broader transition literature, which often emphasizes rising demand for critical minerals in aggregate (Boer et al., 2021), by showing that different transition metals can occupy markedly different positions in the connectedness network.

The empirical evidence of this study suggests that the post-IRA environment is associated with a structural reorganization of commodity-market connectedness characterized by stronger intra-group transmission among transition-relevant commodities and weaker inter-group contagion across the broader system. Relative to the existing literature, which has largely emphasized crisis-driven or geopolitical spillovers, the present findings point to a different mechanism: policy-linked transition dynamics may reshape not only the magnitude but also the direction and concentration of commodity spillovers. This helps explain why industrial metals, especially copper, gain systemic prominence, while fossil-fuel commodities and some biofuel-linked markets become less central in the network.

5. Robustness check

5.1. Excluding sugar from the agricultural group

We reclassified sugar outside the agricultural commodity group, focusing only on corn and soybeans as biofuel-linked crops. This adjustment reflects that sugar, primarily a food commodity, may not respond as directly to renewable energy policies as biofuel feedstocks. Table 5 illustrates the estimation results.

Table 5. Partial connectedness before and after the IRA (after excluding sugar).

	Agriculture		Industrial metals			Energy		
	Corn	Soybean	Copper	Nickel	Aluminum	Oil	Gas	FROM
Net	−0.35	0.35						
Agriculture	(−2.55)	(2.55)						
Net industrial			2.39	0.28	−2.67			
			(4.16)	(−3.83)	(−0.33)			
Net energy						0.40	−0.40	
						(0.53)	(−0.53)	
Net external	0.44	0.85	1.87	0.95	0.71	−3.63	−1.20	9.68/8.29(13.86/11.88)
	(−0.12)	(2.02)	(1.83)	(−1.05)	(0.59)	(−2.39)	(−0.87)	

Note: The post-Inflation Reduction Act is noted in parentheses (after August 16, 2022). Net agriculture, net industrial, and net energy refer to internal connectedness within each commodity group. Net external measures the external spillovers each commodity receives from outside its own group.

The key patterns observed in the baseline analysis remain primarily robust. Internal connectedness among industrial metals remains strong, with copper continuing to be the dominant net transmitter (increasing from 2.39 pre-IRA to 4.16 post-IRA), reinforcing its role as a critical input for the clean energy transition. Soybeans also retain their importance within the agricultural sector, shifting from a weak transmitter (0.35) to a stronger net transmitter (2.55) post-IRA, consistent with the growing demand for biofuel-related crops. Corn, conversely, consolidates its position as a net receiver, suggesting a continued divergence in biofuel-linked agricultural commodities. Traditional energy commodities (oil and gas) remain net receivers, and the magnitude of external spillovers (FROM) slightly declines from 13.86 to 11.88 after the IRA, confirming the trend toward reduced cross-sector contagion.

5.2. Subsample analysis pre-COVID vs. COVID/post-COVID

To further validate that our findings are driven by the IRA rather than broader pandemic-related shocks, we conduct a subsample analysis, splitting the data into a pre-COVID period (2017–2019) and a COVID/post-COVID period (2020–2024). Table 6 illustrates the estimation results.

Table 6. Connectedness before and after COVID-19.

	Agriculture commodities			Industrial metals			Energy		
	Corn	Soybean	Sugar	Copper	Nickel	Aluminum	Oil	Gas	TCI
Net pre-COVID	−0.28	1.50	−1.89	3.14	2.67	−2.60	−1.94	−0.60	27.07/23.69
Net post-COVID	0.21	3.69	−3.27	6.70	−2.48	−0.66	−1.95	−2.24	36.55/31.98

The results show that during the COVID-19 crisis, total connectedness surged across all commodities, reflecting generalized market-wide stress and intensified volatility. This distinction is particularly important for interpreting corn dynamics because the COVID-19 shock temporarily depressed gasoline and ethanol demand, thereby weakening the corn-biofuel linkage well before the IRA's implementation phase. The subsequent post-2022 evolution of corn connectedness should therefore be interpreted as reflecting both recovery from the pandemic shock and the growing structural influence of electrification and clean-energy policy. In contrast, the post-IRA period indicates a targeted reconfiguration. Industrial metals exhibit stronger internal cohesion, while external spillovers across sectors weaken. This key distinction confirms that the patterns observed in our main results, particularly the internal strengthening of metals and the reduction of cross-sector contagion, are specific to structural policy-driven changes induced by the IRA rather than a generic crisis effect alone. Accordingly, the weakening of corn's systemic role is better interpreted as the outcome of overlapping forces rather than as a standalone effect of the IRA. Hence, the IRA's impact on commodity market dynamics represents a fundamental realignment linked to clean energy transition priorities, not a residual effect of COVID-19 disruptions.

5.3. Alternative event windows

To ensure that our results are not sensitive to the precise choice of the Inflation Reduction Act (IRA) event date, we conduct an additional robustness check by varying the cutoff dates around the official signing. Specifically, we re-estimate internal and external connectedness measures by shifting the cutoff date from August 16, 2022 (the official IRA signing) to August 1, 2022 (to capture potential market anticipation effects) and September 1, 2022 (to account for possible delayed market reactions). This approach allows us to verify whether the observed shifts in commodity market interdependencies are robust to minor adjustments in the event window. Table 7 illustrates the estimation results.

Table 7. Partial connectedness before and after the IRA for different cutoff dates.

Partial connectedness before and after the IRA (cutoff date: August 1, 2022)									
	Agriculture commodities			Industrial metals			Energy		
	Corn	Soybean	Sugar	Copper	Nickel	Aluminum	Oil	Gas	FROM
Net agriculture	0.31 (−2.09)	1.30 (3.58)	−1.62 (−1.49)						
Net industrial				2.46 (4.45)	0.23 (−3.90)	−2.69 (−0.55)			
Net energy							0.44 (0.61)	−0.44 (−0.61)	
Net external	0.45 (−0.01)	0.88 (2.02)	−1.21 (−0.98)	2.12 (2.45)	1.14 (−1.03)	0.82 (0.98)	−2.86 (−1.80)	−1.33 (−1.63)	10.93/9.56 (15.16/13.27)
Partial connectedness before and after the IRA (cutoff date: September 1, 2022)									
	Agriculture commodities			Industrial metals			Energy		
	Corn	Soybean	Sugar	Copper	Nickel	Aluminum	Oil	Gas	FROM
Net agriculture	0.30 (−2.15)	1.36 (3.53)	−1.66 (−1.38)						
Net industrial				2.50 (4.43)	0.19 (−3.97)	−2.69 (−0.46)			
Net energy							0.44 (0.62)	−0.44 (−0.62)	
Net external	0.48 (−0.12)	0.97 (1.85)	−1.24 (−0.90)	2.15 (2.39)	1.08 (−0.96)	0.81 (1.00)	−2.85 (−1.79)	−1.41 (−1.46)	11.19/9.79 (14.70/12.86)

The findings in Table 7 confirm that the structural changes observed in commodity market connectedness are robust to alternative event window specifications. Regardless of the precise cutoff date, the IRA's effects on strengthening internal ties within industrial metals and weakening external spillovers remain evident.

6. Conclusions

This study investigates how the IRA, the most ambitious U.S. climate legislation to date, has reshaped interdependencies across agricultural commodities, industrial metals, and traditional energy markets. Utilizing a time-varying connectedness framework based on TVP-VAR models and incorporating decomposed and partial connectedness measures, we analyze structural changes in commodity market dynamics from 2017 to 2024, particularly concerning the post-IRA period.

The findings indicate that the post-IRA period was associated with a significant realignment in commodity market structures, consistent with the view that the IRA reinforced and accelerated ongoing transition-related dynamics. Total connectedness declined following the IRA's enactment, reflecting a weakening of broad systemic spillovers. A sharp decline in external connectedness primarily drove this, while internal cohesion within commodity groups, particularly among industrial metals, strengthened. Copper consistently emerged as the dominant net transmitter before and after the IRA, highlighting its critical role in supporting the electrification and renewable energy transition. In contrast, traditional energy commodities such as crude oil and natural gas remained net receivers, underscoring their declining systemic relevance in a decarbonizing economy.

The behavior of agricultural commodities further supports the structural shift hypothesis. Corn transitioned from a transmitter to a receiver of shocks, suggesting reduced systemic importance as electrification initiatives diminish ethanol's strategic role. Soybeans, conversely, strengthened their market influence, aligning with their growing role in biofuel production and sustainable agriculture supported by the IRA. Within the industrial metals sector, nickel became more externally dependent, reflecting supply chain vulnerabilities despite its strategic role in battery technology. Partial and inclusive-exclusive connectedness measures further confirm that commodities linked to clean energy, such as copper and soybeans, have gained more significant internal sectoral influence, while cross-sector contagion has weakened. These findings align with the theoretical channels outlined earlier: policy-driven reallocation and electrification strengthened the internal role of industrial metals, while market segmentation and differentiated transition pathways reduced external spillovers and weakened the systemic centrality of fossil-fuel commodities.

This study contributes to the growing literature on commodity market dynamics under significant policy interventions. It is among the first to empirically quantify the IRA's effects on commodity interconnectedness, employing a detailed decomposition between internal, external, inclusive, and exclusive connectedness. The results demonstrate how policy-driven sectoral specialization reshapes systemic relationships, offering a novel perspective on the interaction between climate legislation and financial market structures.

The findings have important implications for policymakers and investors. Climate legislation, such as the IRA, not only shifts commodity demand but also restructures the interconnections that define systemic risk and opportunity. Commodities critical to clean energy transitions, especially copper, nickel, and aluminum, should be treated as strategic resources, warranting investment in supply chain resilience and infrastructure security. While still significant, traditional fossil fuels are losing their central systemic position, suggesting that policy efforts to diversify energy systems are beginning to manifest in financial and commodity network structures. For investors, the increasing sectoral specialization implies that traditional cross-commodity diversification strategies may be less effective, requiring more targeted risk management approaches. However, because our sample ends in December 2024, it does not capture the subsequent 2025 legislative modifications to clean-energy incentives, including those introduced under the One, Big, Beautiful Bill Act. Accordingly, our findings should be interpreted as reflecting only the original IRA enactment and the early implementation phase. More generally, the results should be interpreted with appropriate caution, as the empirical framework identifies dynamic associations and reconfigurations in connectedness rather than causal effects attributable solely to the IRA. Because the analysis does not explicitly control for all concurrent influences, including post-pandemic recovery dynamics, geopolitical shocks, and broader energy-transition trends, the findings are best understood as evidence consistent with a post-IRA structural realignment rather than as a definitive causal estimate of policy impact. Future research can build upon these findings by incorporating higher-frequency data to capture immediate policy reactions, exploring global spillover effects given the international implications of U.S. climate policy, and integrating climate-linked financial instruments such as carbon markets into connectedness analyses. Further examination of asymmetric connectedness under positive and negative shocks would enrich the understanding of dynamic transmission mechanisms during significant policy shifts.

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Use of AI tools declaration

AI-assisted tools were used only to improve phrase structure, grammar, readability, and language clarity. All conceptual development, analysis, interpretation of results, and final content were conducted and verified by the author.

Conflict of interest

The author declares no conflict of interest.

Data Availability Statement

The data that support the findings of this study are available from the author upon reasonable request.

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