The Evolving Role of Energy Futures Markets: A Survey

Highlight
-We provide a comprehensive overview of the evolving role of energy futures markets.
-We emphasize the extensive connectedness of energy futures prices with diverse market sectors.
-Volatility dynamics characterize energy futures markets.
-We underscore the growing importance of the energy futures markets in contemporary research.

Abstract
Energy markets are important in global trade and economic stability, and energy futures play a critical role in energy market dynamics. This study reviews: i) the important role energy futures market prices play as reliable forecasts of future spot prices for energy commodities; ii) the connectedness of energy futures and spot markets; iii) how energy futures markets facilitate managing exposure to energy price risk; iv) the systemic influence of energy futures prices and volatility on other markets and how this influence frequently surges during crises. Our survey provides economic insights for energy market participants and policymakers.

Keywords: Derivatives; Energy futures; Global energy sector; Spot-futures relationship; Volatility

JEL Classification: G13, G14, G15

1. Introduction
Energy futures play a critical role in modern energy markets. Yet, the introduction of energy futures was largely the result of the failure of an agricultural commodity futures contract. Heating oil futures, the first energy futures contract, were introduced on the New York Mercantile Exchange (NYMEX) in 1978 as the NYMEX searched for new futures contracts to trade after the 1976 default on Maine potatoes—it’s principal futures contract at that time. The default, the only default on a U.S. futures exchange, threatened the NYMEX’s survival. The success of heating oil futures prompted the NYMEX to introduce other energy futures contracts from unleaded gasoline to natural gas and crude oil. These futures contracts changed the modern energy market by bringing greater transparency and faster price discovery to energy
commodities, as well as better tools to manage exposure to uncertain changes in energy prices. Although commodity futures have always been “financial” contracts, there has been a surge in their use by hedge funds and other alternative asset managers. The financialization of commodity markets has increased the importance of energy futures markets further.

The energy sector is an important component of international trade with crude oil and natural gas ranking as the top two commodities traded in terms of market value in recent years. Fluctuations in oil, natural gas, and other energy commodity prices impact economies around the world (Brockway, Sorrell, Semieniuk, Heun, and Court, 2021; Gozgor, Mahalik, Demir, and Padhan, 2020; Son and Ryu, 2024). These price dynamics wield substantial influence over observed inflation rates, trade balances, economic activity, and sometimes geopolitics. They also expose market participants to substantial risk. Although spot prices predominantly reflect local market conditions and short-term demand and supply considerations, crude oil and natural gas prices are essentially determined in futures markets where there is greater transparency and often lower transaction costs. While a substantial amount of research on the energy sector has been conducted (Gielen, Boshell, Saygin, Bazilian, Wagner, and Gorini, 2019), much of the existing research tends to focus on the spot market (Algieri and Leccadito, 2017; Asl, Canarella, and Miller, 2021; Rehman, Bouri, Eraslan, and Kumar, 2019; Vacha and Barunik, 2012) with fewer studies specifically examining the impact of energy futures markets. This study attempts to redress that deficiency by reviewing the literature on energy futures markets. Any review of the literature must necessarily be selective. This review is no different. More attention is given to recent studies than older ones. Particular attention is directed towards bouts or instances of heightened volatility in the energy sector and its impact on energy futures markets. Similarly, the influence of recent crises or events that change volatility in the energy sector such as the COVID-19 pandemic or Russia’s invasion of Ukraine are given greater attention than older ones.

The financialization of commodity markets—that is an environment where speculators with no interest in the physical commodity dominate the derivatives markets that determine changes in prices—has changed the composition of market participants and the significance of various market participant groups (Ding, Cui, Zheng, and Du, 2021; Goldstein and Yang, 2022; Yu and Ryu, 2020). Commodity futures have become a popular asset class for some commodity market participants (Ham, Cho, Kim, and Ryu, 2019). There are two main types of market participants: hedgers and speculators. Hedgers, such as farmers, millers, and manufacturers, use commodity futures for hedging or risk management purposes. Their primary objective is
to manage the risk associated with adverse price movements in the underlying physical commodities. By buying or selling futures contracts, they can protect themselves from potential losses by locking in prices. On the other hand, speculators, often institutional investors and hedge funds, engage in commodity futures for speculative purposes. They aim to generate profits by capitalizing on price movements in the commodity markets. Unlike hedgers, speculators may not have a direct interest in the physical commodities themselves or a natural exposure to commodity risk. In addition to hedging and speculation, commodity futures are also sometimes utilized for portfolio diversification. Investors incorporate commodities into their portfolios to achieve diversification benefits, as commodity prices may not always move in tandem with traditional asset classes like stocks and bonds. Moreover, during financial crises or stock market declines, commodity futures can serve as a hedge, providing a potential safeguard for investors. Unlike physical commodity markets, where local market conditions, factors such as short-term supply-demand dynamics, or physical characteristics influence the price, futures prices are influenced by longer-term fundamental economic factors that might arise before contract expiration, as well as speculation and behavioral finance factors.

By delving into the realm of energy futures markets, this review aims to provide valuable insights for both market participants and policymakers in understanding the dynamics of energy futures markets. By identifying key factors influencing this relationship, policymakers can better anticipate and mitigate potential risks, and make informed decisions to ensure energy security and stability. On the other hand, market participants can benefit from the findings of this review to make informed investment decisions in energy markets. Understanding the interplay between energy futures and other markets can help investors identify opportunities and manage risks more effectively. Considering the implications of these findings, investors can optimize their investment strategies and enhance their returns. Overall, this review provides a more nuanced understanding of the role of energy futures in modern energy markets.

The remainder of this paper is organized as follows. Section 2 presents the findings of the bibliometric analysis of the overall trajectory of research and identifies key themes and keywords within the literature. Section 3 discusses the relationship between energy spot and futures markets. Section 4 presents the relationship between the energy futures market and other non-energy markets, which contains an explanation of the spillover and contagion effects. Section 5 discusses other factors affecting energy futures markets, such as recent crises. Section 6 concludes this review.
2. Bibliometric analysis

2.1. Methodology

We employ a methodology grounded in bibliometric analysis, integrating both quantitative and qualitative dimensions of the literature. We adopt this methodology to ascertain the overarching direction and flow of research within our study. By conducting bibliometric citation analysis, and co-authorship analysis, we aim to gain insights into the broader landscape of our research domain. This approach allows us to examine the interconnections among scholarly works, identify influential authors and key research themes, and understand the evolution of ideas within this field. We leverage VOSviewer for our analysis, a tool widely utilized for visualizing and exploring bibliometric data. This enables us to conduct a comprehensive examination and interpretation of the literature, facilitating insights into the broader trends, patterns, and relationships within our research domain.

2.2 Data selection

We use the Web of Science database, renowned for its extensive coverage and meticulous curation of high-quality peer-reviewed articles. By selecting the keywords “Energy*” AND “Futures*”, we aimed to cast a wide net, ensuring a comprehensive examination of 1,699 articles published between 2000 and 2024, all of which were restricted to the English language. Figure 1 illustrates the trends in annual publications related to energy futures. Publications in this field have shown a consistent increase over time, with a notable surge observed after 2008-2009. The milestone of surpassing 100 publications annually was achieved in 2018, signifying a significant growth in scholarly output. Moreover, the trend continues to exhibit a steep upward trajectory, even in recent years.

[Figure 1 inserted]

2.3. Co-word analysis

We conduct a co-word analysis to further explore the relationship between key terms and concepts within the literature. Co-word analysis involves identifying frequently co-occurring terms within documents, thereby uncovering underlying thematic structures and associations. By examining the co-occurrence patterns of terms, we gain insights into the semantic relationship and thematic clusters present in the research domain. This method enables us to identify central themes, emerging trends, and areas of interest within the literature, providing
a deeper understanding of the subject matter. For the analysis, a minimum occurrence threshold of 5 and 10 is set for each term, resulting in a pool of 556 and 285 terms each meeting this criterion.

Figure 2 presents the word cloud visualization created before the analysis of co-occurring relationships. Among research articles focusing on “Energy Futures,” the most frequently appearing term is “volatility.” Surrounding this central term, we observe other common terms such as “futures,” “returns,” “prices,” “markets,” and “crude oil.” Additionally, terms like “financialization,” “spillovers,” “valuation,” “transmission,” “volatility spillovers,” and “dependence” provide insights into the subtopics addressed within the research. This visualization offers a quick overview of the main themes and subtopics prevalent in the literature on “Energy Futures.”

[Figure 2 inserted]

Figures 3 and 4 present the results of co-word analysis based on co-occurrence. Figure 3 depicts the analysis conducted with a minimum number of occurrences of a keyword set to 5, resulting in 556 words out of a total of 5,299 keywords being used. Figure 4, on the other hand, illustrates the analysis with a threshold set to 10, resulting in the use of 285 words. While the word cloud highlights key terms such as “volatility,” “futures,” “energy,” and “crude oil.” These figures provide a comprehensive overview of the interconnectedness between various research directions. The main research directions identified include: i) analysis of price dynamics: Studies in this direction focus on analyzing price dynamics and examining factors such as valuation, pricing, hedging, and their association with commodity prices. ii) Volatility and return analysis: Research in this area primarily focuses on volatility and return, with a particular emphasis on implied volatility (Song, Ryu, and Webb, 2016, 2018; Yang, Kutan, and Ryu, 2019), realized volatility, and their implications. iii) Spillover and transmission: This research direction explores spillover effects and transmission mechanisms within energy markets, shedding light on how shocks propagate across different segments of the market. iv) Diverse energy sectors: Studies in this category are interconnected with research on various energy sectors, including renewable and policy-related research, highlighting the broad scope of research within the energy domain.

[Figure 3 inserted]
2.4. **Co-citation analysis**

In this section, we undertake a co-citation analysis to examine the interconnectedness of scholarly works within the literature. Co-citation analysis involves evaluating the frequency with which two documents are cited together by other documents. By scrutinizing the co-citation patterns, we attempt to reveal the intellectual structure and dynamics of the research field. For this analysis, we set a minimum threshold of 20 citations for each cited reference, resulting in the selection of 363 references. These selected references constitute a comprehensive dataset that allows for a robust examination of co-citation patterns and the identification of significant contributions within the research domain. The results of the key studies from co-citation analysis Figure 5 are presented in Table 1 in chronological order.

3. **Energy spot-futures price relationship**

The futures market offers two key benefits: **risk transference** and **price discovery**.\(^1\) Price discovery refers to determining the “correct” or market clearing price. The process entails impounding relevant and often incorporating bits of information into market prices. Futures prices are often good predictors of future spot prices. This makes the futures market a valuable tool for forecasting future spot prices and provides a means of managing the risk related to it. If the market is efficient, the spot-futures price relationship will remain simple (Lee, Kang, and Ryu, 2015; Lee, Lee, and Ryu, 2019). At any moment in time, the futures price is considered to be an accurate forecast of what the actual spot price will be at contract expiration. Understanding the spot-futures relationship in the energy sector is useful for hedging and forecasting purposes. As the energy market is closely tied to broader economic trends, studying

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\(^1\) In general, derivatives products are essential vehicles for implementing hedging, arbitrage, and speculation. Derivative markets can play key roles in price discovery and provide investment opportunities for both informed and uninformed investors (Baker, Kumar, and Pandey, 2021; Garbade and Silber, 1983; Hou, Wang, Chen, and Härdle, 2020; Hu, Kirilova, Park, and Ryu, 2024; Lee and Ryu, 2019, 2024; Lee, Ryu, and Yang, 2021; Luo, Cai, and Ryu, 2022; Ryu and Yang, 2020; Ryu, and Yu, 2021; Ryu, Ryu, and Yang, 2021; Ryu, Webb, and Yu, 2022; Yu, Kim, and Ryu, 2024).
the relationship and helping the prediction of price movements will benefit market participants and policymakers alike.

The spot-futures relationship can be explained by different mechanisms from a theoretical viewpoint. The theory of market efficiency states that a market is considered efficient if it correctly reflects available information. One implication of market efficiency is that one is not able to consistently earn an abnormal return. Additionally, the theory of storage, introduced by Kaldor (1983), posits that futures prices align with spot prices adjusted for the cost of carry. Factors such as risk premium, convenience yield, and cost of storage influence the basis (the difference between spot and futures prices) and futures spread (the difference between two futures prices) (Lee and Zeng, 2011). The basis plays a crucial role in determining whether the commodity market is experiencing contango or backwardation, indicating the presence of a shortage or surplus of the physical commodity in the market.\(^2\) As the market approaches maturity, the basis gradually diminishes until it reaches zero, resulting in the convergence of spot and futures prices. Arbitrage profit opportunities would arise if futures and spot prices don’t converge. Spot-futures parity also theoretically explains the relationship between spot and futures prices. It implies that constant arbitrage opportunities based on exploiting the spot-futures relationship are unlikely, contributing to the overall efficiency and rational formation of prices in the marketplace.

3.1. **Fundamental dynamics of the energy spot-futures relationship**

Numerous studies delve into the fundamental dynamics of the energy spot-futures relationship. In most cases, the Johansen cointegration test is the most common approach for analyzing long-term relationships, while short-term relationships are explored using methods such as Granger causality tests and Vector Error Correlation Models (VECM). Among energy futures, oil futures are the subject of extensive analysis for several reasons, including its status as a representative energy commodity and its significant economic impact. One of the main

\(^2\) Contango is a term used in futures markets to describe a situation where the futures price of a commodity exceeds the expected spot price at the time of delivery. This occurs when hedgers exhibit greater risk aversion compared to short hedgers. On the contrary, when hedgers hold net short positions, or if short hedgers display more risk aversion than long hedgers, the futures price of a commodity is lower than the expected spot price, a scenario known as normal backwardation. Both backwardation and contango emerge as a result of the imbalance between long and short hedging positions, necessitating the presence of speculators to restore equilibrium (Anderson and Danthine, 1983; Miffre, 2000; Hull, 2022).
purposes of investigating the spot-futures relationship is to determine whether spot and futures prices aid in forecasting each other. Bopp and Sitzer (1987) conduct a test using a conventional equation and confirm that heating oil futures prices enhance the forecasting ability of spot prices. Abosedra and Baghestani (2004) also show futures prices are unbiased at all forecast horizons.

Most early studies in this domain employ conventional cointegration tests, primarily those proposed by Engle and Granger (1987) and Johansen (1988). These tests serve as fundamental tools for examining the relationship between spot and futures prices in various commodities. Specifically, they enable researchers to identify the existence of a long-term equilibrium relationship between these prices, which is crucial for understanding market dynamics and informing trading strategies. Serletis and Banack (1990) examine the efficiency of three oil markets using a cointegration model, identifying a long-term cointegration relationship between spot and futures prices of crude oil, gasoline, and heating oil. Crowder and Hamed (1993) investigate the cointegration between spot and futures prices in NYMEX crude oil contracts, supporting speculative efficiency during a specific period. The identification of the long-term relationship between spot and futures prices in early studies sparked the exploration of distinct price discovery effects for each, leading to subsequent research endeavors. Schwarz and Szakmary (1994) observe cointegration between spot and futures prices, with their study emphasizing the dominance of futures in the price discovery process. Building upon this, Gülen (1998) further investigates the dynamics of oil markets, specifically highlighting the significant role played by oil futures prices in the overall price discovery mechanism. Additionally, Maslyuk and Smyth (2009) contribute to this discourse by establishing a consistent cointegration relationship, consolidating the understanding of the long-term dynamics between spot and futures prices. Kawamoto and Hamori (2011) extend the scope of existing research by examining futures markets with diverse maturities, thereby providing a more comprehensive exploration compared to prior studies, which primarily focused on cointegration tests to determine long-term relationships. Their study investigates the efficiency of futures prices and finds consistent efficiency across different maturities. Mamatzakis and Remoundos (2011) use TVECM and demonstrate the cointegration relationship between Brent oil spot and futures prices. Wang and Wu (2013) show that there is a different relationship between the long run and short run, but still, they demonstrated futures prices dominate in the short run.

Numerous studies have confirmed both long-term and short-term relationships between spot and futures prices, as well as their role in price discovery. However, opinions regarding
which one leads to the price differ among researchers. Theoretically, both markets should react to the same news at the same time. In practice, the speed of reaction to news may differ between the spot and futures markets. Moreover, one should not expect one market to always lead or lag the other market. In the realm of lead-lag relationship and causality, Quan (1992) identifies the cointegration between monthly crude oil futures and spot prices, with the spot market leading the futures market, and investigates causal relationships. This assertion stems from the perspective that arbitrageurs and speculators commonly utilize spot prices as reference points to justify their transactions in the futures market. Despite the prevalence of studies utilizing conventional cointegration tests in examining the spot-futures relationship, many of these studies overlook the potential for changes in the relationship due to structural breaks. Consequently, there has been a notable shift towards the adoption of non-linear models to deepen the comprehension of the spot-futures relationship. Bekiros and Diks (2008) use a new nonparametric test for nonlinear causality. The results of nonlinear models indicate a lack of consistency in the lead-lag pattern changing over time. This finding aligns with the conclusions drawn by Silvapulle and Moosa (1999), who also observe similar variations in the lead-lag pattern over time. There are also studies focusing on bidirectional relationships. Kaufmann and Ullman (2009) and Mehrara and Hamldar (2014) also suggest empirical evidence of a bidirectional relationship. Table 2 provides a summary of the research that deals with the relationship between spot and futures prices in energy markets.

[Table 2 inserted]

3.2. Impact of volatility changes on energy futures-spot relationship

The relationship between spot and futures prices in the energy sector can be affected by announcements and conferences of the Organization of Petroleum Exporting Countries (OPEC) (Demirer and Kutan, 2010). Particularly noteworthy are numerous studies highlighting changes in the relationship during periods of heightened price volatility in energy commodities or instances of structural breaks. Moosa and Al-Loughani (1994) reject futures market speculative efficiency for the West Texas Intermediate (WTI) contract from January 1986 to July 1990. This period doesn't include the volatility spike that occurred during the Iraqi invasion of Kuwait, but the rejection of speculative efficiency remains consistent in subsequent periods and can be explained by rational expectations with a time-varying risk premium. The speculative efficiency hypothesis suggests that forward prices serve as the optimal unbiased predictors of
future spot prices, which is a narrower focus compared to the broader Efficient Market Hypothesis. Peroni and McNown (1998) conduct an empirical analysis covering the period from 1984 to 1996, a timeframe that encompassed the volatility spike associated with the Iraq-Kuwait war. Their findings supported the speculative efficiency hypothesis in the energy futures market during this tumultuous period. Building on the contradictory findings in studies related to the speculative efficiency hypothesis, Lean, McAleer, and Wong (2010) employ the stochastic dominance approach\(^3\) to assess efficiency in the market. The results align with those of Crowder and Hamed (1993). According to Lean, McAleer, and Wong (2010), the spot and futures prices of oil do not dominate one another, and the WTI crude oil spot and futures markets are deemed efficient. The extended duration of the study period strengthens the assertion of long-run market efficiency. Hammoudeh and Li (2004) find that the 1997 Asian crisis affected the symmetric relationship between petroleum prices and futures prices. Switzer and El-Khoury (2007) extend the research, aiming to verify whether the inclusion of extreme volatility cases in their estimates led to discrepancies between speculative efficiency and induced price biases. The conclusion of their study aligns with the findings of previous research, supporting speculative market efficiency. Huang, Yang, and Hwang (2009) analyze daily data covering 22 years from 1986 to 2007, by segmenting it into three periods. The study reports evidence that the relationship between spot and futures prices is not constant and that the relationship can change over time depending on the volatility of crude oil prices. The study also finds that non-linear models have superior predictive power than linear models.

4. Relationship between energy futures and other markets

The energy commodity futures market exhibits diverse interactions with other markets, and the measurement of the correlation between markets, often termed “connectedness”, holds significant importance in modern financial risk assessment and management (Diebold and Yilmaz, 2014). Connectedness is crucial in times of financial crises or elevated risk, as heightened levels make it challenging to mitigate these conditions. Andries and Galasan (2020) observe that elevated global connectivity and systemic risk contribute to contagion risk, potentially leading to the Global Financial Crisis (GFC). Due to these reasons, the degree of

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\(^3\) Stochastic dominance, developed by Hadar and Russell (1969) is a statistical tool in finance that compares and ranks investment prospects based on their risk-return profiles without assuming specific investor preferences or return distributions. It provides a distribution-free approach, offering flexibility beyond traditional methods like mean-variance analysis.
connectivity is often considered an indicator of the potential severity of an economic downturn. Connectedness, by measuring interrelations and interdependencies among components within a system, empirically verifies underlying systemic risk in network variables. Maggi, Torrente, and Uberti (2020) propose methods for confirming systemic risk through connectedness. Moreover, as interest in systemic risk intensified, research on connectedness has expanded across various fields, particularly gaining momentum in the aftermath of the GFC.

4.1. Market connectedness

Commodities within the energy commodity futures markets sector often exhibit high levels of convergence, indicating that futures in the same group closely co-move, as observed by Sensoy, Hacihasanoglu, and Nguyen (2015). Convergence implies that energy commodity futures within the same group have a strong correlation, leading to limited diversification benefits and lower hedging potential. Interestingly, even in futures from different sectors, high co-movement is identified in many cases. Given that this aspect is crucial when constructing portfolios for each commodity, various studies have been conducted to explore these dynamics. Research on the relationship between energy futures and other futures markets encompasses various studies. Particularly noteworthy are investigations into the connectedness between the energy futures market and the agricultural commodity market, driven by the emergence of biofuels and the resulting heightened correlation between the two commodities. Biofuels, primarily produced from agricultural raw materials, have heightened the economic and production interdependence between the agricultural and energy markets. This development has led to increased attention to studies examining the connectedness between the energy futures market and the agricultural commodity market. Studies analyzing the connectedness between agricultural commodity futures and oil futures in the context of biofuel are presented in Table 3. Koirala, Mishra, D'Antoni, and Mehlhorn (2015) analyze the dependence between agricultural commodity futures prices (corn, soybean, and cattle) and energy futures prices (natural gas and crude oil), revealing positive and significant correlations. Silvennoinen and Thorp (2016) and Tiwari, Boachie, Suleman, and Gupta (2021) delve into measuring the co-movement between crude oil futures prices and agricultural commodity futures, emphasizing a robust correlation. Natanelov, Alam, McKenzie, and Van Huyslenbroeck (2011) also explore the co-movement between crude oil futures and agricultural commodity futures, noting the potential influence of economic and policy developments. Biofuel policies act as a buffer, impacting the co-movement between crude oil and corn futures until crude oil prices surpass a
specific threshold. Du and McPhail (2012) analyze the relationship between crude oil futures and corn and US ethanol, attributing the strengthened relation to recent developments in the biofuel industry. Teterin, Brooks, and Enders (2016) further refine the study by investigating the relationship between crude oil futures and grain futures along the maturity dimension. They demonstrated that the interrelationships between corn and crude oil futures prices increased with the development of biofuel technologies, confirming time-varying correlation coefficients. These research findings underscore the intricate connections between the two markets, influenced by the emergence of new energy sources, such as biofuels, or changes in policies, shaping the mutual influence of price movements between the energy futures market and the agricultural commodity market. While research predominantly centers on the relationship between the energy futures market and the agricultural futures market, studies examining connections with other futures markets also exist. Liu, Pan, Yuan, and Chen (2019) analyze the dependence between oil futures prices and prices of 12 Chinese agricultural commodity futures. They confirm a strong dependence but emphasize that the strength of dependence varied based on different regimes or market conditions. Not only connectedness with agricultural commodities is addressed. Narayan, Narayan, and Zheng (2010) conduct cointegration tests, uncovering a long-term correlation between the gold futures market and the energy futures market. This finding suggests the potential for mutual influence between these two distinct markets. Silvennoinen and Thorp (2013) explore the connection between conventional assets and commodity futures returns. In the energy futures market, natural gas demonstrated a low correlation with conventional assets, while the oil futures market experienced a sharp increase in correlation during the GFC. In this manner, the energy futures market interacts with various markets. Given that energy is a major component of international trade, the economies of both exporting and importing countries are significantly impacted. This underscores the intricate relationship between energy futures and various markets.

[Table 3 inserted]

4.2. Directional connectedness

The exploration of correlations and connectedness between the energy futures market and other markets has evolved into studies on directional connectedness. Directional connectedness involves the concept that movements in one market, through the transmission of information, have a discernible impact on another market in a specific direction (Chen, Han,
Ryu, and Tang, 2022; Chun, Cho, and Ryu, 2023; Han, Kutan, and Ryu, 2015; Kim, Ryu, and Seo, 2015). This notion is frequently employed in the analysis of spillover or contagion effects and is measured using various econometric and statistical techniques such as Granger causality tests, network analysis, and time-varying dynamic models. Post the 2007-2008 GFC, studies focusing on terms like “contagion” and “negative spillover” gained prominence. According to Billio, Getmansky, Lo, and Pelizzon (2012), the significance of spillover and contagion risk increases after the GFC. Experts initiated research on how markets and their distinct components transit risk following the contagion experienced during the GFC. Recently, with the heightened financial market volatility due to events like COVID-19 and the Russia-Ukraine war, research on spillover effects has increased. Concerns have been raised about the significant increase in the volatility of energy prices during these crises, and whether this volatility might be transmitted to other markets. This content will be addressed specifically in Section 5. Studies investigating the impact of the energy futures market on other markets are critical for implementing the appropriate policies to ensure financial stability, as financial assets designed for stability may inadvertently transfer volatility to other markets. During periods of economic uncertainty, investors may seek energy futures as a secure option. This can exacerbate fluctuations in other markets like stocks or currencies. Hence, comprehending the workings of the energy futures market and its possible impacts on other financial domains is essential for devising policies to uphold financial stability.

Key studies on market connectedness and volatility spillovers are contained in Table 4. Xiao, Yu, Fang, and Ding (2020) utilize a network approach to measure the connectedness of 18 commodity futures while also observing directional connectedness. The analysis highlighted copper futures as the most influential, with a “received impact” percentage of 88.4%, signifying its substantial influence on other futures. In contrast natural gas futures (53.1%) and gasoline futures (57.9%), exhibited comparatively smaller degrees of impact received from other futures. Also, when assessing the impacts exerted on other futures markets, the impact of energy futures is relatively small. Balcilar, Gabauer, and Umar (2021) delve into the directional connectedness between commodity futures markets, categorizing them as either transmitters or receivers of impacts. Crude oil emerges as a net transmitter, indicating a greater influence on other markets than it receives from them. Nevertheless, the pairwise connectedness analysis suggested that crude oil is not only an influencer but is also significantly influenced by innovations occurring in most of these markets, highlighting extensive interconnectedness within the network. These bidirectional return and volatility
spillovers across commodity futures can also be seen in Kang, McIver, and Yoon (2017). However, in this study, six commodity futures, gold, and silver served as information transmitters, while the remaining commodity futures, including oil, were identified as receivers of spillovers during financial stress. Trujillo-Barrera, Mallory, and Garcia (2012) measure the spillover effects of crude oil on the corn and ethanol market, finding similar spillovers in both markets. However, the impact on the ethanol market was moderately stronger, and these spillover effects were more pronounced during periods of high volatility, including crises and times of strong price variability. Research also investigates the relationship between gold futures and other markets. Ewing and Malik (2013) analyze the volatility dynamics between gold futures and other markets, emphasizing the importance of considering structural breaks in the analysis. Structural changes over time can alter the underlying economy or fundamentals, leading to potential changes in dynamics. Gong, Liu, and Wang (2021), and Yang, Li, and Miao (2021) both show evidence of energy futures as a volatility transmitter. Mensi, Shafiullah, Vo, and Kang (2021) show volatility spillover depends on the term. Research on market connectedness and volatility spillover has been consistently investigated and remains actively researched to this day. Particularly, recent studies have extended this research to explore the connectedness with new assets. Li, Umar, and Huo (2023) address the spillover effect between the Chinese crude oil futures market and the Chinese green energy stock market.

[Table 4 inserted]

Energy futures, as a subset of commodity futures, not only influence the spot price and volatility of the respective energy commodity but also have repercussions on the prices of other commodities. Numerous studies have sought to empirically analyze the impact of energy futures on the agricultural commodity market by investigating the relationship between these two markets. Focusing on various agricultural commodities, Wu, Guan, and Myers (2011) concentrate their analysis on corn, examining the influence of crude oil futures on both corn spot prices and corn futures prices. They demonstrated the significance of volatility spillovers, noting similar impacts on both the spot and futures prices of corn. The importance of spillovers was emphasized, particularly during specific periods, such as the substantial increase following the Energy Policy Act of 2005. Notably, during times of heightened ethanol-gasoline consumption, the volatility spillover effect was more pronounced. In a related study, Luo and Ji (2018) investigate the spillover effects, highlighting the existence of volatility spillover from
US crude oil to China's agricultural commodity market. Moreover, they report that, while the size of the spillover is relatively small, the volatility spillover exhibits an asymmetric effect on market interdependence. Specifically, during periods of negative volatility, market interdependence experienced a comparatively more significant increase, showcasing the asymmetric nature of volatility connectedness.

Futures markets exhibit connections with stock markets. Kang and Lee (2019) provide insights into the positive equicorrelation\footnote{Dynamic equicorrelation is a modeling approach designed to capture volatility clustering and dynamic correlations in financial time series. It simplifies the covariance structure by assuming that all correlations are equal but vary over time within a dynamic conditional correlation framework. This technique is introduced to improve the estimation of parameters for dynamic correlations, particularly in high-dimensional data scenarios (Engle and Kelly, 2012).} between WTI crude oil and gold futures and global index futures. Through the analysis of the topology of the spillover framework, the authors explored the net and directional connectedness among various futures. Employing dynamic volatility spillover analysis and network approaches, the study revealed that volatility spillovers reached their peak during the GFC and the European Sovereign Debt Crisis, suggesting that financial crises can significantly impact the intensity and direction of volatility spillovers between index and commodity futures markets. Moreover, the research identified FTSE 100 as the most significant spillover contributor, while the KOSPI200 futures index emerged as the largest net receiver of shocks (Hwang, Kang, and Ryu, 2010; Ryu, 2015; Ryu, Ryu, and Yang, 2023a; Ryu, Webb, and Yu, 2023). Souček and Todorova (2013) delve into the spillover effects of UK, US, and Japanese equity markets on oil futures volatility. Notably, the study found that, during the entire sample period, equity markets led to volatility of crude oil. However, when the sample was divided into three subsamples (long-term, mid-term, and short-term), the results varied. Pre-crisis, there were no significant Granger casualties, but post-crisis, US and UK equity market volatilities Granger-caused oil futures volatility, with oil futures volatility leading the Japanese market. This research underscores the need for segmentation to accurately delineate volatility transmission between international equity markets and crude oil futures markets.

Studies examining the impact of energy market price changes on other markets and commodities have been ongoing, alongside research on how volatility in the energy markets affects other markets. Particularly in the crude oil market, there is a focus on studies related to the crude oil volatility index (OVX) and its impact on oil futures volatility. The OVX serves
as a commonly used measure to assess uncertainty in the oil market, akin to the VIX for the stock market and the GVZ for gold prices. To address the need for updated information during periods of heightened uncertainty, the Chicago Board Options Exchange (CBOE), a prominent options marketplace in the United States, introduced the initial OVX in 2007. This index utilizes the CBOE Volatility Index methodology applied to options on the United States Oil Fund to measure the markets’ anticipation of 30-day volatility in crude oil prices. Subsequently, in March 2012, the CBOE and CBOE Futures Exchange introduced new investment products based on the OVX, including security futures and options on the OVX Index. Consequently, investors gained the opportunity to invest in these novel volatility products amidst escalating uncertainty in the crude oil market. Haugom, Langeland, Molnár, and Westgaard (2014) demonstrate the improvement of forecasting realized volatility in the WTI futures market through the crude oil volatility index and WTI futures. Lv (2018) investigates the impact of OVX on futures volatility, finding a significantly positive impact. These findings highlight the potential utility of the crude oil volatility index in predicting volatility and financial data. Yip, Brooks, Do, and Nguyen (2020) seek to examine volatility spillover with OVX and other implied volatility indices. Their analysis reveals spillover between commodity futures markets and stock markets.

5. Recent issues with the energy futures markets
5.1. Effects of the COVID-19 pandemic on energy futures markets

The global economy has undergone significant repercussions from the COVID-19 pandemic (Adekoya, Oliyide, and Tiwari, 2022; Ahmed, 2022; Chung, Jhang, and Ryu, 2023; Polat, 2022), especially in terms of supply chain disruptions and supply-demand mismatches, which have reverberated through commodity futures markets. The COVID-19 pandemic prompted an overall change in commodity prices; however, the magnitude of its impact varies across commodity categories. The decline in energy commodity prices, in contrast to the rise in prices for other commodities such as agricultural products, precious metals, and raw materials, can be directly attributed to the implementation of lockdown policies. Lockdown measures, aimed at mitigating the spread of COVID-19, significantly reduced the demand for energy commodities, particularly in the transportation sector. Given the close association of energy commodities with diverse economic activities, commodities experienced the most pronounced price drop compared to other commodities. Notably, crude oil bore the brunt of this impact, with its monthly average price plummeting from nearly $62 per barrel in January
2020 to $21 per barrel in April, marking an 18-year low (Qiao and Han, 2023).\(^5\) According to Zhang and Hamori (2021), the long-term impact of COVID-19 on the oil markets is greater than that of the 2008 GFC. In this manner, COVID-19 has led to significant price fluctuations in energy commodities, including crude oil. Furthermore, examining changes in the commodity futures market provides additional insights. The pandemic’s reverberations in the commodity futures market stand out prominently in the volume, price, and volatility of the futures. In the third quarter of 2020, commodity futures volumes surged by 23.2\% compared to the same period in 2019, reaching a total of 2.3 billion contracts (World Federation of Exchanges, 2020). This increase was primarily driven by a rise in volumes in the Asia-Pacific region. In contrast, the American, European, Middle Eastern, and Africa regions experienced a decline in volumes (Borgards, Czudaj, and Van Hoang, 2021). These regional variations in trading volumes underscore the global impact of the pandemic on commodity markets, with unique regional dynamics influencing trading activities. Also, the occurrence of negative oil futures prices for one day for WTI crude oil traded on the CME Group during April 2020 shows the profound shock waves extended to the commodity futures market.\(^6\) Considering these events, numerous studies have explored the impact of COVID-19 on the commodity futures market, especially on the oil market.

Table 5 presents relevant studies on energy futures and COVID-19. Sifat, Ghafoor, and Mand (2021) use Speculation Ration (SR)\(^7\), and find that, compared to other crisis periods, speculation in energy futures was more prevalent during the COVID-19 pandemic. This suggests that energy futures exhibit inefficient behavior during the pandemic, with both price and volatility experiencing more significant impacts than during other crises. The research on the influence of COVID-19 on energy futures' price and volatility is further explored in the

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\(^5\) The decline in crude oil prices was exacerbated by competition between Russia and Saudi Arabia in extracting crude oil.

\(^6\) There are other reasons behind the occurrence of negative crude oil futures prices. Factors such as the competition between Saudi Arabia and Russia, along with a shortage of storage space in Crushing, Oklahoma, have played a role in driving oil futures prices into negative territory. Additionally, certain observers contend that the negative crude oil futures price was influenced by trading at settlement orders on the CME. This practice allows traders to engage in transactions at a spread either above or below the settlement price.

\(^7\) Speculation Ration (SR) is defined based on the specification by Garcia, Leuthold, and Zapata (1986), which suggests that open interest information, coupled with aggregate volume, indicates the proportion of speculative and hedging traders. This SR builds on financial literature stating that open interest implies hedging intent, while total volume reflects speculation, as adopted by Bessembinder and Seguin (1993).
following studies. Borgards, Czudaj, and Van Hoang (2021) conduct an intraday analysis of price overreactions in twenty commodity futures contracts during the COVID-19 period, revealing a significant overreaction in prices during this period. Significantly, the research revealed a higher occurrence of negative overreactions compared to positive ones, emphasizing the prevalence of downward price movements during the pandemic. They further identify notable differences between soft and hard commodities, highlighting crude oil as a unique commodity with distinct price overreaction behavior. The study emphasizes that extreme overreactions observed during the COVID-19 pandemic presented a potential for profitable trading returns that could be exploited by traders. Zhang and Wang (2022) conduct a nuanced analysis of the pandemic’s impact on commodity futures volatility, distinguishing between the long run and short run. In the long run, volatility increased, this was attributed to the pandemic-induced lockdowns and subsequent disruptions in the supply chain, leading to severe undersupply or oversupply of commodities and substantial movements in futures prices. The daily infection speed had varying impacts on instantaneous volatilities across different commodities, with negative effects observed on oil futures volatility. This was explained by the competing forces that drive prices in opposite directions during a surge in the pandemic. The short-term decrease in demand for oil exerted downward pressure on prices, while oil suppliers anticipating a sharp economic slowdown reduced supply, leading to upward price movements. The interpretation was that the conflicting influences driving prices in different directions contributed to a reduction in volatility.

[Table 5 inserted]

As mentioned in Sections 3 and 4, exposure to commodities is becoming an indispensable component of many investment portfolios. Therefore, investors need to accurately understand the price linkages among commodities to optimize asset allocation and diversify portfolio risk. Price linkages increase the likelihood of shocks spreading to other markets. This is especially problematic during times of crisis as the volatility spillovers could potentially exacerbate the severity of the crisis. Consequently, a substantial amount of research has been conducted to examine the impact of COVID-19 on risk contagion by investigating market linkages. This heightened focus on understanding the interconnections among markets has been driven by the need to comprehend the implications of the pandemic on risk transmission dynamics. Notably, Wang, Shao, and Kim (2020) underscore the heightened correlation between oil futures and
agricultural futures markets after the onset of the COVID-19 pandemic. To address the limitations associated with simplistic correlation studies, various research endeavors have delved into more intricate analyses, including the examination of volatility spillovers between markets. Building upon this research, Qiao and Han (2023) investigate the impact of COVID-19 on tail risk contagion across commodity futures markets. Their findings revealed an escalation in tail risk contagiousness of commodities futures following the occurrence of COVID-19. Particularly noteworthy was the heightened tail risk connectedness among commodities within the same category. Furthermore, it was observed that oil-related commodities exhibited less contagiousness compared to agricultural commodities.

5.2. Effects of the Russia-Ukraine war on energy futures markets

On February 24, 2022, Russian military forces invaded Ukraine, The Russia-Ukraine War, coupled with the COVID crisis in Section 5.1, emerged as a significant global economic upheaval. Russia, a major energy-producing country, accounts for around 20% of the annual global natural gas market production. The energy supply disruption caused by the war led to a surge in oil prices to $105 per barrel, a level not seen since 2014. Several ongoing studies have investigated how the Russia-Ukraine War influences energy market risk dynamics. Banerjee (2023) analyzes the impact of the Russia-Ukraine war on the risk dynamics of the NYMEX energy futures. The result indicated that the war increased the risk exposure of energy futures contracts, particularly for oil and gas-importing countries. Saad (2023) examines the effects of the Russia-Ukraine War on returns and volatility in the US natural gas futures market, discovering significant positive effects. The war, marked by restrictions on the energy supply chain, elevated both returns and volatility in natural gas futures. This contrasted with negative reactions observed in the US and other leading stock markets, suggesting that US natural gas futures could serve as effective hedging instruments. Additionally, during the crisis, the US natural gas futures market exhibited efficiency, and investors demonstrated risk-averse behavior. In March 2022, the European Federation of Energy Traders, an association comprising the largest energy traders in Europe requested emergency assistance from governments and central banks in response to the turmoil in the energy markets (Jones, Hume, and Arnold, 2022). A surge in spot market prices prompted a sharp increase in related futures margins which, posed a potential cash crunch for trading firms who hedge their positions in the energy futures markets. An inability to use the futures markets for hedging, in turn, threatened their ability to make liquid markets in the affected commodities. This situation highlights a
funding liquidity crisis in both spot and futures markets. Vasileiou (2022) investigates the impact of the Russia-Ukraine War on commodity markets by examining futures data and confirming leverage effects. Anti-leverage effects were observed in the natural gas commodity and wheat futures markets, while a leverage effect was identified in the Brent market. Pan and Sun (2023) explore how the volatility leverage and spillover effects of crude oil futures markets (WTI, Brent, and Oman) changed before and after the Russia-Ukraine conflict. The study revealed significant alterations in the leverage effect, stabilization of dynamic conditional correlation, and weakening of volatility spillover. The research emphasizes Oman's potential role in portfolios and underscores the importance of risk-taking for Asian crude oil-exporting countries.

5.3. Effects of uncertainty on energy futures markets

Bakas and Triantafyllou (2018) empirically analyze the impact of uncertainty shocks, including macroeconomic uncertainty and financial uncertainty, on commodity price volatility. The findings revealed that turbulence in the commodity market is influenced not by macroeconomic or stock-market fluctuations but by the unpredictability of these fluctuations. Additionally, the study demonstrated that the impact of uncertainty shocks was stronger in the energy market compared to agricultural or metal markets. The results also highlighted the significant impact of financial uncertainty shocks in the futures market, emphasizing the importance of research in this domain.

Xiao and Wang (2022) analyze the impact of macroeconomic uncertainty (MU) on energy futures returns using Jurado, Ludvigson, and Ng (2015)’s macroeconomic uncertainty index. The study reveals that the influence varies based on conditions and the type of energy. The influence of MU on futures returns is predominantly noticeable in the average context, particularly for crude oil and heating oil. Nevertheless, during bearish market conditions, there is a detrimental effect of MU changes on the futures market returns. The negative impact of MU changes is evident on natural gas futures returns in extremely bearish periods. This study also highlights the role of speculation in alleviating the adverse effects of MU changes on energy futures returns during bearish market conditions, with a notable moderating effect observed specifically for crude oil futures returns. Watugala (2019) examines the impact of economic uncertainty on commodity futures volatility and shows that the volatility was significantly predictable using variables reflecting macroeconomic uncertainty.
Financial uncertainty, especially geopolitical uncertainty, has recently gained prominence as a significant factor influencing the state economy and asset prices (Glick and Taylor, 2010). Despite the challenges in measuring geopolitical uncertainty, recent research has made strides in developing a geopolitical uncertainty index. While early studies, such as those focusing on specific geopolitical actions like armed conflicts (Schneider and Troeger, 2006) laid the foundation, Caldara and Iacoviello (2018) define geopolitical risk as the risk associated with wars, terrorist acts, and tensions between states affecting the normal course of international relations. They construct a Geopolitical Uncertainty Index using a method that involves counting newspaper mentions related to geopolitical events or risks. Liu, Han, and Xu (2021) utilize the GPR index to examine the influence of geopolitical uncertainty on the volatility of key energy commodities, including crude oil, heating oil, and natural gas. The findings indicate a consistently positive effect of geopolitical uncertainty on both energy volatilities and energy futures volatilities over the long term. Zhang, He, Zhang, and Wang (2022) utilize trends in geopolitical risk are effective predictors of oil prices. Furthermore, their findings reveal that an upward trend in geopolitical risk has a more pronounced impact on future oil demand shocks compared to supply shocks. Leading to a substantial decrease in oil prices. Recent studies broaden the scope of spillover analysis by incorporating novel risk dimensions and exploring their impact on energy futures. Jin, Zhao, Bu, and Zhang (2023) delve into the intricate interplay between geopolitical risk, climate risk, and energy markets, offering a dynamic spillover analysis that illuminates the evolving landscape of financial risks. Chang (2024) focuses on economic uncertainty and its implications for the occurrence of price bubbles in energy markets.

5.4. Other factors affecting energy futures

Climate change has emerged as an important factor affecting commodity markets. This is likely to continue to remain important given the significant impact of climate change and extreme weather events on commodity production, economies, and financial market dynamics (Bang, Ryu, and Webb, 2023; Bang, Ryu, and Yu, 2023; Cheng, Kim, and Ryu, 2024; Kim, Ahn, and Ryu, 2014; Park, Kim, and Ryu, 2022; Shim, Kim, Kim, and Ryu, 2015; Yang, Bae, and Ryu, 2024). Jia, Chen, Han, and Jin (2023), report a noteworthy correlation between commodity futures and a climate change index, with the highest correlation coefficients observed in agricultural futures. Additionally, the research demonstrated a substantial relationship between energy futures and agricultural futures, indicating their joint sensitivity to
climate-related factors. Furthermore, in an analysis of the tail-risk spillover effect between the two, it was revealed that both energy and agricultural futures exhibit more significant reactions to extreme climate risks. The study also discusses the derivation of optimal hedge ratios for commodity futures investors seeking to hedge risks using climate indices.

Climate change has prompted governments and companies worldwide to reshape their energy policies, exerting a more direct influence on energy spot and futures prices. In response to climate change, many nations and corporations are actively investing in and developing renewable energy sources, implementing coal phase-out strategies, striving for carbon neutrality, and advancing carbon capture technologies. These efforts aim to effectively reduce carbon emissions (Kim, Park, and Ryu, 2017). Notably, policies such as the “Renewable Fuel Standard” in the United States, encompassing biofuel and ethanol mandates, have impacted not only agricultural commodities but also energy commodities. The active development and promotion of biofuel technology within the framework of such policies have heightened the linkage between agricultural and energy commodities. Additionally, the influence of climate change on energy commodities has been accentuated (Diffenbaugh, Hertel, Scherer, and Verma, 2012). This shows policy developments related to climate change can influence the energy futures market in various aspects. Other possible factors add complexity to the energy futures landscape, such as advancements in technologies, changing consumer preferences favoring clean energy sources, and economic policy uncertainty in the country (Zhang, Lei, Ji, and Kutan, 2019; Ren, Tan, Zhu, and Zhao, 2022). Zhang, Zhang, Wang, and Wang (2024) underscore the intricate relationship between energy futures markets and environmental considerations by exploring the predictability of carbon futures volatility through the spillovers of fossil energy futures returns.

6. Conclusions and Implications

Futures markets play a critical role in commodity markets in general and energy markets in particular. The greater transparency and usually lower transaction costs of energy futures markets than the corresponding energy spot markets encourage both price discovery and risk transference. Indeed, spot commodity prices are often effectively determined in the corresponding futures market. So it is with energy commodities as well. Financialization has increased the importance of energy futures markets further.

There is a substantial amount of literature on the energy spot market and a significant amount of literature on the energy futures markets. This study provides a selective review of
the literature on energy futures markets with a bias towards more recent contributions and a focus on periods of heightened volatility. In particular, we reviewed the literature on the relationship between energy spot and futures markets; analyzed the influence of energy futures markets on various spot energy markets and noted its central role in managing exposure to energy price risk; discussed the impact of recent increases in the volatility of spot energy prices on the behavior of energy futures markets. The significance of energy futures markets lies in their price discovery and risk transference roles. The connectedness of the energy futures markets with other non-energy spot and futures markets is evident, especially during crisis periods. Moreover, the recent volatility in energy prices in the face of diverse regulatory policies underscores the need to manage exposure to energy price risk.

Potential future avenues of research in spot and futures energy markets include examining the influence of evolving technologies such as energy storage, renewable energy, carbon emission regulation, and energy efficiency on the behavior of spot and futures energy prices. The volatility of energy futures prices, as evidenced in this review, remains a crucial factor for energy market participants and the overall economy. There is a pressing need for research that examines potential factors influencing the volatility of energy futures markets. This includes exploring how regulatory policies, geopolitical events, technological innovations, and market structures impact volatility. Additionally, research on behavioral finance dynamics in the context of energy futures markets is scarce, representing another area where further investigation is needed. Understanding behavioral finance-influenced dynamics may be crucial for understanding market movements, developing effective risk management strategies, and taking appropriate policy actions. By addressing these gaps, we can enhance our understanding of market volatility and make more informed decisions within the energy sector.

References


Figure 1. Public growth of publications about energy futures
Note. This figure shows the trend of publication growth from 2000 to 2023. The x-axis represents the years, while the y-axis indicates the number of annual publications.
Figure 2. Word cloud analysis about energy futures
**Figure 3.** Co-word analysis about energy futures
Panel A. Analysis with threshold 5

Panel B. Analysis with threshold 10
Figure 5. Co-citation analysis about energy futures
<table>
<thead>
<tr>
<th>Author (Year)</th>
<th>Title</th>
<th>Journal</th>
</tr>
</thead>
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<tr>
<td>Andersen and Bollerselv (1998)</td>
<td>Answering the skeptics: Yes, standard volatility models do provide accurate forecasts</td>
<td>International Economic Review</td>
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<tr>
<td>Kilian (2009)</td>
<td>Not all oil price shocks are alike: Disentangling demand and supply shocks in the crude oil market</td>
<td>American Economic Review</td>
</tr>
<tr>
<td>Diebold and Yilmaz (2012)</td>
<td>Better to give than to receive: Predictive directional measurement of volatility spillovers</td>
<td>International Journal of Forecasting</td>
</tr>
<tr>
<td>Kilian and Murphy (2014)</td>
<td>The role of inventories and speculative trading in the global market for crude oil</td>
<td>Journal of Applied Econometrics</td>
</tr>
<tr>
<td>Büyükşahin amd Robe (2014).</td>
<td>Speculators, commodities, and cross-market linkages</td>
<td>Journal of International Money and Finance</td>
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Source: created by the author based on the VOSviewer analysis
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<tr>
<th>Authors (Year)</th>
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<th>Period</th>
<th>Methodology</th>
<th>Empirical Findings</th>
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<tbody>
<tr>
<td>Quan (1992)</td>
<td>Monthly crude oil futures, spot prices (1,3,6,9 monthly contracts) of WTI.</td>
<td>January 1984 to July 1989</td>
<td>Cointegration test, causality test.</td>
<td>Spot-futures prices within 3 months are cointegrated. The spot market leads the futures market.</td>
</tr>
<tr>
<td>Silvapulle and Moosa (1999)</td>
<td>Daily WTI crude oil (one, three, and six maturities) (NYMEX).</td>
<td>January 1985 to July 1996.</td>
<td>Linear &amp; nonlinear causality test.</td>
<td>Lead-lag pattern changes over time and found more evidence for causality from futures prices to spot prices. Futures prices and ‘naïve’ forecasts are unbiased at all forecast horizons. The pattern of the lead-lag relationship changes over time.</td>
</tr>
<tr>
<td>Kaufmann and Ullman (2009)</td>
<td>Oil (WTI, Brent-Blend, Maya, Bonny Light, Dubai-Fateh) spot and futures prices from both OPEC and non-OPEC nations, weekly data.</td>
<td>Varies by oil type. Start date 1980s to early 1990s.</td>
<td>Granger causality, VECM.</td>
<td>Bidirectional relationship.</td>
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<tr>
<td>Kawamoto and Hamori (2011)</td>
<td>WTI crude oil (NYMEX), monthly data.</td>
<td>February 1991 to May 2008.</td>
<td>Cointegration test, error correction model, and GARCH-M-ECM.</td>
<td>WTI futures are consistently efficient within 8-month maturity and consistently efficient and unbiased within 2-month maturity. Cointegration supported. The long-run relationship can be used as a crude oil behavioral indicator.</td>
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</tbody>
</table>
Table 3. Key studies: Interconnection between energy futures and agricultural commodity markets in the context of biofuel

<table>
<thead>
<tr>
<th>Author (Year)</th>
<th>Data</th>
<th>Periods</th>
<th>Methodology</th>
<th>Key Findings</th>
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<tr>
<td>Balcilar, Gabauer, and Umar (2021)</td>
<td>Crude oil futures and 11 agricultural commodity futures, daily data.</td>
<td>July 2005 to May 2020.</td>
<td>TVP-VAR based model.</td>
<td>Crude oil is a net transmitter but also has extensive interconnectedness within the network.</td>
</tr>
<tr>
<td>Yang, Li, and Miao (2021)</td>
<td>25 commodity futures prices (including energy futures: Crude oil, gasoline, heating oil, and natural gas), daily data.</td>
<td>January 2006 to December 2019.</td>
<td>LASSO-VAR model.</td>
<td>On average, energy transfers more volatility shocks to the other groups than it receives.</td>
</tr>
<tr>
<td>Authors (Year)</td>
<td>Data</td>
<td>Periods</td>
<td>Methodology</td>
<td>Key Findings</td>
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<tr>
<td>Borgards, Czudaj, and Van Hoang (2021)</td>
<td>WTI crude oil, Brent crude oil, heating oil, natural gas, daily data.</td>
<td>November 2019 to June 2020.</td>
<td>Non-parametric Mann-Whitney-U test</td>
<td>During the COVID-19, there has been an overreaction in prices.</td>
</tr>
<tr>
<td>Qiao and Han (2023)</td>
<td>Crude oil, heating oil, gasoline, natural gas, and 25 other major commodity futures prices, daily data.</td>
<td>January 2018 to February 2022.</td>
<td>Tail dependence network.</td>
<td>The contagiousness of agricultural commodities is lower than energy commodities.</td>
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</tbody>
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